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# Mesoscale and microscale modelling in NE China:

## A new application-ready numerical wind atlas for Dongbei

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### **Abstract:**

The results of a Sino-Danish project to map the wind resources of NE China (Dongbei) are reported. Measurements, microscale and mesoscale modelling have been applied in the framework of the wind atlas methodology with the purpose of significantly improving wind resource assessment and siting activities for planning and development of wind farms in NE China. The project reports, data and results will be available in public domain, and some highlights are presented.

### **Keywords:**

wind resource assessment, wind measurements, microscale modelling, mesoscale modelling, numerical wind atlas, siting, NE China.

## **Introduction**

The wind resources of NE China have been mapped with a horizontal resolution of 5 km using the KAMM (Risø DTU) and WRF (CMA) mesoscale models, based on wind classification systems adapted or developed for NE China. The modelling results have been verified at 12 sites where measurements of wind speed and direction, temperature, pressure and humidity have been carried out for more than one year. These meteorological stations were erected as part of the project and are also used to test the ability of the microscale model WAsP to model the vertical wind profile over different terrain types in different climatological settings. In addition, two different measurement systems have been compared at 9 masts. Sensitivity studies and uncertainty assessments have been carried out for both the mesoscale and microscale modelling, and an analysis of the measurement uncertainties have also been carried out. At 3 of the sites, case studies have been carried out to illustrate the application of the numerical as well as of the observational wind atlases.

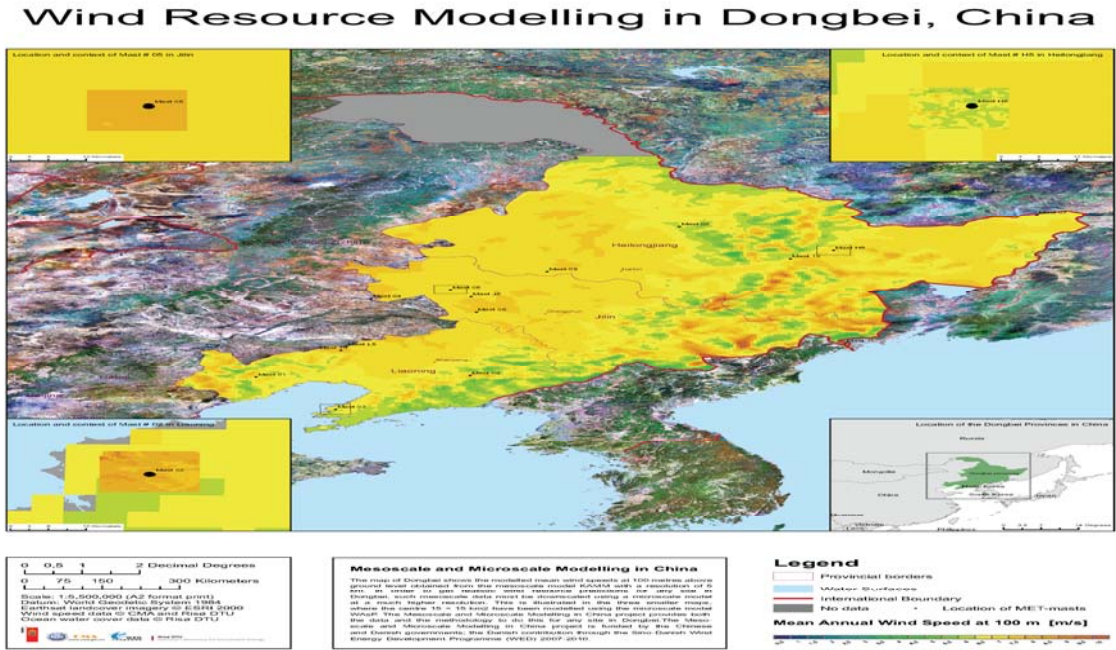
## **Measurements and Modelling**

### **Mesoscale modelling**

KAMM/WAsP, as well as WRF, has been employed by Risø DTU and CMA, respectively, for numerical wind atlas calculations of the wind resource for Dongbei, south of 50°N. The three north-eastern provinces of China cover a large area which needed to be broken down into a number of modelling domains.

The KAMM/WAsP method reported in [1] is built upon a statistical–dynamical downscaling methodology in which wind classes are defined to represent the range of large-scale atmospheric climate conditions. Each of the three modelling domains has its own sets of wind classes, as the large-scale meteorological conditions change over the region of interest.

The results of the numerical wind atlas show a wind resource over the region of interest modulated mainly by topographic features. These are principally elevated terrain features, giving high resources on exposed ridges and lower resources adjacent to the low slopes of mountains and large-scale valley features. In the flat plain regions of the provinces the wind resource is fairly uniform, due to the uniformity of wind speed forcing by the large-scale wind climate.



**Figure 1: The wind resource map for N.E. China giving the mean wind speed at 100 m a.g.l. at 5 km resolution. Also the 12 measurement locations are indicated [1].**

**Measurements**

Twelve 70-meter high meteorological masts were erected during 2008 in the Dongbei region. Nine of these masts were equipped with two different types of instrumentation. Ten-minute statistics of wind speed and direction at four height levels, as well as temperature, atmospheric pressure and heat flux are available.

The measurements have been evaluated in [2] in order to provide guidelines for how to obtain the least uncertain measured data set. Specifically, the wind speed and direction measurements taken by the two instrumentations have been compared and the uncertainties in the measurements have been estimated.

At several masts, very consistent measurement deviations are observed. This shows an impressive precision in fabrication, mounting and handling of the sensors; a high repeatability in the sensor output and high precision in

the calibration procedures. However, at other stations deviations from the expected behaviour are observed.

It is seen that mounting and position of sensors impact uncertainties and produce a bias in the wind speed measurement caused by turbulence. These errors can be mitigated by post-correction.

For the year 2009, a complete set of Risø wind data has been obtained at 7 out of 9 stations. A complete coverage for all twelve masts can be obtained by combining measurements from the two types of sensors. A database containing all measured data has been established.

## Microscale modelling

Microscale modelling and analyses have been carried out for 12 meteorological stations in NE China, four in each of the three provinces of Dongbei, as reported in detail in [3].

Wind speed and direction data from the twelve 70-m masts have been analysed using the Wind Atlas Analysis and Application Program (WAsP 10.0). The wind-climatological inputs are the observed wind climates derived using the WAsP Climate Analyst. Topographical inputs are elevation maps constructed from SRTM 3 data and roughness length maps constructed from Google Earth satellite imagery. The maps have been compared to Chinese standard topographical maps and adjusted accordingly.

The main result of the microscale modelling is that an observational wind atlas at each of the 12 measurement locations in NE China is available, which can be used for verification of the mesoscale modelling as well as for direct wind energy studies. In addition, the microscale modelling itself has been verified by comparing observed and modelled vertical wind profiles at the 12 sites.

## Sensitivity studies and uncertainties

Wind resource assessment is known to be associated with numerous types of uncertainties, many of which have been discussed in the literature for many years. As part of this project, the quantification of these uncertainties has been studied through carrying out a large number of sensitivity studies – reported in detail both in [1], [2], [3] and [4].

**Table 1. Sensitivity analysis for mast MH5, Jiamusi. The AEP prediction is made for a single wind turbine and for three different tower heights: 75, 100 and 125 m [3].**

Parameter	Input change	Output change (AEP)		
		75 m	100 m	125 m
$U$ calibration (1%)	0.01	2.2%	2.1%	2.0%
Anemometer height (1%)	-0.01	0.3%	0.3%	0.3%
Adapted atlas heights	standard	1.1%	0.0%	4.1%
Direction offset ( $10^\circ$ )	10	0.2%	0.2%	0.2%
Air density (2.5%)	-0.024	-2.1%	-2.1%	-2.1%
Neutral stability	neutral	-1.3%	-6.2%	-9.4%
Heat flux ( $10 \text{ Wm}^{-2}$ )	$10 \text{ Wm}^{-2}$	0.3%	1.2%	1.8%

BG roughness (half)	half of 20 cm	0.4%	0.6%	-0.1%
BG roughness (double)	double 20 cm	-0.7%	-1.5%	-1.7%
Position of mast (10 m)	±10 m	0.4%	0.2%	0.1%
Elevation detail (SRTM)	SRTM 3	0.0%	0.0%	0.0%

The sensitivity of the WASP modelling to 11 different input parameters, summarised in Table 1, has been investigated in [3] and it is found that the modelling is quite robust to changes in input data and parameters, when using the 70-m level anemometer as predictor. Site-specific air density (power curve) and calibrated anemometers are confirmed to be a prerequisite for reliable predictions; project-specific wind atlas heights are highly recommended. The heat flux parameters of WASP can be used to tweak the modelled wind profiles, but high-quality wind profile measurements are required in order to justify this. – Measurement uncertainty can be estimated from a traditional analysis based on the guidelines in the IEC standard, as in Figure 2.

The largest uncertainties seem to be related to meso-scale modelling and the generation of the Numerical Wind Atlas – at least in parts of N.E. China. A summary of the main impacts of the sensitivity tests is given in Table 2. Although it is difficult to quantify the sensitivities against each other, a qualitative impression of the sensitivity impacts can be obtained. For example, for a finite number of wind class simulations, it is better to include fewer wind speed classes, to allow stability classes to be included, than to use a larger number of wind speed classes ignoring stability. In most cases we also see that the direction distributions are in good agreement. The most sensitive regions can be stated generally as being in mountain/hill terrain and/or coastal regions.

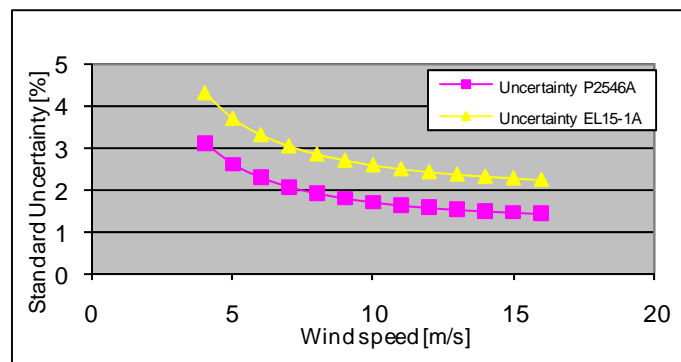


Figure 2: Standard uncertainty for the two types of cup anemometers used in the project [2].

Table 2. Summary of the KAMM/WASP sensitivity test [1].

Sensitivity test	Effect
Resolution (5km, 10km, 20km)	< 5%
Class definition location (2 different NCEP/NCAR reanalysis points)	< 2 %
Class definition height (0m, 1500m)	< 2 %
No. of stability classes (1, 2, 3)	< 1 %
Wind class number (100, 300)	< 1%
Surface roughness (halved, doubled)	< 6 %
Surface temperature (-4.5 deg C, +4.5 deg C)	<13 %

**Table 3: Comparison of Observed Wind Atlas and Numerical Wind Atlas at 9 mast locations [1].**

Mean wind speed at $z = 50$ m; $z_0 = 0.03$ m			
mast	Observed wind atlas	Numerical wind atlas	Error [%]
M01	4.70	4.88	3.83
M02	6.81	5.66	-16.89
M03	5.51	6.22	12.89
M04	6.78	6.32	-6.78
M05	6.74	6.37	-5.49
M06	6.72	6.41	-4.61
M07	6.01	6.27	4.33
M08	5.60	6.20	10.71
M09	6.83	6.20	-9.22
<b>Mean error</b>			<b>-1.25</b>
<b>Mean absolute error</b>			<b>8.31</b>

Overall the qualitative agreement of the modelling and measured results is good as seen from

Table 3. Using the best modelling configuration for each station gives a mean error of -1.25% (slight negative bias) and a mean absolute error for the 9 stations of 8% for 50-m wind speeds. If we use just a single mesoscale model configuration for the entire region of interest, the mean error is -4% and mean absolute error is 13%. This indicates that the region has a diversity of climate conditions. Further improvement of the wind resource modelling by KAMM/WAsP may be achieved through more specific configurations for smaller domains, as was performed from the Wind Atlas for Egypt study [5]. – The simulated wind resources from WERAS (CMA) give similar results, though somewhat smoother, compared to KAMM/WAsP.

Any user or application project can establish one or more masts and perform their own verification at any other location in NE China and thereby confirm and quantify the usefulness and uncertainty levels associated with the application of the Numerical Wind Atlas in NE China.

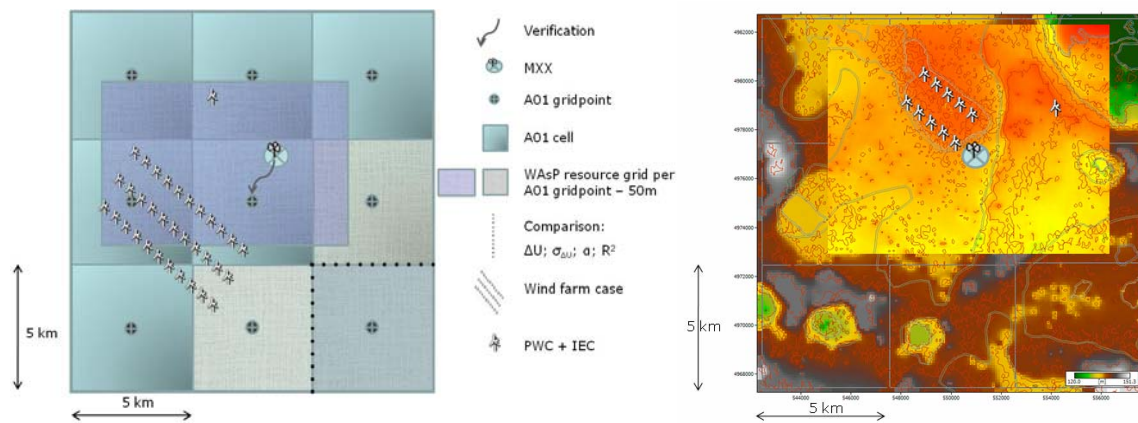
## Application

An overview of the various elements and methods applied to generate the data and wind atlases that can be applied, as well as the collection of the necessary information and instructions to any interested party to be able to apply these results of the “Meso-Scale and Micro-Scale Modelling in China” project, is made available in the public domain, containing description of the Wind Atlas Method and application opportunities as well as how to apply the Numerical Wind Atlas for wind energy planning or wind farm project development. Finally, some best practices and brief guidance with check lists are summed-up.

Case studies for illustration of possible ways of application of the Numerical Wind Atlas have been made. The results provide illustrations of the use and limitations; an example is shown in Figure 3.

For each of the three case study sites, an area of  $15 \times 15 \text{ km}^2$  (corresponding to 9 grid cells of the mesoscale models) has been defined, at which the various case studies have been performed (see Figure 3), including

- Wind resource prediction (surface wind) from the mast measurements at a given height for a selected area inside each study area.
- Wind farm calculations from the mast measurements assuming a given wind turbine – PWC and AEP
- Verification comparing measurements to Numerical Wind Atlas for the nearest cell
- Wind resource prediction (surface wind) derived from the generalized wind climate for the nearest Numerical Wind Atlas grid cell at a given height for a selected area inside each study area.
- Wind farm calculations derived from the generalized wind climate for the nearest Numerical Wind Atlas Numerical Wind Atlas grid cell assuming a given wind turbine – PWC and AEP.



**Figure 3. Sketch indicating the elements of each case study and a real WASP resource grid at one case[4].**

## Conclusions and recommendations

The main result is a complete and updated view of the wind resources of NE China (Dongbei). Comprehensive model-derived and measured datasets have been created for user applications and will be available in the public domain. Procedures for transforming the mesoscale modelling results to actual wind resource assessments on the microscale have been established, as well as guidelines and best practices. The overall mean absolute error for wind resource estimates in NE China is less than 10%.

It has been shown that WASP generally works well for microscale modelling in Dongbei, even in its default set-up, though hilly-forested and complex sites are less well modelled. Modelling of the wind profiles can be improved by using project-specific wind atlas heights and also in some cases by changing the heat flux parameters of WASP. At the southernmost sites, the atmospheric stratification seems to be slightly more unstable on average than the default settings in WASP; the northern and most elevated sites seem somewhat more stable.

The mesoscale numerical wind atlas for NE China, in combination with an observational wind atlas, offers new opportunities for wind energy planning and wind farm project preparation. At wind farm sites and in project preparation, it provides a consistent basis for verification of model results against each other and against measurements and the methodology may be applied with a view to reducing uncertainties and risks in wind farm planning and development. However, it should be noted that

- any use of these databases will be fully at the users own risk. Neither CMA nor Risø DTU will have any liability in connection with the use of the databases or the reports made by the project.
- bankability of wind farm projects requires on-site measurements
- recommendations for measurements have been made based on the analyses comparing the different types of sensors used.

Future work would be well directed towards i) improving the method for importing WRF results into WAsP, ii) developing more direct relationships between the model sensitivity analysis and uncertainties, iii) continuing the measurements at the current sites and additional sites, in order to improve and enhance the verification analysis and to possibly be able to reduce project development time and cost through MCP.

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