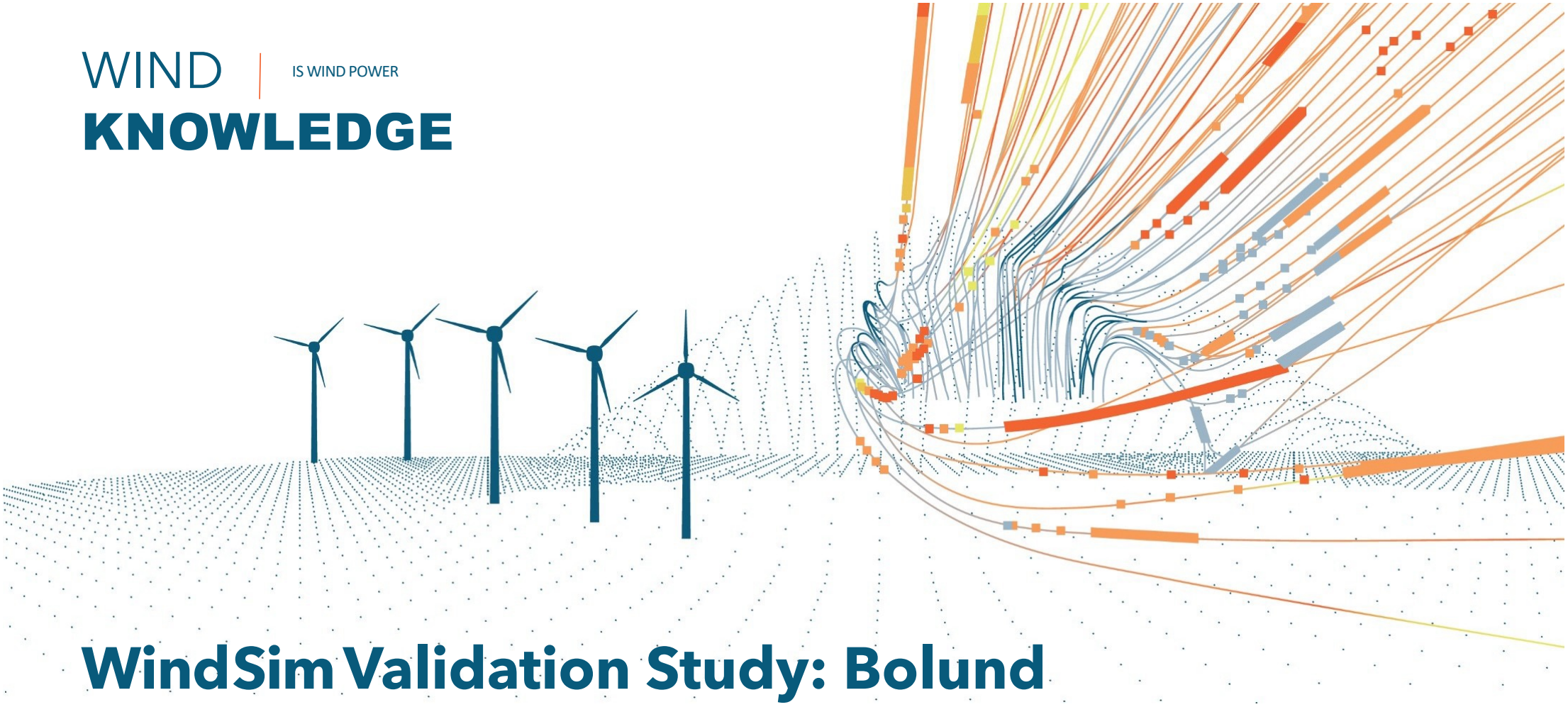
WIND | IS WIND POWER

KNOWLEDGE

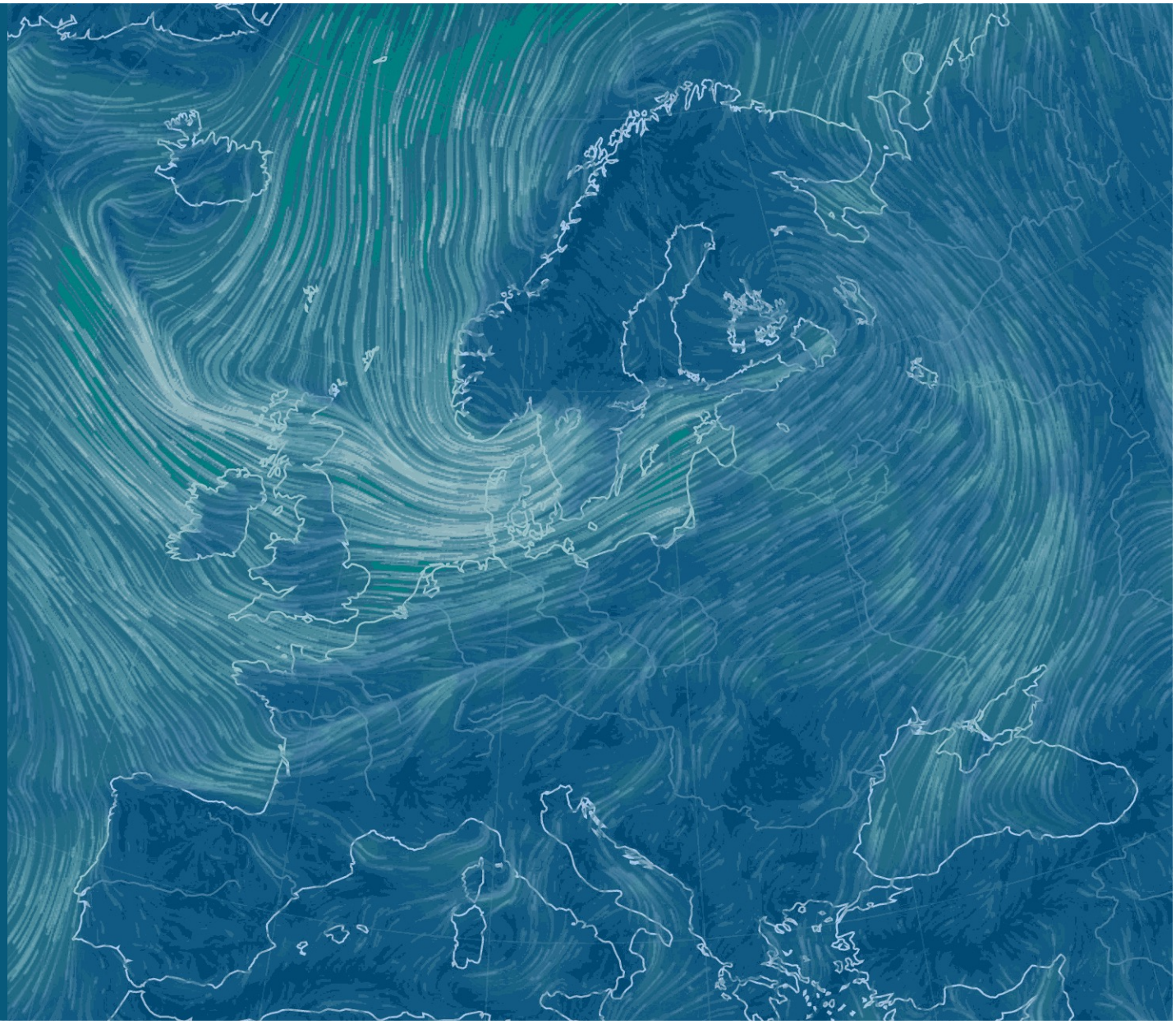


WindSim Validation Study: Bolund

2025

windsim

Bolund Hill: Proven Accuracy in Complex Terrain



The Bolund Experiment – Proven Accuracy in Complex Terrain

windsim

Objective:
- Validation of WindSim's ability to predict wind field variations in complex terrain
- Comparison against other commonly used solutions within the wind sector

Snapshot:
- Project: Bolund Hill, a 12m high coastal hill located in Denmark
- Comparison: WindSim simulations vs. measurement data and other software solutions in a blind test
- Data Sources: Measurements from Risø laboratory (DTU) along two lines passing over the island (2010)

Key Validation Results:
- Errors in velocity predictions at 5 meters height were found to be in the range of 5-6% for the best RANS k-ε models
- In general, the 2-equation k-ε models showed superior accuracy compared to 1-equation models

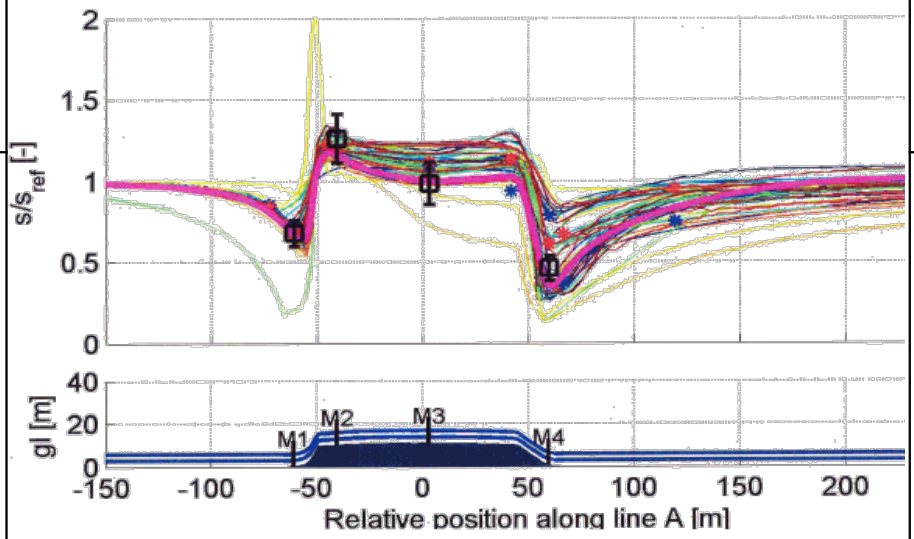


Figure: Normalized wind speed at 5 meters height, measurements are given by black boxes, solid pink line is the WindSim results, while the other lines are results from other methods

Value Proposition:
- Accurate Flow Predictions: The RANS k-ε model aligns closely with experimental measurement mean wind speed
- The retardation zone over the island plateau is reproduced by the RANS k-ε model, which is not captured by the linear solutions

Summary:
- CFD models are excellent choices for simulating flow and turbulence over complex terrains, contributing to more accurate wind resource assessments
- Access the study here: " CFD Validation – A Simple Approach"
- Contact us for a personalized demo or case study to see how WindSim can optimize your wind resource assessments

The Bolund Experiment – Proven Accuracy in Complex Terrain

windsim

Objective:
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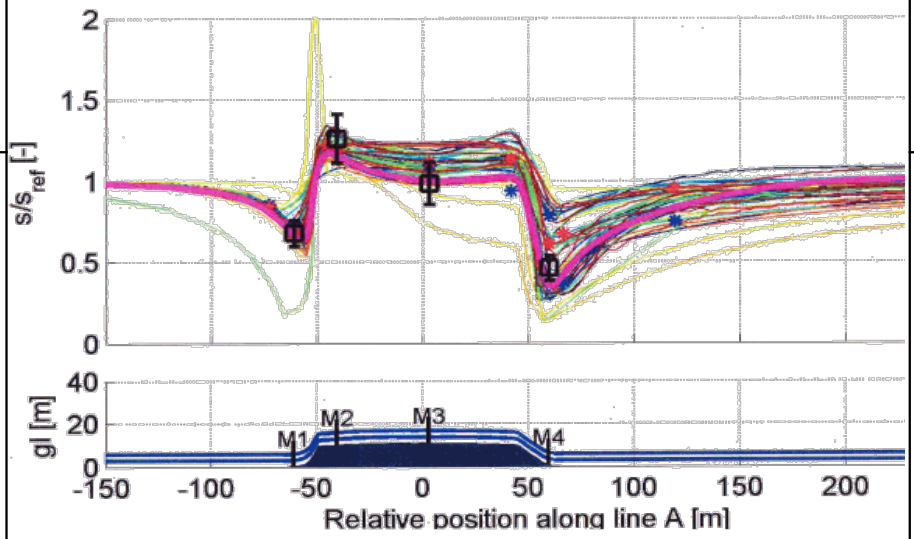
Key Validation Results:
- Errors in velocity predictions at 5 meters height were found to be in the range of 5-6% for the best RANS k-ε models
- The k-ω model showed superior accuracy in predicting turbulent kinetic energy compared to k-ε models



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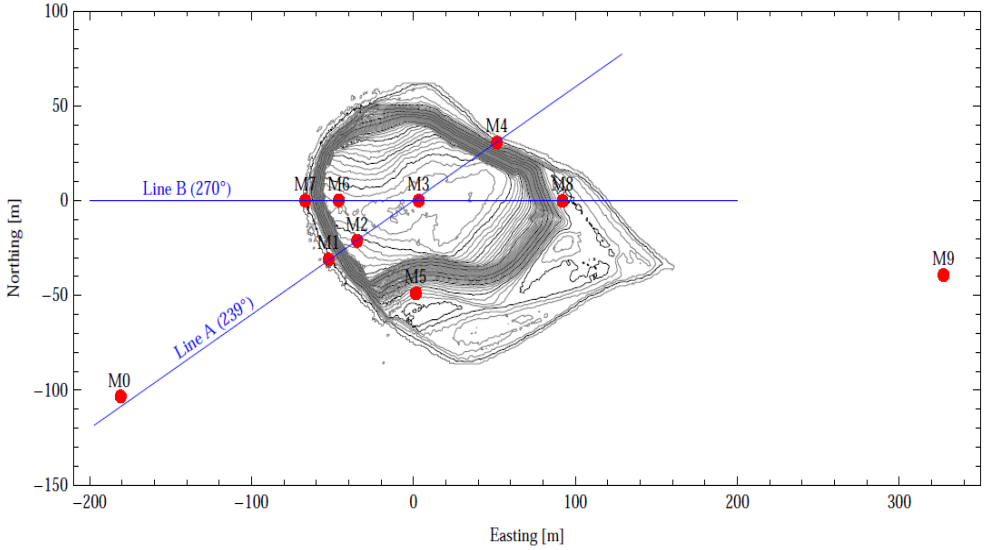
Value Proposition:
- Accurate Flow Predictions: The RANS k-ε model aligns closely with experimental measurement mean wind speed
- Enhanced Understanding of Turbulence: The k-ω models enhances further the prediction of the turbulence levels

Summary:
- CFD models are excellent choices for simulating flow and turbulence over complex terrains, contributing to more accurate wind resource assessments
- Access the full study here: "A Comparison between Two-Equation Turbulence Models for Simulating Flow over Complex Terrain"
- Contact us for a personalized demo or case study to see how WindSim can optimize your wind resource assessments

The Bolund experiment

The Bolund experiment is a field campaign that provides a new dataset for validating numerical models of flow in complex terrain and is the basis for a unique blind comparison of flow models. Today, many flow models are evaluated against hill experiments of simple geometry often performed at laboratory scales in wind tunnels. However, in order to validate the models, full scale field experiments with realistic terrain formations are necessary. The Bolund experiment allows such a validation.

The Bolund island

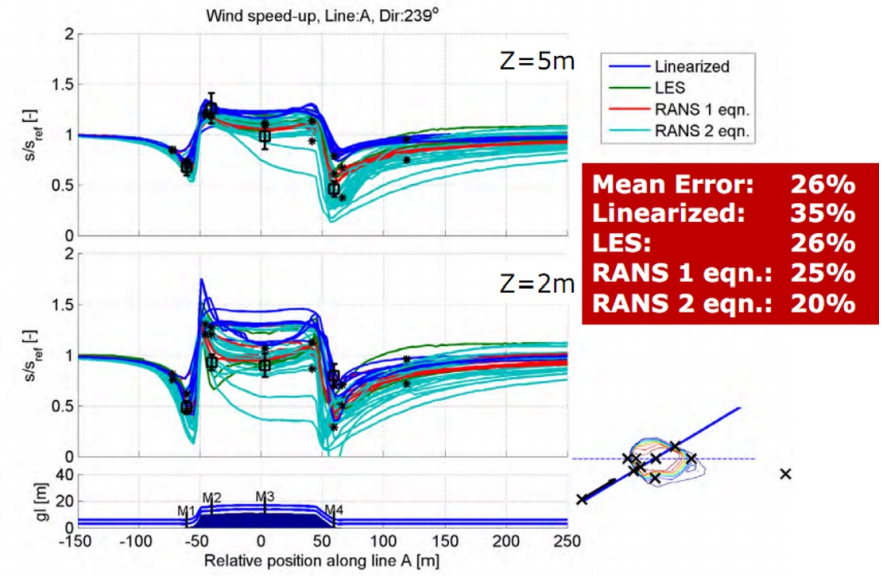


Terrain model of the Bolund island including the location of the measurement masks, measuring at 2, 5 and 10 meters height

The Bolund experiment – RANS k-epsilon best in class

Among the 50 results handed in the RANS k-epsilon models showcase the smallest error in the mean wind speed

Top 10 ListID	Turb.model	Error [%]	Error 5m [%]
ID0053	RANS k-epsilon	13	6
ID0037	RANS k-epsilon	14	4
ID0000	RANS k-epsilon	14	5
ID0036	RANS k-epsilon	14	5
ID0016	RANS k-epsilon	14	5
ID0015	RANS k-epsilon	15	5
ID0077	RANS k-epsilon	15	5
ID0010	RANS k-epsilon	15	7
ID0009	RANS k-epsilon	15	5
ID0034	RANS 1 eqn.	17	7
ID0068	RANS k-epsilon	17	10
ID0006	RANS k-epsilon	17	6



Best results are obtained with RANS k-epsilon models. The errors at 5 meters height is in the order of 5-6% for the best models

The Bolund experiment – RANS k-epsilon best in class

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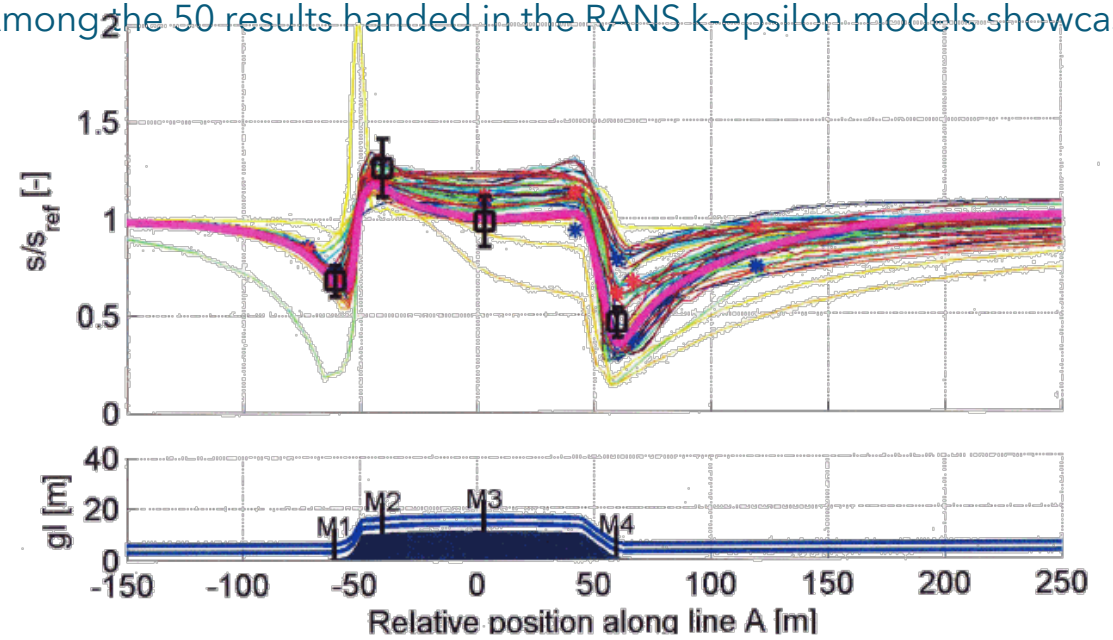


Normalized wind speed at 5 meters height with wind direction from 239 degrees for the Bolund experiment. Measurements are given by black boxes, solid pink line is the WindSim results, while the other lines are results from other methods.

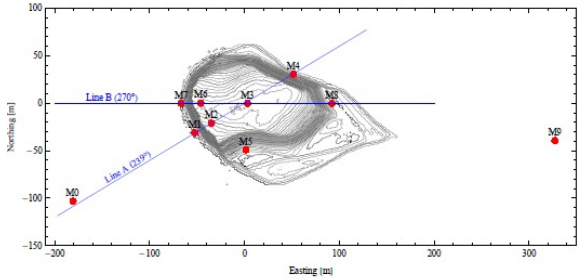
The Bolund experiment

Proving CFD's value

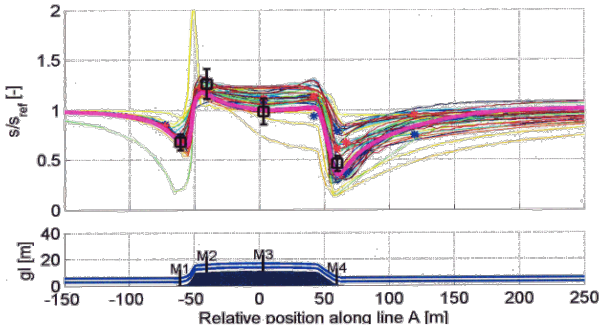
- When WindSim was launched in 2003, it was not immediately accepted by the wind energy sector
- Apparently, the software had to be "bankable", meaning that the software would be trusted by the financiers financing wind farms.
- To become bankable is not a formal process, but something earned over time as WindSim was trusted by more and more well reputed wind companies
- 2010 was a tuning point, when the Bolund experiment was performed. Bolund was a validation organized as a blind test
- WindSim performed very well, we were best in class. In addition, it became clear that the new CFD models performed much better than the existing linear models

The Bolund experiment in 2010

- The measurement setup at Bolund. In particular the conditions at location M0 was used to set the boundary conditions for all the numerical models
- Measurements along the two lines A and B used for validation
- Measurements for neutral conditions used for validation
- Best results are obtained with RANS k-epsilon models. The errors at 5 meters height are in the order of 5-6% for the best models



Terrain model of the Bolund island including the location of the measurement masts



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Source: Ramechecandane S., Gravdahl A.R., "*Numerical Investigations on Wind Flow over Complex Terrain*", WIND ENGINEERING, Volume 36, No. 3, 2012

Source: Gravdahl A.R., Ramechecandane S., Meissner C., "*A Comparison between the Various Two-Equation Turbulence Models for Simulating Flow over Complex Terrain*", AWEA, 2012