

WindSim - Annual User Meeting

WindSim CFD validation in densely forested terrain

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WINDSIM ANNUAL USER MEETING - TØNSBERG

COWI

Agenda

- > Introduction
- > Method of validation
- > Description of test cases and test sites
- > Result of test cases
- > Summary and conclusions

Introduction

> Motivation

Improving wind flow modelling in densely forested terrain.

Analyse forest model performance for two test sites.



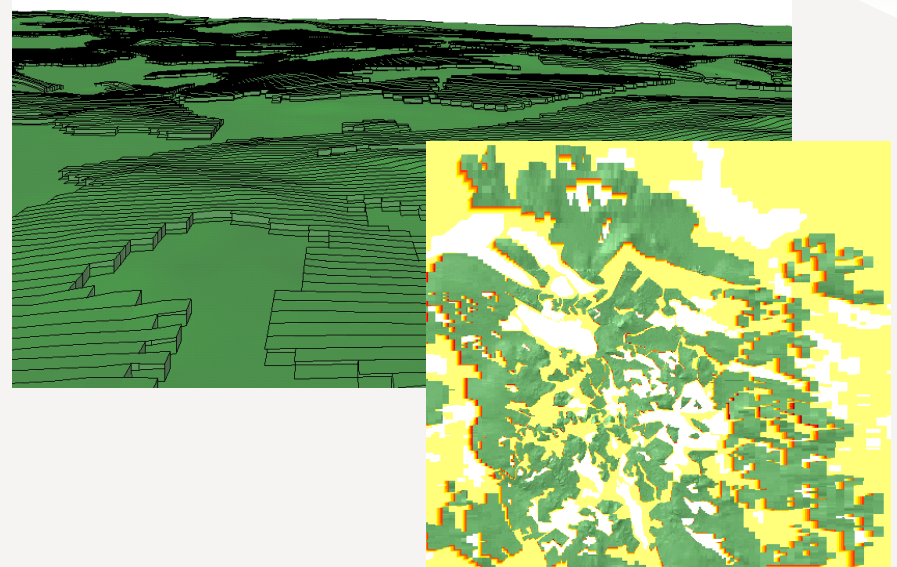
Introduction

> Description of test sites

The test sites are characterized by dense forest of varying height with some open fields vegetated by bushes and smaller trees.

Both test sites are similar in terms of topography and terrain surface characteristics.

Tree heights varying from 6 to 18 m are treated in forest model. Lower heights are treated as roughness.



Introduction

> Description of test sites

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Method

> Validation approach

Running 5 x test cases on 2 separate test sites.

4 meteorological masts on each test site, resulting in 8 validation points in total.

Analyse cross-prediction error and compare measured shear with modelled shear.

| Test site 1 | | | | |
|--------------|------|------|------|------|
| Distance [m] | A | B | C | D |
| A | 0 | 284 | 2217 | 2377 |
| B | 284 | 0 | 2083 | 2218 |
| C | 2217 | 2083 | 0 | 284 |
| D | 2377 | 2218 | 284 | 0 |

| Test site 2 | | | | |
|--------------|------|------|------|------|
| Distance [m] | A | B | C | D |
| A | 0 | 228 | 5392 | 5543 |
| B | 228 | 0 | 5251 | 5401 |
| C | 5392 | 5251 | 0 | 226 |
| D | 5543 | 5401 | 226 | 0 |

Input

- > **Oreography:** 40 x 40 km height contour maps. Approximately 10 x 10 km with 5 m resolution in interest area. Remaining area extended with 10 m resolution data.
- > **Roughness:** 25 x 25 km roughness map, digitized based on satellite images/photos/site visits.

Forests (1.1 m, 0.9 m, 0.8 m).

Background roughness (0.2 m).

Open plains (0.1 m).

- > **Wind data:** Two sites with 4 meteorological masts on each site. 8 validation points in total.
- > All validation masts comply with IEC and MEASNET recommendations.

Test cases and simulation settings

- > Fixed settings for numerical model, boundary and initial conditions, physical models for all test sites.
- > Refinement used for area
- > Maximum number of cells 8000000
- > Solver: GCV

| Terrain | |
|--|-----------------------|
| Refinement | Yes |
| Maximum number of cells | 8000000 |
| Ratio additive length to resolution | 0.5 |
| Height distribution factor | 0.1 |
| Cells in Z direction | 40 |
| Boundary and initial conditions | |
| Height of boundary layer | 500 |
| Speed above boundary layer height | 10 |
| Physical models | |
| Potential temperature | Disregard temperature |
| Air density | 1.2 |
| Turbulence model | Standard k-epsilon |

Test cases and simulation settings

One default run and four runs with forest model per test site.

Changes applied to:

Resistive force constant, C1.

- > Resistive force constant, C2.
- > Forest cell count in Z direction.
- > Turbulence model (TRUE/FALSE).

| Fixed forest settings | |
|-----------------------|-------------------------------------|
| Roughness length [m] | Forest height [m] |
| 1.1 | 18 |
| 0.9 | 11 |
| 0.8 | 6 |
| Porosity | Disregarded due to using GCV solver |

| Run 1 - Default run | Run 2 - Default forest run | | Run 3 - Turbulence test | | Run 4 - C1 | | Run 5 - C1 + Turb | |
|---------------------|----------------------------|-------------------|-------------------------|-------------------|------------|--------------------|-------------------|--------------------|
| No forest model | C1 | 0/0/0 | C1 | 0/0/0 | C1 | 0.005/00.003/0.001 | C1 | 0.005/00.003/0.001 |
| | C2 | 0.005/0.005/0.005 | C2 | 0.005/0.005/0.005 | C2 | 0.005/00.003/0.001 | C2 | 0.005/00.003/0.001 |
| | Turbulence | FALSE | Turbulence | TRUE | Turbulence | FALSE | Turbulence | TRUE |
| | Z | 6 | Z | 6 | Z | 6 | Z | 6 |

Results

> Test site 1

Run 1

- > Cross prediction error
- > Modelled vs. measured shear

| | |
|---------------------|--|
| Run 1 - Default run | |
| No forest model | |
| | |
| | |

| Reference | Target | Reference measured | Target measured | Target modelled | Abs. error |
|--------------------------------------|--------|--------------------|-----------------|-----------------|------------|
| | | [m/s] | [m/s] | [m/s] | [%] |
| A | B | 7.07 | 7.36 | 7.26 | 1.36 |
| A | C | 7.04 | 7.12 | 7.22 | 1.40 |
| A | D | 7.04 | 7.35 | 7.38 | 0.41 |
| B | A | 7.34 | 7.03 | 7.14 | 1.56 |
| B | C | 7.34 | 7.11 | 7.33 | 3.09 |
| B | D | 7.34 | 7.35 | 7.49 | 1.90 |
| C | A | 7.11 | 6.96 | 6.91 | 0.72 |
| C | B | 7.12 | 7.29 | 7.13 | 2.19 |
| C | D | 7.16 | 7.37 | 7.31 | 0.81 |
| D | A | 7.3 | 6.93 | 6.97 | 0.58 |
| D | B | 7.32 | 7.26 | 7.17 | 1.24 |
| D | C | 7.35 | 7.11 | 7.19 | 1.13 |
| Weighted error all cross-predictions | | | | | 1.35 |

Results

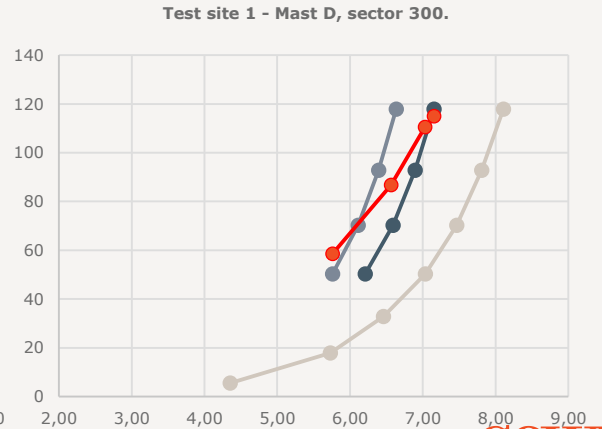
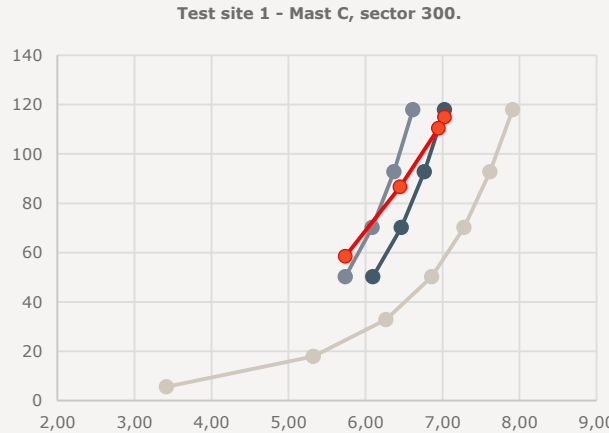
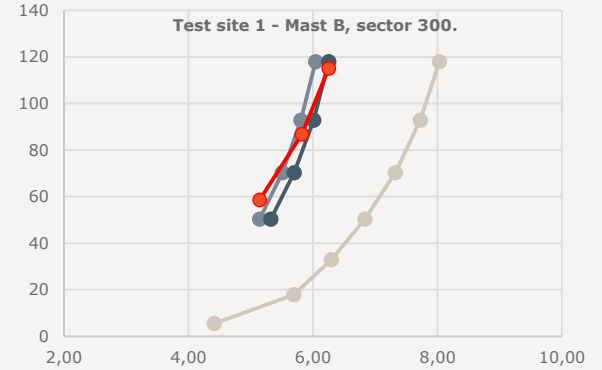
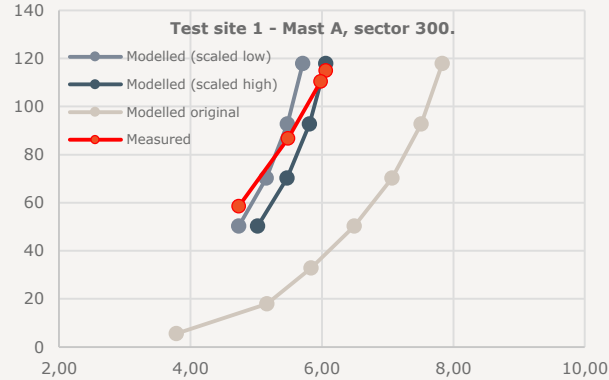
> Test site 1

Run 1

- > Cross prediction error
- > **Modelled vs. measured shear**

| Run 1 - Default run | |
|---------------------|--|
| No forest model | |
| | |
| | |

| | Measured shear | Modelled shear | Difference |
|--------|----------------|----------------|------------|
| Mast A | 0.366 | 0.220 | 0.146 |
| Mast B | 0.290 | 0.189 | 0.101 |
| Mast C | 0.300 | 0.167 | 0.133 |
| Mast D | 0.321 | 0.166 | 0.155 |



Results

> Test site 1

Run 2

- > Cross prediction error
- > Modelled vs. measured shear

| Run 2 - Default forest run | |
|----------------------------|-------------------|
| C1 | 0/0/0 |
| C2 | 0.005/0.005/0.005 |
| Turbulence | FALSE |
| Z | 6 |

| Reference | Target | Reference measured | Target measured | Target modelled | Abs. error |
|--------------------------------------|--------|--------------------|-----------------|-----------------|------------|
| | | [m/s] | [m/s] | [m/s] | [%] |
| A | B | 7.07 | 7.36 | 7.29 | 0.95 |
| A | C | 7.04 | 7.12 | 7.27 | 2.11 |
| A | D | 7.04 | 7.35 | 7.46 | 1.50 |
| B | A | 7.34 | 7.03 | 7.11 | 1.14 |
| B | C | 7.34 | 7.11 | 7.35 | 3.38 |
| B | D | 7.34 | 7.35 | 7.53 | 2.45 |
| C | A | 7.11 | 6.96 | 6.88 | 1.15 |
| C | B | 7.12 | 7.29 | 7.1 | 2.61 |
| C | D | 7.16 | 7.37 | 7.32 | 0.68 |
| D | A | 7.3 | 6.93 | 6.9 | 0.43 |
| D | B | 7.32 | 7.26 | 7.12 | 1.93 |
| D | C | 7.35 | 7.11 | 7.18 | 0.98 |
| Weighted error all cross-predictions | | | | | 1.57 |

Results

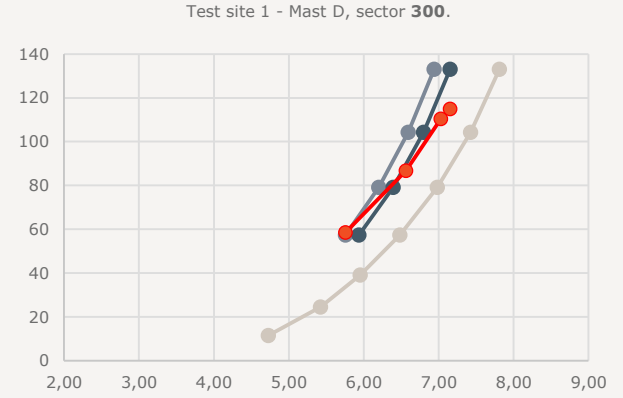
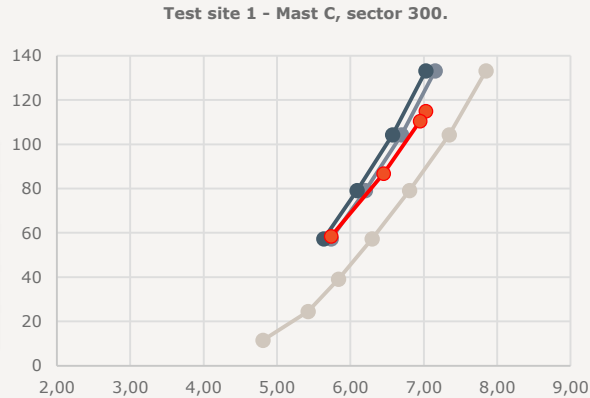
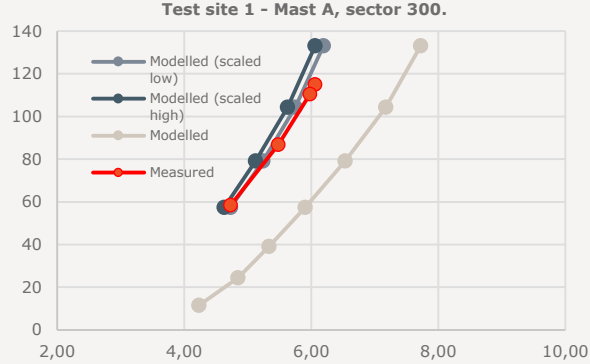
> Test site 1

Run 2

- > Cross prediction error
- > **Modelled vs. measured shear**

| Run 2 - Default forest run | |
|----------------------------|-------------------|
| C1 | 0/0/0 |
| C2 | 0.005/0.005/0.005 |
| Turbulence | FALSE |
| Z | 6 |

| | Measured shear | Modelled shear | Difference |
|--------|----------------|----------------|------------|
| Mast A | 0.366 | 0.326 | 0.040 |
| Mast B | 0.290 | 0.242 | 0.048 |
| Mast C | 0.300 | 0.258 | 0.042 |
| Mast D | 0.321 | 0.227 | 0.094 |



Results

> Test site 1

Run 3

- > Cross prediction error
- > Modelled vs. measured shear

| Run 3 - Turbulence test | |
|-------------------------|-------------------|
| C1 | 0/0/0 |
| C2 | 0.005/0.005/0.005 |
| Turbulence | TRUE |
| Z | 6 |

| Reference | Target | Reference measured | Target measured | Target modelled | Abs. error |
|--------------------------------------|--------|--------------------|-----------------|-----------------|------------|
| | | [m/s] | [m/s] | [m/s] | [%] |
| A | B | 7.07 | 7.36 | 7.29 | 0.95 |
| A | C | 7.04 | 7.12 | 7.28 | 2.25 |
| A | D | 7.04 | 7.35 | 7.47 | 1.63 |
| B | A | 7.34 | 7.03 | 7.12 | 1.28 |
| B | C | 7.34 | 7.11 | 7.36 | 3.52 |
| B | D | 7.34 | 7.35 | 7.55 | 2.72 |
| C | A | 7.11 | 6.96 | 6.87 | 1.29 |
| C | B | 7.12 | 7.29 | 7.09 | 2.74 |
| C | D | 7.16 | 7.37 | 7.32 | 0.68 |
| D | A | 7.3 | 6.93 | 6.89 | 0.58 |
| D | B | 7.32 | 7.26 | 7.11 | 2.07 |
| D | C | 7.35 | 7.11 | 7.18 | 0.98 |
| Weighted error all cross-predictions | | | | | 1.68 |

Results

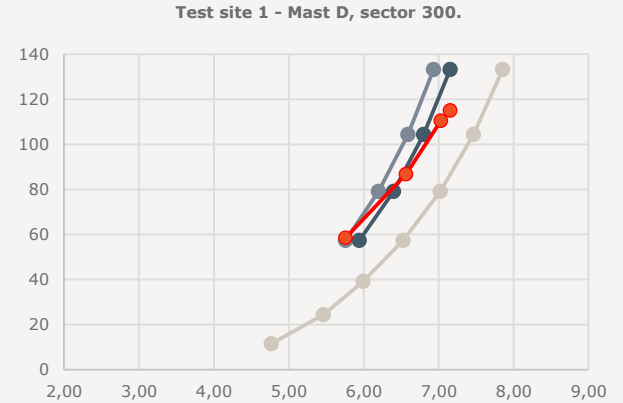
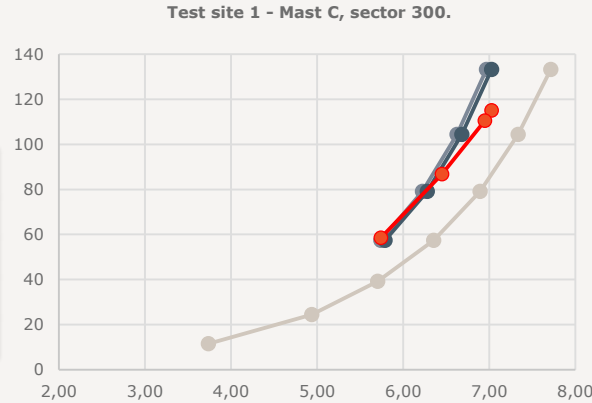
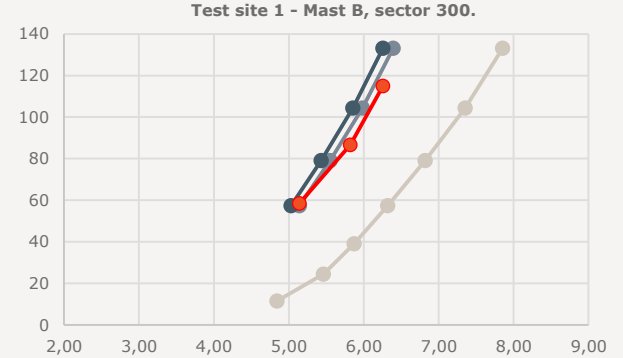
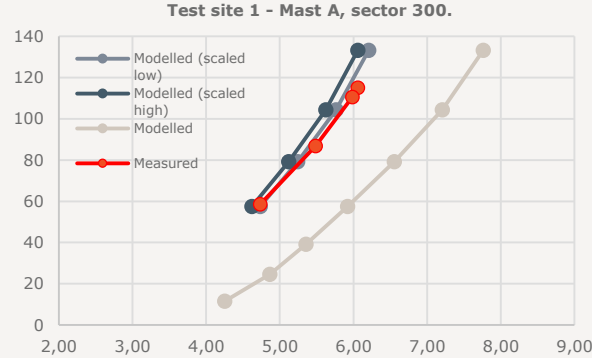
> Test site 1

Run 3

- > Cross prediction error
- > **Modelled vs. measured shear**

| Run 3 - Turbulence test | |
|-------------------------|-------------------|
| C1 | 0/0/0 |
| C2 | 0.005/0.005/0.005 |
| Turbulence | TRUE |
| Z | 6 |

| | Measured shear | Modelled shear | Difference |
|--------|----------------|----------------|------------|
| Mast A | 0.366 | 0.328 | 0.037 |
| Mast B | 0.290 | 0.253 | 0.037 |
| Mast C | 0.300 | 0.240 | 0.059 |
| Mast D | 0.321 | 0.225 | 0.096 |



Results

> Test site 1

Run 4

- > Cross prediction error
- > Modelled vs. measured shear

| Run 4 - C1 | |
|------------|-------------------|
| C1 | 0.005/0.003/0.001 |
| C2 | 0.005/0.003/0.001 |
| Turbulence | FALSE |
| Z | 6 |

| Reference | Target | Reference measured | Target measured | Target modelled | Abs. error |
|--------------------------------------|--------|--------------------|-----------------|-----------------|------------|
| | | [m/s] | [m/s] | [m/s] | [%] |
| A | B | 7.07 | 7.36 | 7.28 | 1.09 |
| A | C | 7.04 | 7.12 | 7.41 | 4.07 |
| A | D | 7.04 | 7.35 | 7.57 | 2.99 |
| B | A | 7.34 | 7.03 | 7.12 | 1.28 |
| B | C | 7.34 | 7.11 | 7.49 | 5.34 |
| B | D | 7.34 | 7.35 | 7.64 | 3.95 |
| C | A | 7.11 | 6.96 | 6.77 | 2.73 |
| C | B | 7.12 | 7.29 | 6.99 | 4.12 |
| C | D | 7.16 | 7.37 | 7.29 | 1.09 |
| D | A | 7.3 | 6.93 | 6.82 | 1.59 |
| D | B | 7.32 | 7.26 | 7.04 | 3.03 |
| D | C | 7.35 | 7.11 | 7.21 | 1.41 |
| Weighted error all cross-predictions | | | | | 2.66 |

Results

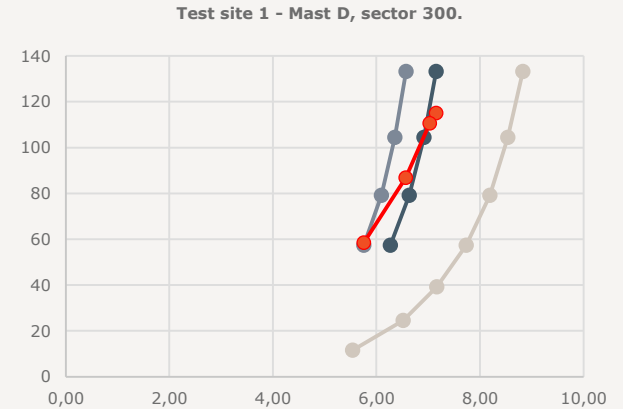
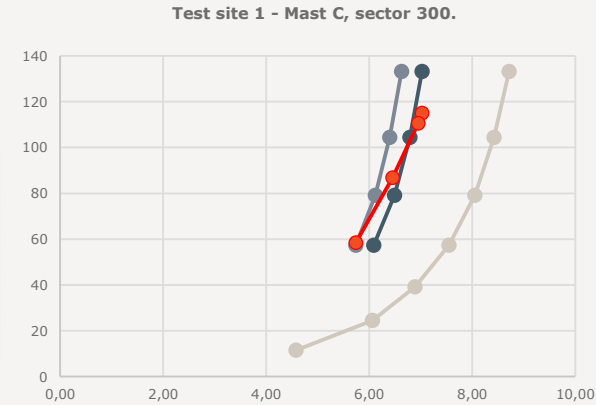
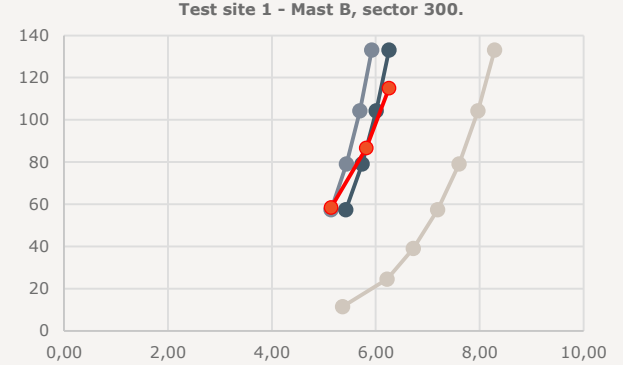
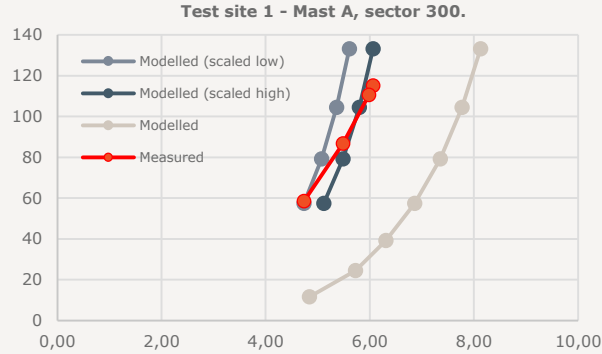
> Test site 1

Run 4

- > Cross prediction error
- > **Modelled vs. measured shear**

| Run 4 - C1 | |
|------------|-------------------|
| C1 | 0.005/0.003/0.001 |
| C2 | 0.005/0.003/0.001 |
| Turbulence | FALSE |
| Z | 6 |

| | Measured shear | Modelled shear | Difference |
|--------|----------------|----------------|------------|
| Mast A | 0.366 | 0.209 | 0.157 |
| Mast B | 0.290 | 0.172 | 0.118 |
| Mast C | 0.300 | 0.182 | 0.117 |
| Mast D | 0.321 | 0.165 | 0.156 |



Results

> Test site 1

Run 5

- > Cross prediction error
- > Modelled vs. measured shear

| Run 5 - C1 + Turb | |
|-------------------|-------------------|
| C1 | 0.005/0.003/0.001 |
| C2 | 0.005/0.003/0.001 |
| Turbulence | TRUE |
| Z | 6 |

| Reference | Target | Reference measured | Target measured | Target modelled | Abs. error |
|--------------------------------------|--------|--------------------|-----------------|-----------------|------------|
| | | [m/s] | [m/s] | [m/s] | [%] |
| A | B | 7.07 | 7.36 | 7.28 | 1.09 |
| A | C | 7.04 | 7.12 | 7.37 | 3.51 |
| A | D | 7.04 | 7.35 | 7.53 | 2.45 |
| B | A | 7.34 | 7.03 | 7.12 | 1.28 |
| B | C | 7.34 | 7.11 | 7.45 | 4.78 |
| B | D | 7.34 | 7.35 | 7.61 | 3.54 |
| C | A | 7.11 | 6.96 | 6.8 | 2.30 |
| C | B | 7.12 | 7.29 | 7.02 | 3.70 |
| C | D | 7.16 | 7.37 | 7.3 | 0.95 |
| D | A | 7.3 | 6.93 | 6.85 | 1.15 |
| D | B | 7.32 | 7.26 | 7.07 | 2.62 |
| D | C | 7.35 | 7.11 | 7.2 | 1.27 |
| Weighted error all cross-predictions | | | | | 2.33 |

Results

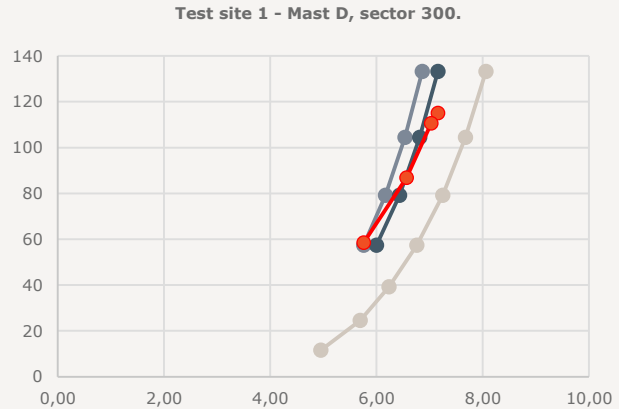
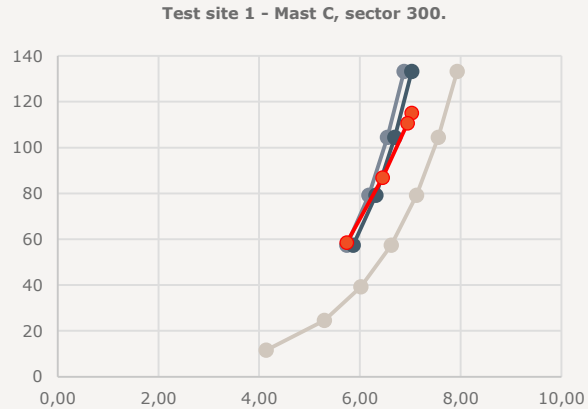
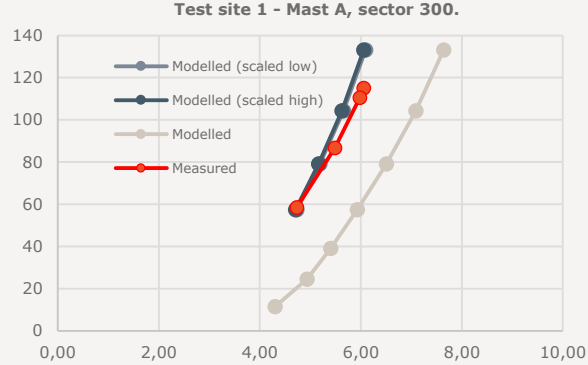
> Test site 1

Run 5

- > Cross prediction error
- > **Modelled vs. measured shear**

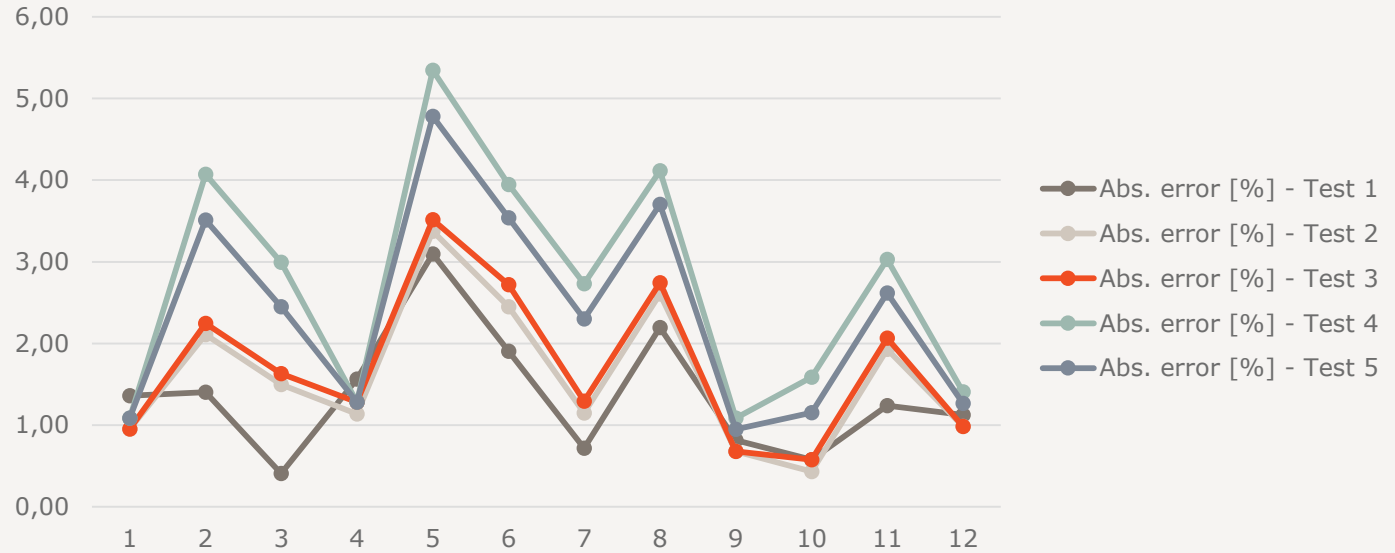
| Run 5 - C1 + Turb | |
|-------------------|-------------------|
| C1 | 0.005/0.003/0.001 |
| C2 | 0.005/0.003/0.001 |
| Turbulence | TRUE |
| Z | 6 |

| | Measured shear | Modelled shear | Difference |
|--------|----------------|----------------|------------|
| Mast A | 0.366 | 0.298 | 0.068 |
| Mast B | 0.290 | 0.246 | 0.044 |
| Mast C | 0.300 | 0.220 | 0.079 |
| Mast D | 0.321 | 0.212 | 0.109 |



Results

> Test site 1



| Run 1 - Default run | Run 2 - Default forest run | | Run 3 - Turbulence test | | Run 4 - C1 | | Run 5 - C1 + Turb | |
|---------------------|----------------------------|-------------------|-------------------------|-------------------|------------|-------------------|-------------------|-------------------|
| No forest model | C1 | 0/0/0 | C1 | 0/0/0 | C1 | 0.005/0.003/0.001 | C1 | 0.005/0.003/0.001 |
| | C2 | 0.005/0.005/0.005 | C2 | 0.005/0.005/0.005 | C2 | 0.005/0.003/0.001 | C2 | 0.005/0.003/0.001 |
| | Turbulence | FALSE | Turbulence | TRUE | Turbulence | FALSE | Turbulence | TRUE |
| | Z | 6 | Z | 6 | Z | 6 | Z | 6 |

Results

> Test site 2

Run 1

- > **Cross prediction error**
- > Modelled vs. measured shear

| Run 1 - Default run | |
|---------------------|--|
| No forest model | |
| | |
| | |

| Reference | Target | Reference measured | Target measured | Target modelled | Abs. error |
|--------------------------------------|--------|--------------------|-----------------|-----------------|------------|
| | | [m/s] | [m/s] | [m/s] | [%] |
| A | B | 7.68 | 7.65 | 7.65 | 0.00 |
| A | C | 7.76 | 7.89 | 7.66 | 2.92 |
| A | D | 7.72 | 7.84 | 7.6 | 3.06 |
| B | A | 7.67 | 7.69 | 7.7 | 0.13 |
| B | C | 7.71 | 7.86 | 7.64 | 2.80 |
| B | D | 7.73 | 7.84 | 7.63 | 2.68 |
| C | A | 7.83 | 7.65 | 7.91 | 3.40 |
| C | B | 7.8 | 7.6 | 7.84 | 3.16 |
| C | D | 7.76 | 7.74 | 7.72 | 0.26 |
| D | A | 7.79 | 7.63 | 7.93 | 3.93 |
| D | B | 7.79 | 7.62 | 7.89 | 3.54 |
| D | C | 7.76 | 7.77 | 7.79 | 0.26 |
| Weighted error all cross-predictions | | | | | 2.17 |

Results

> Test site 2

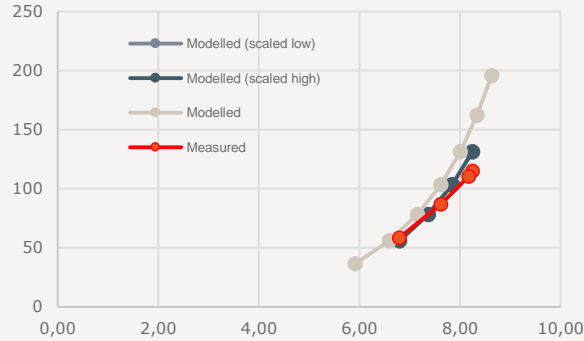
Run 1

- > Cross prediction error
- > **Modelled vs. measured shear**

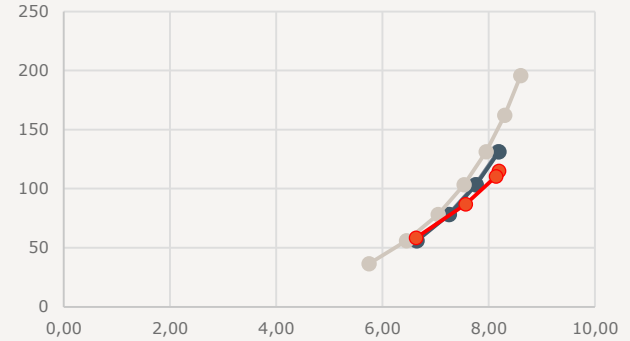
| Run 1 - Default run | |
|---------------------|--|
| No forest model | |
| | |
| | |

| | Measured shear | Modelled shear | Difference |
|--------|----------------|----------------|------------|
| Mast A | 0.288 | 0.235 | 0.053 |
| Mast B | 0.312 | 0.253 | 0.059 |
| Mast C | 0.299 | 0.227 | 0.073 |
| Mast D | 0.307 | 0.212 | 0.094 |

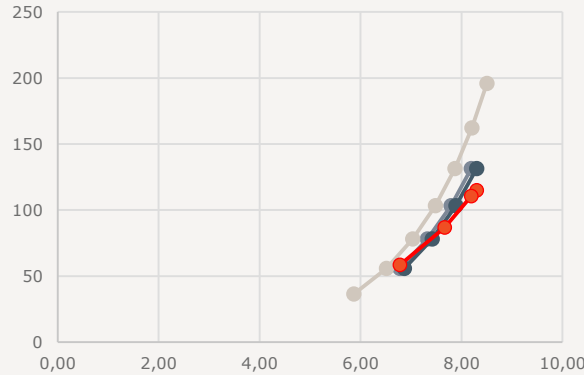
Test site 1 - Mast A, sector 300.



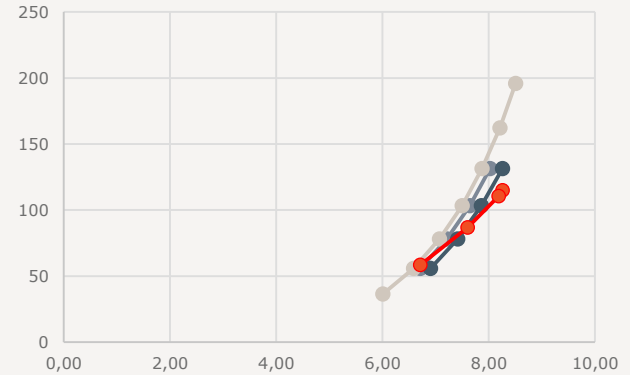
Test site 1 - Mast B, sector 300.



Test site 1 - Mast C, sector 300.



Test site 1 - Mast D, sector 300.



Results

> Test site 2

Run 2

- > Cross prediction error
- > Modelled vs. measured shear

| Run 2 - Default forest run | |
|----------------------------|-------------------|
| C1 | 0/0/0 |
| C2 | 0.005/0.005/0.005 |
| Turbulence | FALSE |
| Z | 6 |

| Reference | Target | Reference measured | Target measured | Target modelled | Abs. error |
|--------------------------------------|--------|--------------------|-----------------|-----------------|------------|
| | | [m/s] | [m/s] | [m/s] | [%] |
| A | B | 7.68 | 7.65 | 7.64 | 0.13 |
| A | C | 7.76 | 7.89 | 7.69 | 2.53 |
| A | D | 7.72 | 7.84 | 7.64 | 2.55 |
| B | A | 7.67 | 7.69 | 7.72 | 0.39 |
| B | C | 7.71 | 7.86 | 7.69 | 2.16 |
| B | D | 7.73 | 7.84 | 7.69 | 1.91 |
| C | A | 7.83 | 7.65 | 7.9 | 3.27 |
| C | B | 7.8 | 7.6 | 7.83 | 3.03 |
| C | D | 7.76 | 7.74 | 7.74 | 0.00 |
| D | A | 7.79 | 7.63 | 7.88 | 3.28 |
| D | B | 7.79 | 7.62 | 7.83 | 2.76 |
| D | C | 7.76 | 7.77 | 7.77 | 0.00 |
| Weighted error all cross-predictions | | | | | 1.83 |

Results

> Test site 2

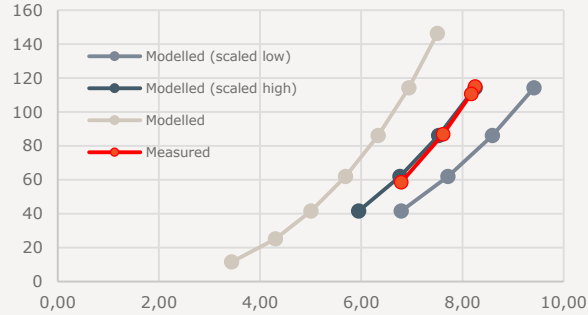
Run 2

- > Cross prediction error
- > **Modelled vs. measured shear**

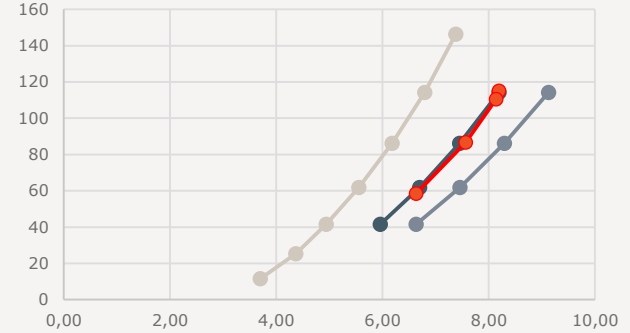
| Run 2 - Default forest run | |
|----------------------------|-------------------|
| C1 | 0/0/0 |
| C2 | 0.005/0.005/0.005 |
| Turbulence | FALSE |
| Z | 6 |

| | Measured shear | Modelled shear | Difference |
|--------|----------------|----------------|------------|
| Mast A | 0.288 | 0.324 | -0.036 |
| Mast B | 0.312 | 0.329 | -0.017 |
| Mast C | 0.299 | 0.278 | 0.022 |
| Mast D | 0.307 | 0.246 | 0.061 |

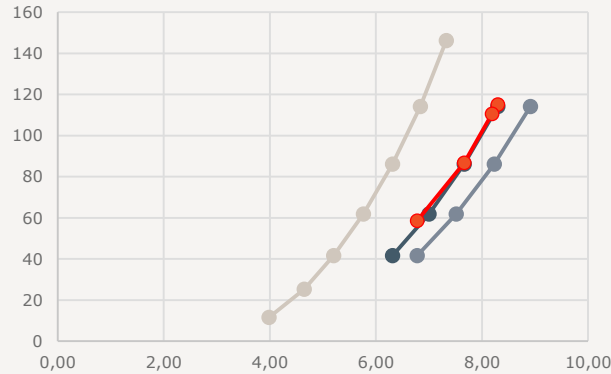
Test site 1 - Mast A, sector 300.



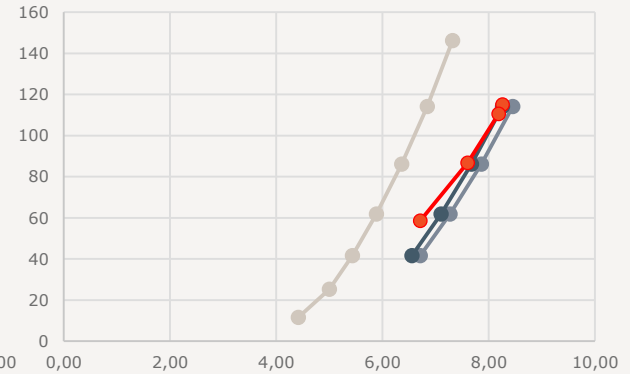
Test site 1 - Mast B, sector 300.



Test site 1 - Mast C, sector 300.



Test site 1 - Mast D, sector 300.



Results

> Test site 2

Run 3

- > Cross prediction error
- > Modelled vs. measured shear

| Run 3 - Turbulence test | |
|-------------------------|-------------------|
| C1 | 0/0/0 |
| C2 | 0.005/0.005/0.005 |
| Turbulence | TRUE |
| Z | 6 |

| Reference | Target | Reference measured | Target measured | Target modelled | Abs. error |
|--------------------------------------|--------|--------------------|-----------------|-----------------|------------|
| | | [m/s] | [m/s] | [m/s] | [%] |
| A | B | 7.68 | 7.65 | 7.63 | 0.26 |
| A | C | 7.76 | 7.89 | 7.71 | 2.28 |
| A | D | 7.72 | 7.84 | 7.66 | 2.30 |
| B | A | 7.67 | 7.69 | 7.72 | 0.39 |
| B | C | 7.71 | 7.86 | 7.71 | 1.91 |
| B | D | 7.73 | 7.84 | 7.7 | 1.79 |
| C | A | 7.83 | 7.65 | 7.87 | 2.88 |
| C | B | 7.8 | 7.6 | 7.78 | 2.37 |
| C | D | 7.76 | 7.74 | 7.73 | 0.13 |
| D | A | 7.79 | 7.63 | 7.88 | 3.28 |
| D | B | 7.79 | 7.62 | 7.83 | 2.76 |
| D | C | 7.76 | 7.77 | 7.78 | 0.13 |
| Weighted error all cross-predictions | | | | | 1.70 |

Results

> Test site 2

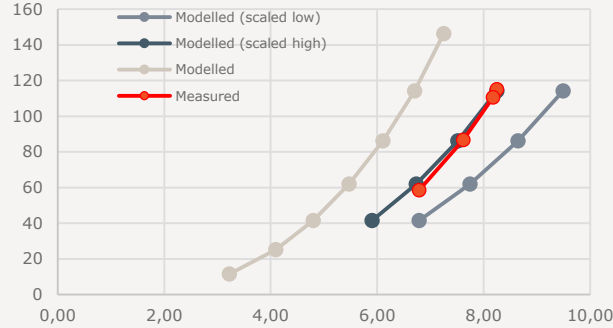
Run 3

- > Cross prediction error
- > **Modelled vs. measured shear**

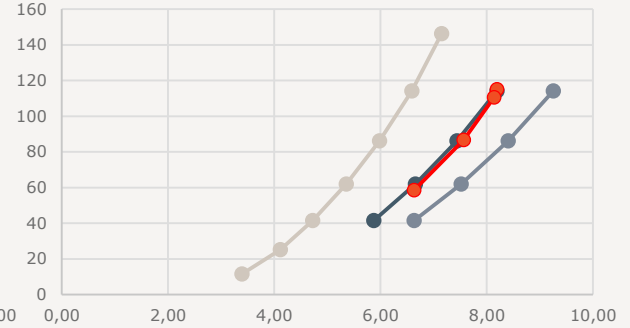
| Run 3 - Turbulence test | |
|-------------------------|-------------------|
| C1 | 0/0/0 |
| C2 | 0.005/0.005/0.005 |
| Turbulence | TRUE |
| Z | 6 |

| | Measured shear | Modelled shear | Difference |
|--------|----------------|----------------|------------|
| Mast A | 0.288 | 0.331 | -0.043 |
| Mast B | 0.312 | 0.338 | -0.026 |
| Mast C | 0.299 | 0.273 | 0.026 |
| Mast D | 0.307 | 0.243 | 0.064 |

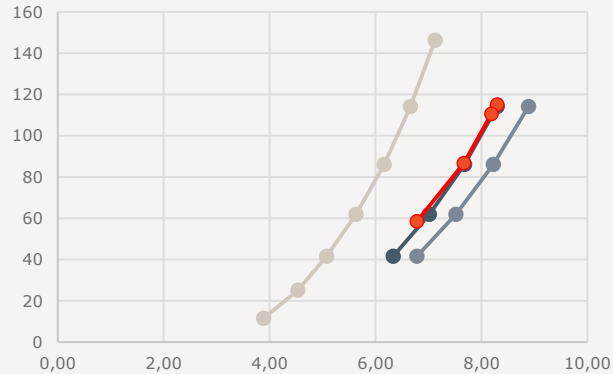
Test site 1 - Mast A, sector 300.



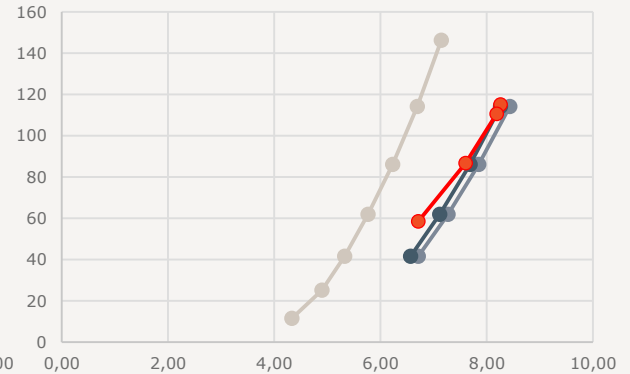
Test site 1 - Mast B, sector 300.



Test site 1 - Mast C, sector 300.



Test site 1 - Mast D, sector 300.



Results

> Test site 2

Run 4

- > Cross prediction error
- > Modelled vs. measured shear

| Run 4 - C1 | |
|------------|-------------------|
| C1 | 0.005/0.003/0.001 |
| C2 | 0.005/0.003/0.001 |
| Turbulence | FALSE |
| Z | 6 |

| Reference | Target | Reference measured | Target measured | Target modelled | Abs. error |
|--------------------------------------|--------|--------------------|-----------------|-----------------|------------|
| | | [m/s] | [m/s] | [m/s] | [%] |
| A | B | 7.68 | 7.65 | 7.64 | 0.13 |
| A | C | 7.76 | 7.89 | 7.51 | 4.82 |
| A | D | 7.72 | 7.84 | 7.48 | 4.59 |
| B | A | 7.67 | 7.69 | 7.72 | 0.39 |
| B | C | 7.71 | 7.86 | 7.5 | 4.58 |
| B | D | 7.73 | 7.84 | 7.52 | 4.08 |
| C | A | 7.83 | 7.65 | 8.08 | 5.62 |
| C | B | 7.8 | 7.6 | 8.01 | 5.39 |
| C | D | 7.76 | 7.74 | 7.74 | 0.00 |
| D | A | 7.79 | 7.63 | 8.06 | 5.64 |
| D | B | 7.79 | 7.62 | 8.01 | 5.12 |
| D | C | 7.76 | 7.77 | 7.76 | 0.13 |
| Weighted error all cross-predictions | | | | | 3.36 |

Results

> Test site 2

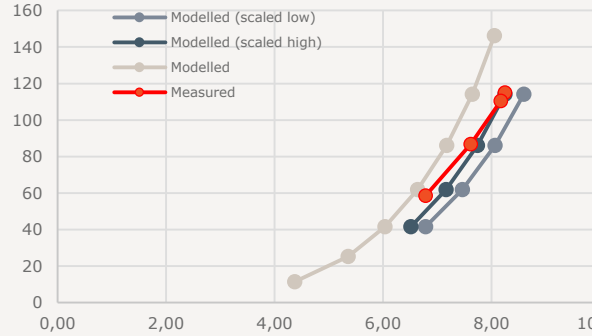
Run 4

- > Cross prediction error
- > **Modelled vs. measured shear**

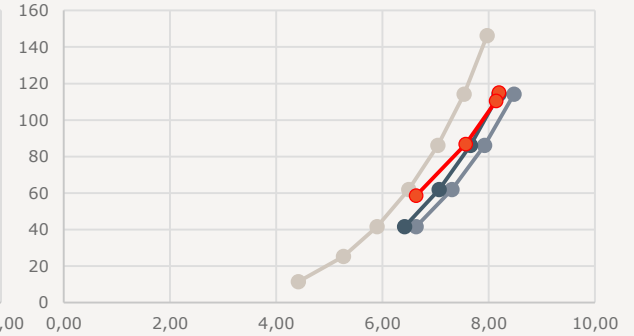
| Run 4 - C1 | |
|------------|-------------------|
| C1 | 0.005/0.003/0.001 |
| C2 | 0.005/0.003/0.001 |
| Turbulence | FALSE |
| Z | 6 |

| | Measured shear | Modelled shear | Difference |
|--------|----------------|----------------|------------|
| Mast A | 0.288 | 0.230 | 0.058 |
| Mast B | 0.312 | 0.242 | 0.070 |
| Mast C | 0.299 | 0.254 | 0.045 |
| Mast D | 0.307 | 0.233 | 0.074 |

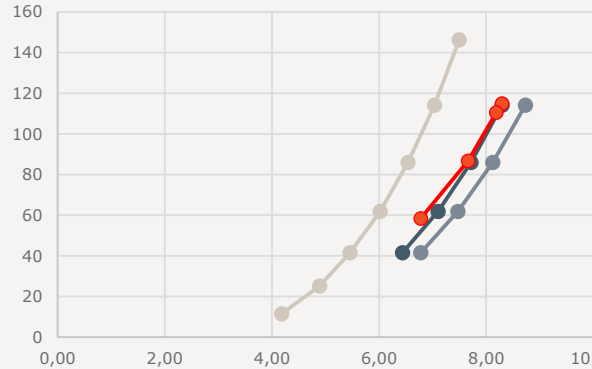
Test site 1 - Mast A, sector 300.



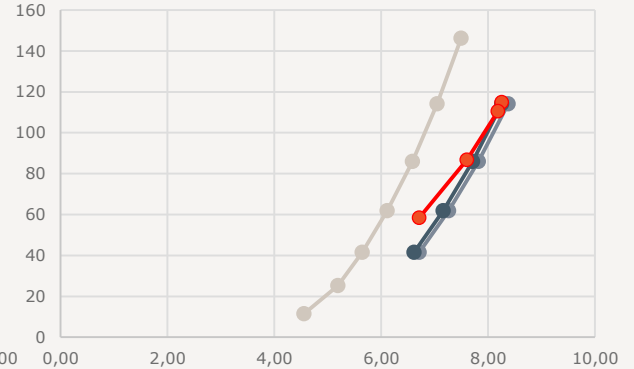
Test site 1 - Mast B, sector 300.



Test site 1 - Mast C, sector 300.

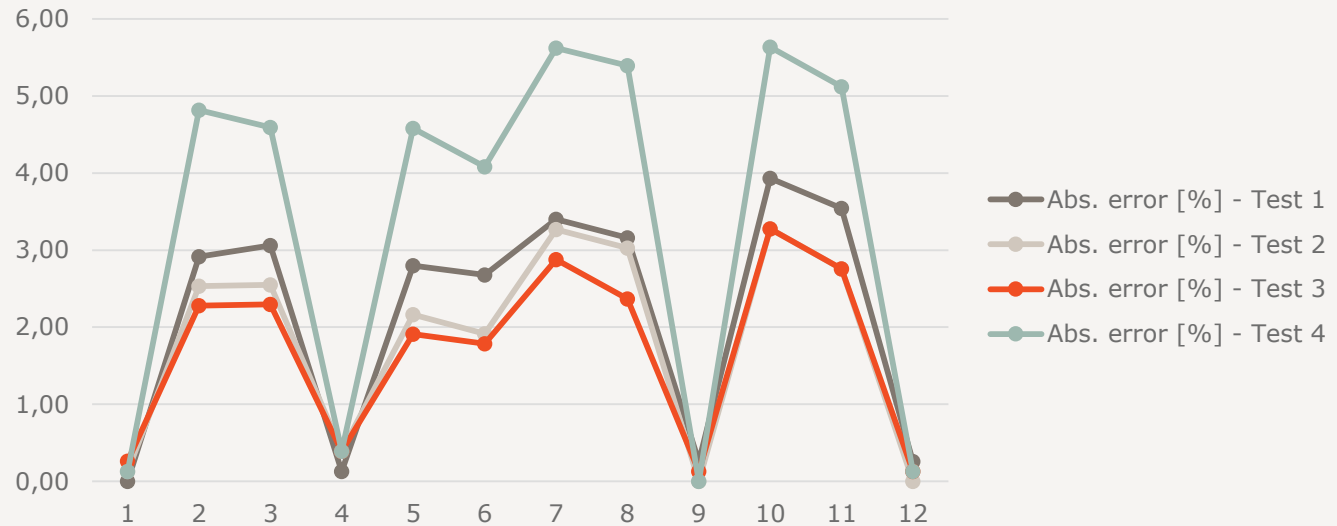


Test site 1 - Mast D, sector 300.



Results

> Test site 2



| Run 1 - Default run | Run 2 - Default forest run | | Run 3 - Turbulence test | | Run 4 - C1 | |
|---------------------|----------------------------|-------------------|-------------------------|-------------------|------------|-------------------|
| No forest model | C1 | 0/0/0 | C1 | 0/0/0 | C1 | 0.005/0.003/0.001 |
| | C2 | 0.005/0.005/0.005 | C2 | 0.005/0.005/0.005 | C2 | 0.005/0.003/0.001 |
| | Turbulence | FALSE | Turbulence | TRUE | Turbulence | FALSE |
| | Z | 6 | Z | 6 | Z | 6 |

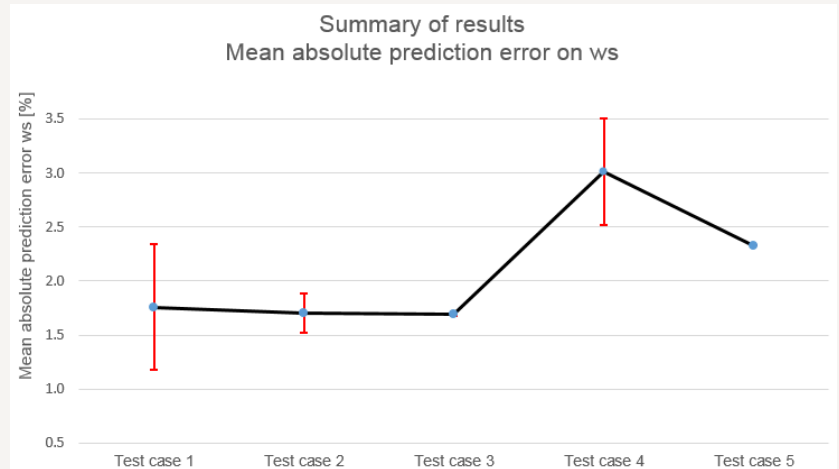
Summary

> Summary of results for all test cases

Based on our test cases:

- > First test site: better cross predictions without forest model. Second site: better cross prediction with forest model. On average better with forest model.
- > Better modelling of the shear by using forest model.
- > Changing resistive force C1 led to poorer result.
- > "Default" resistive force (0.005) + turbulence forest model led to accurate shear result and good cross prediction results.
- > Chosen roughness lengths seems to be good for test sites.

| Absolute prediction error | | | | |
|---------------------------|-------------|-------------|---------|--------------------|
| | Test Site 1 | Test site 2 | Average | Standard deviation |
| Test case 1 | 1.3 | 2.2 | 1.8 | 0.6 |
| Test case 2 | 1.6 | 1.8 | 1.7 | 0.2 |
| Test case 3 | 1.7 | 1.7 | 1.7 | 0.0 |
| Test case 4 | 2.7 | 3.4 | 3.0 | 0.5 |
| Test case 5 | 2.3 | Not run | 2.3 | - |



Summary

> Future work

Considering atmospheric stability.

Applying different solvers.

Adding turbulence intensity comparison results.

Applying different turbulence models.

Adding more test sites.

Adding more test cases.