Comparison of flow models

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Agenda

1. Presentation of DONG Energy
2. Today's presentation
   1. Introduction
   2. Purpose
   3. Methods
   4. Results
3. Discussion

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Presentation of DONG Energy

- Danish Company (70% state-owned)

- Oil and Gas: Exploration and Production in the North Sea
- Coal, Gas and biomass fired power plants in DK, UK, DE

- Wind Energy historically in DK
- Now expanding to UK, DE, PL, NO

- Mostly offshore, but onshore projects in complex terrain and forested area represent a non negligible part of our portfolio

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Today's presentation

- Deals with comparison of flow models in complex terrain:
  - WAsP
  - MeteodynWT
  - WindModeller (CFD, Ansys)
  - EllipSys (CFD, Risø – The Danish National Laboratory)

  in RANS we trust, so far*

1. The test site (potential wind farm area)
2. General considerations
3. Comparison of the flow models on the site
4. Summary of the observations

- Summary of our experience with CFD in complex terrain and call for collaboration (R&D and/or good practices)

*see limitations p19

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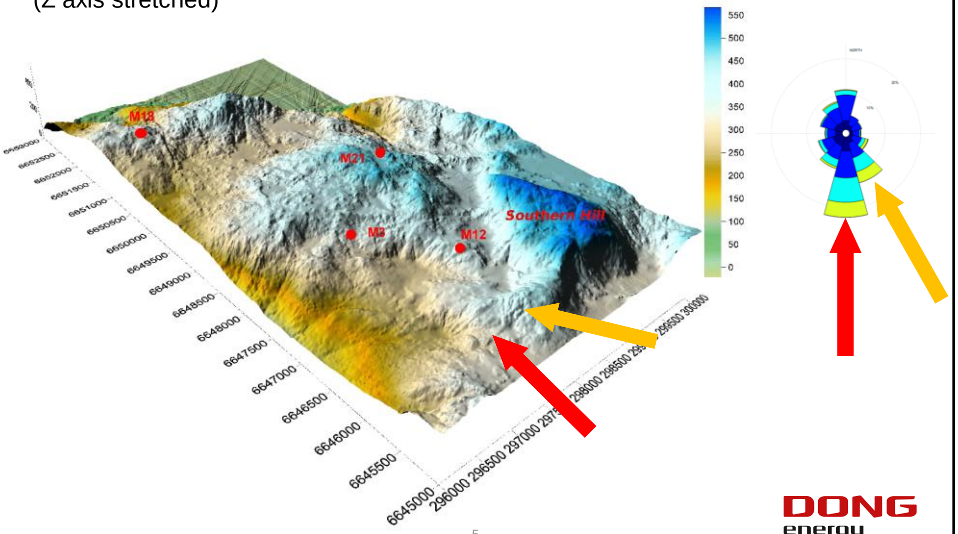
The test site

(Z axis stretched)



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General considerations

- Not the first study of such kind
- This was performed on a 32 bits machine for MeteodynWT
- Approx a 1.5 years old (Master Thesis), not fully representative of the way we do things now. Includes some preliminary results from the Ansys WindModeller (which is mostly used for wake calculations offshore at the moment)
- Met masts incl. cup anemometers (no remote sensing)

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General considerations

- Well known results over theoretical hills:

$$SU = \frac{u_3 - u_2}{u_2}$$

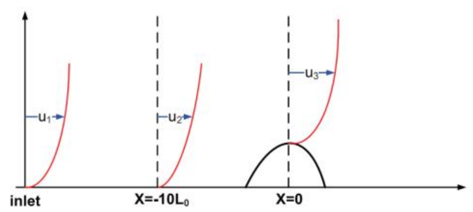

Figure 4.4.: Definition of the wind speed for the speed-up calculation with WAsP

Observation #1: the maximum speed-up increases with height.

Observation #2: the trend is different with WAsP and CFD

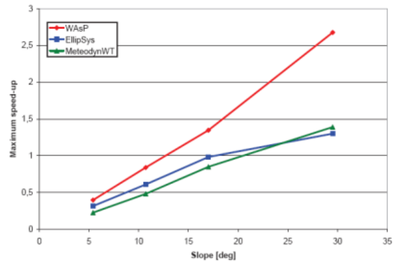

Figure 4.20.: Maximum speed-up at the top versus the hill's slope

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General considerations

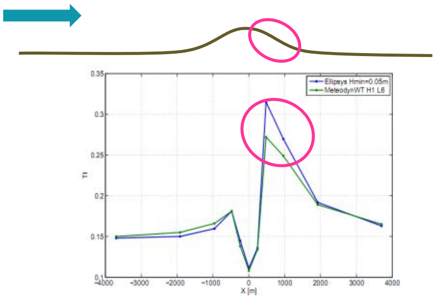

Figure 4.31.: Turbulence intensity horizontal profiles. **Moderately** steep Gaussian hill, simulated on MeteodynWT and EllipSys with the finest meshes; at 40m above ground

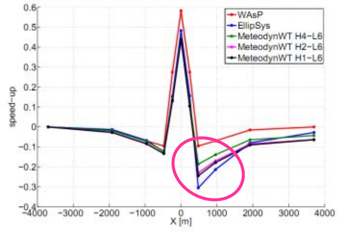

Figure 4.24.: Horizontal speed-up profiles. **Moderately** steep Gaussian hill, simulated on MeteodynWT and EllipSys with the finest meshes; at 40m above ground

Observation #3: CFD can handle transportation of the turbulence in the upper parts of the surface layer behind a steep hill (the *wake*). Larger near wake differences are observed than further downstream.

= scatter in the results

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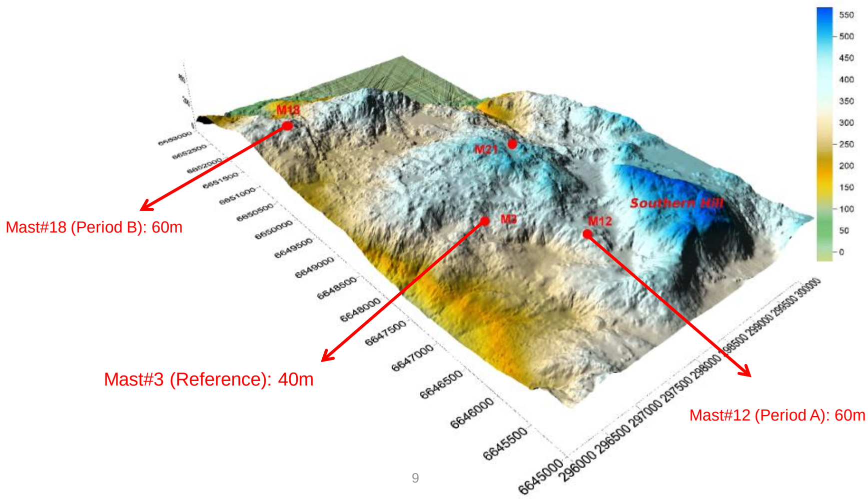
Comparison part 1 – Test Cases Definition

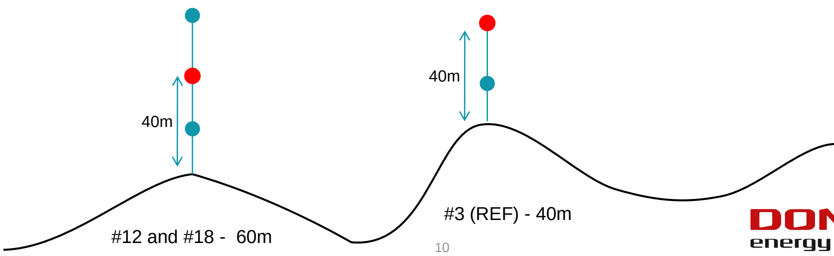
- Two main test cases: 150 and 180 degrees
- Three masts, two conccurency periods



Comparison part 1 – Test Cases Definition

- Comparison with measurements (● & ● = anemometers)

1. Get the wind direction at each mast from CFD
2. Show the normalised wind speed profile at each mast
3. Compute:
   a. The wind direction offset (later on called deviation [deg])
   b. The wind speed ratio ([-]) at the same height (40m)
   c. The turbulence intensity (later on called TI [%])



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Comparison part 1 – Test Cases Definition

- Filering of the wind data:
  - Strong wind speeds (>10 m/s)
  - Wind direction bin width = 16 deg.

Comparison part 2 – Case setup

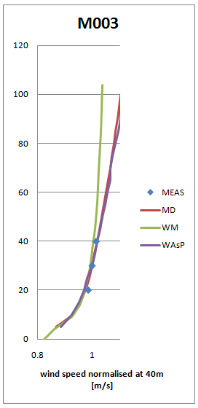
- Radius ~6km
- Mapping all around the wind farm area + Southern hill
- Horizontal resolution: 20m (down to 15m for 180 degrees wind direction)
- Vertical resolution: 4m
- Neutral stability
- 5-m contour lines
- No forest areas

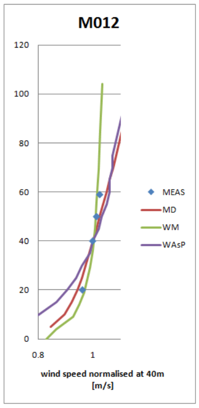
- Same setup with WM and EllipSys

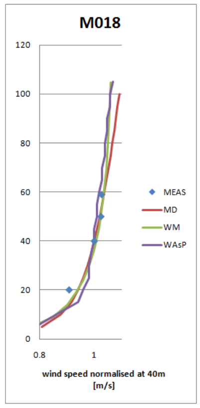
Comparison part 3 – Results: profiles at the masts (150 deg)

Warning: not the exact same minimum wind direction for both CFD codes. Less than 3 degrees difference between MeteodynWT and WM on the wind direction. The one given by MeteodynWT has been used.

- 150deg (synop) at the masts with MeteodynWT, WASP and WindModeller







M003: free stream direction. Roughness tuning needed in the WM.

M0012: Mast in a turbulent location. Big scatter in CFD results.

M0018: free stream direction, 1.5% difference between the CFD codes at hub height (both overestimate the speed compared to WAsP) when profiles are scaled at 60m.

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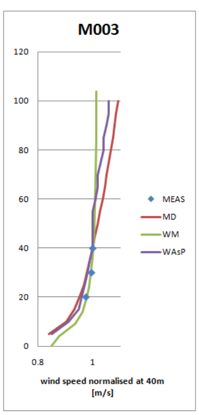
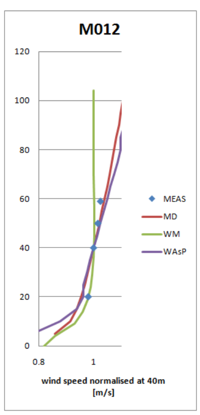
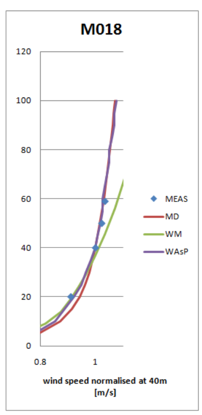
Comparison part 3 – Results : profiles at the masts (180 deg)

Warning: not the exact same minimum wind direction for both CFD codes. Less than 3 degrees difference between MeteodynWT and WM on the wind direction. The one given by MeteodynWT has been used.

- 180deg (synop) at the masts with MeteodynWT, WASP and WindModeller







M003: WM better at lower heights, additional measurements needed, too much scatter

M0012: Mast right in a turbulent location. Big scatter in CFD results.

M0018: Same as M003/150, here the roughness in the wind modeller must be adjusted (treated differently than in meteodynWT). WAsP very good in not complex terrain.

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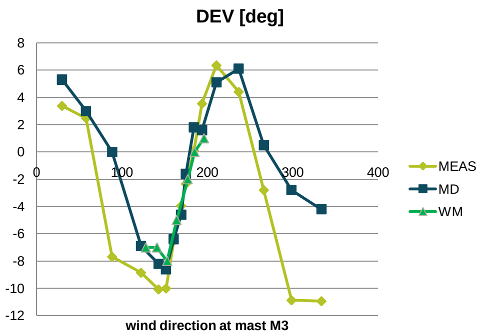
Comparison part 3 – Results: deviation

		MEAS.	WAsP	MD	EI	WM
M#12-M#3	150 deg	**-10**	-8	-9	-11	-8
	180 deg	**0**	0	+2	-1	0
M#18-M#3	150 deg	**+5**	+2	+4	+5	+5
	180 deg	**+1**	+2	+2	+2	+2



Observation#1: agreement of all codes for WD offsets at 40m

Observation#2: averaging helps ☺

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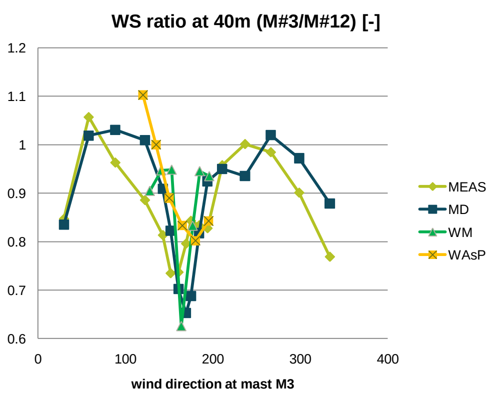
Comparison part 3 – Results: speed-up @40m

		MEAS.	WAsP	MD	EI	WM
M#12/M#3	150 deg	**74%**	89%	78%	71%	77%
	180 deg	**83%**	83%	87%	87%	77%



Observation#1: WAsP is doing a very good job for not-so-complex wind directions.

Observation#2: For complex wind directions, one CFD code may not be enough -> big scatter as expected in the near wake

Observation#3: Averaging would help, but leads to a high number of simulations for site calibration.

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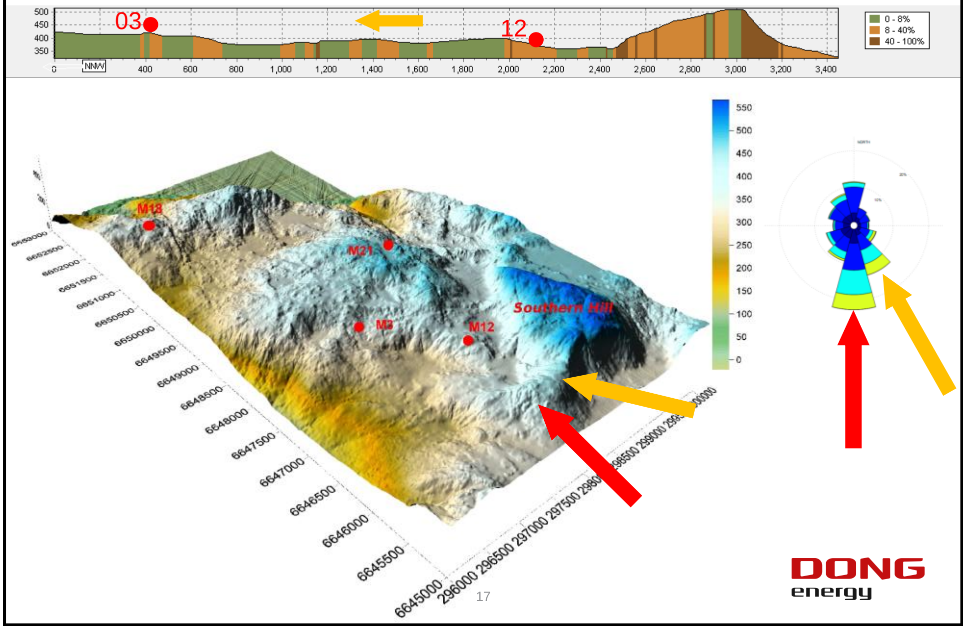
Reminder



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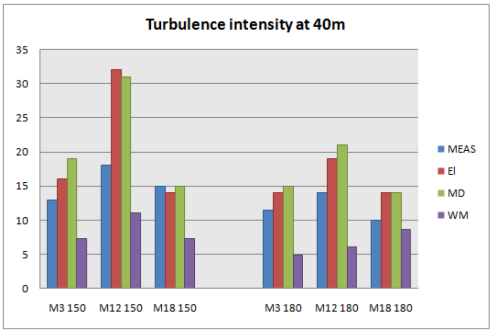
Comparison part 3 – Results: TI at 40m



Observation#1: Definition of the turbulence varies between CFD people and wind people:

$$TI_{meas} = \frac{\sigma_U}{\bar{U}} \text{ and } TI_{CFD} = \frac{\sqrt{k}}{V_h}$$

Observation#2: TI levels must be scaled, there are various methods -> need for good practices.

Observation#3: It would be easier to work with TKE, but sonic anemometers are needed at all heights. This may not be worth if we stick to RANS. In some complex cases, since the flow is far to be steady state and neutral. Having better measurements will thus make us try more advanced models in the future.

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Summary of the observations

- WAsP performs very well in not very complex conditions, as long as the sensors are placed far from the layers where turbulence is transported.
- CFD codes agree very well on flow directions.
- In complex situations, CFD codes are better than WAsP for shear estimation, and almost as good as WAsP for cross predictions of the masts. Additional output: turbulence intensity. Small scatter between the models compared with uncertainty on meas.
- In very complex situation (ex: near wake) there is a bigger spread in the CFD results. More advanced models can perform better than MeteodynWT, but questions remain:

1. Gap between CFD world and wind ressource world for comparison with measurements: are "classical" measurement methods detailed enough ?
2. More advanced closures and transient simulations seem very attractive
3. Risk mitigation: micro siting must take all this into account

Foreword

- Wind Resource is a small world, and CFD applied to Wind Resources is even smaller -> High potential for cross cooperation
- Three reasons:
    1. Business is moving very fast, growing demand for reliable and bankable assessments (not only in CFD, but also in MCP or wake losses calculations)
    2. Many tools: need for validations and comparisons
    3. Our work is always reviewed by a third party (consultant, manufacturer, etc). In CFD, standards are most likely not a solution, but good practices and common understanding of procedures will make projects move faster, and with lower risks for everybody (banks, manufacturers, developers).
- Let's keep in touch -> mailing list of MeteodynWT users ?
- This afternoon: brief presentations of the challenge we are facing in evaluating the convergence of a simulation. One step towards good practices ?