

Results of the Blind Comparison

Risø DTU: **Andreas Bechmann** (andh@risoe.dtu.dk),
Pierre-Elouan Rethore, Mike Courtney, Hans E. Jørgensen,
Jacob Berg, Jakob Mann and Niels N. Sørensen
Vestas Technology R&D: Lars Chr. Christensen
and many others ...



Content

1. Introduction
2. Measurements & Simulations
3. Results
4. Analysis
5. Conclusions



Introduction: Purpose of Blind Comparison

- 1. Make The Bolund Data Visible**
- 2. Evaluate Flow Modeling Accuracy**
(TPWind: uncertainty less than 3% ¹)
- 3. Standardize Resource Assessment Modeling?**
(Top Priority of TPFWind)

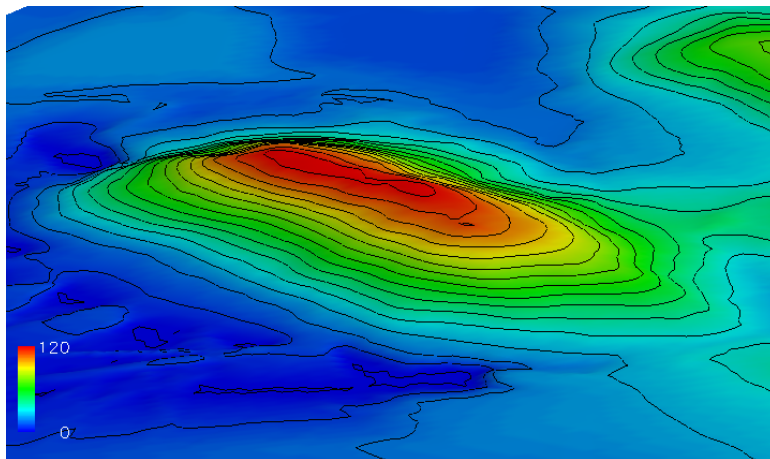
¹European Wind Energy Technology Platform.
Strategic research agenda, market deployment
strategy, from 2008 to 2030



Introduction: 1. The Bolund Data

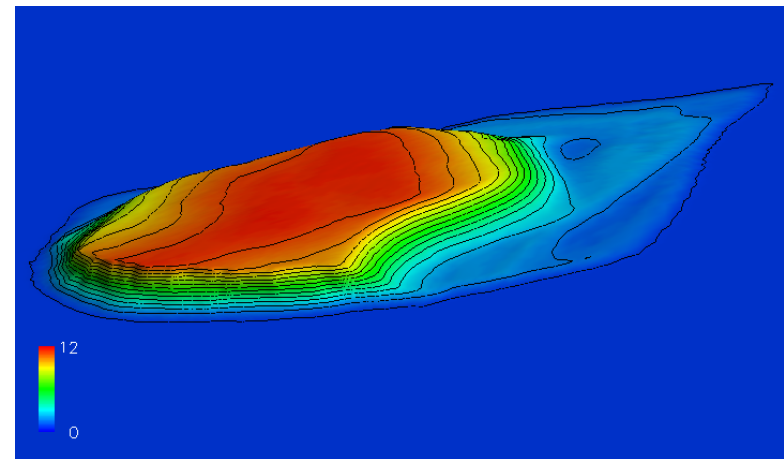
Askervein Experiment, 83

- Well-defined inflow conditions
- Well-defined and Uniform roughness
- 120m high
- Low hill / “simple” terrain



Bolund Experiment, 08

- Well-defined inflow conditions
- Well-defined roughness change
- 12m high
- Steep escarpment / “complex”



Introduction: 2. Evaluate Model Accuracy

Uncertainties:

- **Modeling** (Turb. model, Discretization, Experience)
- **Boundary Conditions** (Orography, Free wind description etc.)
- **Measurements**

Blind Comparison:

- **Evaluation of Modeling Accuracy** (Measure & BC Errors Minimized)
- **Evaluation of Different Approaches** (WAsP, CFD, Wind tunnel etc.)
- **Only constraint: Boundary Conditions** (Evaluation of state-of-the-art)

Introduction: 3. Standardize the Modeling

**52 Different Submissions,
52 Different Approaches,
52 Different Results!**

Model types:

- 3: Experimental method {
 - 1: Wind tunnel
 - 1: Flow channel
- 3: No answer
- 9: Linearized flow model {
 - 3: WAsP like
 - 5: WAsP Eng.
- 0: Mesoscale model
- 37: Non-linear CFD model {
 - 5: LES / hybrid RANS-LES
 - 7: RANS 1 eqn. (k-l, Spalart-Allmaras)
 - 25: RANS 2 eqn. (k-epsilon, k-omega)

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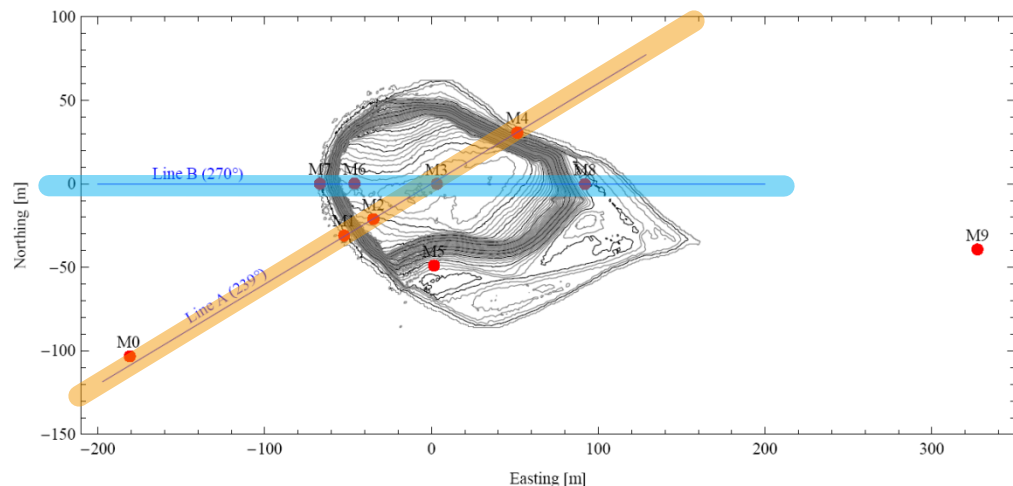


Measurements: Selected cases

data for 4 Cases:

1. 270 direction
2. 255 direction
3. 239 direction
4. 90 direction

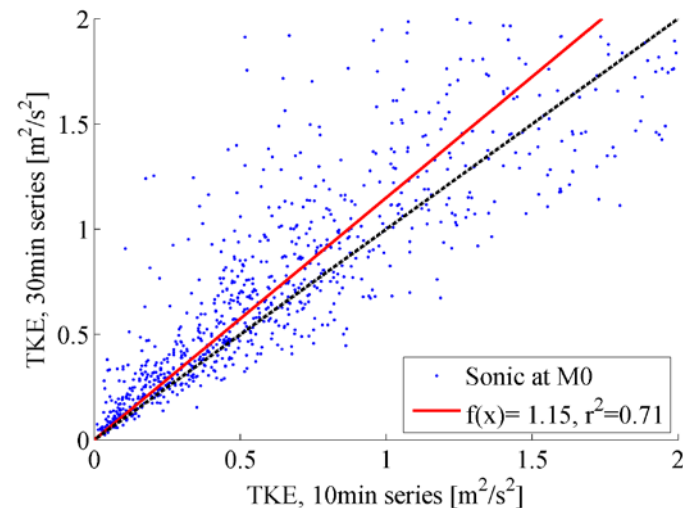
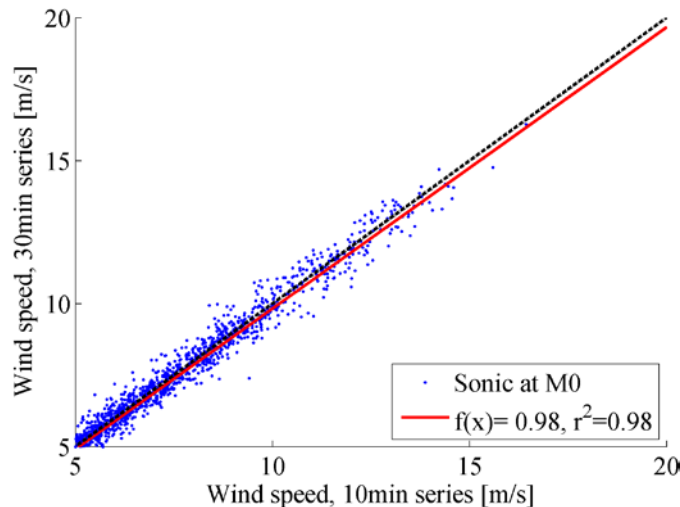
Mast. ID	2m	5m	9m	15m	Lidar
M0	C	C,S	C	C	-
M1	S	S	S	-	-
M2	S	S	C,S	-	L
M3	S	S	C,S	-	-
M4	S	S	S	-	-
M5	S	S	-	-	-
M6	S	S	C	-	-
M7	S	S	-	-	-
M8	S	S	C	-	-
M9	C	C,S	C	C	L



Measurements: Selecting Data

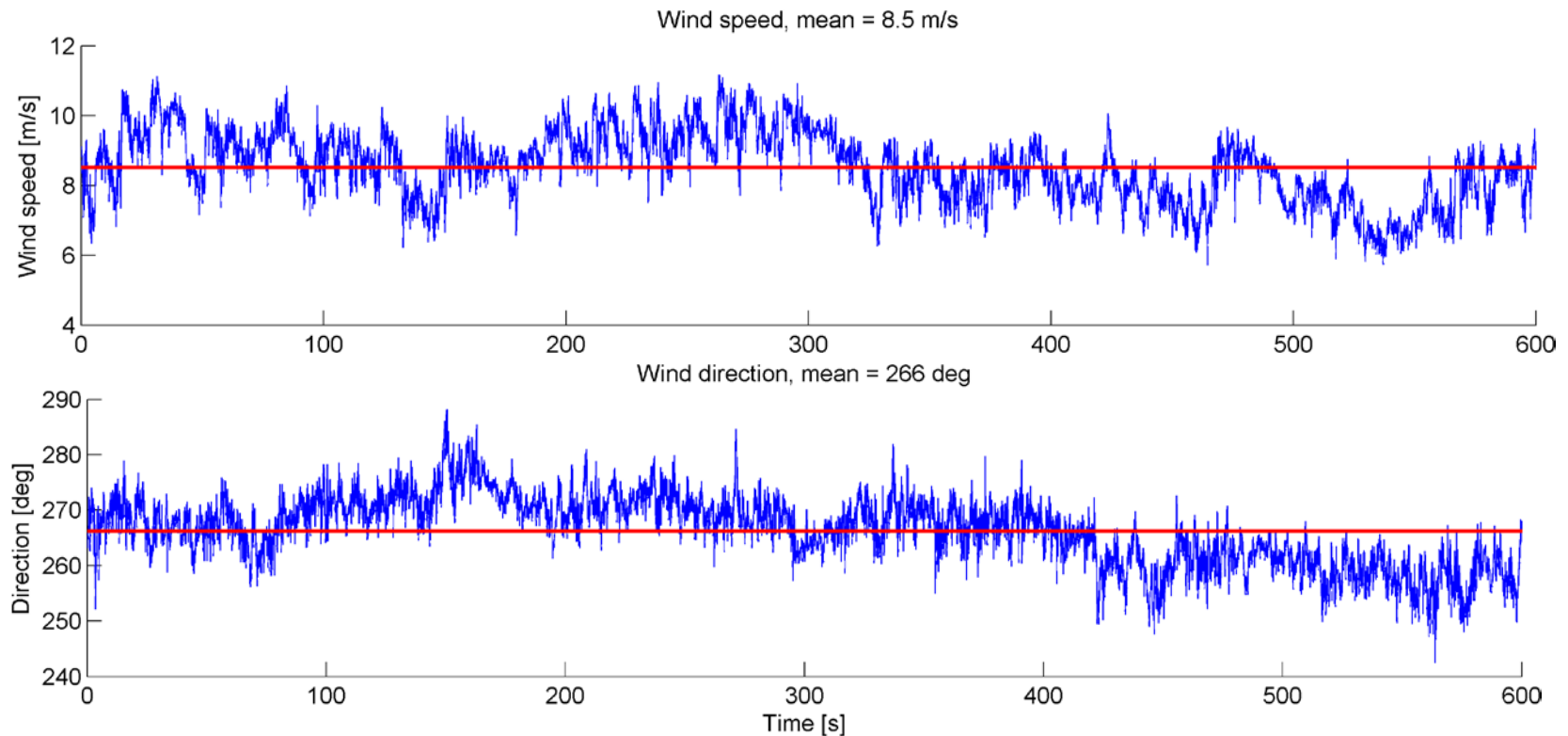
Selection Criteria (evaluated at upstream mast, M0/M9)

1. Wind direction: $\pm 8^\circ$
2. Monin-Obukhov length: $|1/L| < 0.004 \text{ m}^{-1}$ ($L > 250 \text{ m}$)
3. Water level: $\pm 0.4 \text{ m}$
4. Wind speed 5 m agl: $5 \text{ ms}^{-1} < s < 12 \text{ ms}^{-1}$ ($z_0 \approx 1 \cdot 5 \cdot 10^{-4} \text{ m}$, Charnock)
5. 10 min time series

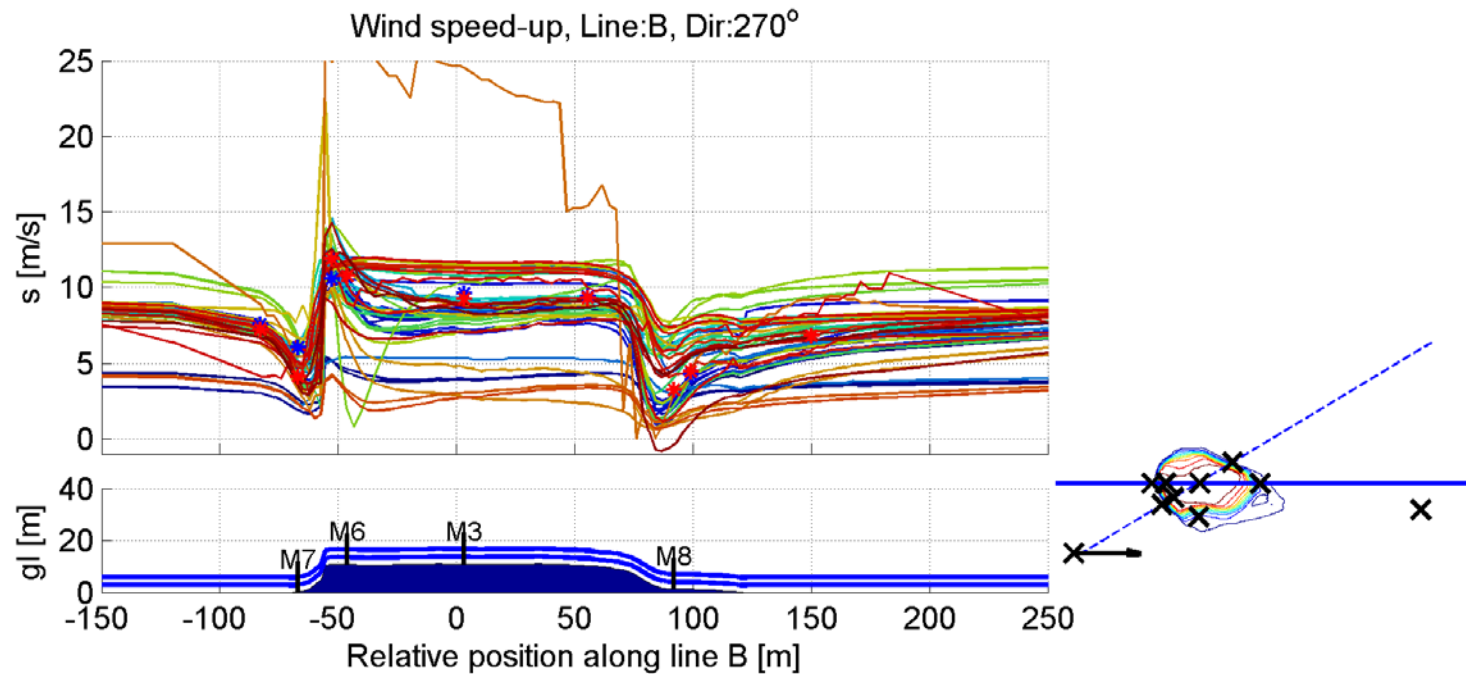


Measurements: Comparing with Simulation

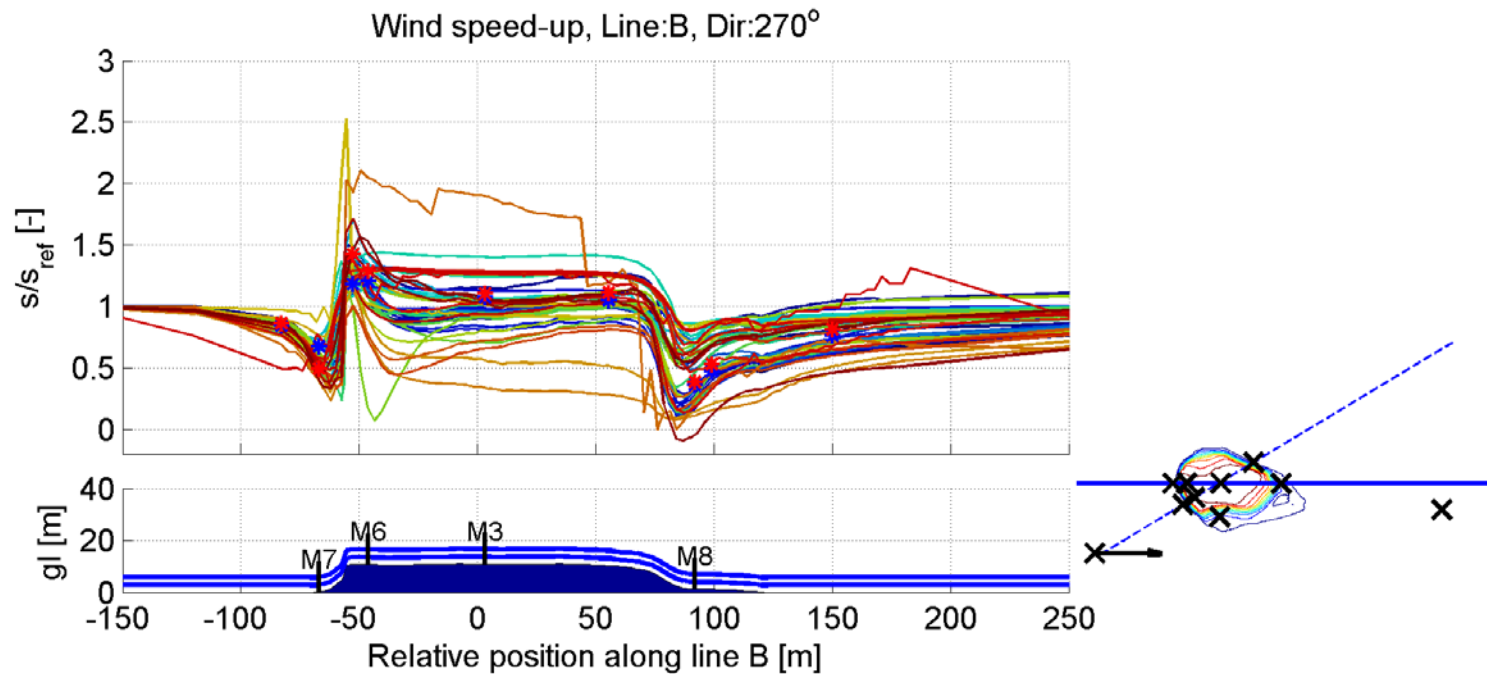
1. u^* : 0.4 / 0.469 ms^{-1} (42 time-series) Direction: 270 / 268.4
2. u^* : 0.4 / 0.582 ms^{-1} (25 time-series) Direction: 255 / 254.3
3. u^* : 0.4 / 0.356 ms^{-1} (9 time-series) Direction: 239 / 241.7
4. u^* : 0.5 / 0.509 ms^{-1} (19 time-series) Direction: 90 / 94.1



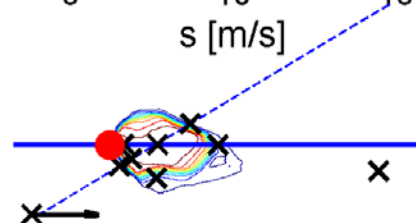
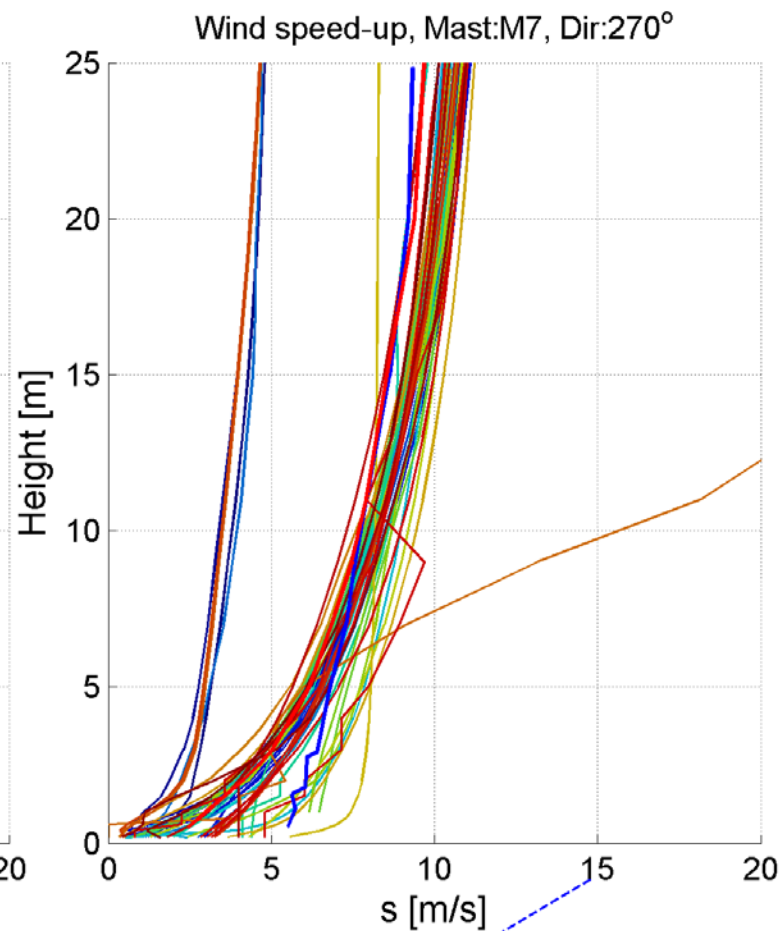
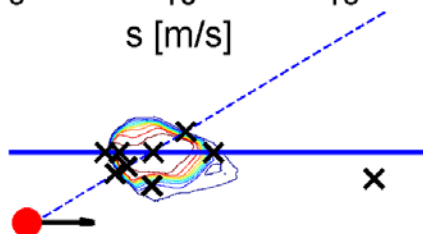
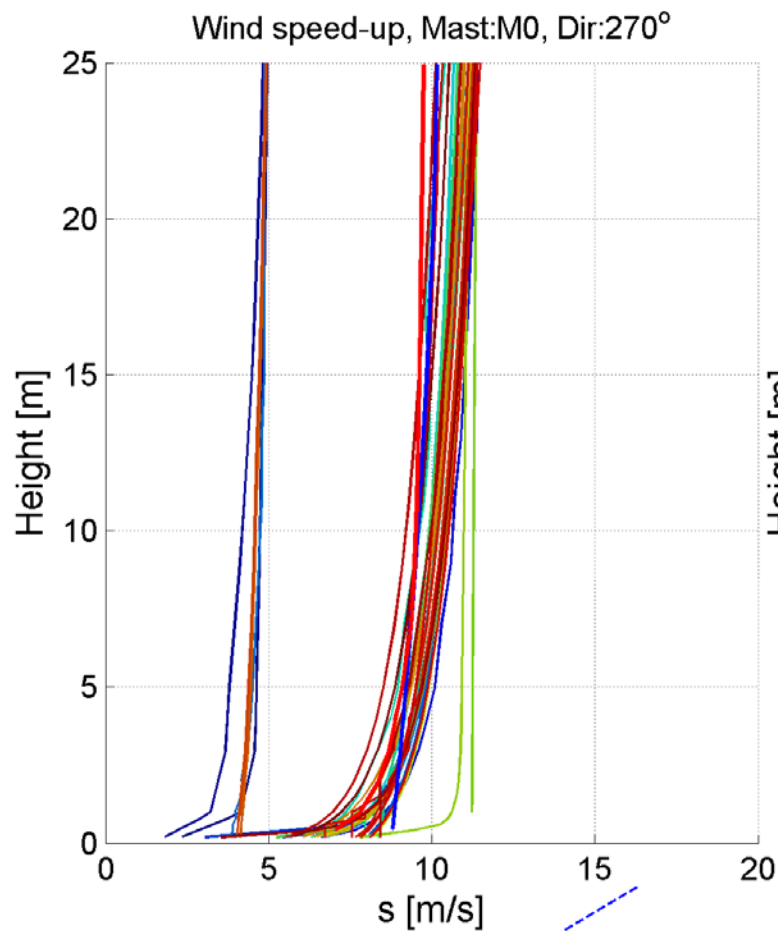
Simulation: Normalizing



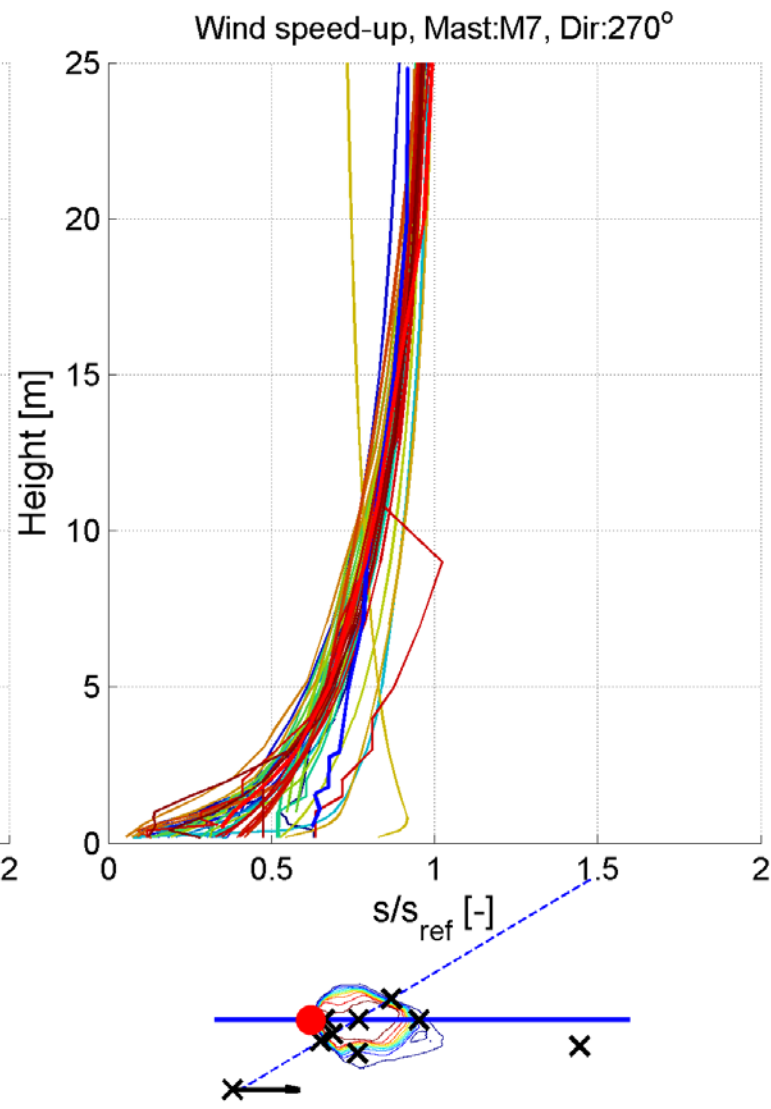
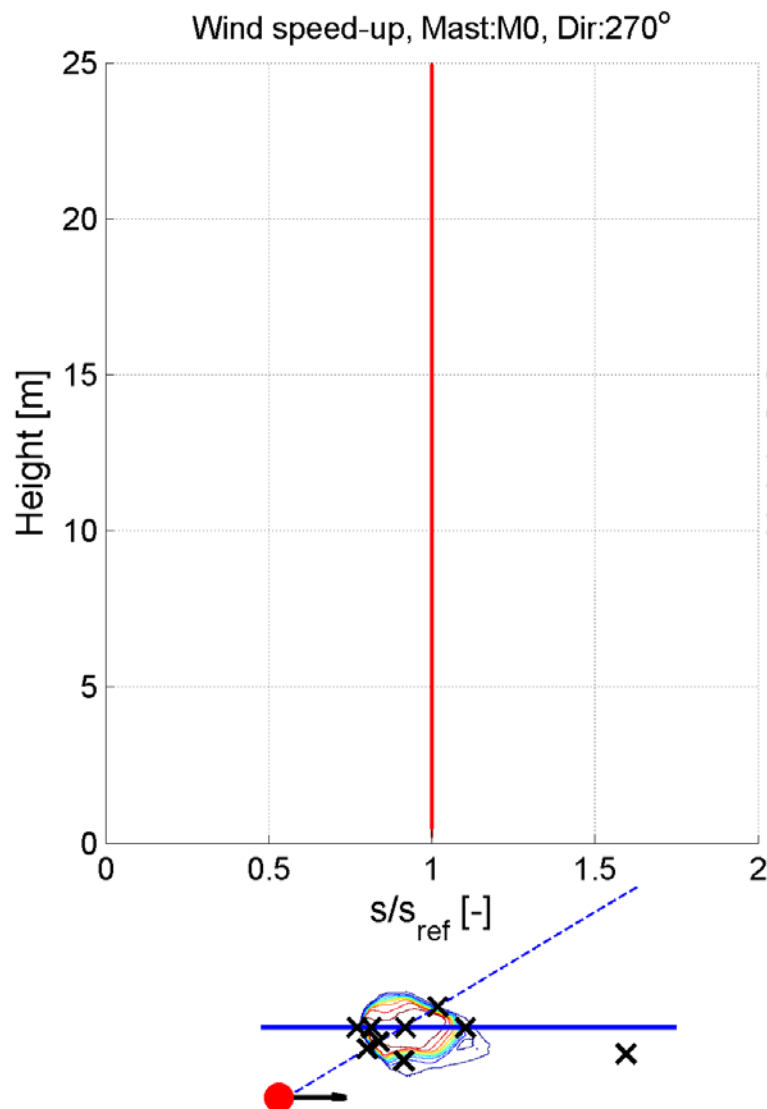
Simulation: Normalizing



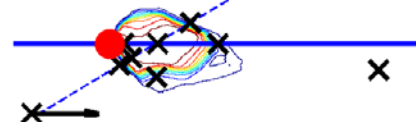
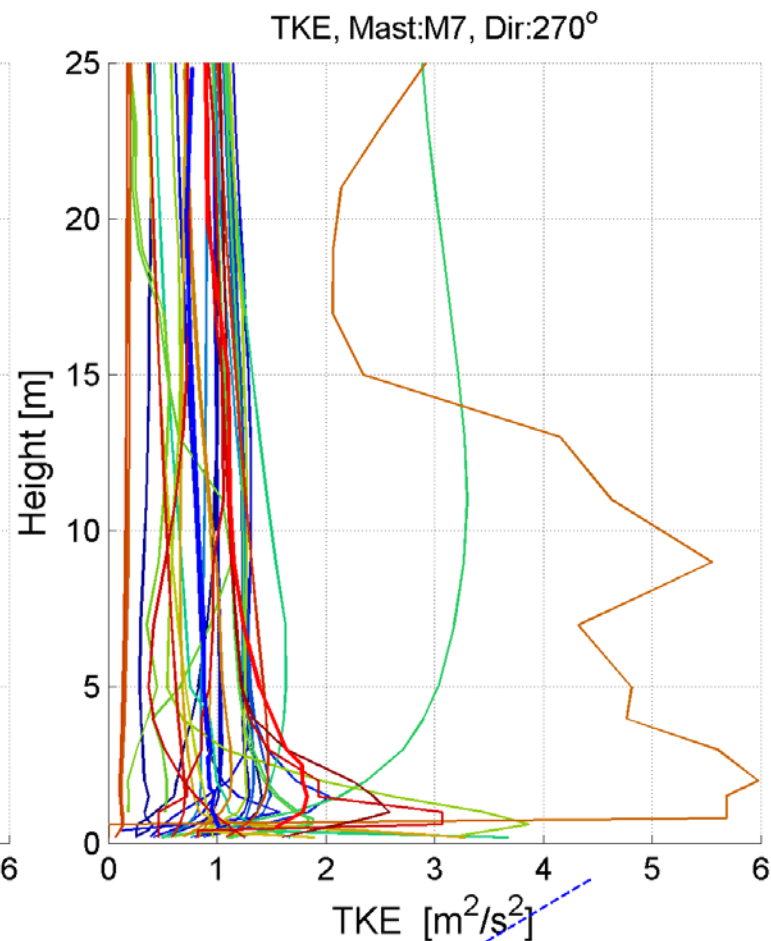
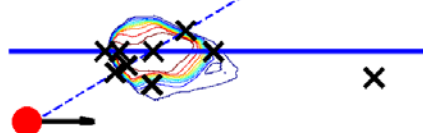
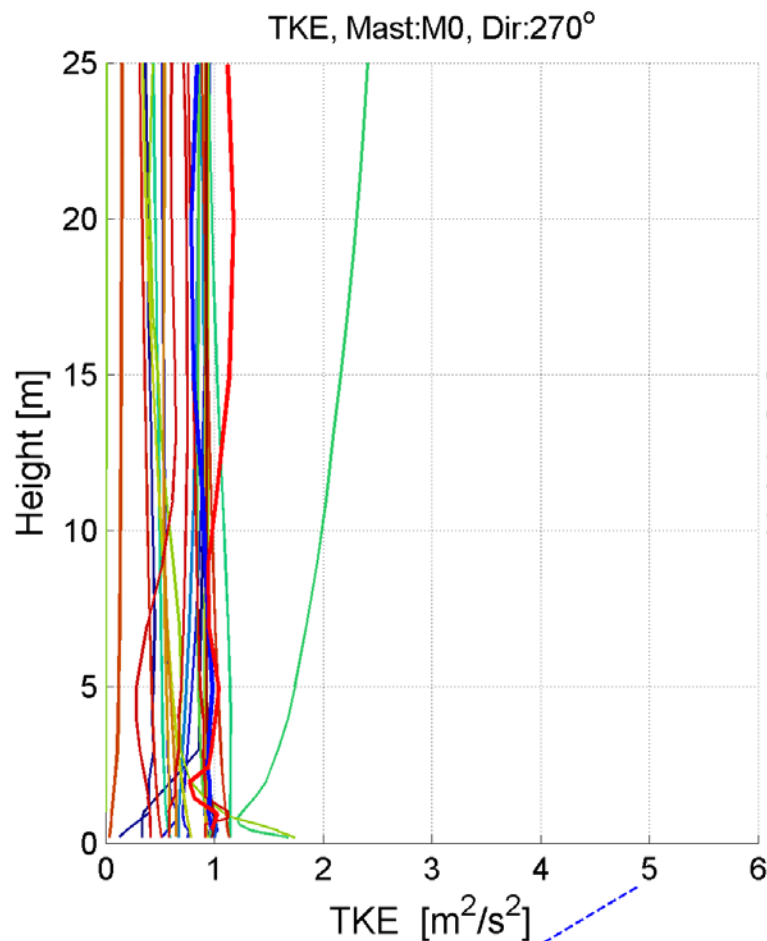
Simulation: Normalizing



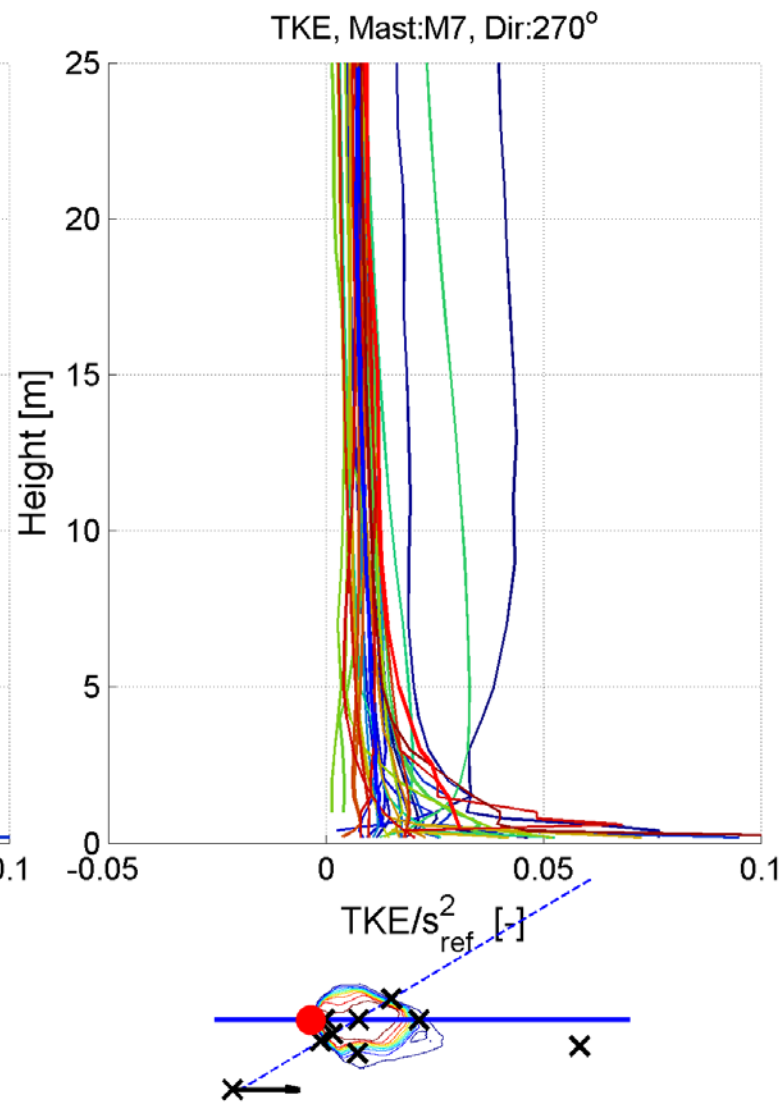
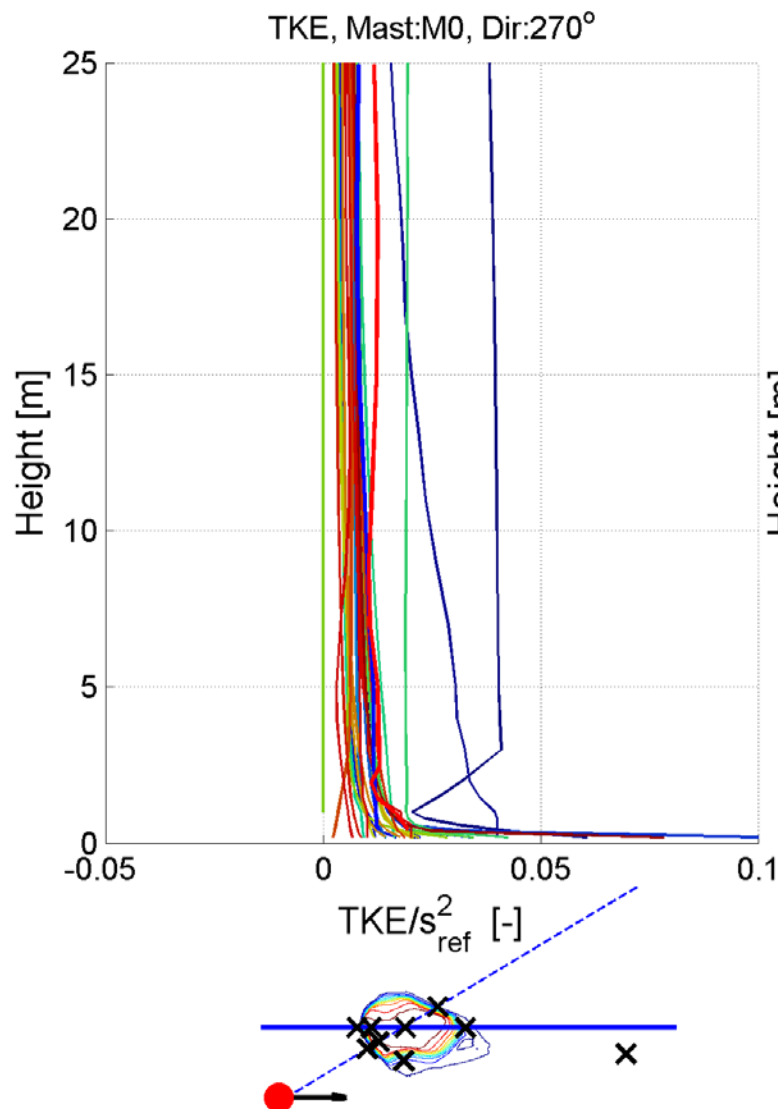
Simulation: Normalizing



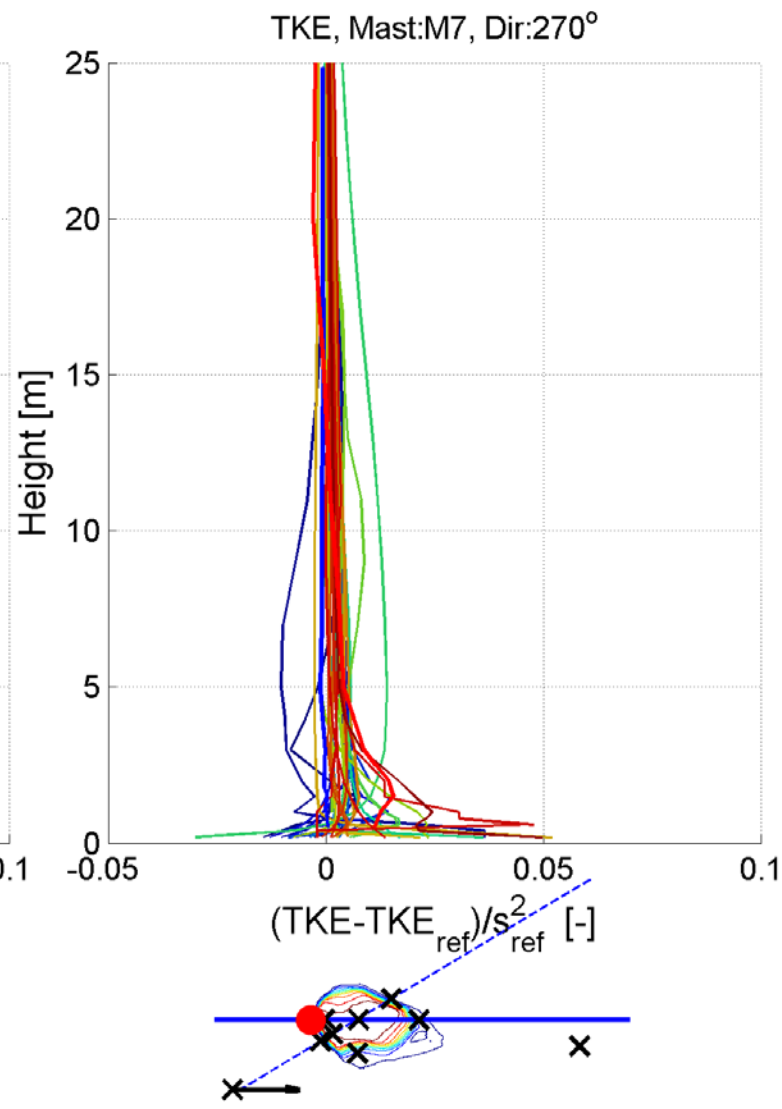
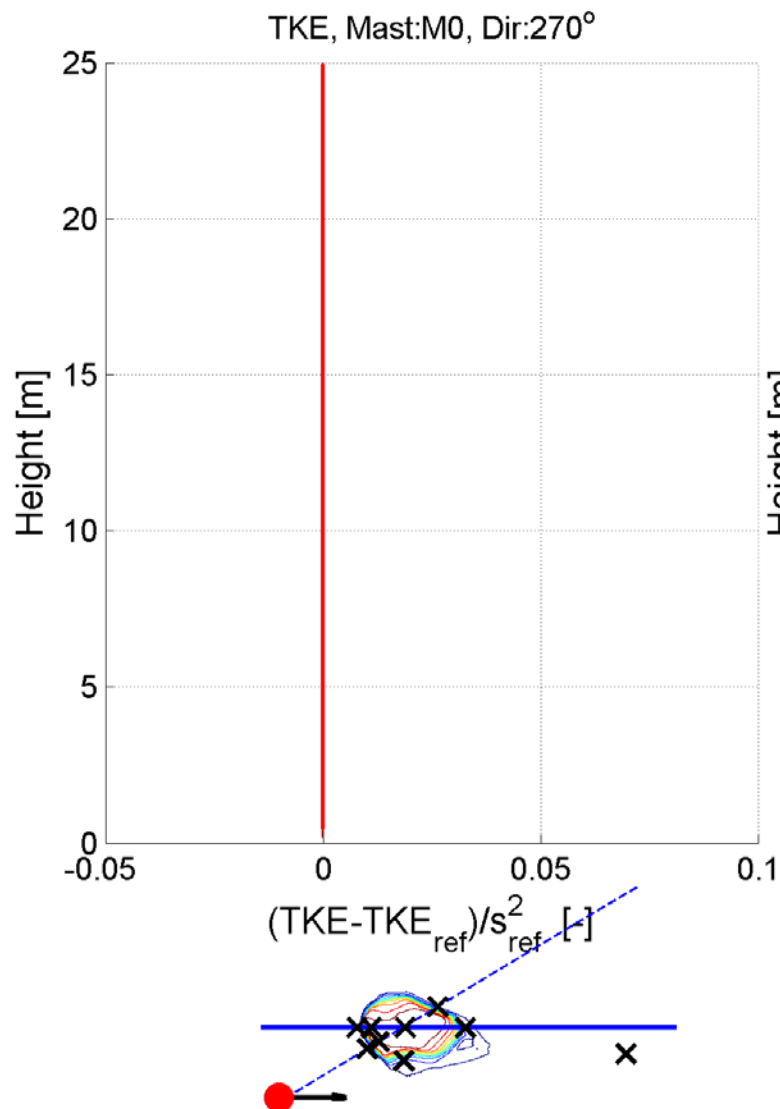
Simulation: Normalizing



Simulation: Normalizing



Simulation: Normalizing

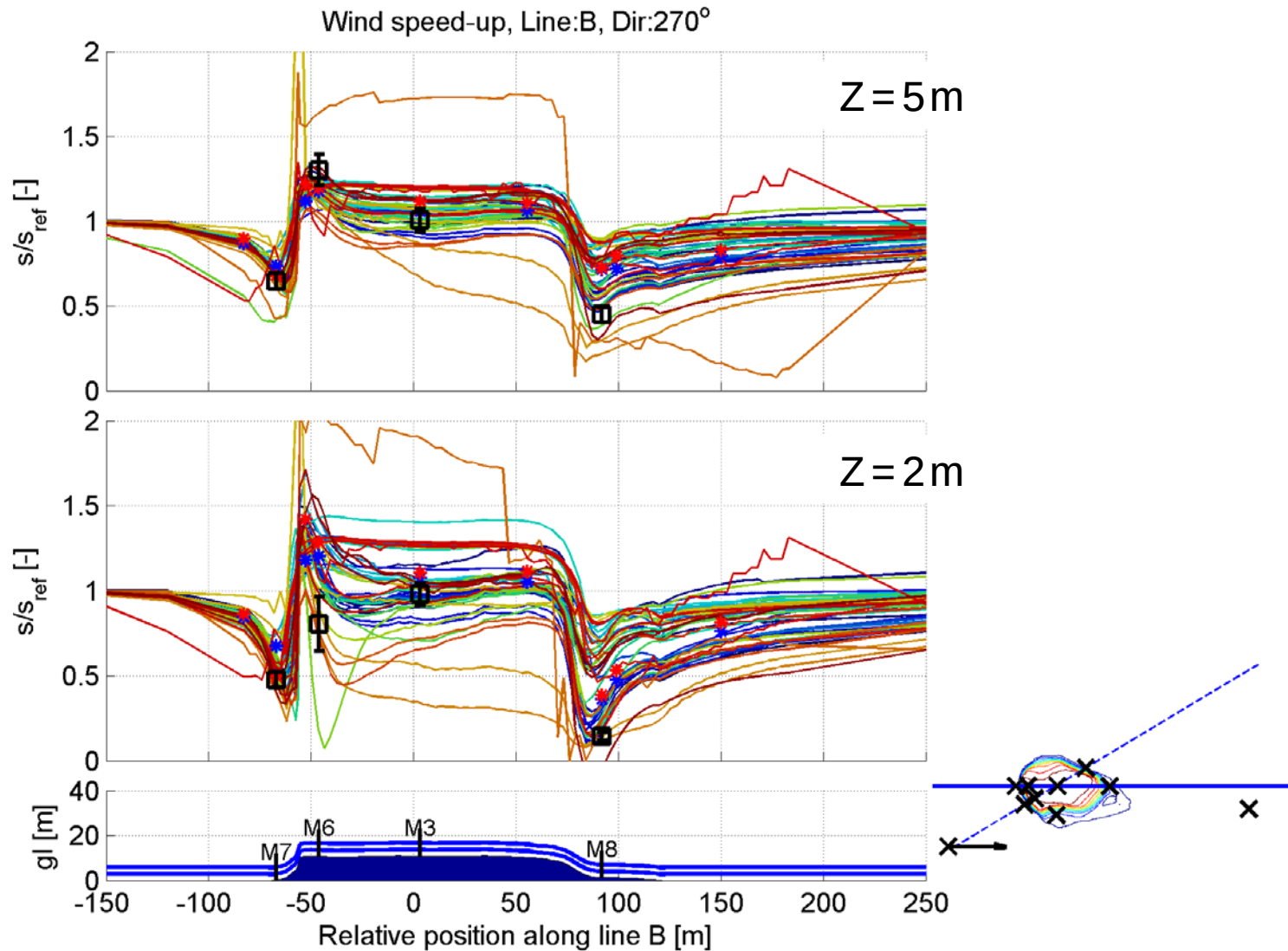


Content

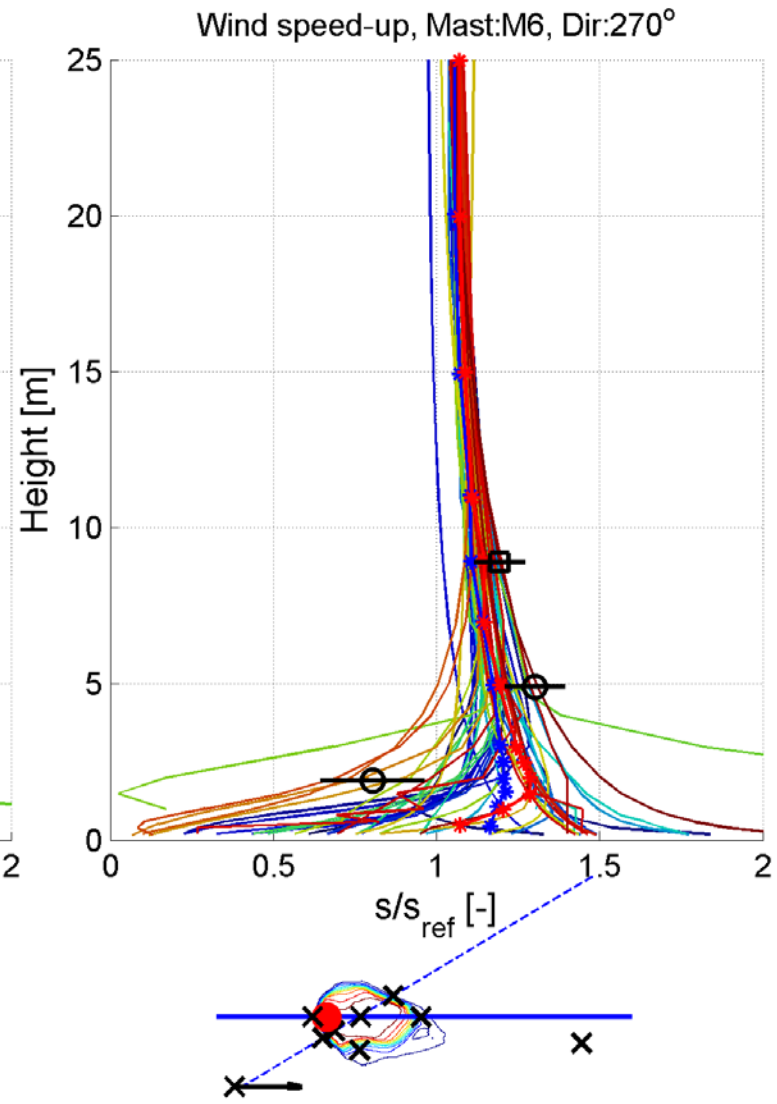
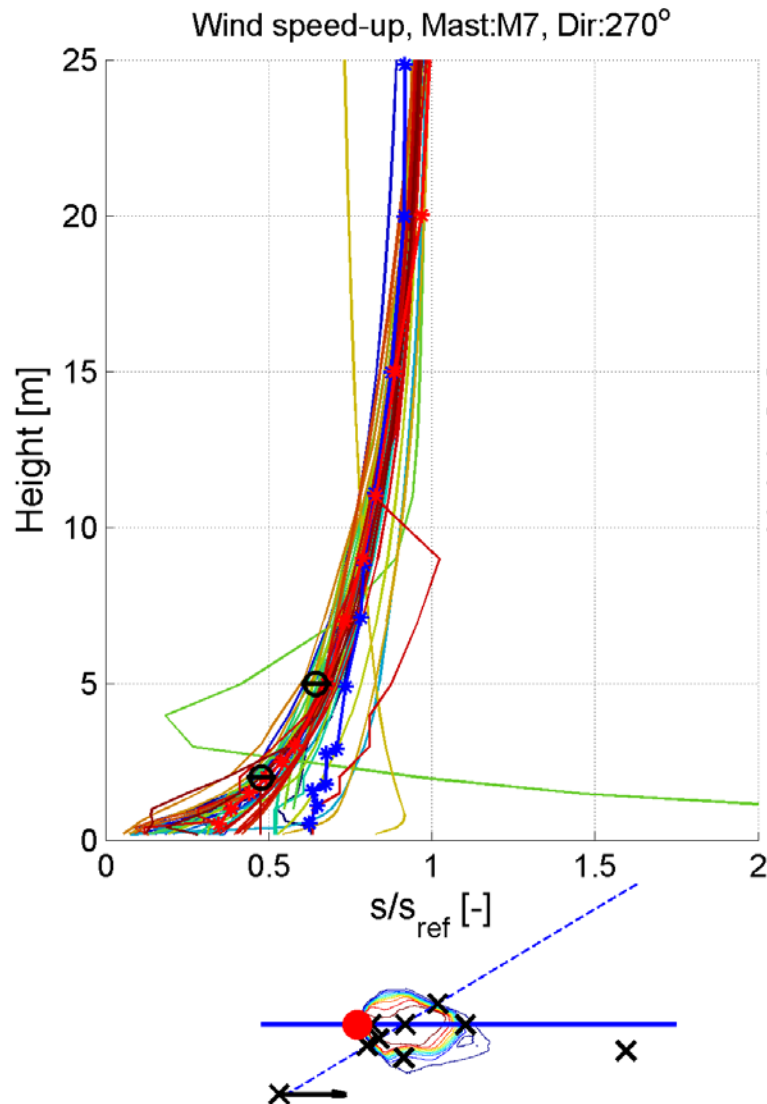
1. Introduction
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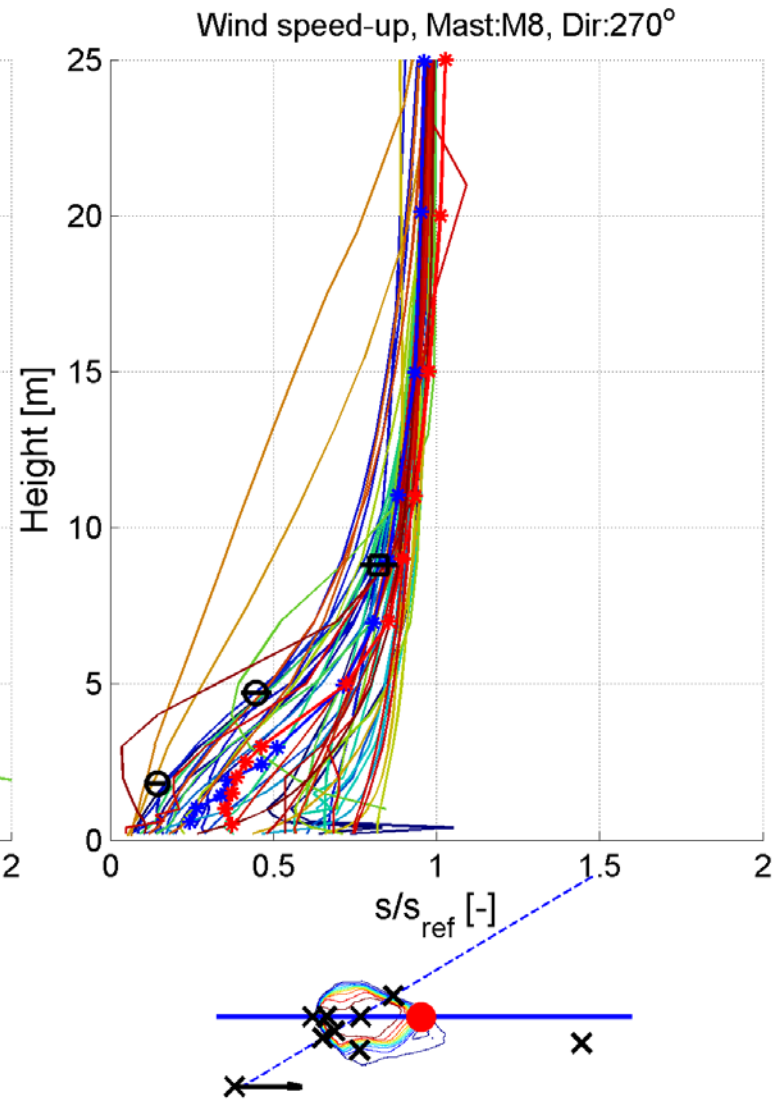
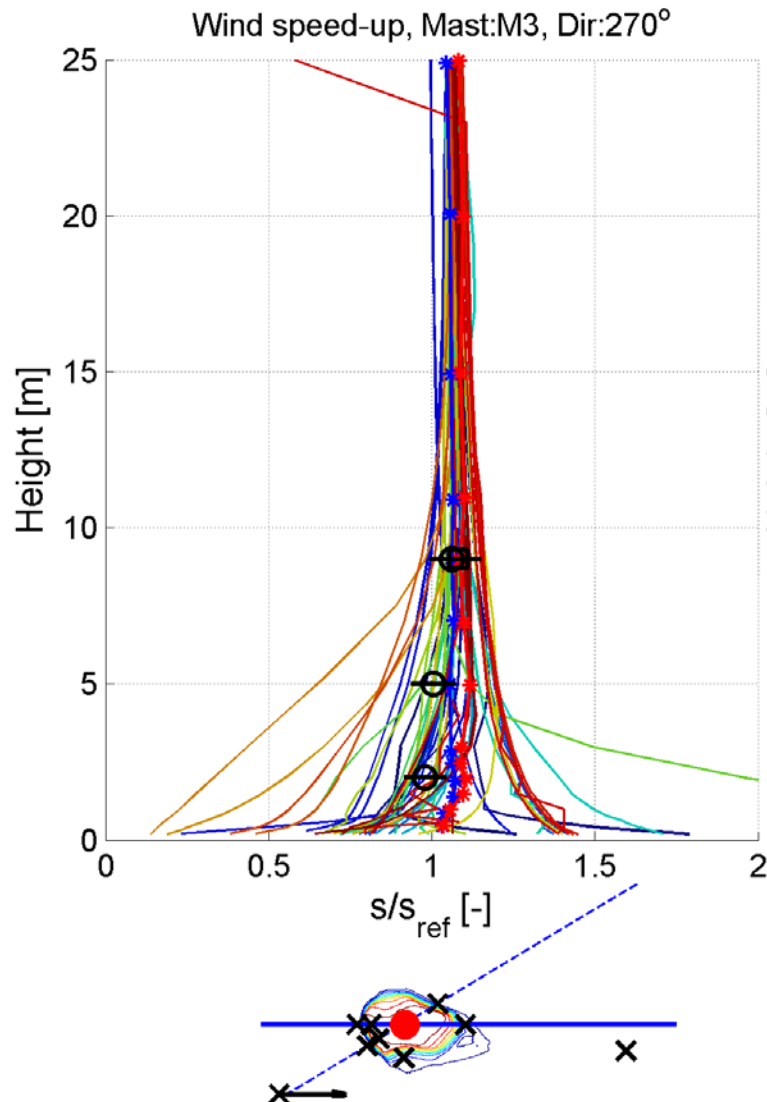
Results: Speed-up



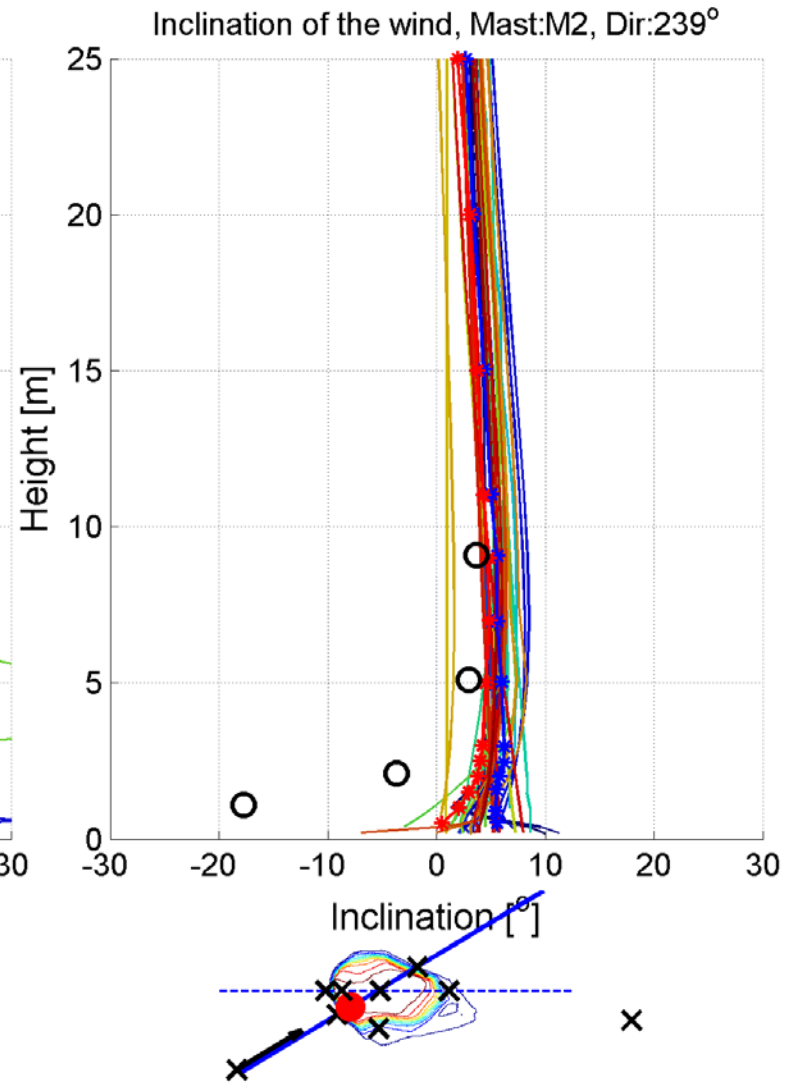
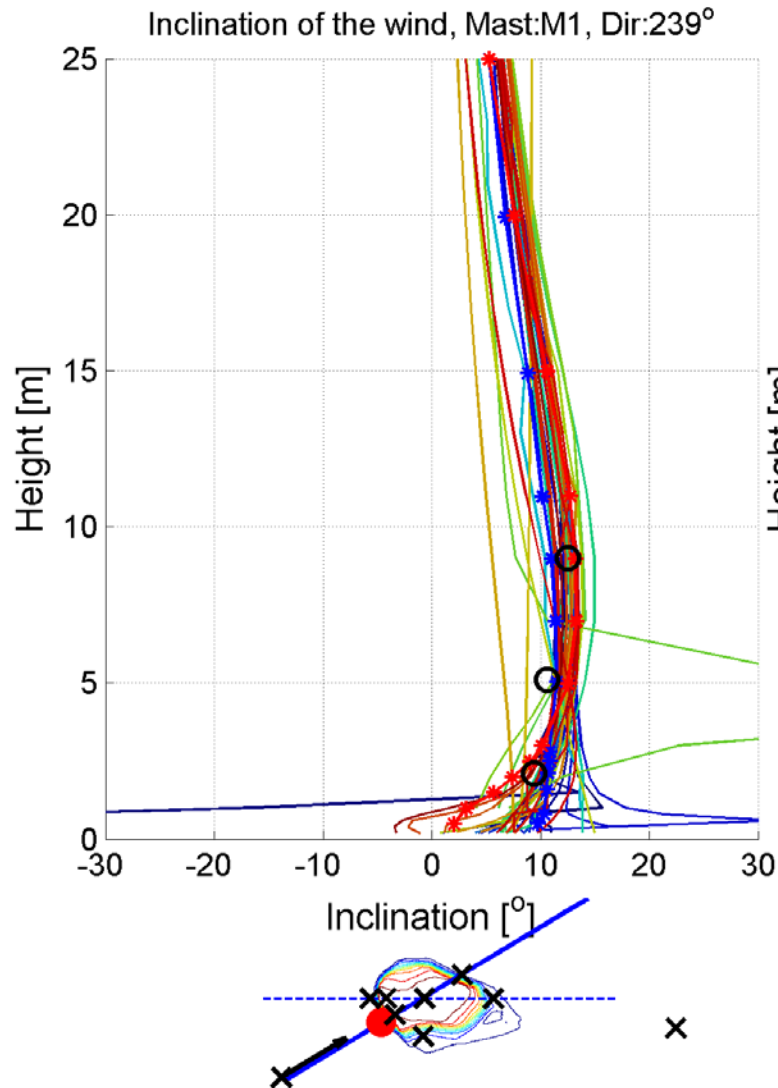
Results: Speed-up



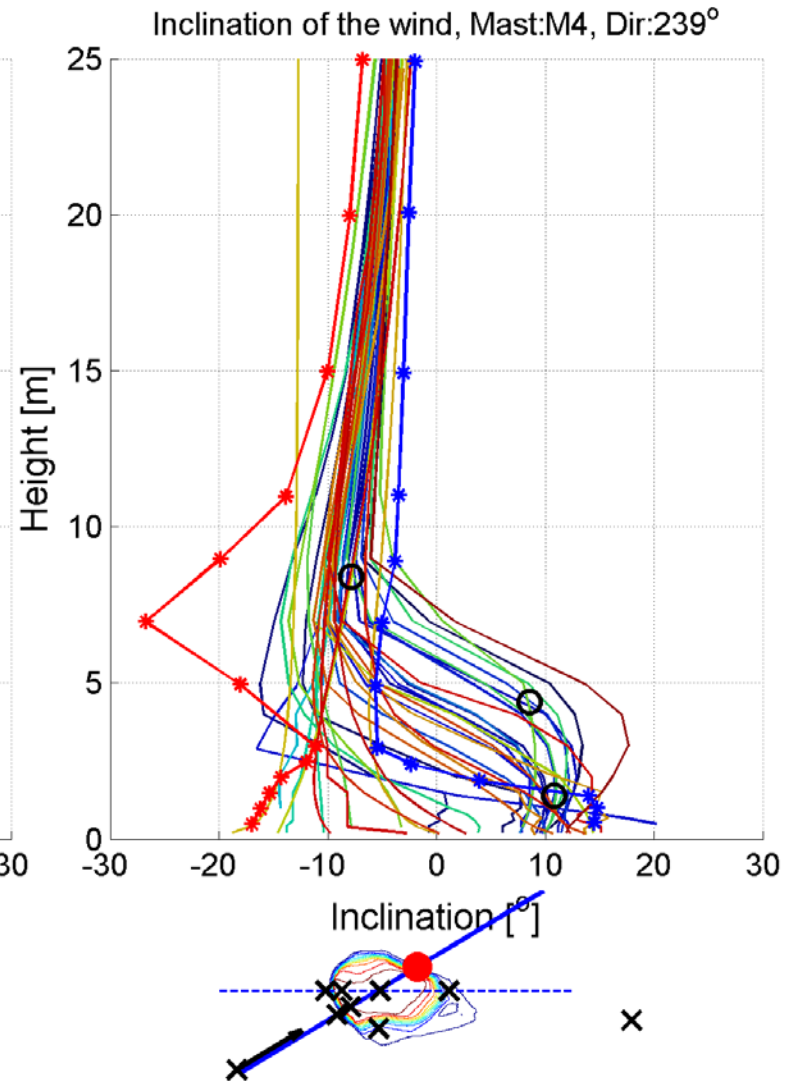
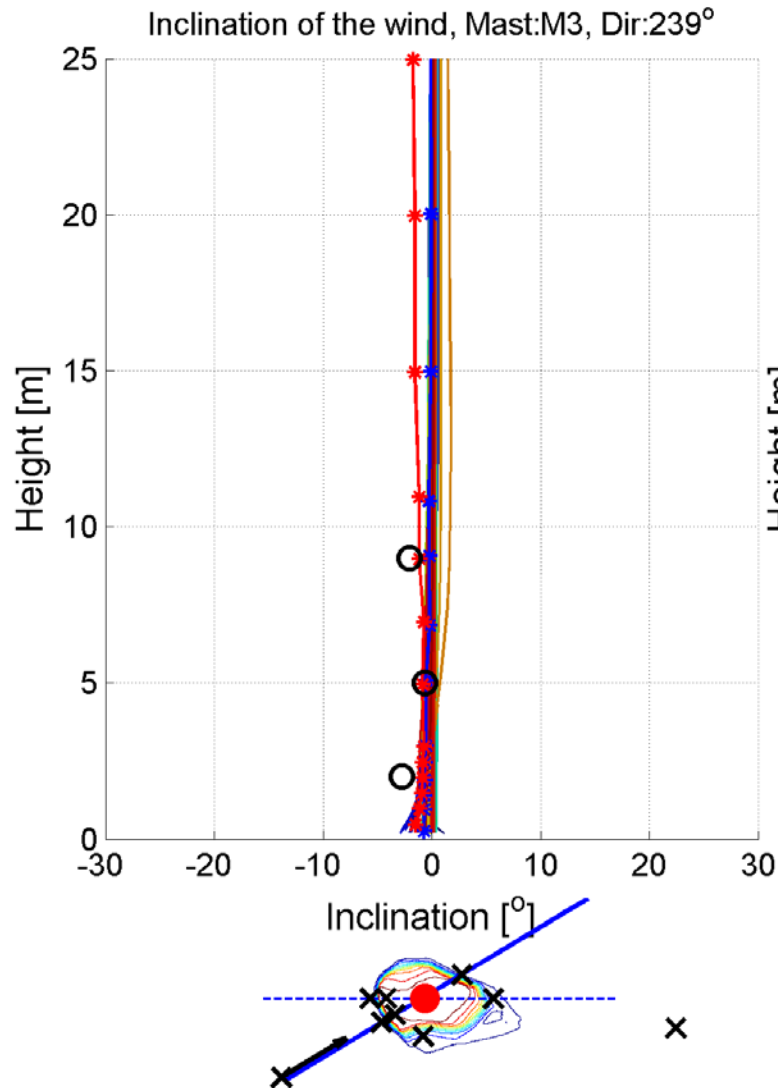
Results: Speed-up

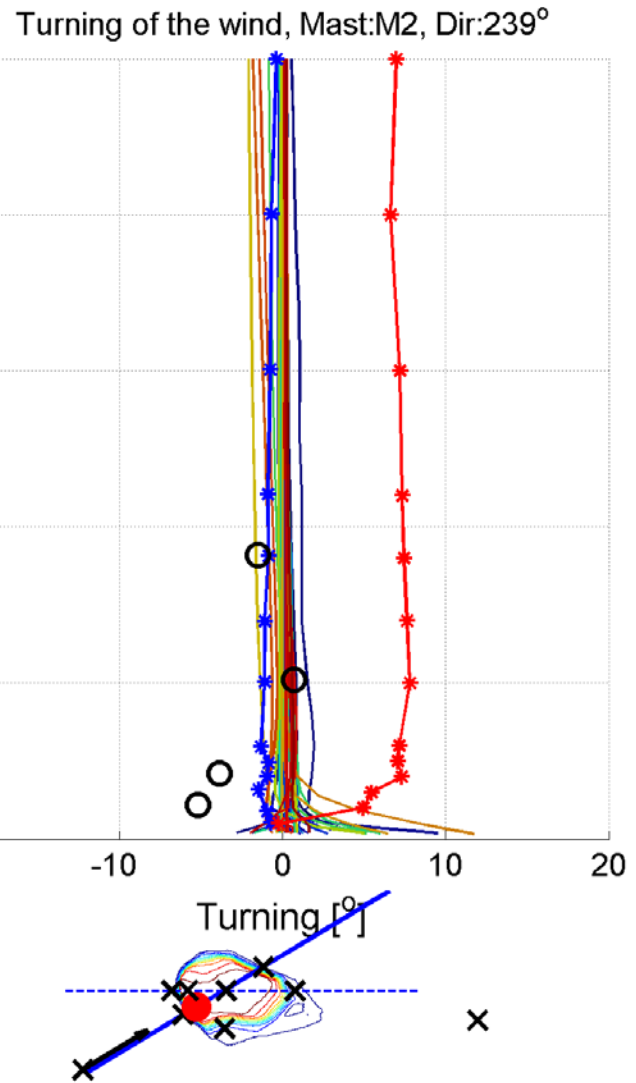


Results

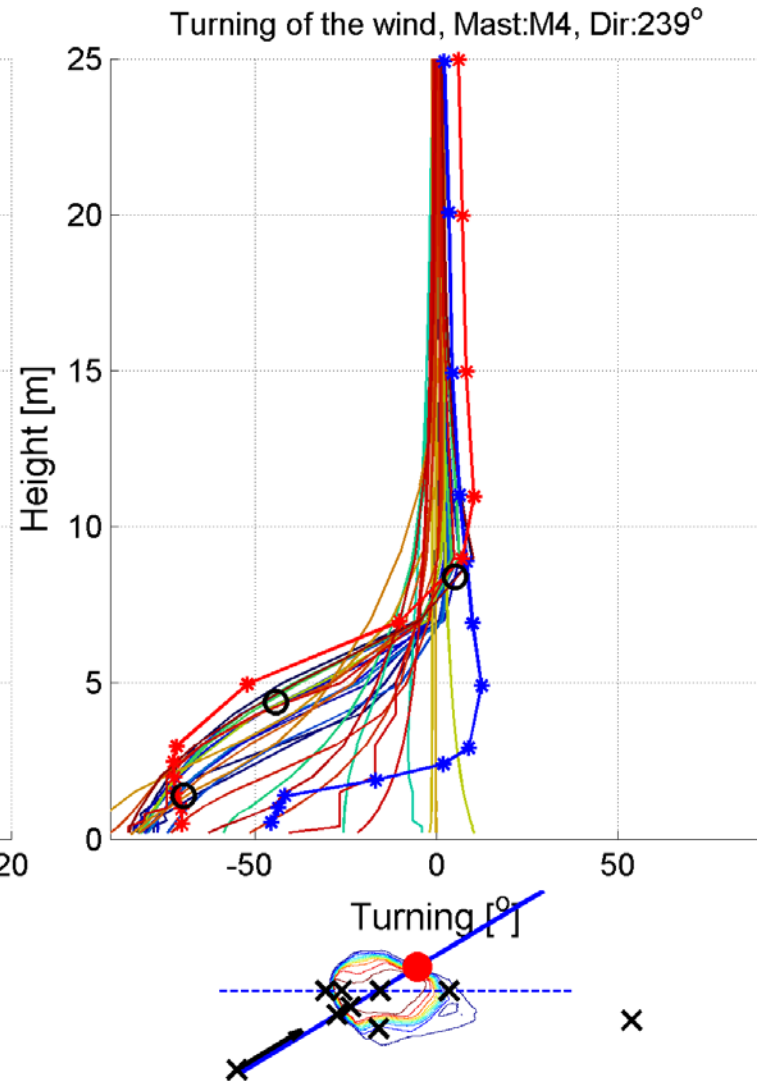
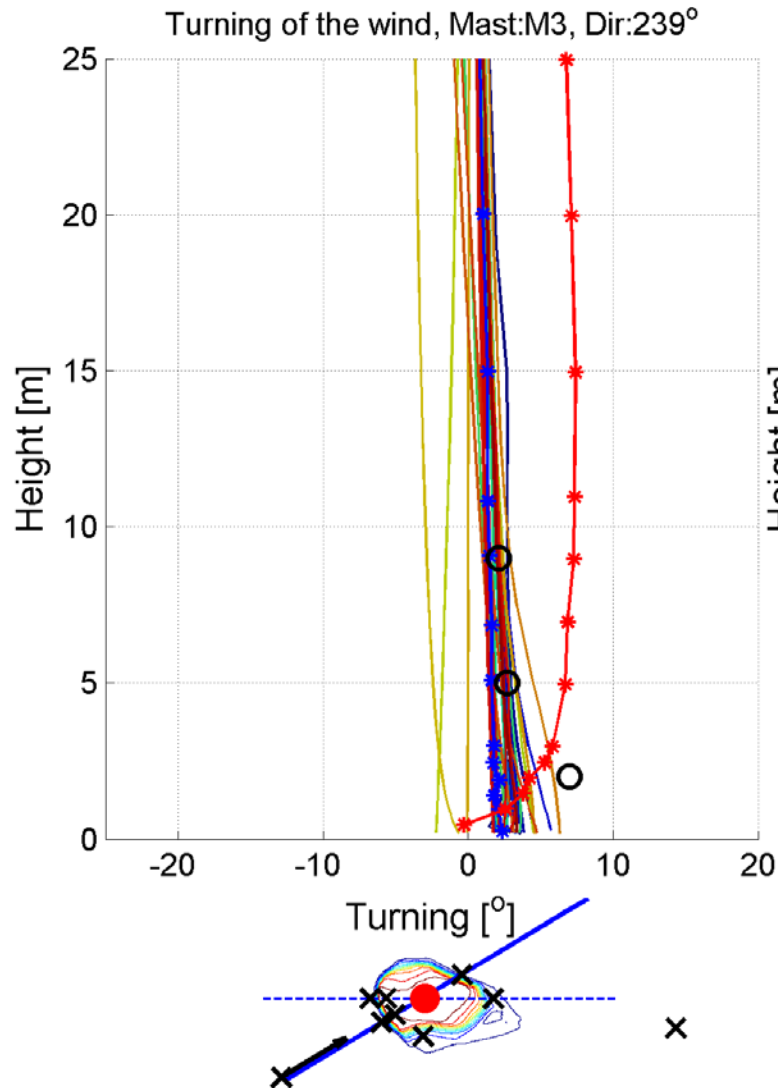


Results

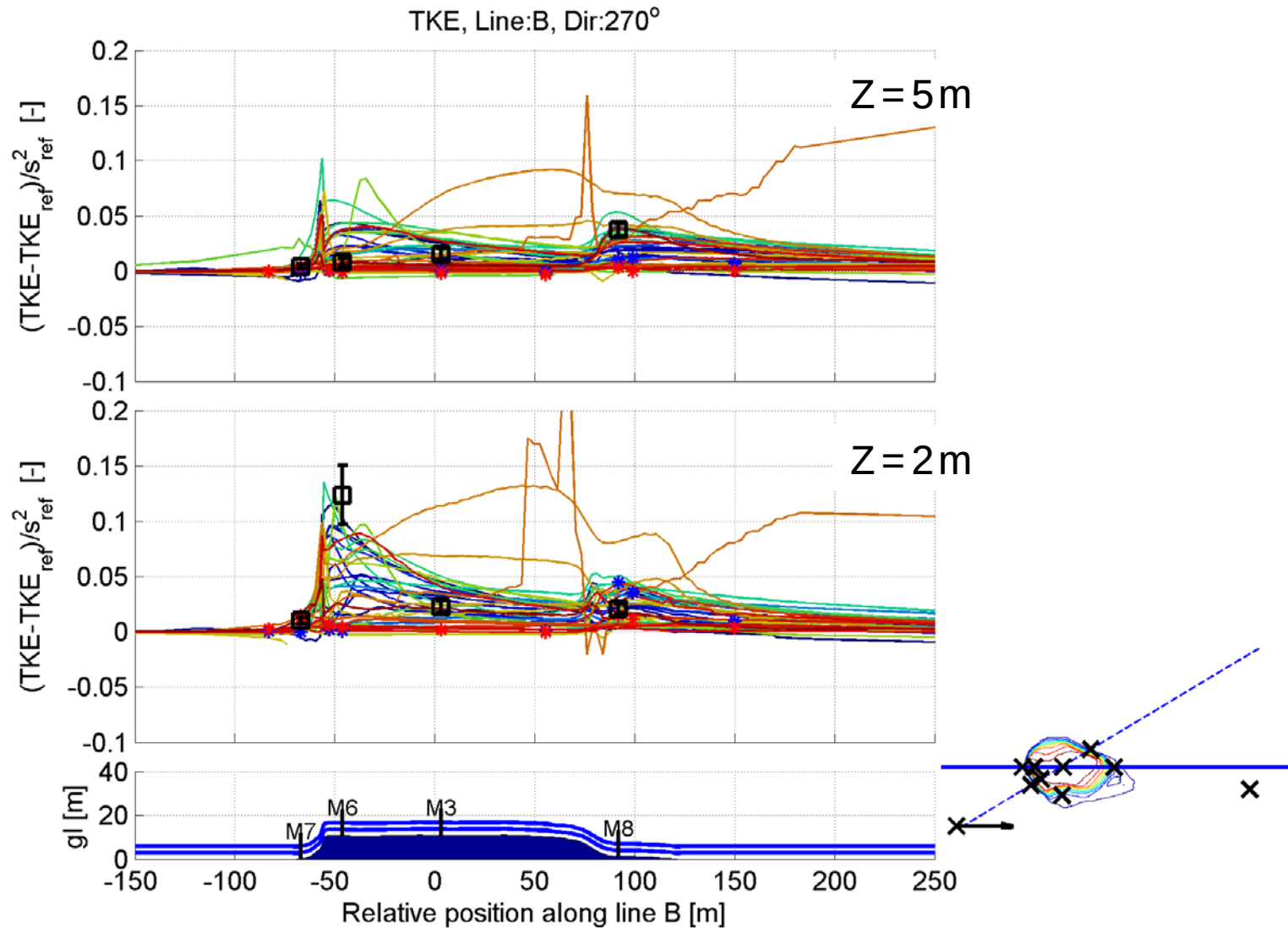




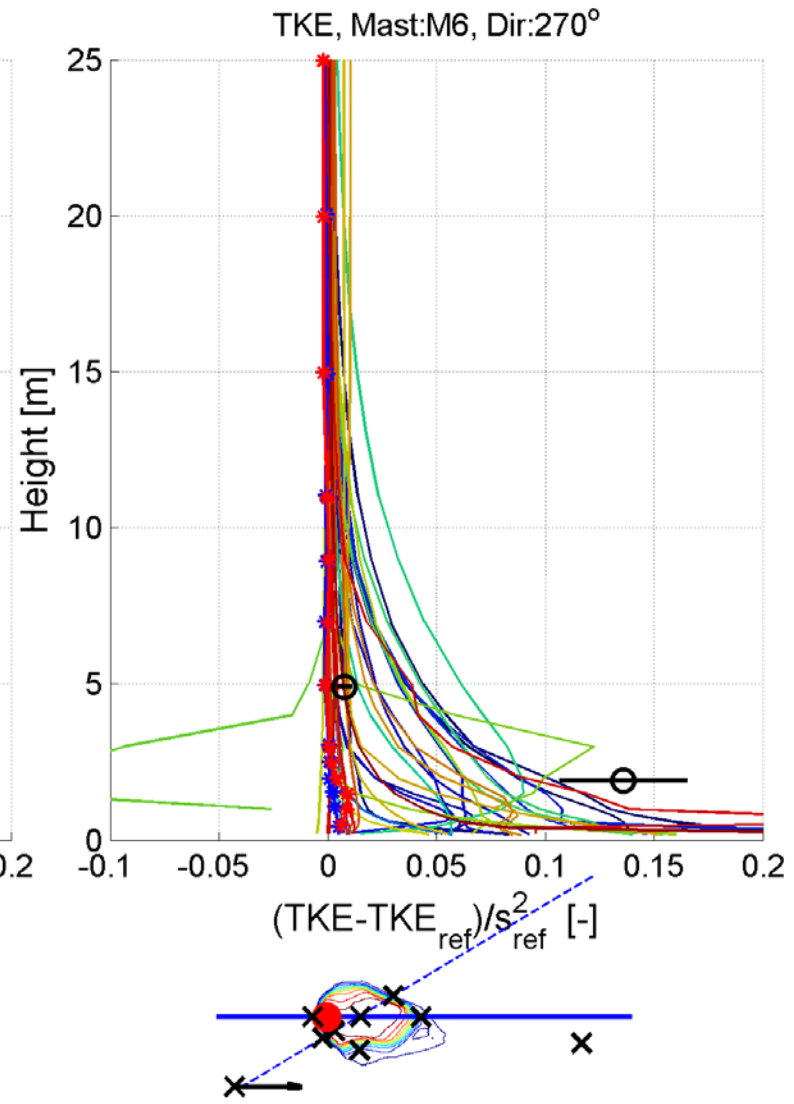
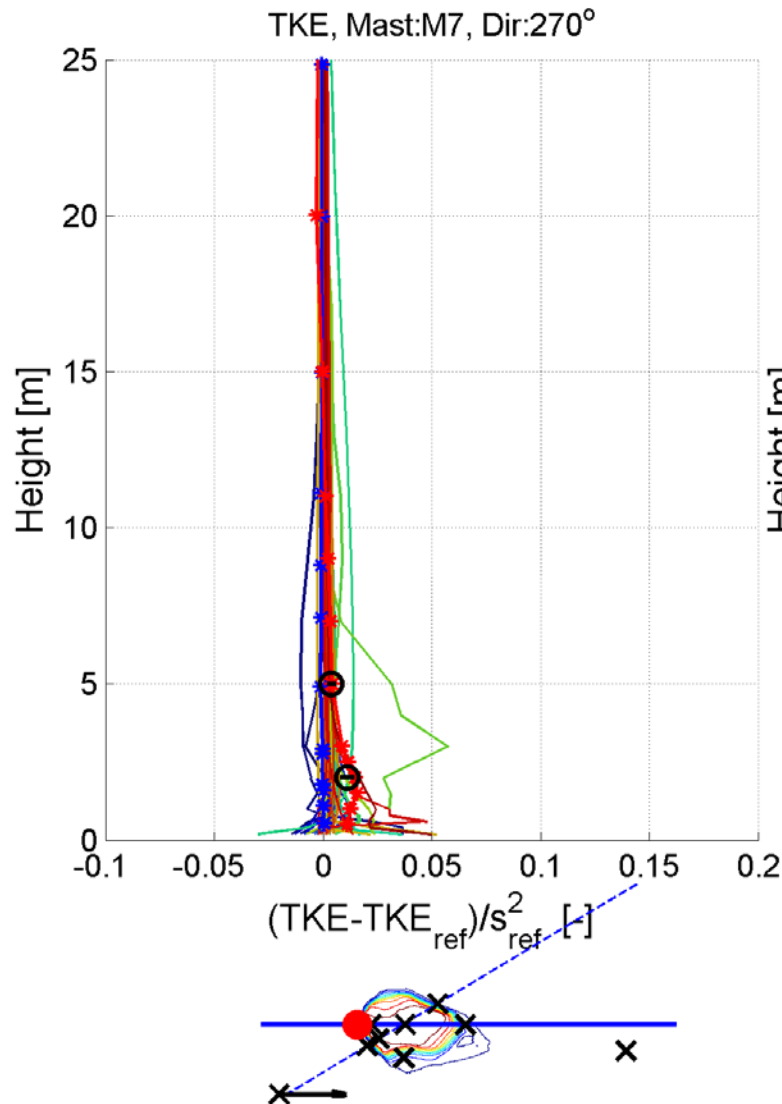
Results



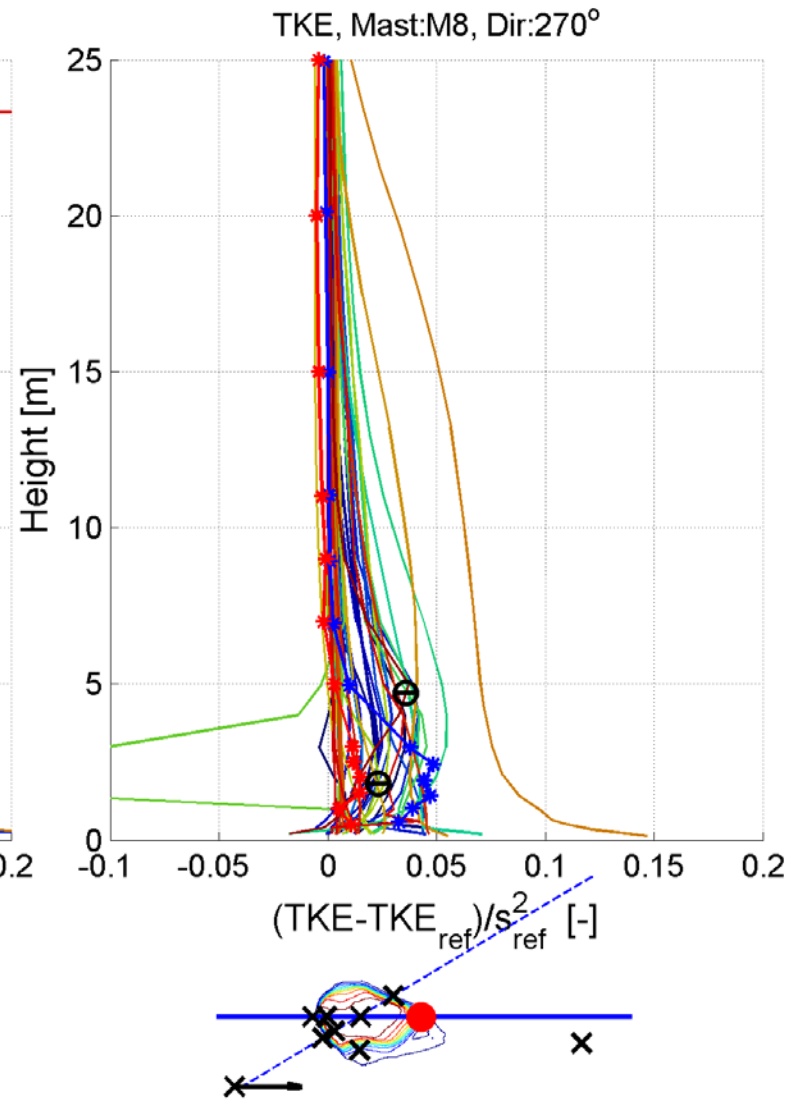
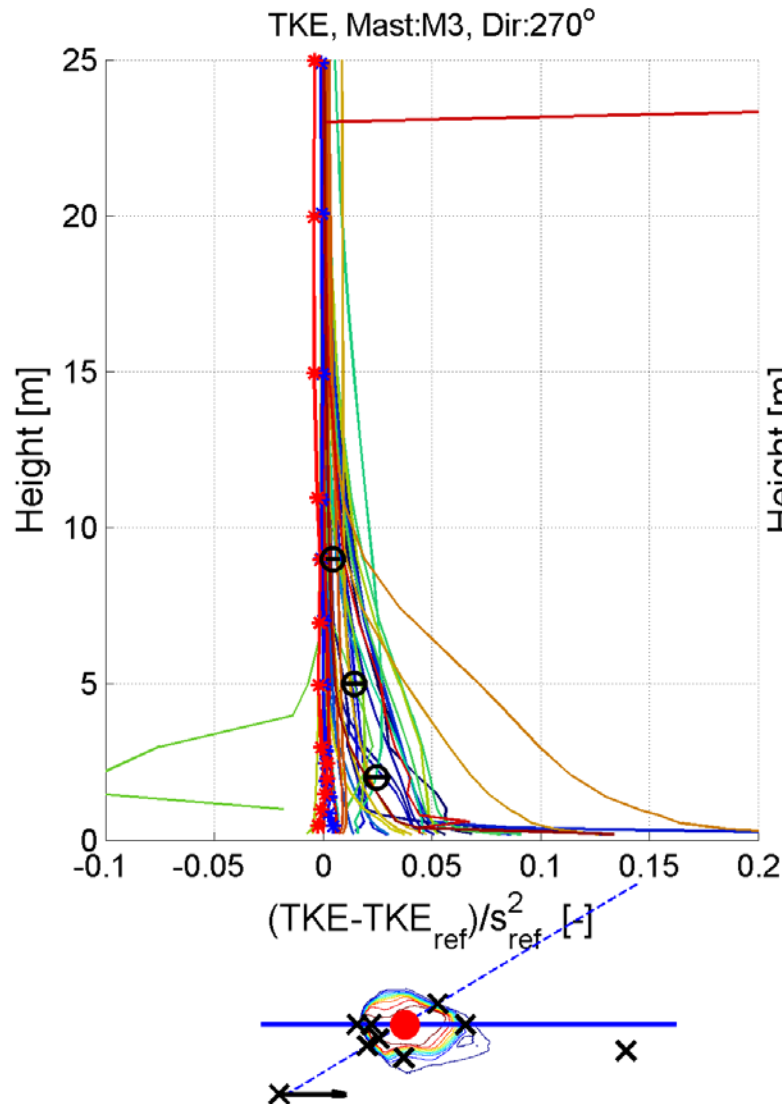
Results



Results



Results



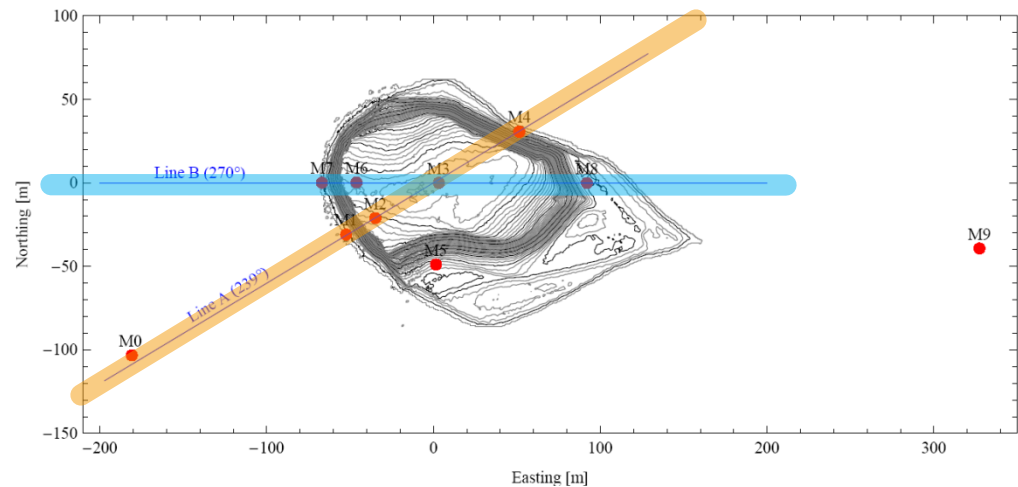
ERROR

- The averaged error in velocity for line A and B (TPWind: 3%)

@ 2m above ground = 35%

@ 5m above ground = 17%

Mean Error: 26 %



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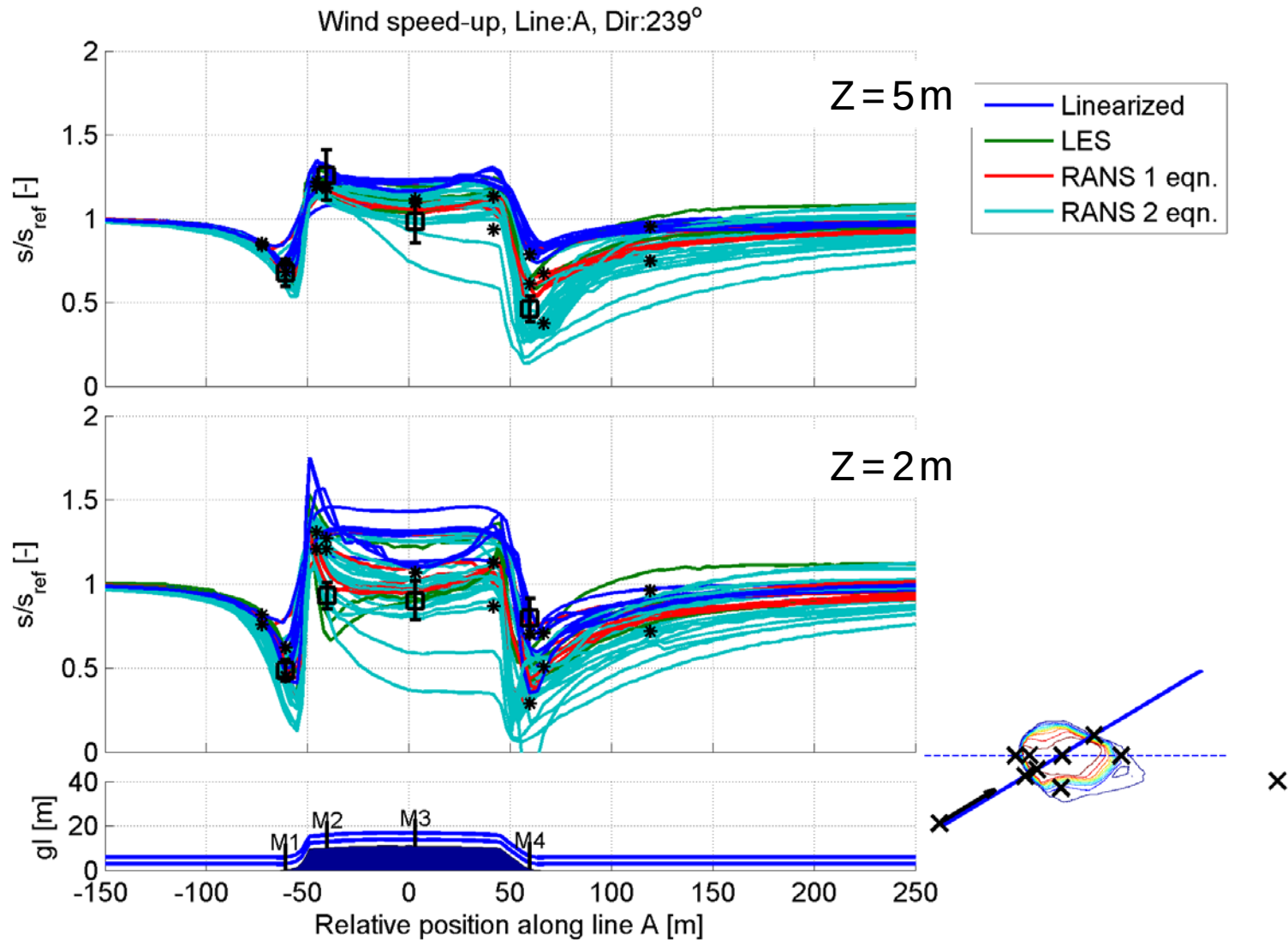


Analysis

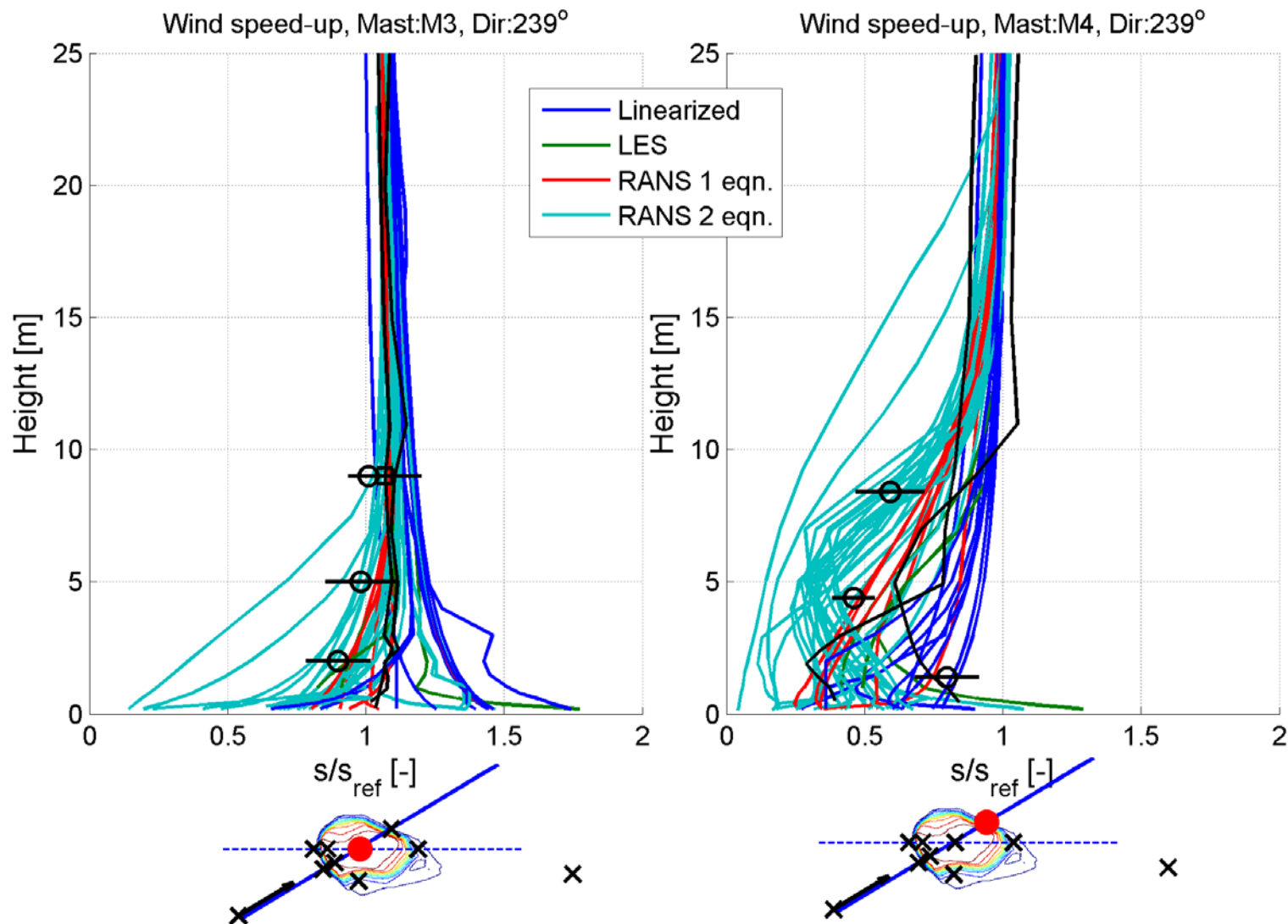
Model types:

1. Experimental method
2. Linearized flow model
3. LES
4. RANS 1 eq.
5. RANS 2 eq.

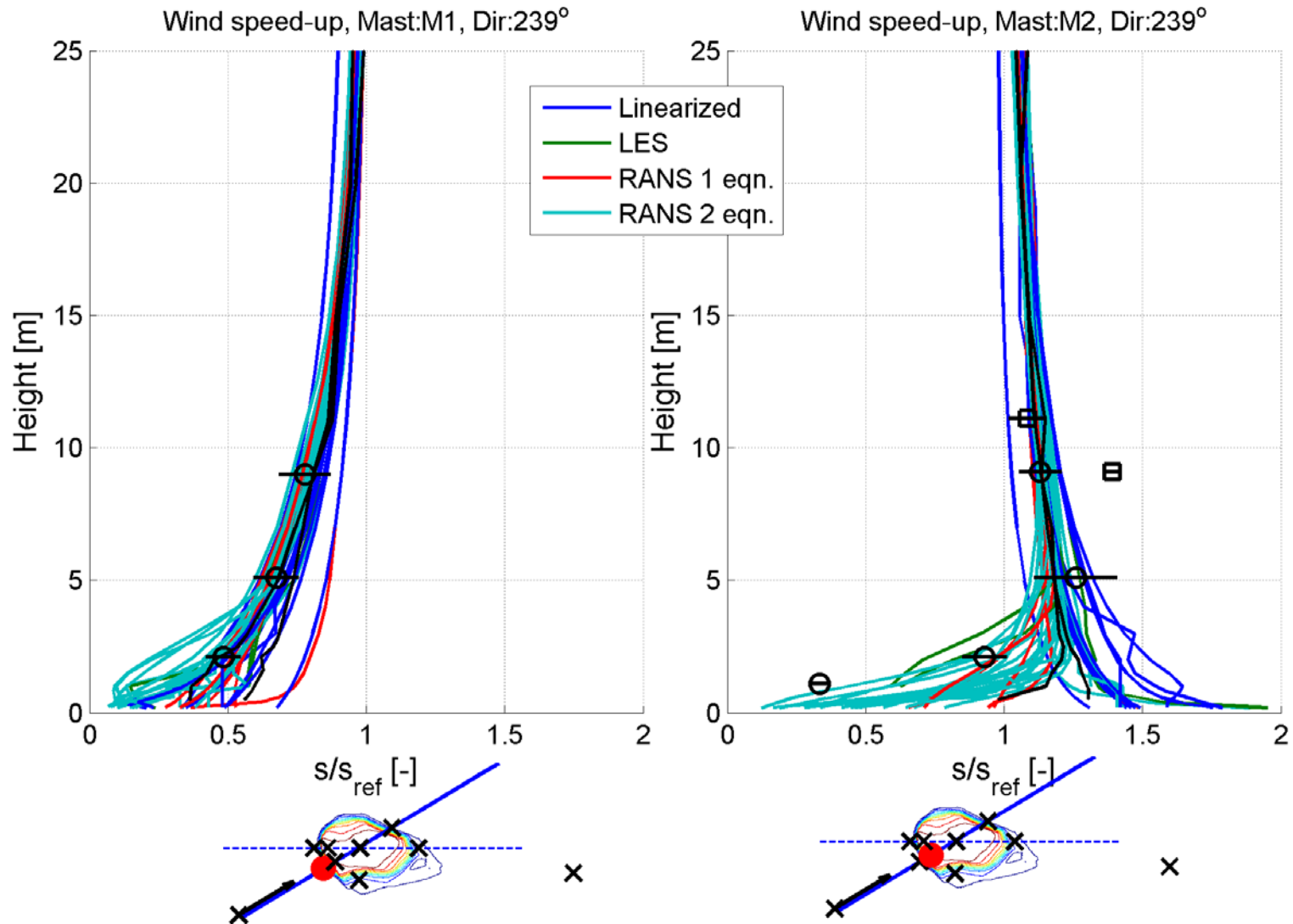
All models



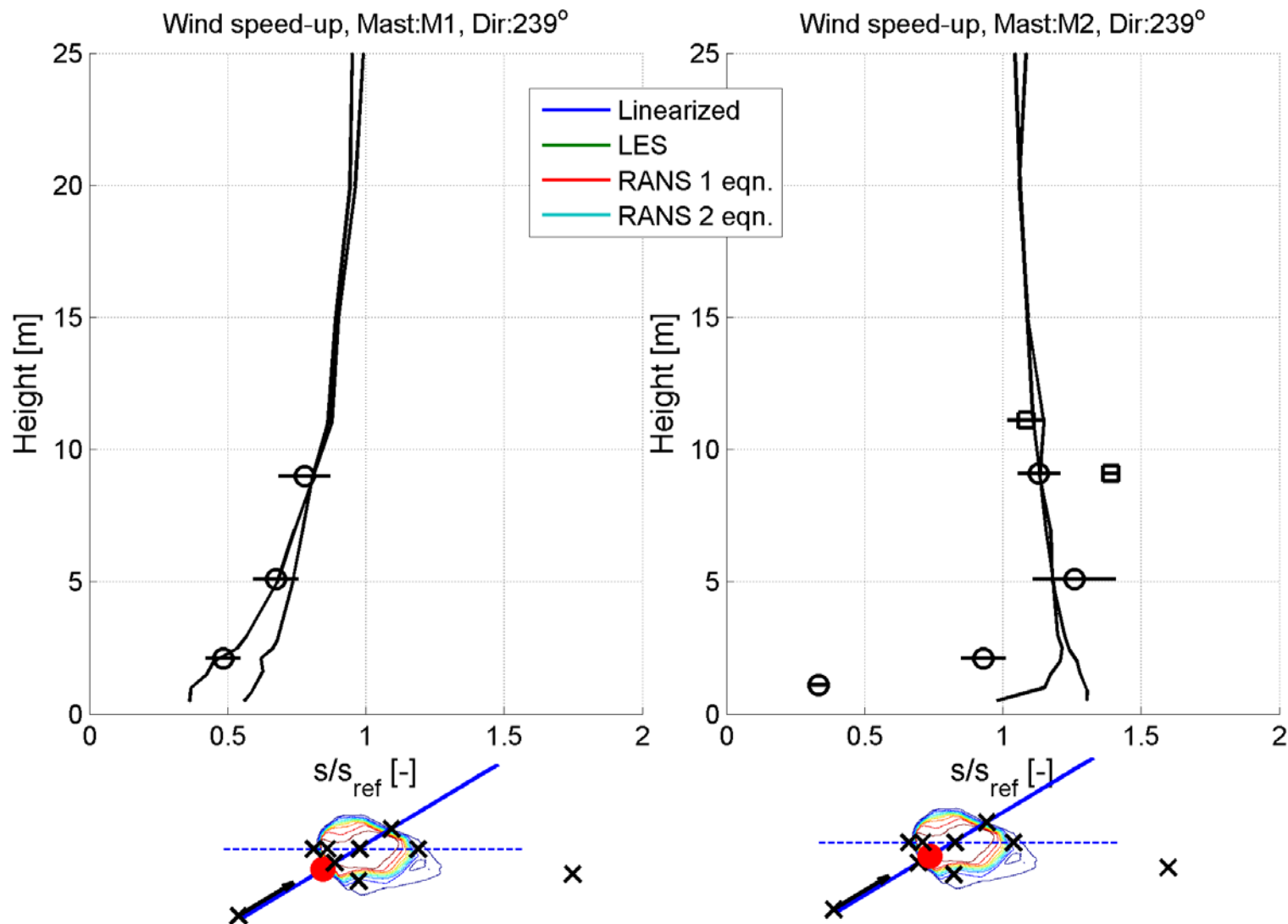
All models



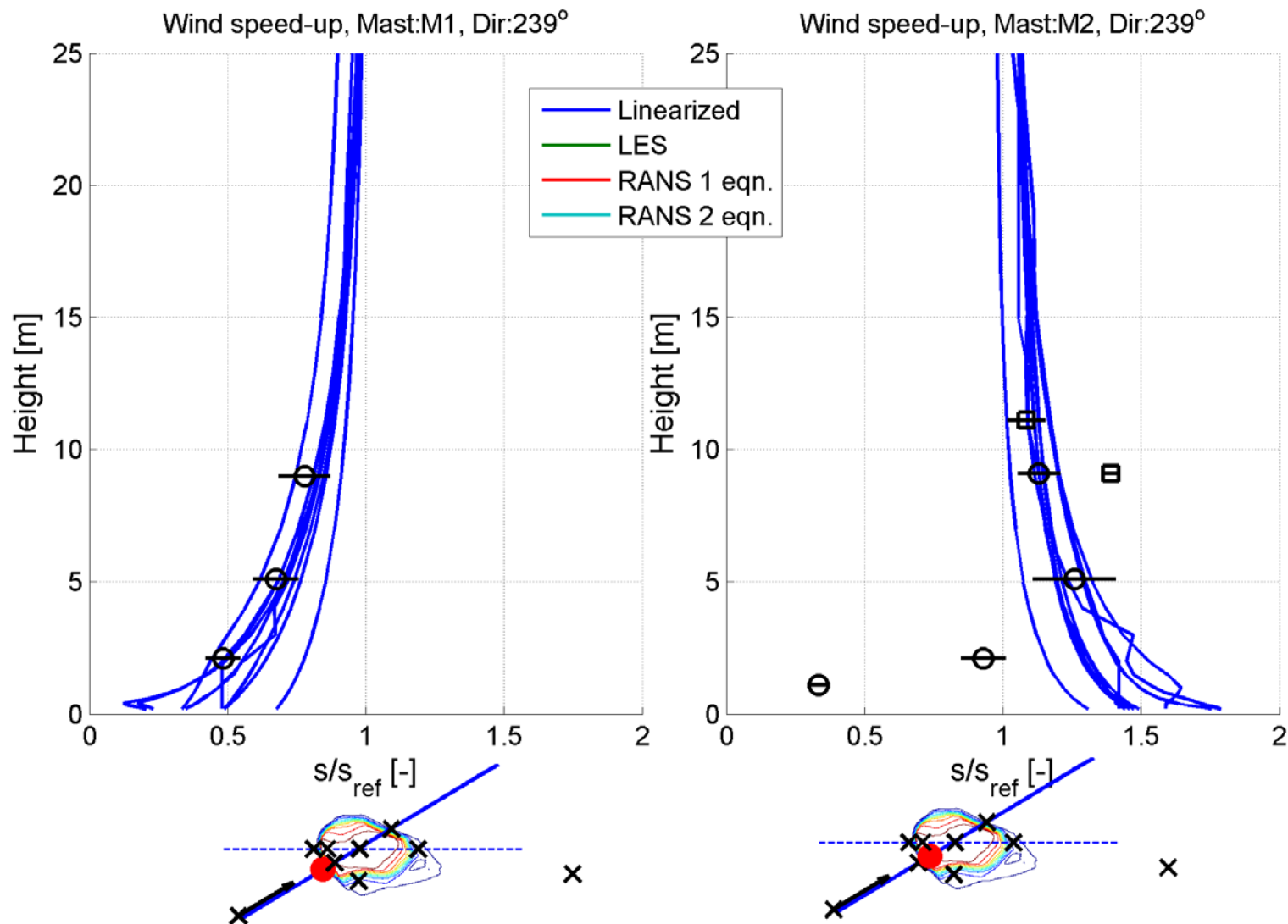
All models



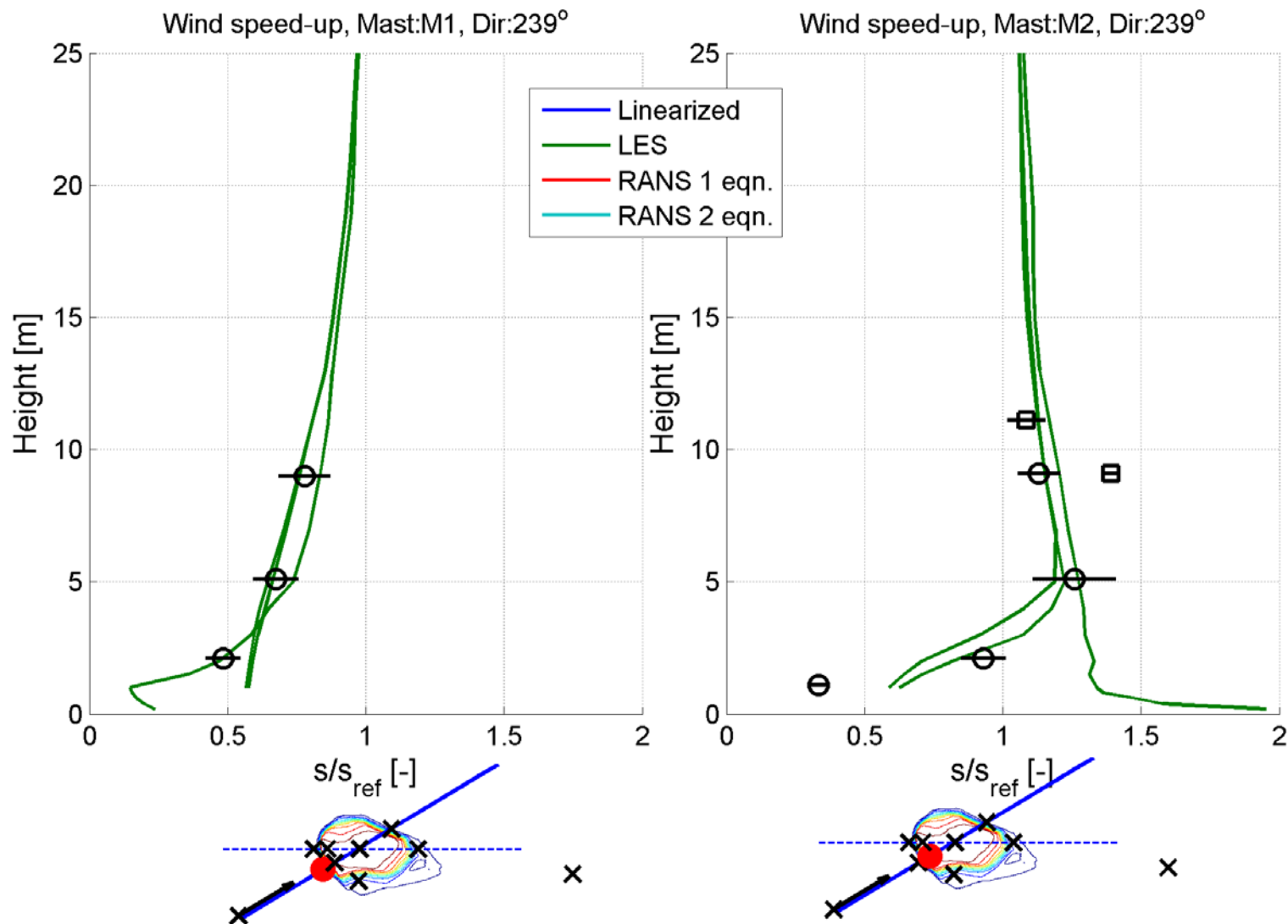
Experimental method



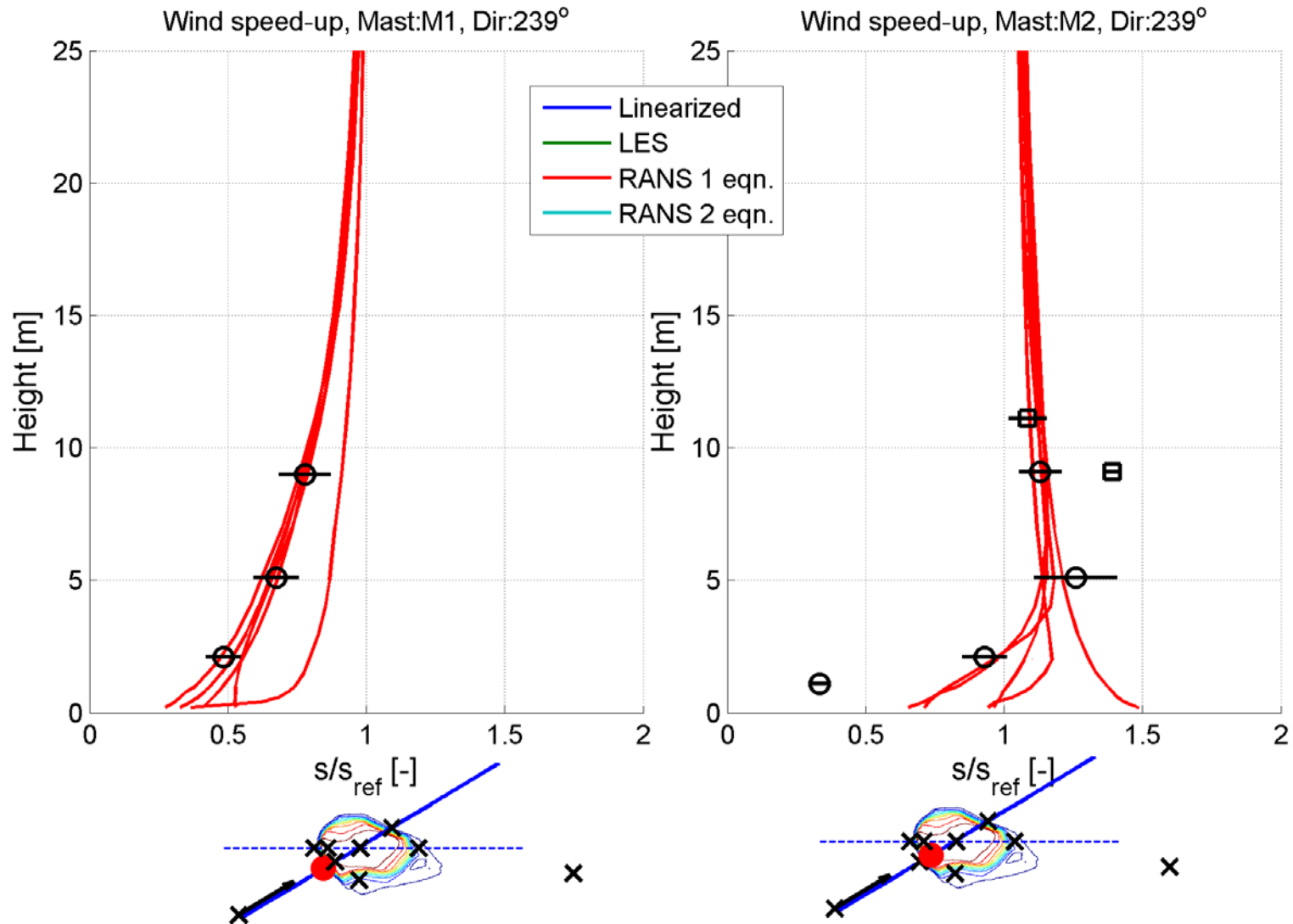
Linearized flow models



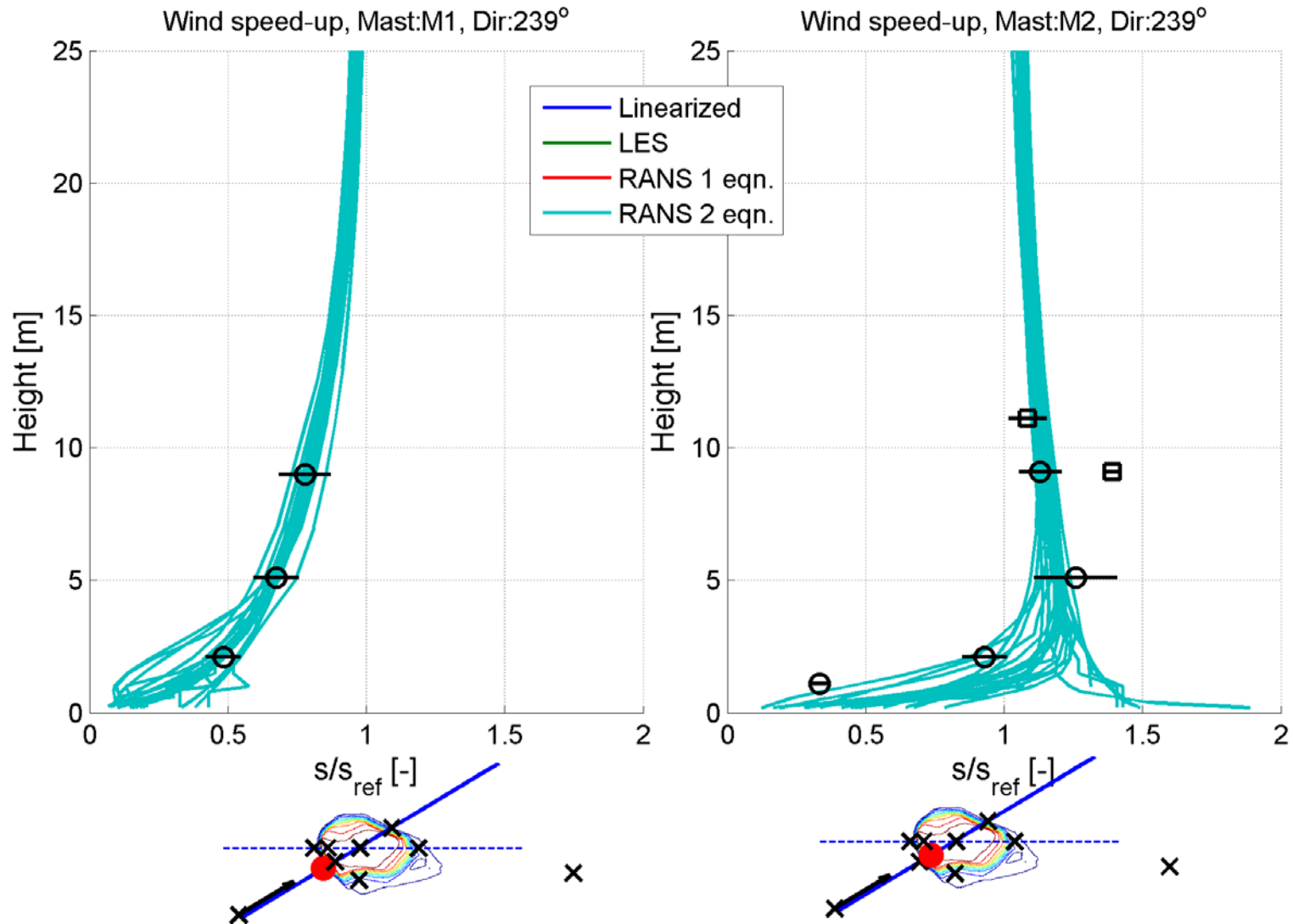
LES models



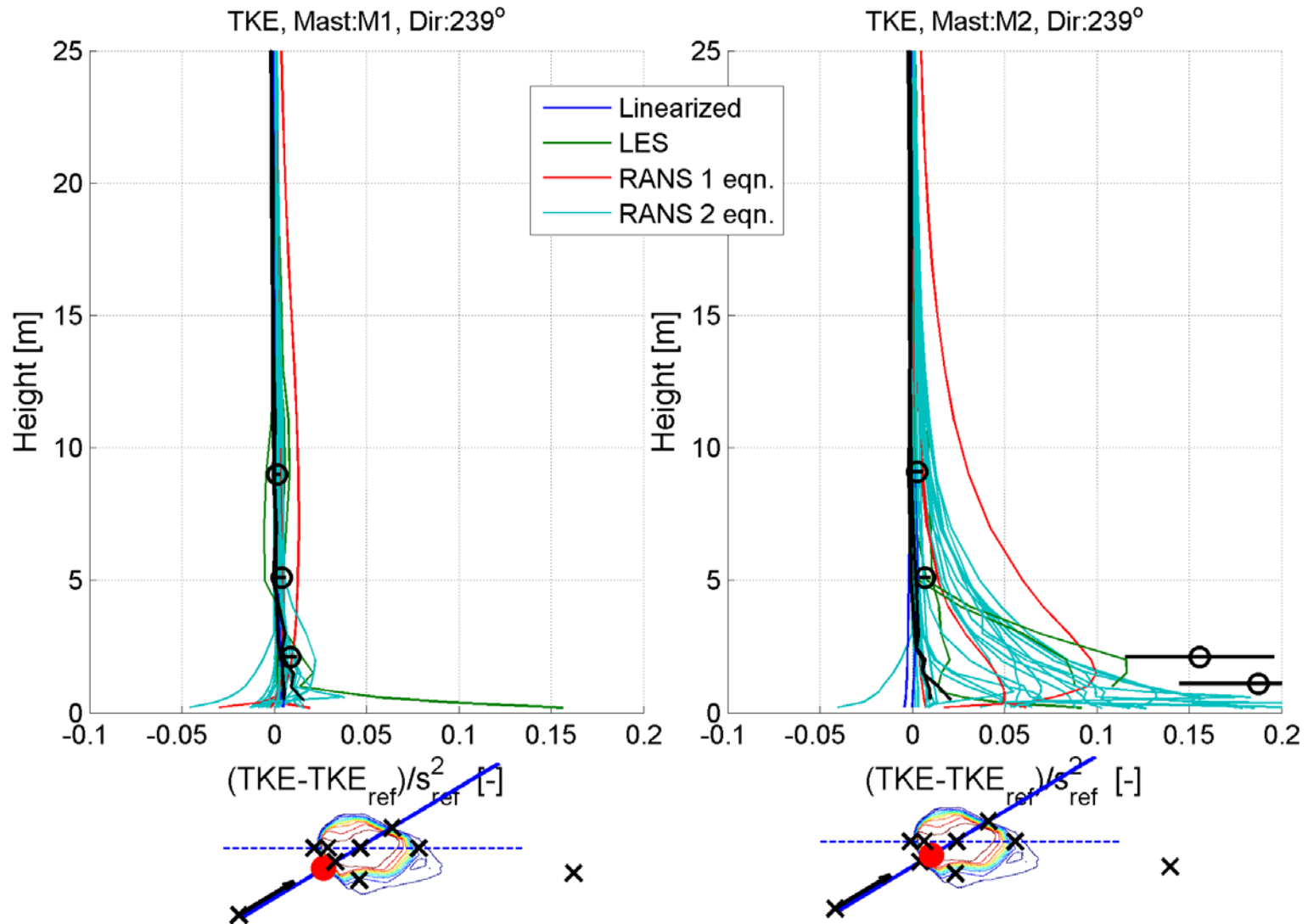
RANS 1 eq. models



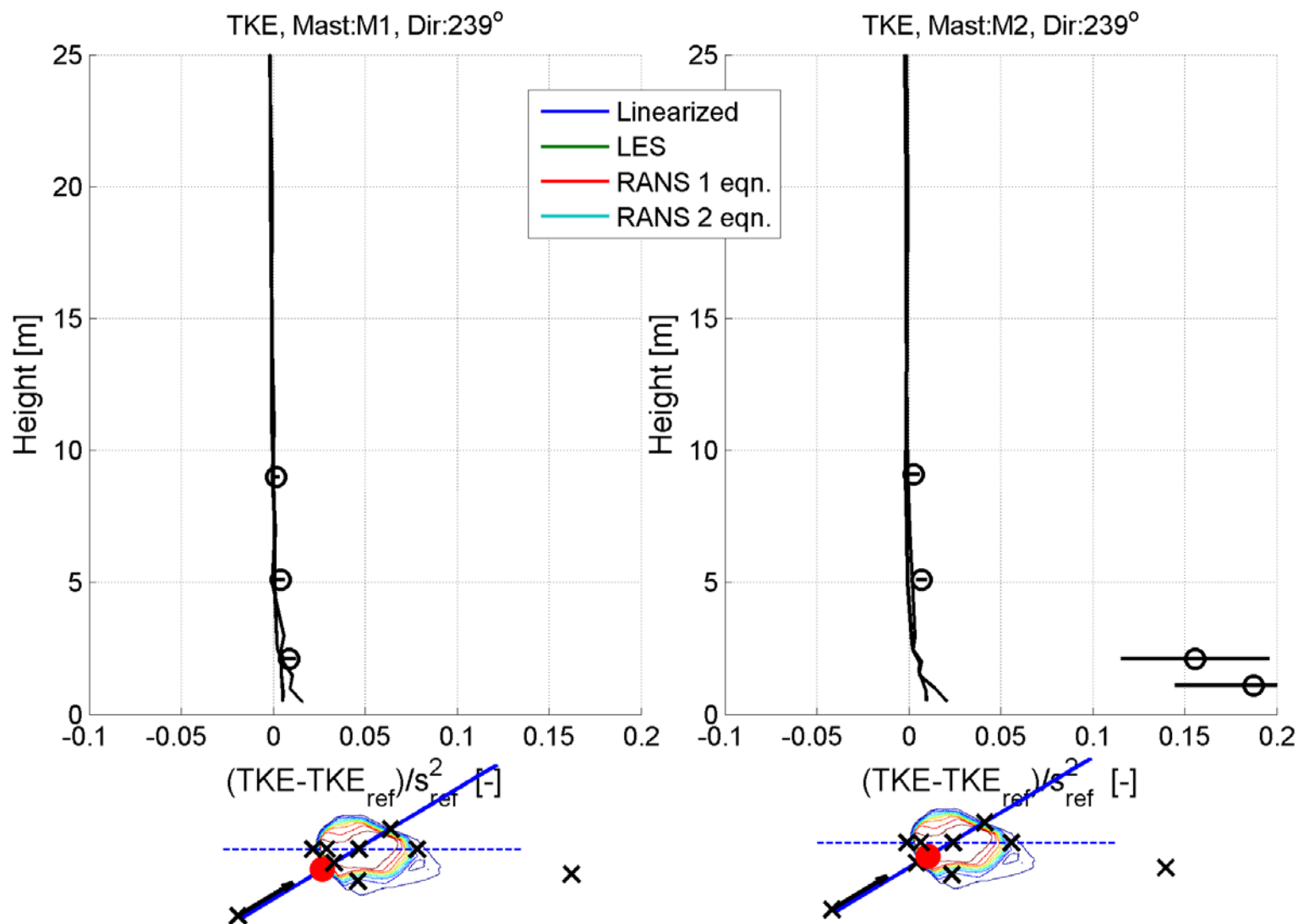
RANS 2 eq. models



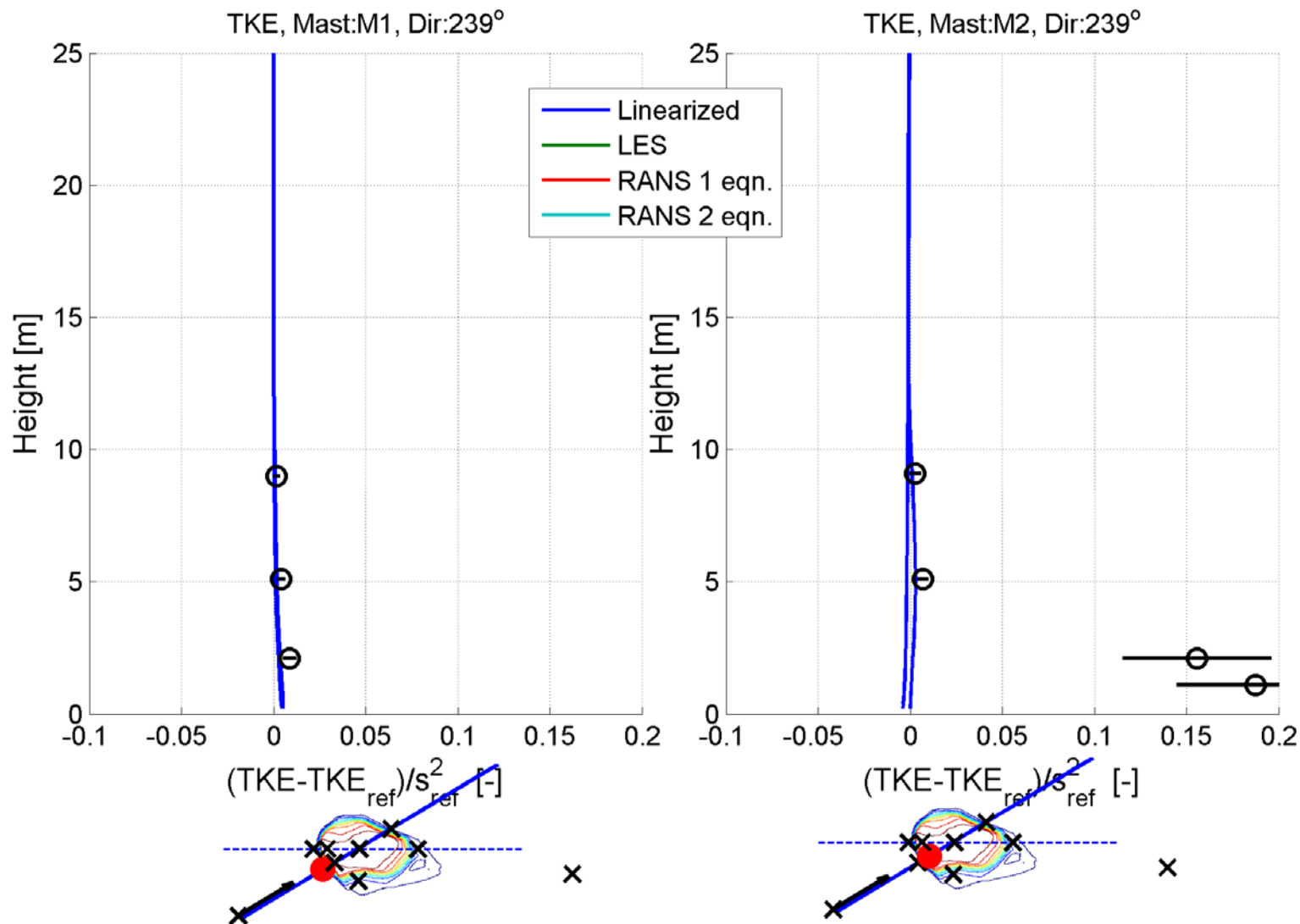
All models



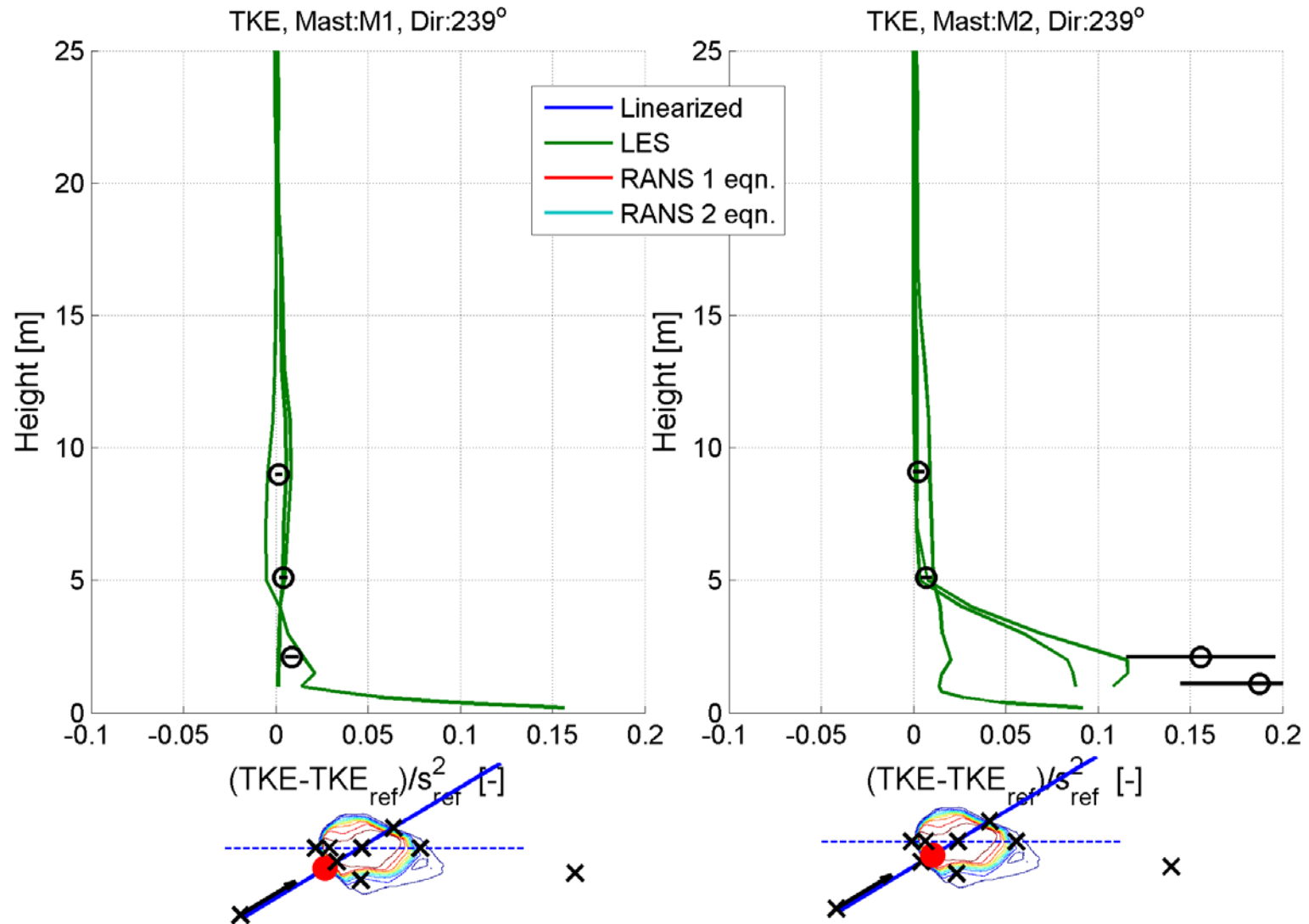
Experimental method



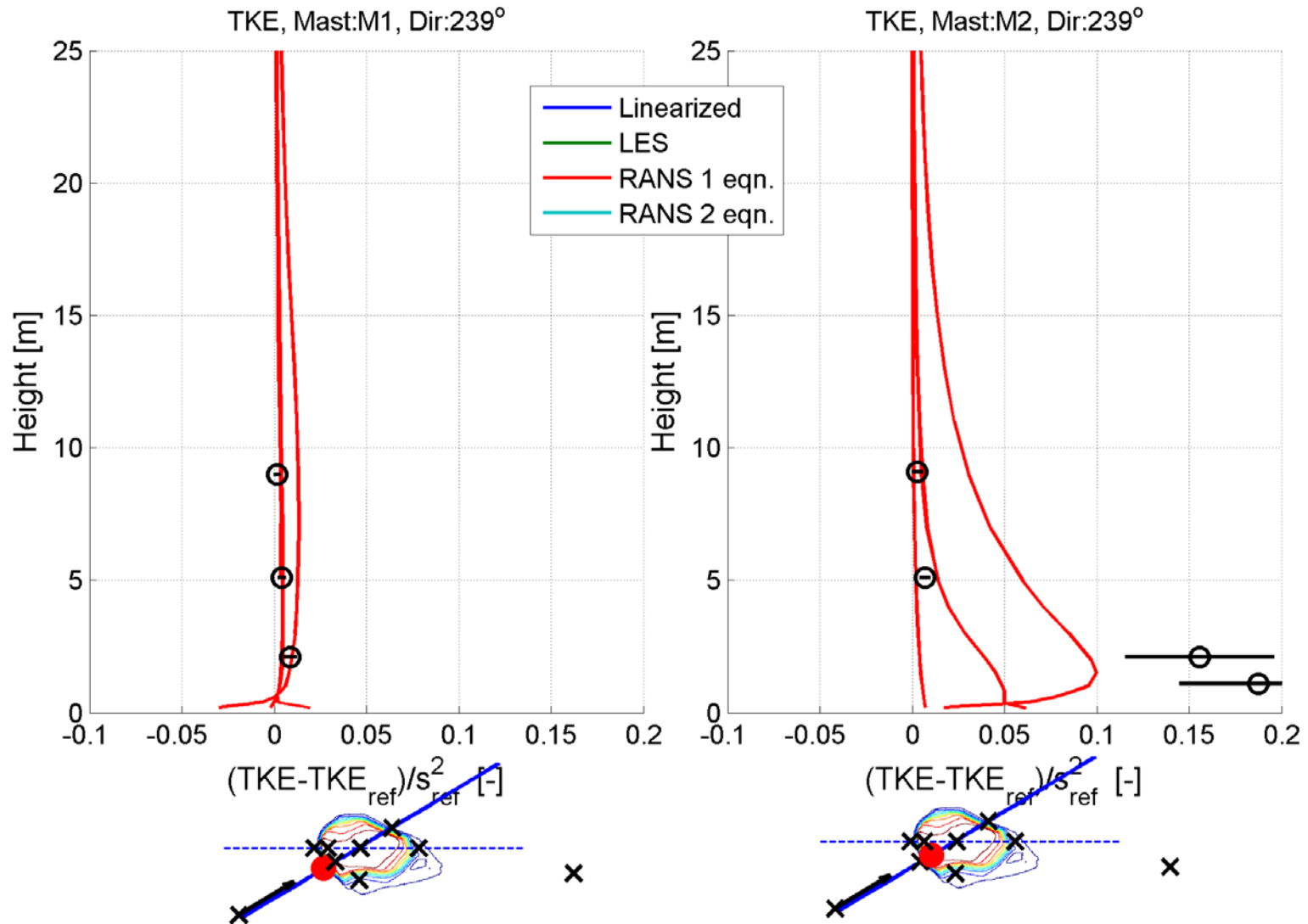
Linearized flow models



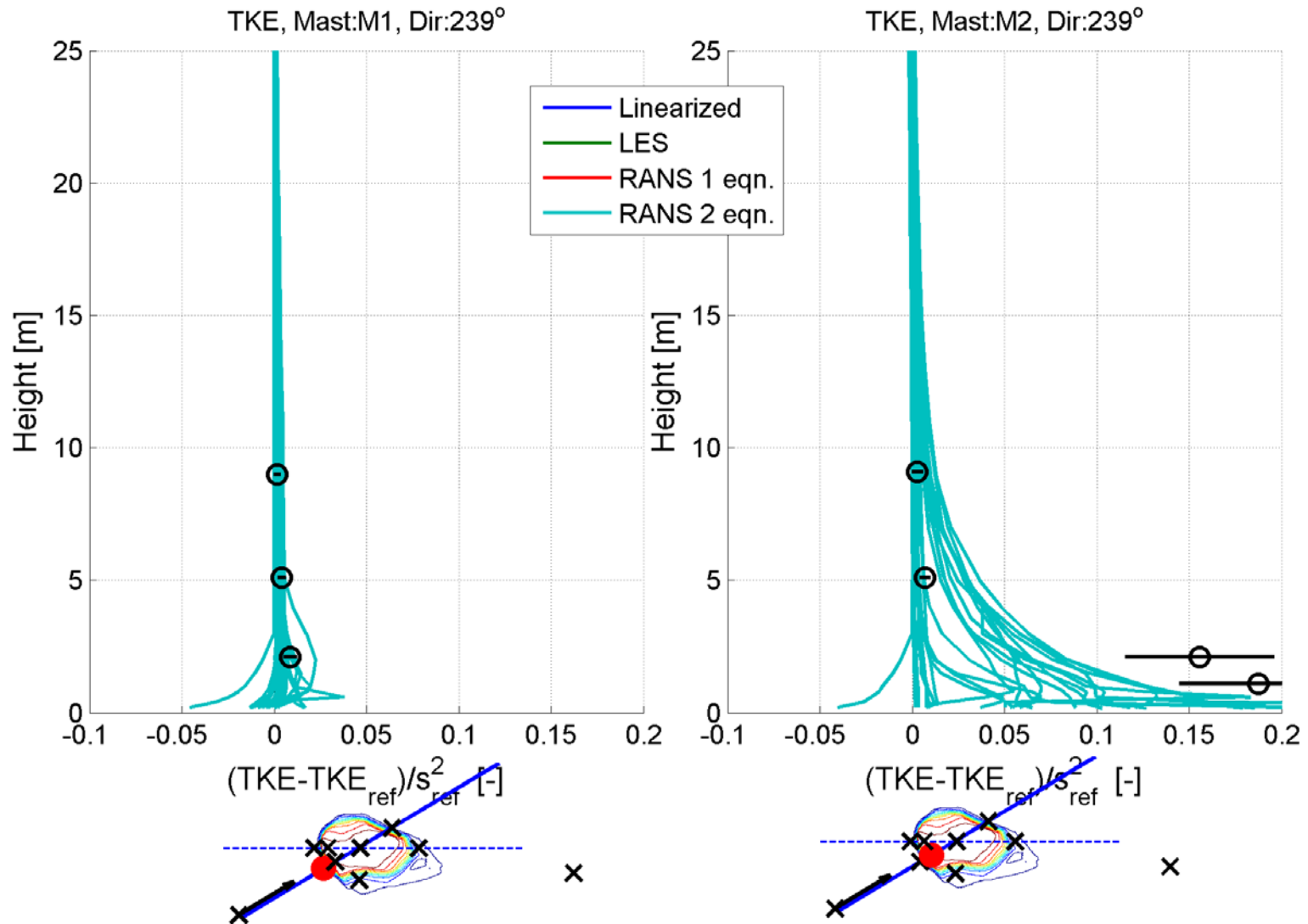
LES models



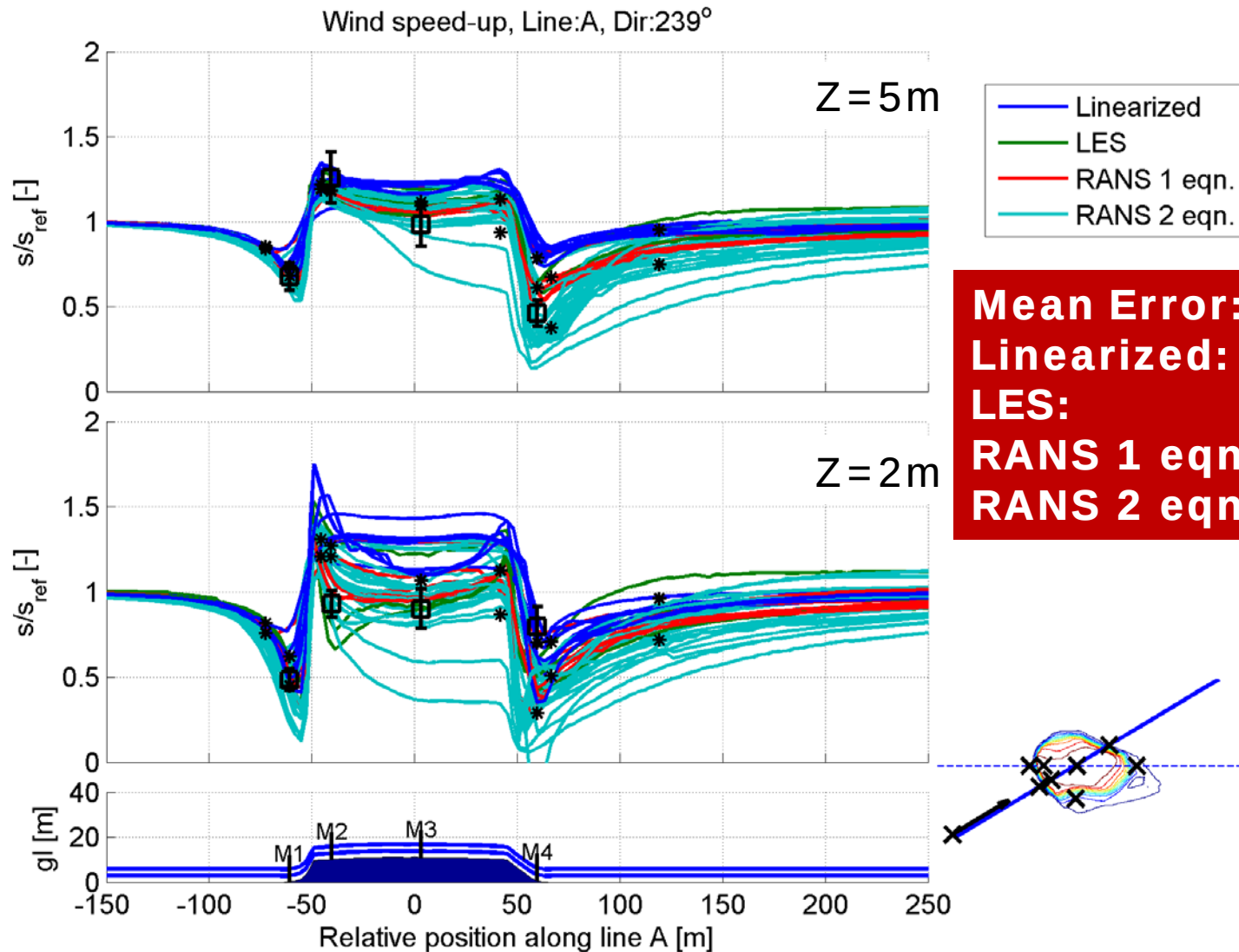
RANS 1 eq. models



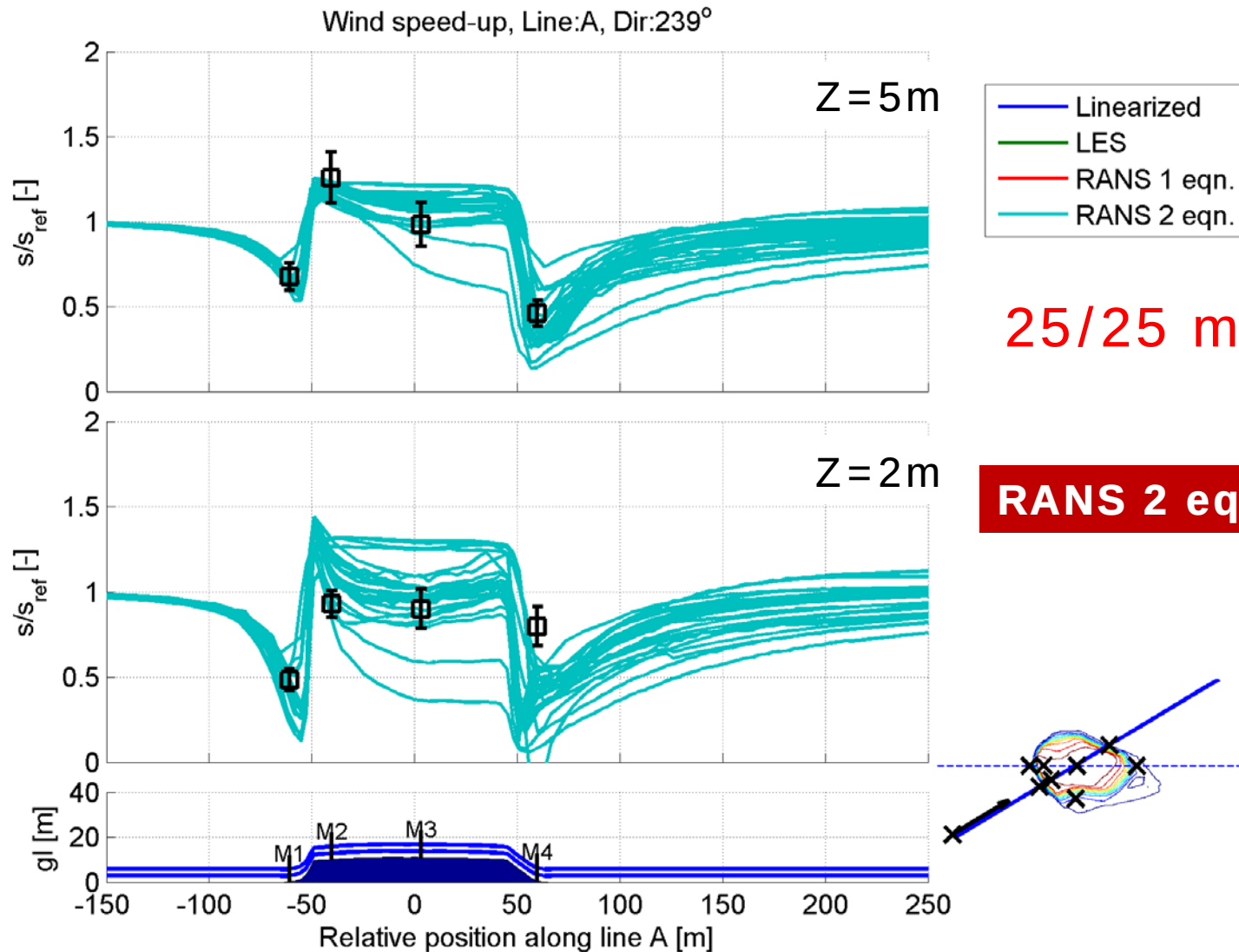
RANS 2 eq. models



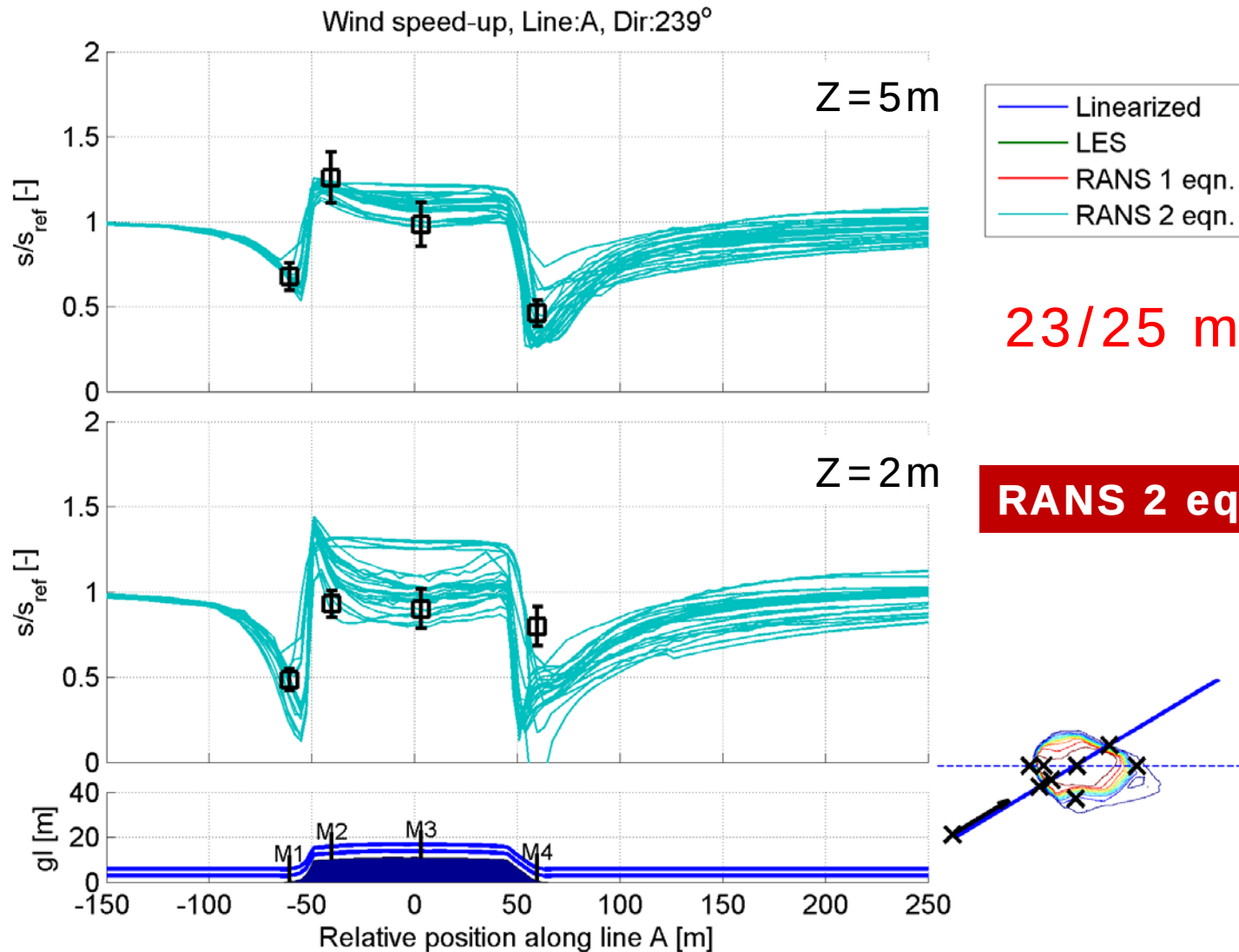
All models



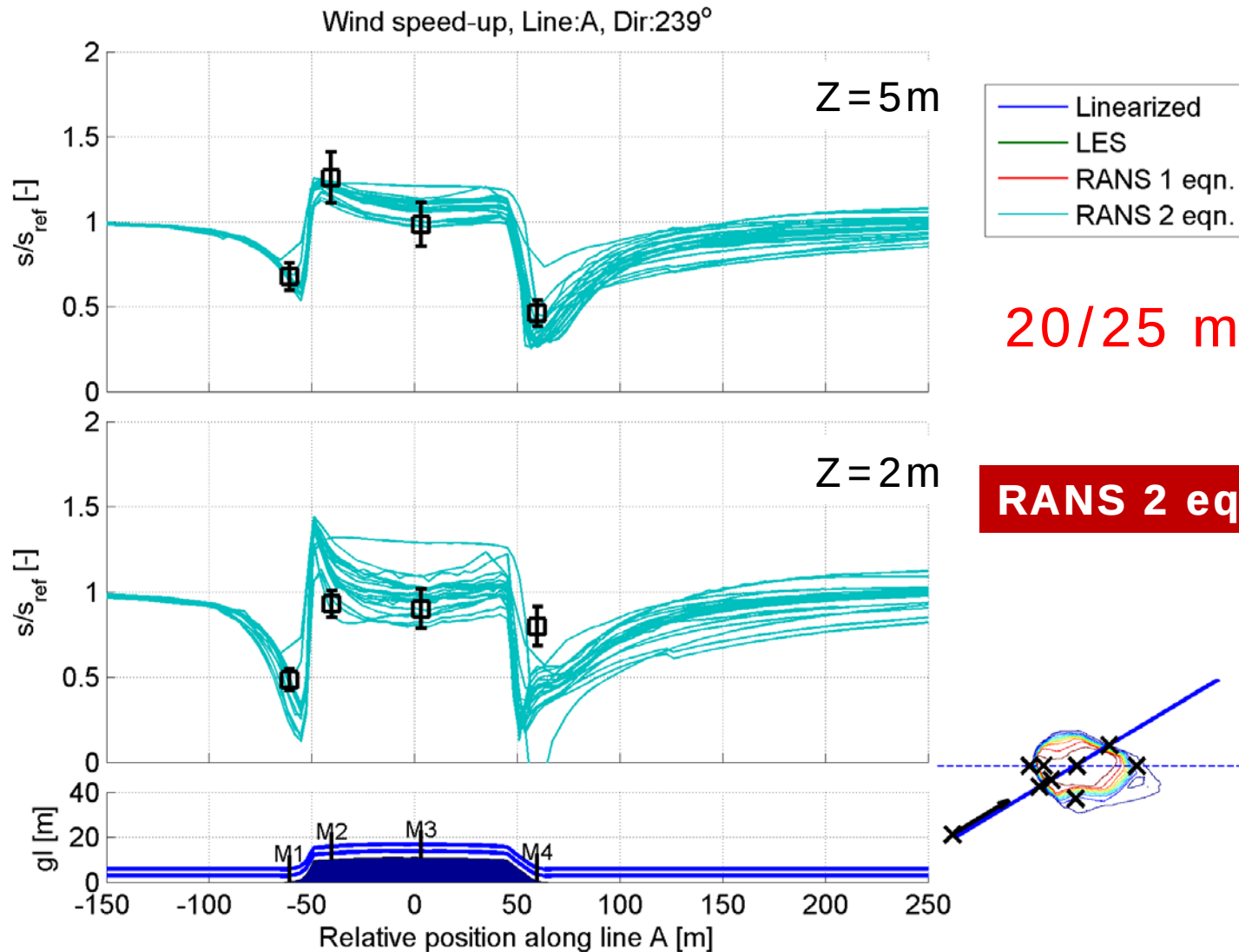
RANS 2 eq. models



RANS 2 eq. models

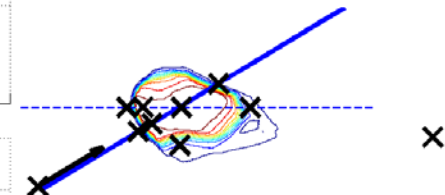


RANS 2 eq. models

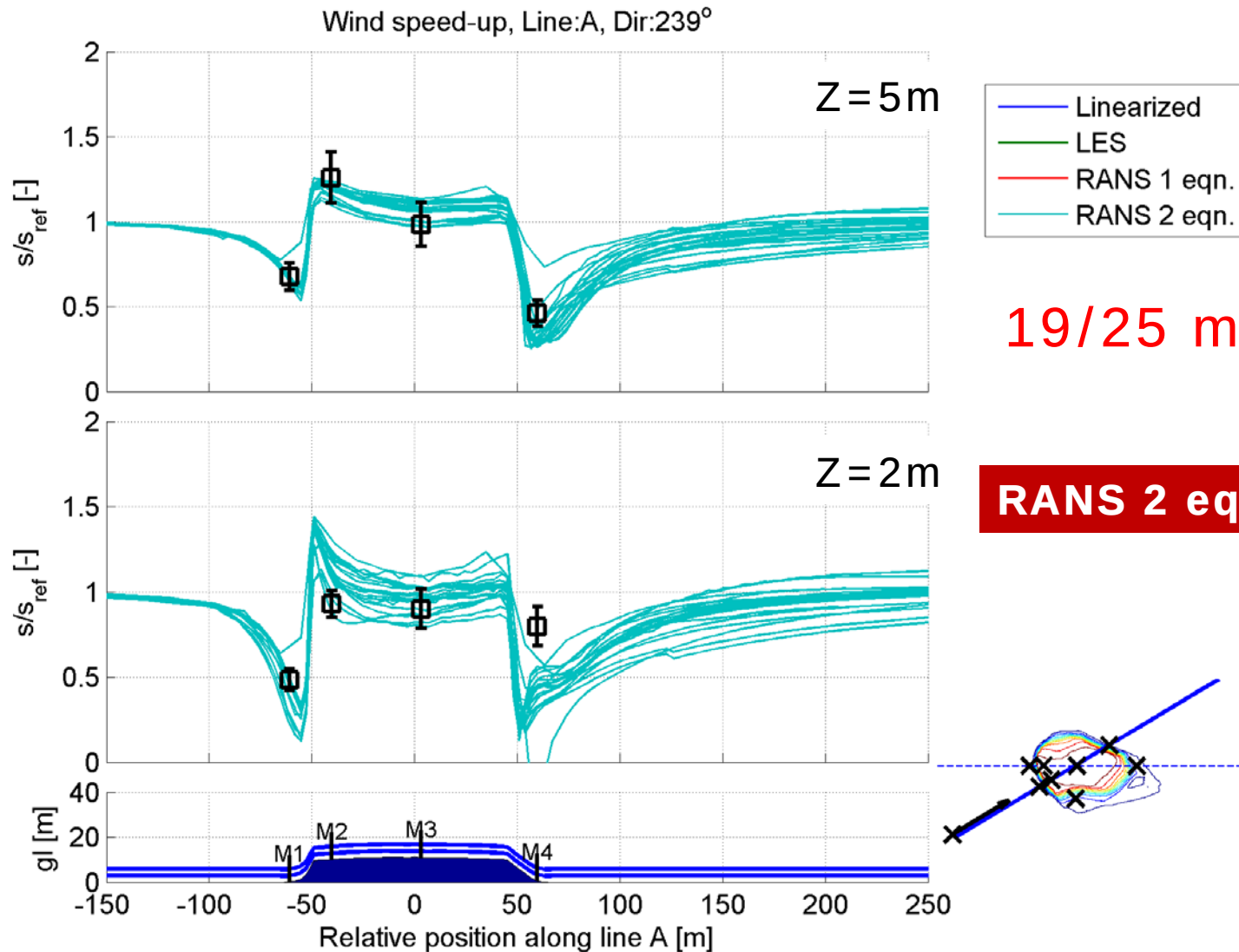


20/25 models

RANS 2 eqn.: 18 %

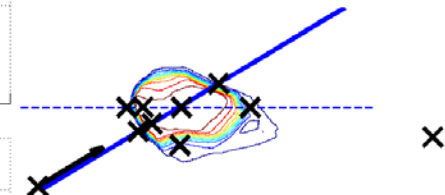


RANS 2 eq. models

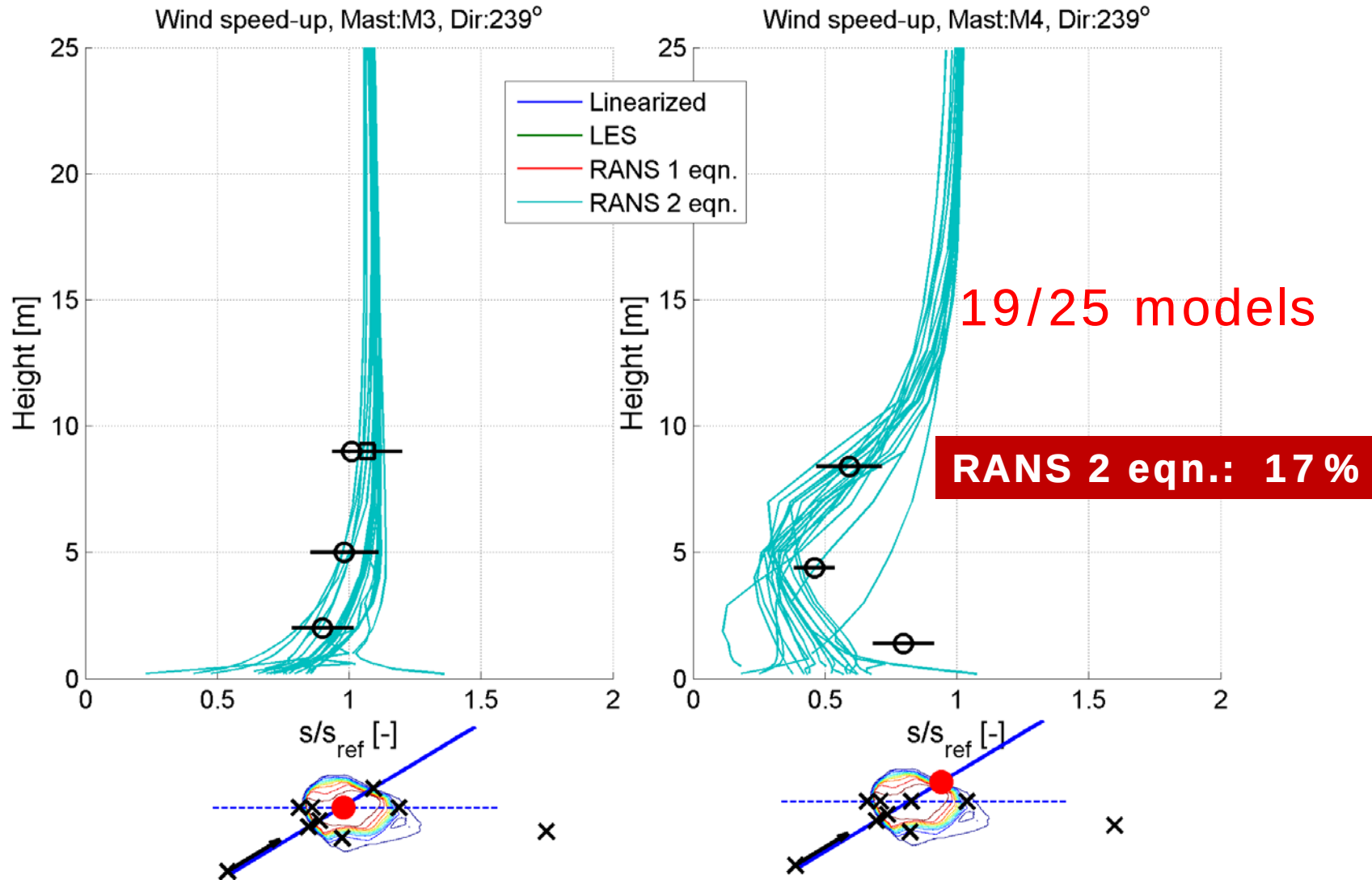


19/25 models

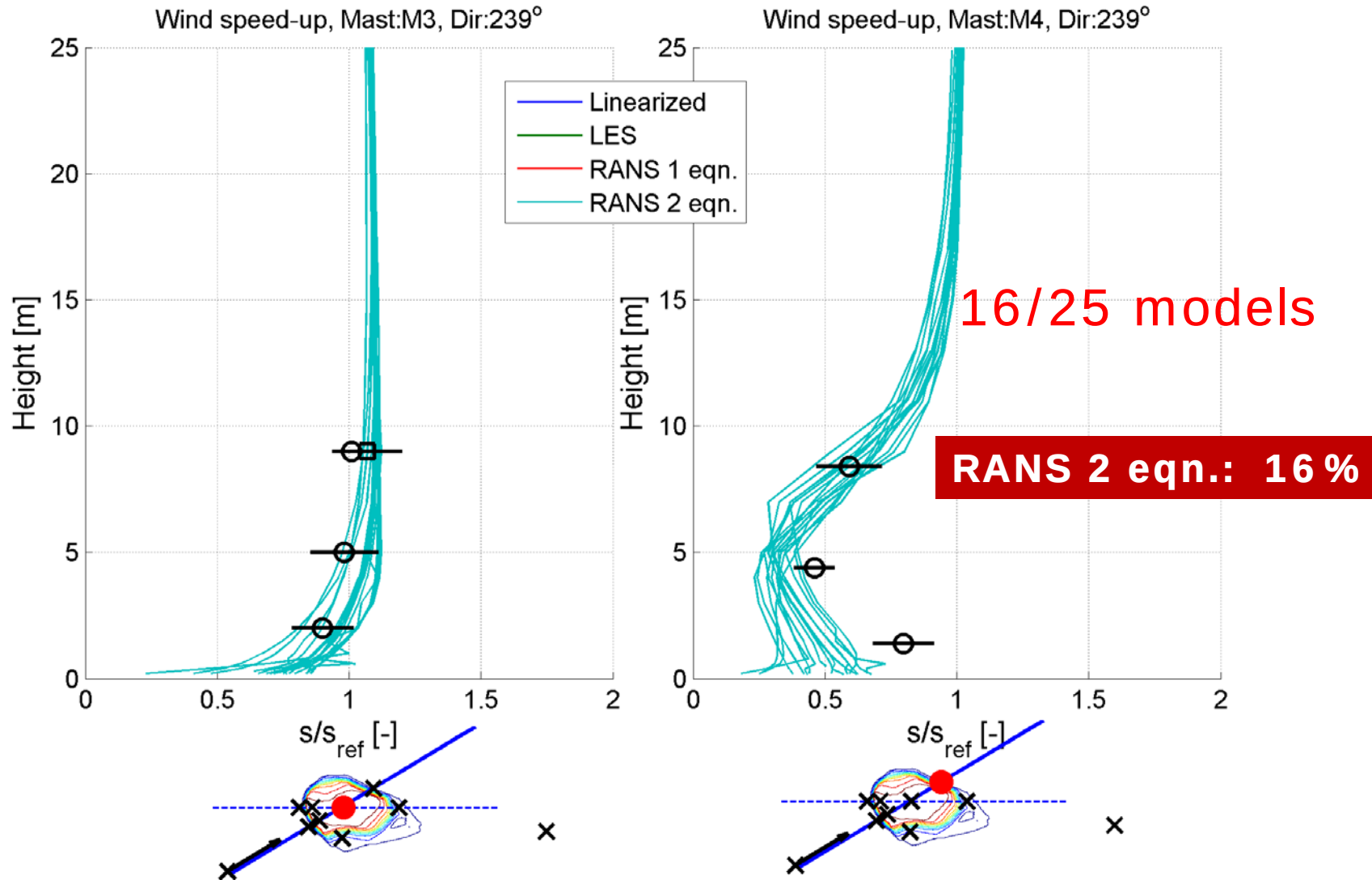
RANS 2 eqn.: 17 %



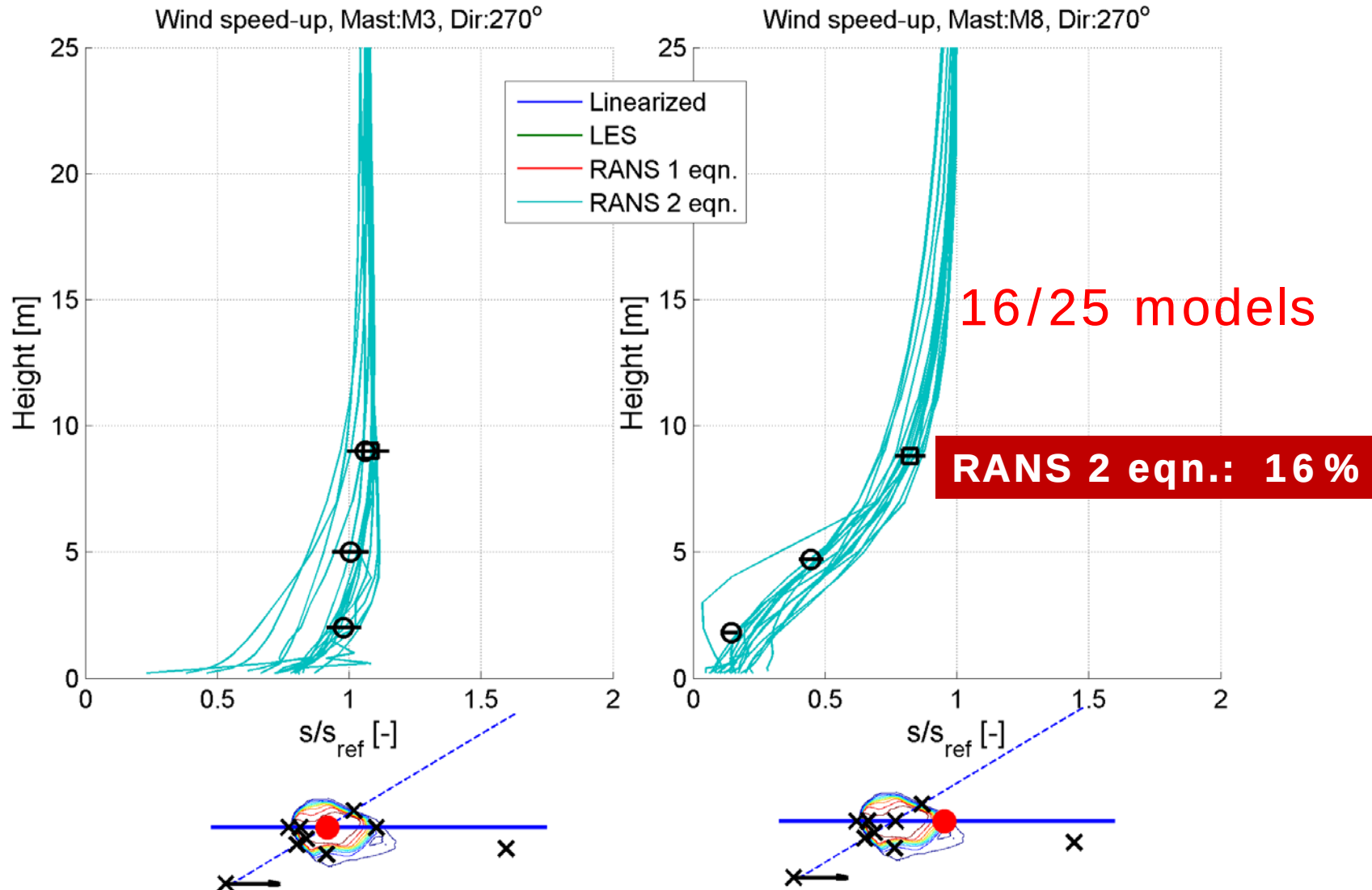
RANS 2 eq. models



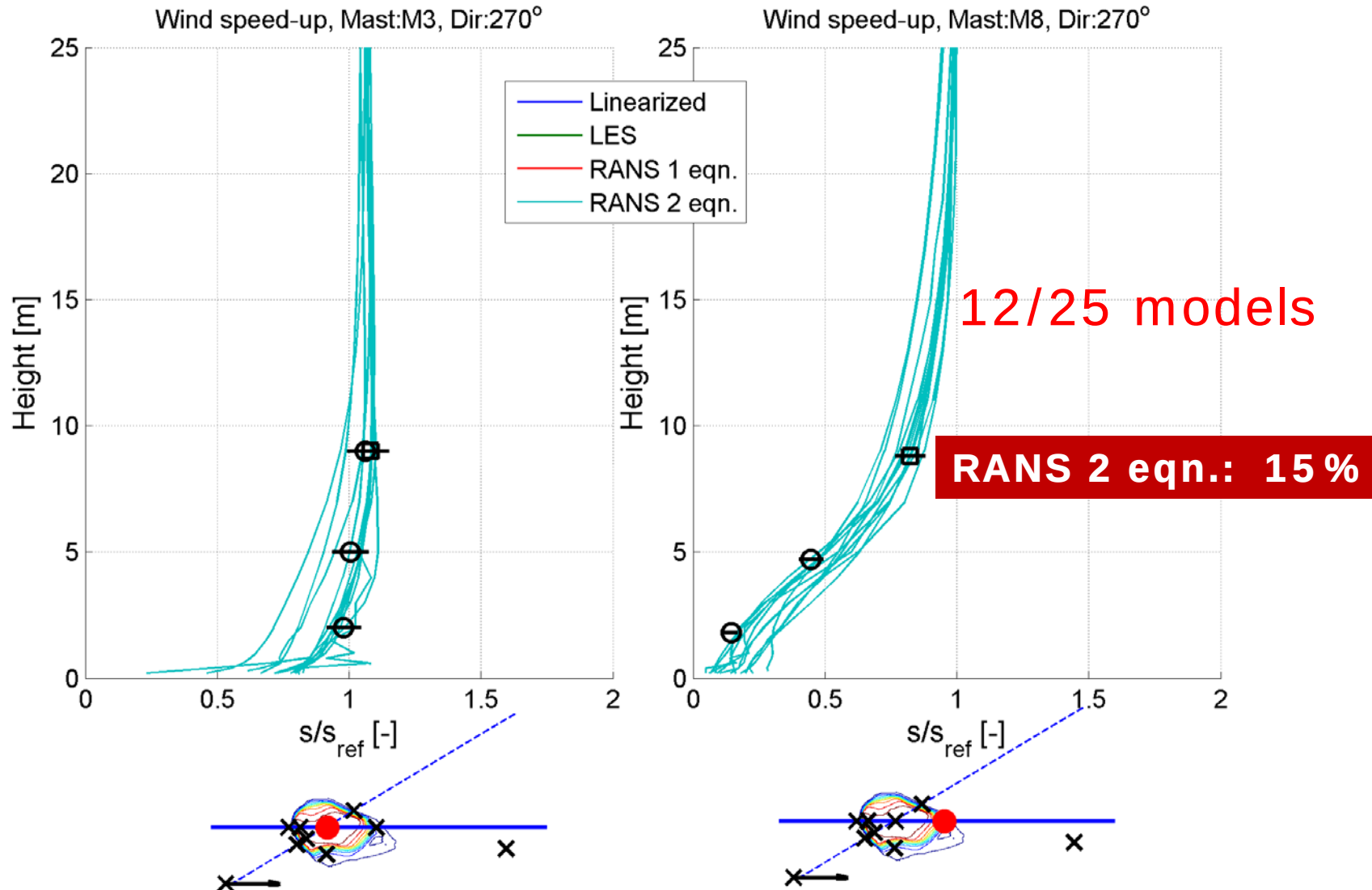
RANS 2 eq. models



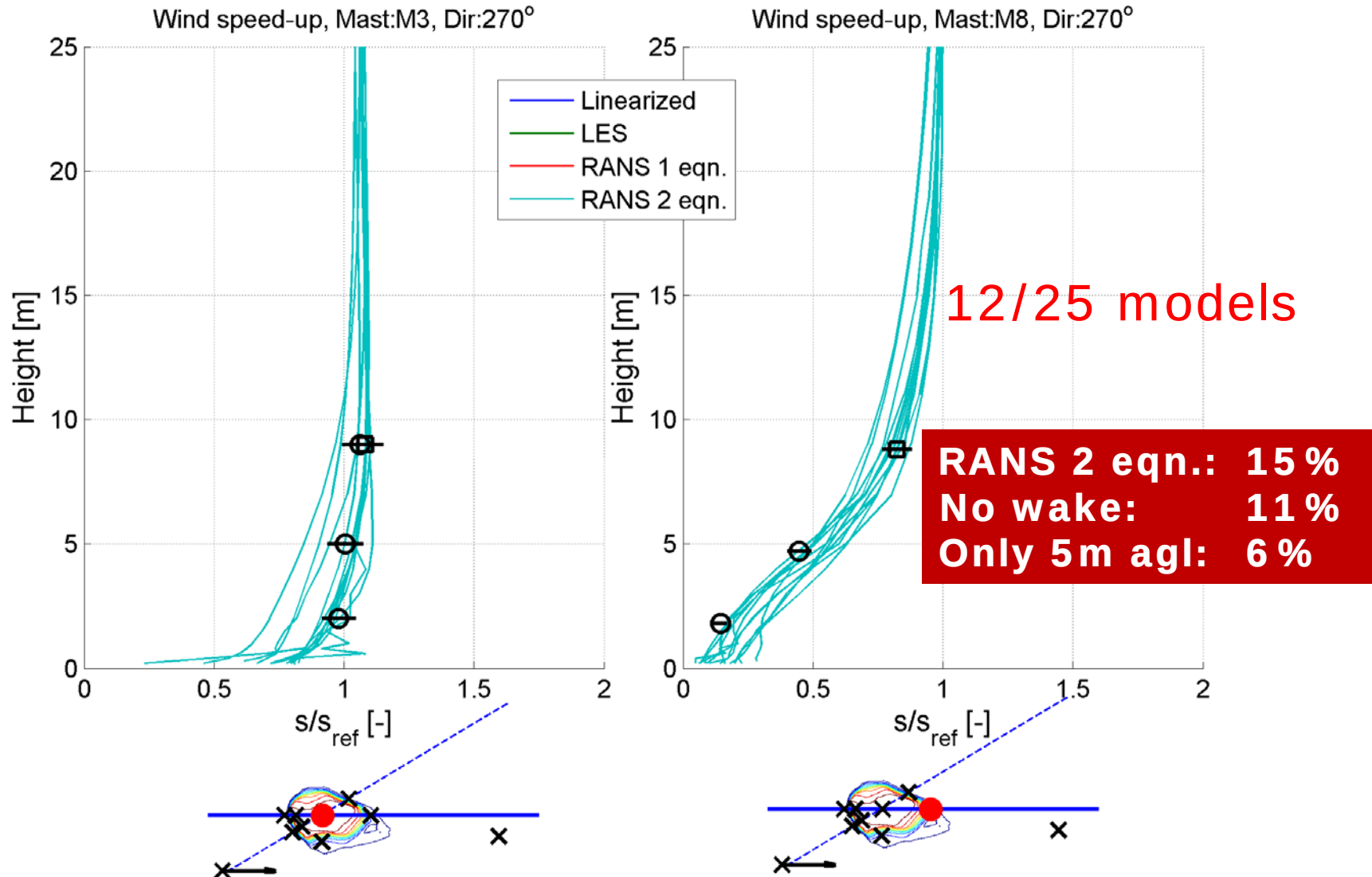
RANS 2 eq. models



RANS 2 eq. models



RANS 2 eq. models



Top 10 List

ID	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

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Conclusions

Physical models:

- Mean velocity looks well predicted
- TKE is too low

Lin. Models:

- Gave the largest error – not designed for Bolund (90 dir better)
- The peak in speedup was missing and a some spread in model results

LES:

- Many modelers had problems doing LES of Bolund
- The spread was large (not matured but showed potential)

RANS:

- State-of-the-art!
- Many models showed similar trends
- Some RANS simulations seems to be too “coarse” (two trends)

Conclusions

- TPWind: uncertainty of less than 3% - We have a long way!
- Bolund is an “ideal” case to test flow models. The uncertainty would be larger on “real” WT-sites
- How do you compare measurements and simulations?
- With best practice CFD guides results could probably be improved considerable (eg. Convergence test: results must be grid independent)
- The top 10 list consisted of 7 different CFD solver:
 1. You can get good results with most solvers
 2. The user is more important than the solver
- Recommendation: RANS will be the workhorse for many years to come
- Take a break – look at your results and discuss – make your own conclusions 😊

Thank you

Program

Thursday December 3

- 9:00 Registration / Coffee
- 9:30 Welcome
- 9:45 **The Askervein Experiment**
Peter A. Taylor, York University
- 10:30 Coffee
- 10:40 **The Bolund Experiment**
J. Berg, J. Mann & H.E. Jørgensen, Risø DTU
- 12:10 **Group Photo**
- 12:30 Lunch
- 13:30 **Blind Comparison Results**
Andreas Bechmann, Risø DTU
- 14:45 Coffee
- 16:00 **Questions to Bolund Team**
- 17:00 Bus to Scandic Hotel & Dinner
- 19:00 **Conference Dinner**
Sponsored by Vestas Technology R&D

Friday December 4

- 9:00 Resume / Coffee
- 9:15 **LES Simulation of Terrain**
Vijayant Kumar, Macquarie Capital
Marc Parlange & Chad Higgins, EPFL
- 10:00 Coffee
- 10:10 **Wind Tunnel Modeling of Bolund**
Brad C. Cochran, CPP Wind
- 10:50 **RANS Simulation of Bolund**
Niels Sørensen, Risø DTU
- 11:30 **Poster Introduction**
- 12:00 Lunch + Poster / Coffee
- 14:00 **Panel Discussion: Flow modeling**
Peter Taylor, Brad Cochran, Vijayant Kumar
Niels Sørensen, Jakob Mann
- 15:45 Close