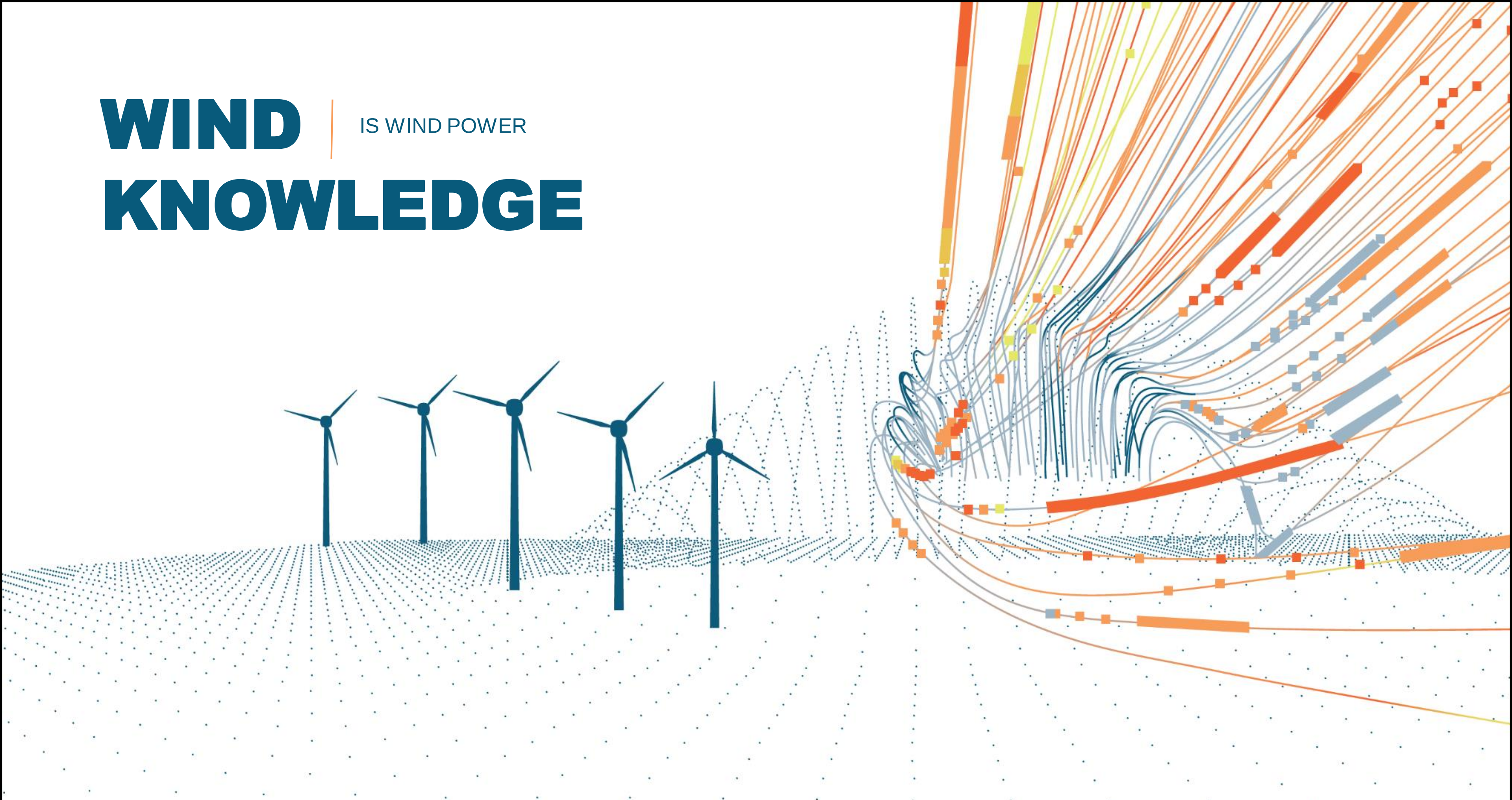
WIND KNOWLEDGE IS WIND POWER



Meso-microscale coupling

WindSim 13th User Meeting, Hamburg 24 September 2018

PRESENTED BY: Pablo Duran

windsim

Content

- What is meso-microscale coupling?
- Meso-microscale coupling in WindSim
- A first approach…
- Proposed coupling methodologies
  - Averaged conditions per sector
  - Averaged conditions per sector + per atmospheric stability
- Validation study
  - Validation sites
  - Validation methodology
  - Boundary conditions
  - Site 1: Honkajoki wind farm
  - Site 2: North America
  - Conclusions of the validation study
- Future work: A new approach

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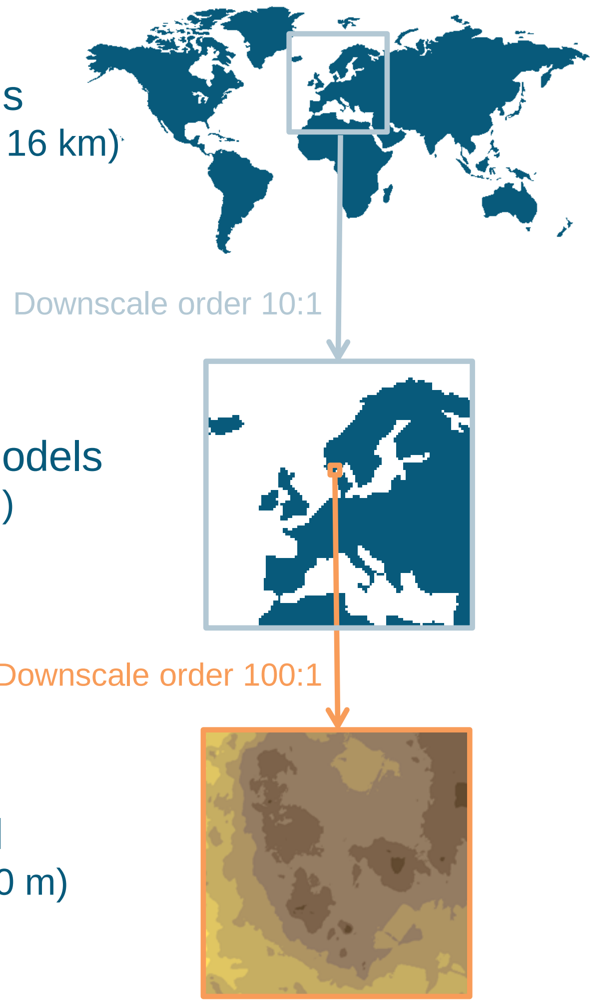
What is meso-microscale coupling?

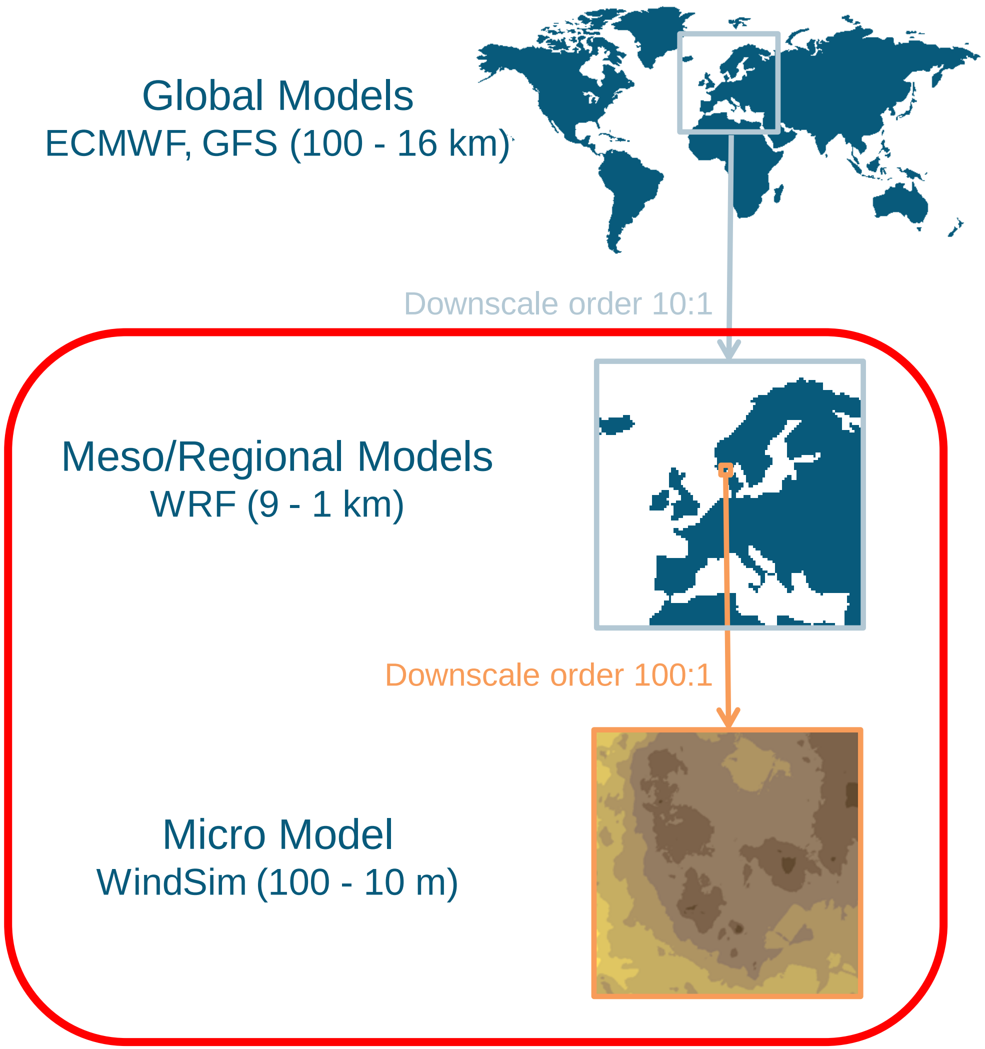
Global Models
ECMWF, GFS (100 - 16 km)

Meso/Regional Models
WRF (9 - 1 km)

Micro Model
WindSim (100 - 10 m)



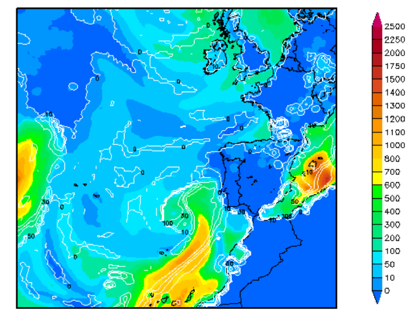
What is meso-microscale coupling?



What is meso-microscale coupling?

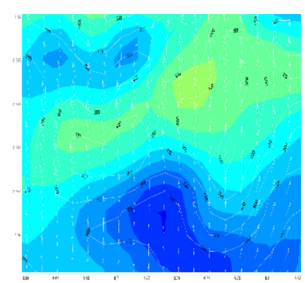
Meso/Regional Models
WRF (9 - 1 km)

Description of regional flows and atmospheric conditions

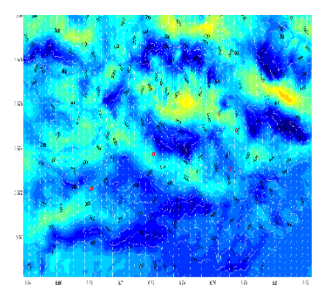


Micro Model
WindSim (100 - 10 m)

Accurate description of **local** flow field and wake effects



WRF wind field



CFD wind field

windsim

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Meso-microscale coupling in WindSim

Meso/Regional Models
WRF (9 - 1 km)

Micro Model
WindSim (100 - 10 m)

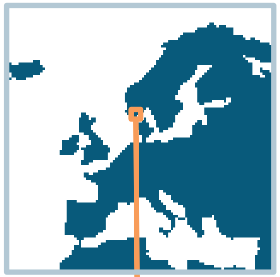
Regional model variables

Initial and boundary conditions in CFD simulation

WindSim Simulation

Meso-microscale coupling in WindSim

Meso/Regional Models
WRF (9 - 1 km)



Micro Model
WindSim (100 - 10 m)

Wind speed

Potential temperature

Interpolated

Turbulence Kinetic Energy (TKE)

Dissipation rate

Derived from: local atmospheric stability + PBL height

Initial and boundary conditions in CFD simulation

WindSim Simulation

Meso-microscale coupling in WindSim

- Why there is interest in coupling methodologies?

Avoid tuning of model parameters

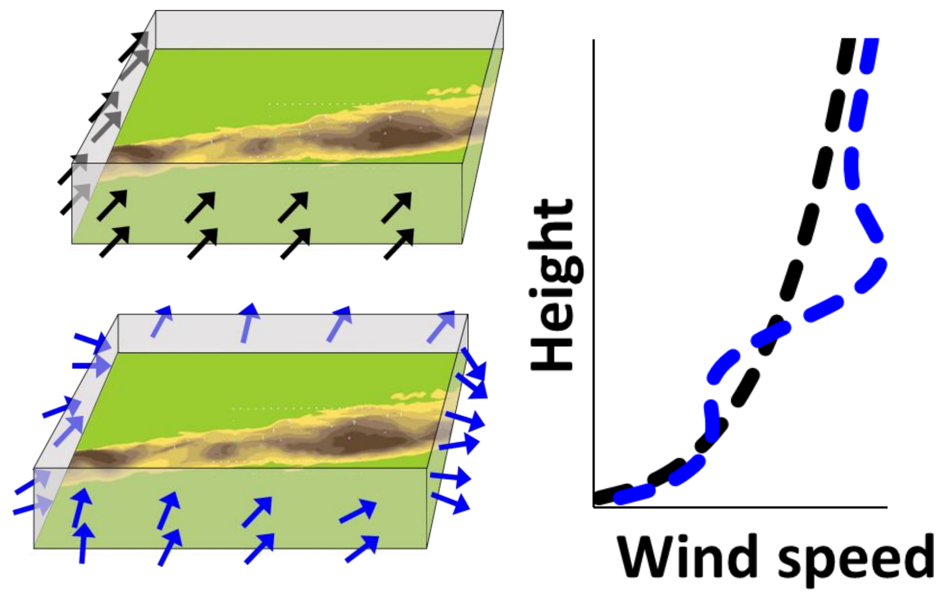
Monin-Obukhov length?

Planetary Boundary Layer (PBL) height?

Wind speed above PBL?

Temperature gradient?

Realistic inlet profiles



Not possible to reproduce with standard CFD !

How can we use this meso-microscale coupling for wind resource assessment?

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A first approach…

In principle **one** WindSim simulation could be conducted per WRF time step:

- e.g. one simulation per hour → 8760 WindSim simulations for one year of WRF simulations

A first approach…

In principle **one** WindSim simulation could be conducted per WRF time step:

- e.g. one simulation per hour → 8760 WindSim simulations for one year of WRF simulations

Not practical !

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Proposed coupling methodologies

Two proposed coupling methodology :

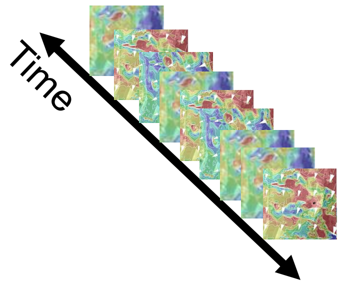
- Averaged conditions per sector (12 simulations)
- Averaged conditions per sector & per atmospheric stability (36 simulations)

Proposed coupling methodologies — Averaged conditions per sector

windsim

Proposed coupling methodologies — Averaged conditions per sector

1 year of
mesoscale
model output

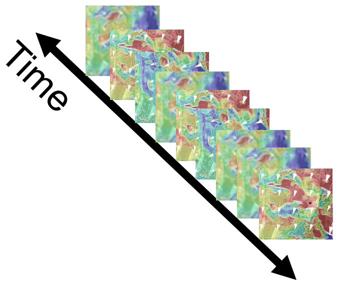


*Processes
*Data

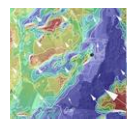
Proposed coupling methodologies — Averaged conditions per sector

1 year of mesoscale model output

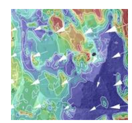
Average according to wind direction



Sector 0°

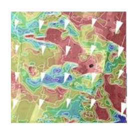


Sector 30°



⋮

Sector 360°



1 WRF field per directional sector

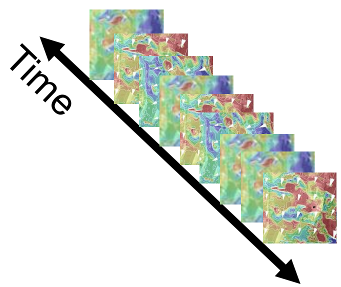
*Processes
*Data

Proposed coupling methodologies — Averaged conditions per sector

1 year of mesoscale model output

Average according to wind direction

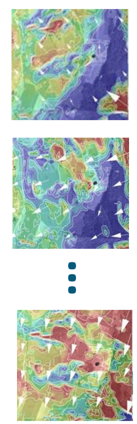
Transfer WRF data to WindSim model



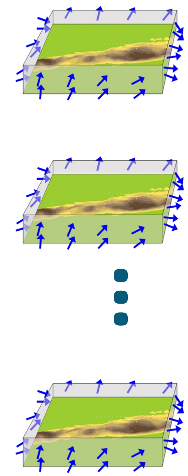
Sector 0°

Sector 30°

Sector 360°



1 WRF field per directional sector



1 CFD Boundary condition per sector

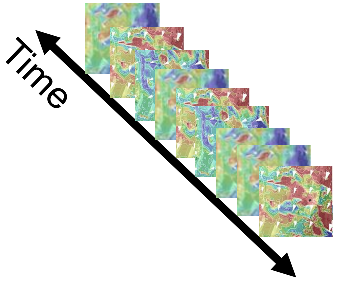
*Processes

*Data

Proposed coupling methodologies — per atmospheric stability

Proposed coupling methodologies — per atmospheric stability

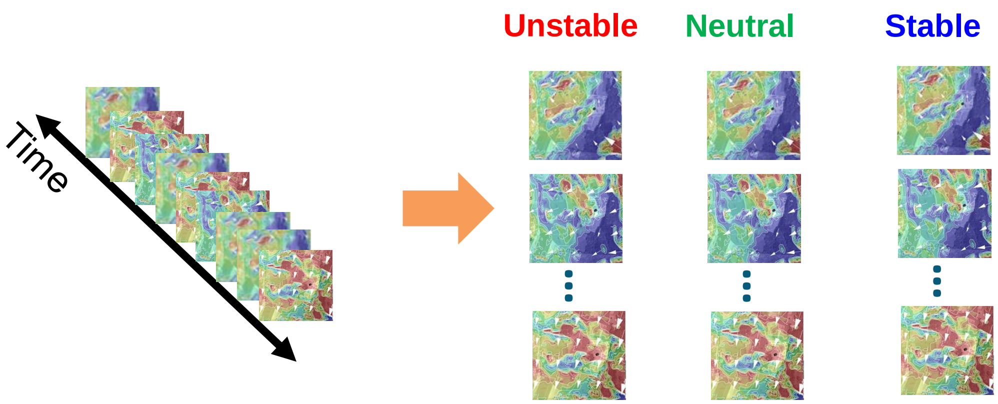
1 year of
mesoscale
model output



*Processes
*Data

Proposed coupling methodologies — per atmospheric stability

1 year of mesoscale model output → Average according to wind direction & **atmospheric stability**



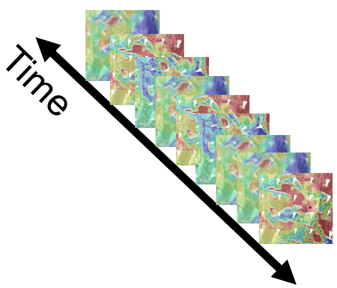
*Processes
*Data

Proposed coupling methodologies — per atmospheric stability

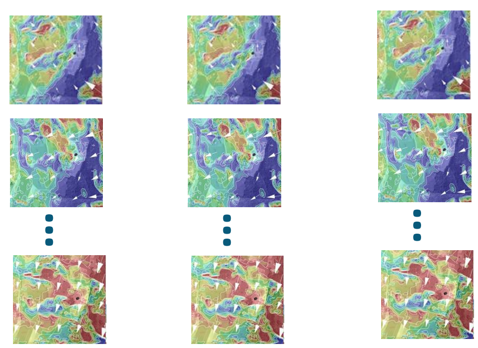
1 year of mesoscale model output

Average according to wind direction & **atmospheric stability**

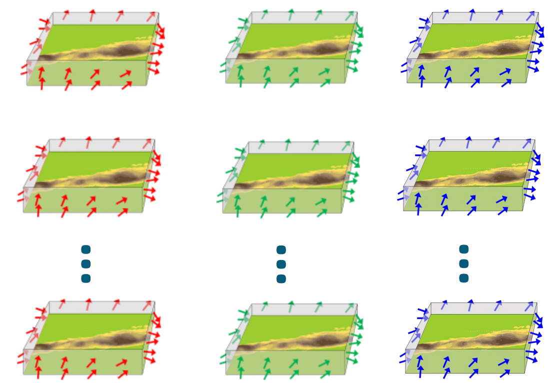
Transfer WRF data to WindSim model



Unstable Neutral Stable



Unstable Neutral Stable



*Processes
*Data

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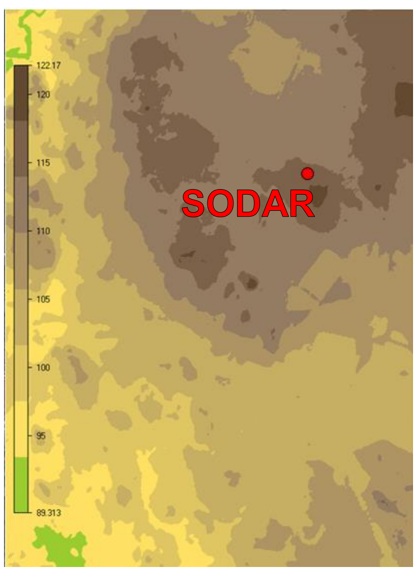
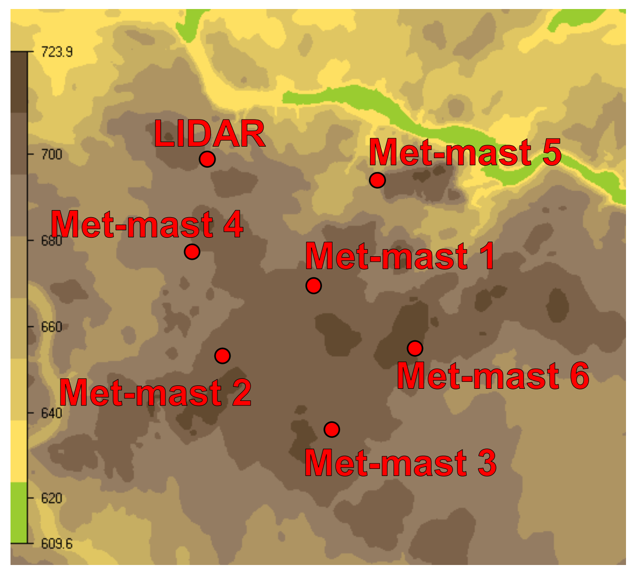
Validation study – Validation sites

Validation site	Location	Terrain	Wind speed sensors
Honkajoki wind farm	Finland	Flat, Forested	1 SODAR (50 to 200 m)
Site 2	North America	Flat	6 Met-mast (20 m / 40 m / 60 m) 1 LIDAR (40 to 180 m)

Honkajoki wind farm



Site 2



Validation study – Validation methodology

Honkajoki wind farm – Both methods are compared with the thermal stand-alone simulations:

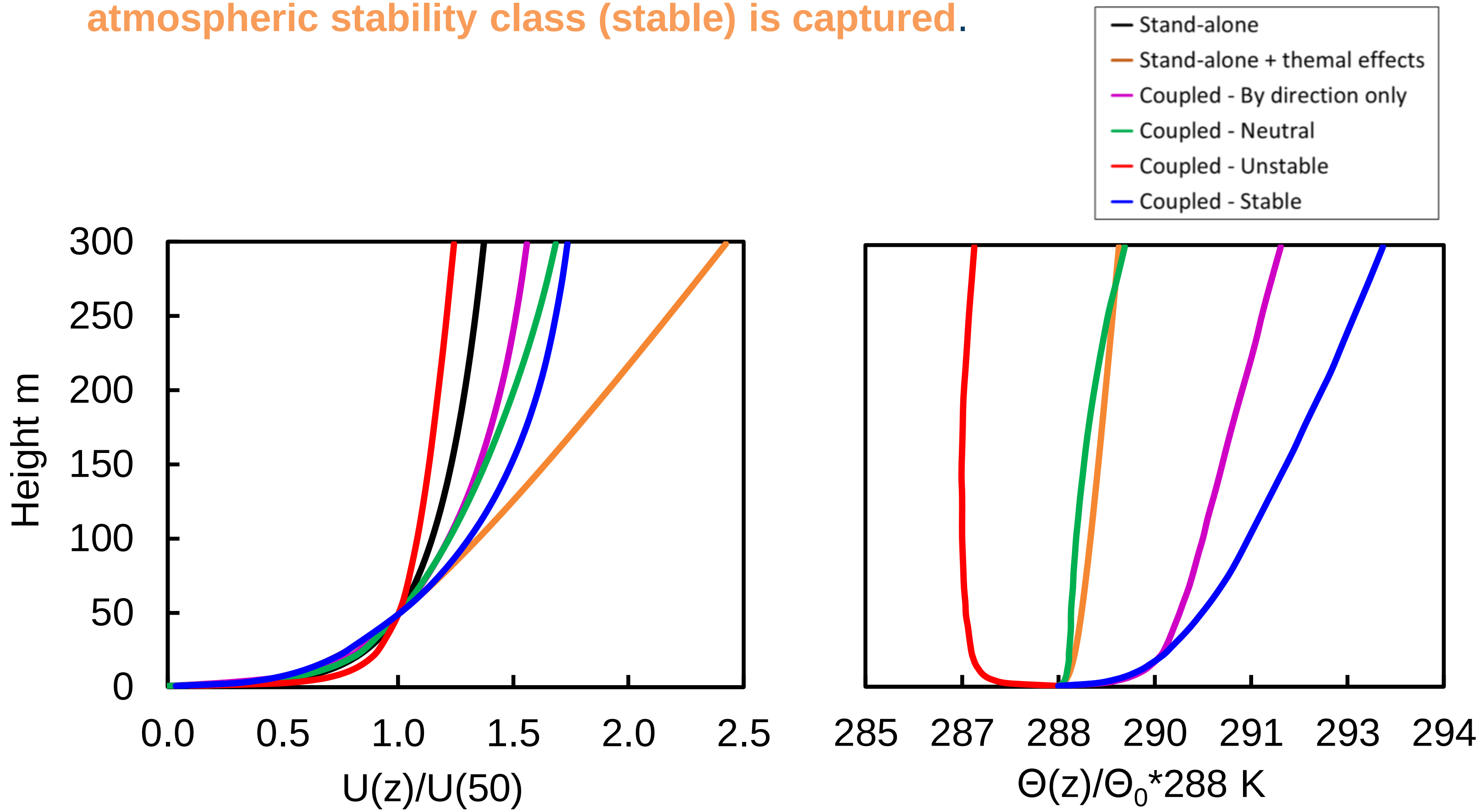
Type of simulation	Atmospheric stability	Stand-alone Monin-Obukhov length (m)											
		0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°
By sector	All stabilities	100	100	100	180	180	180	180	300	300	180	100	100
By sector & atmospheric stability	Unstable	-200											
	Neutral	Infinity											
	Stable	180											

Site 2 – The first method is compared with default and thermal stand-alone simulations

Atmospheric stability	Stand-alone Monin-Obukhov length (m)											
	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°
All stabilities	400	400	400	Inf	400	200	400	200	200	200	Inf	Inf
Neutral	Infinity											

Validation study – Boundary conditions

- The computed boundary conditions capture the **atmospheric stability**.
- Even when classifying the WRF only by direction, **the predominant atmospheric stability class (stable) is captured**.



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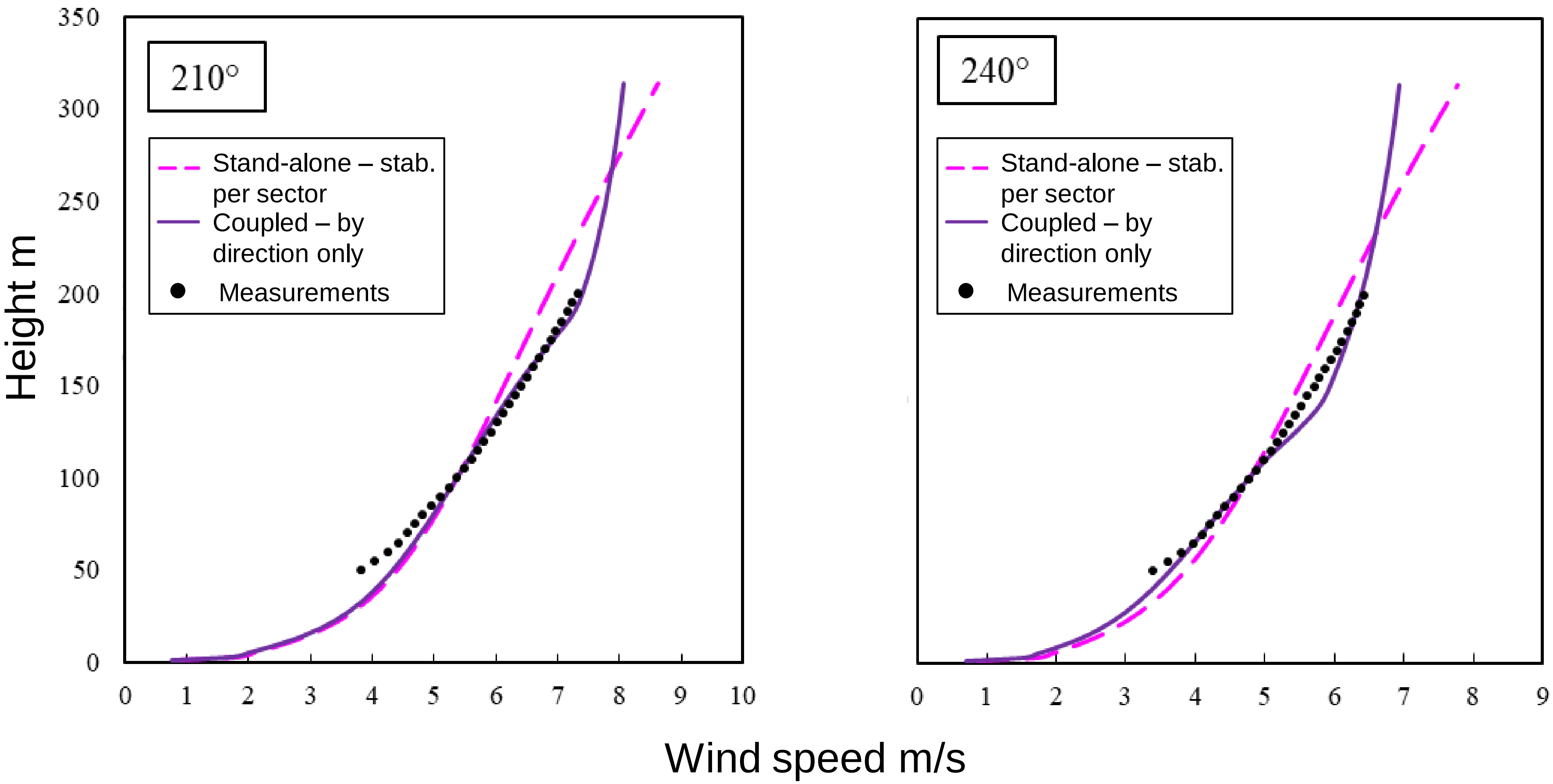
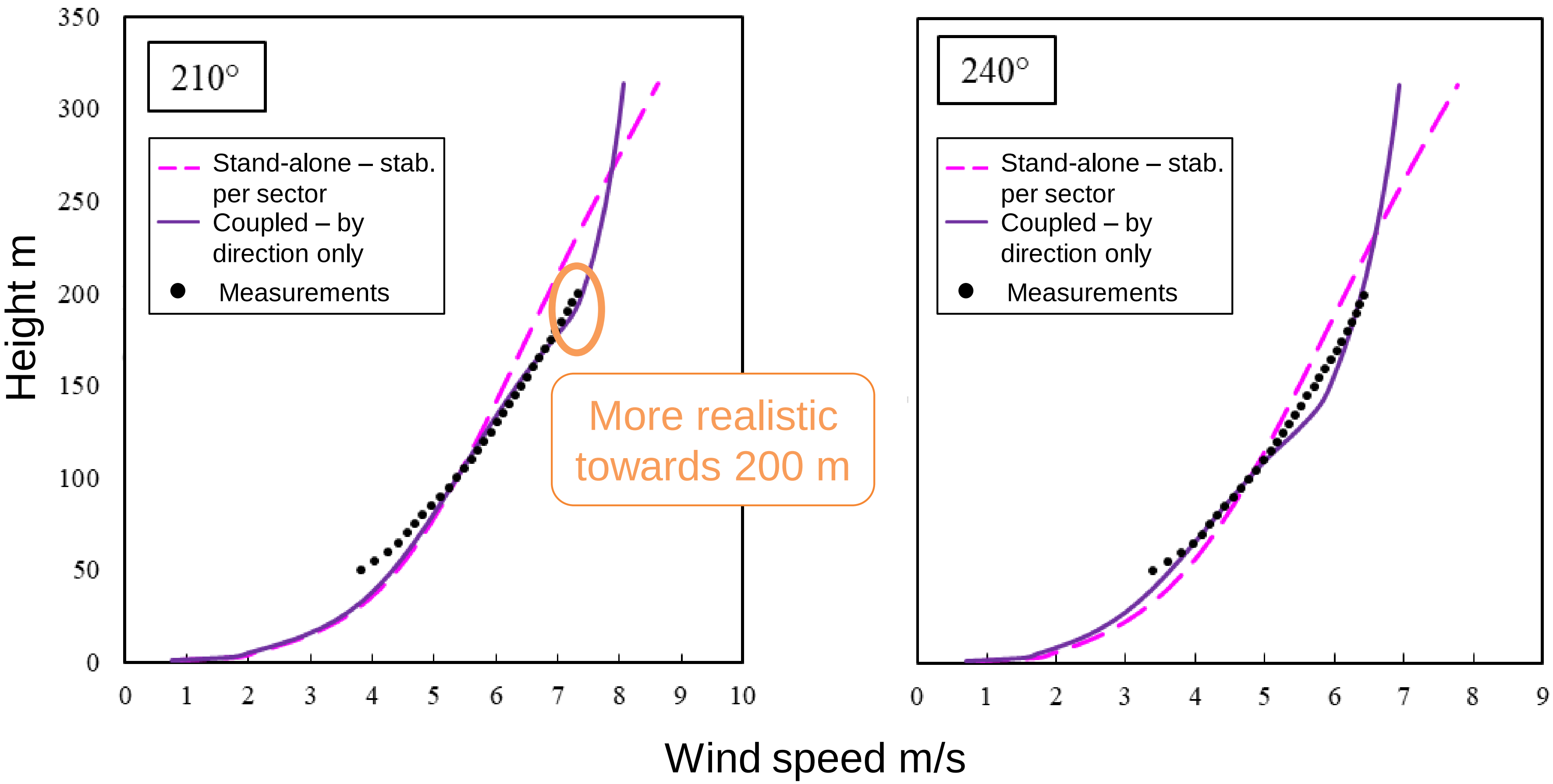
Validation study – Honkajoki wind farm

- By direction only: **Coupled** v/s **Stand-alone**



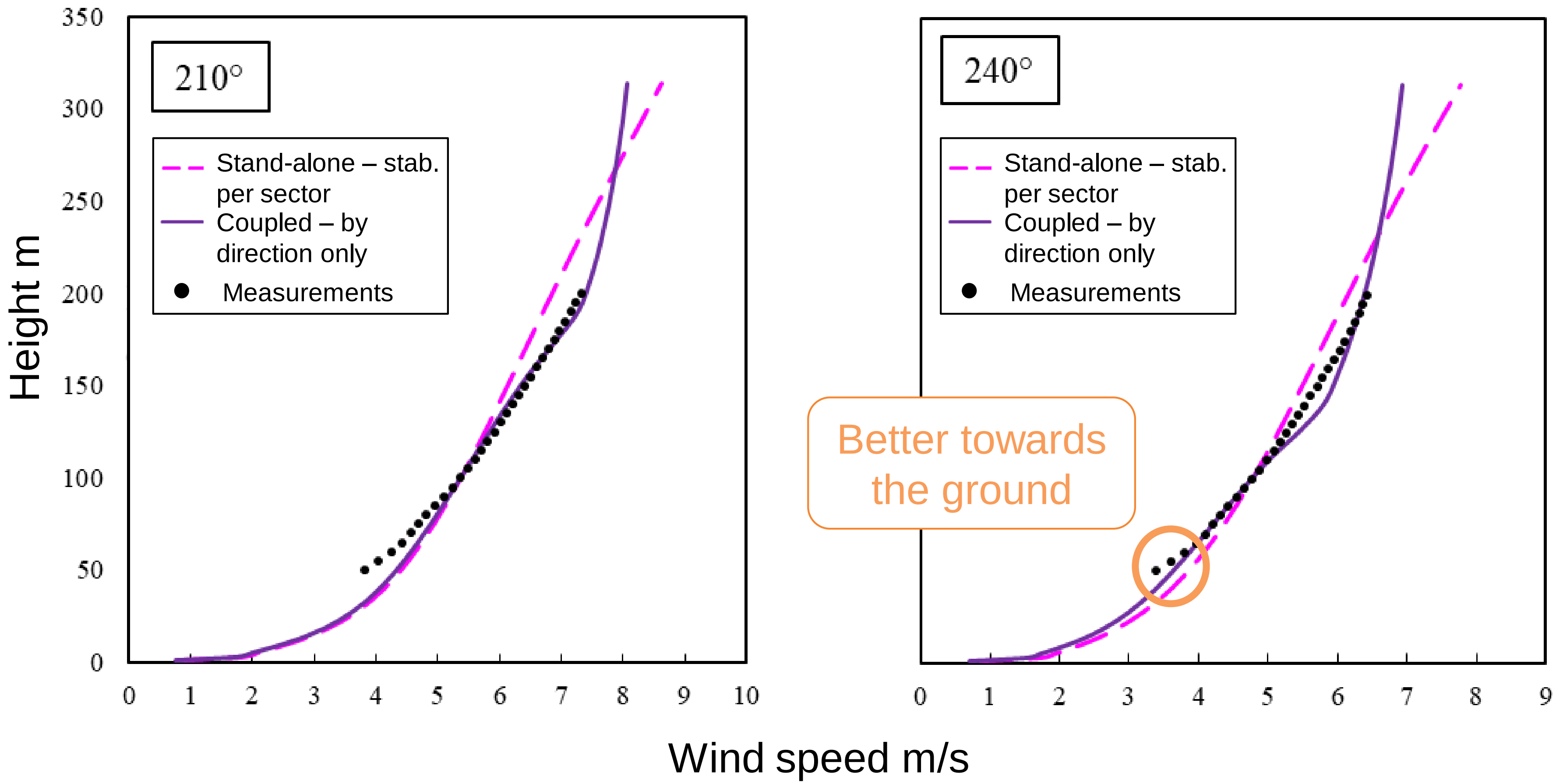
Validation study – Honkajoki wind farm

- By direction only: **Coupled** v/s **Stand-alone**



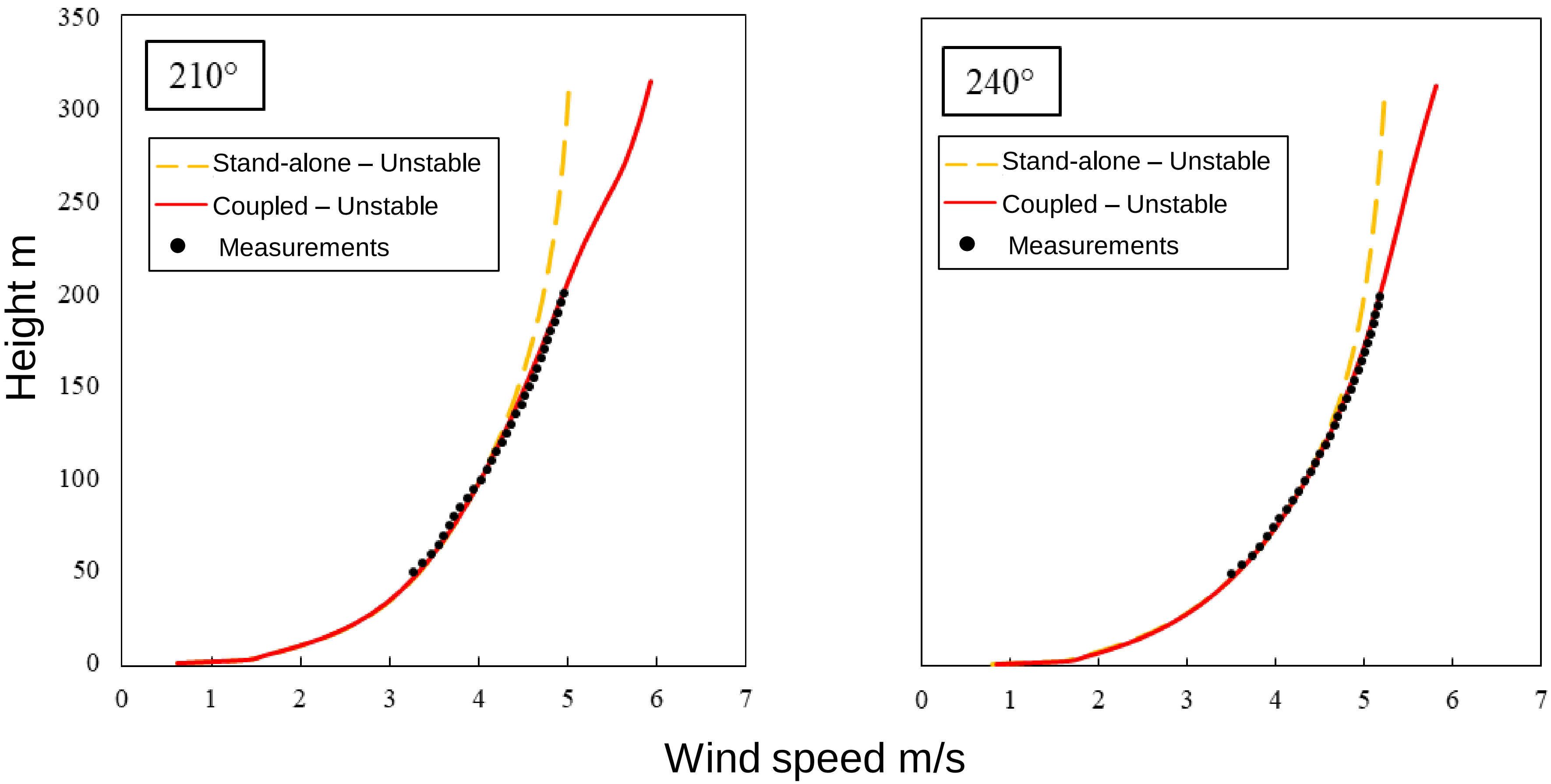
Validation study – Honkajoki wind farm

- By direction only: **Coupled** v/s **Stand-alone**



Validation study – Honkajoki wind farm

- Unstable case: **Coupled** v/s **Stand-alone**



Validation study – Honkajoki wind farm

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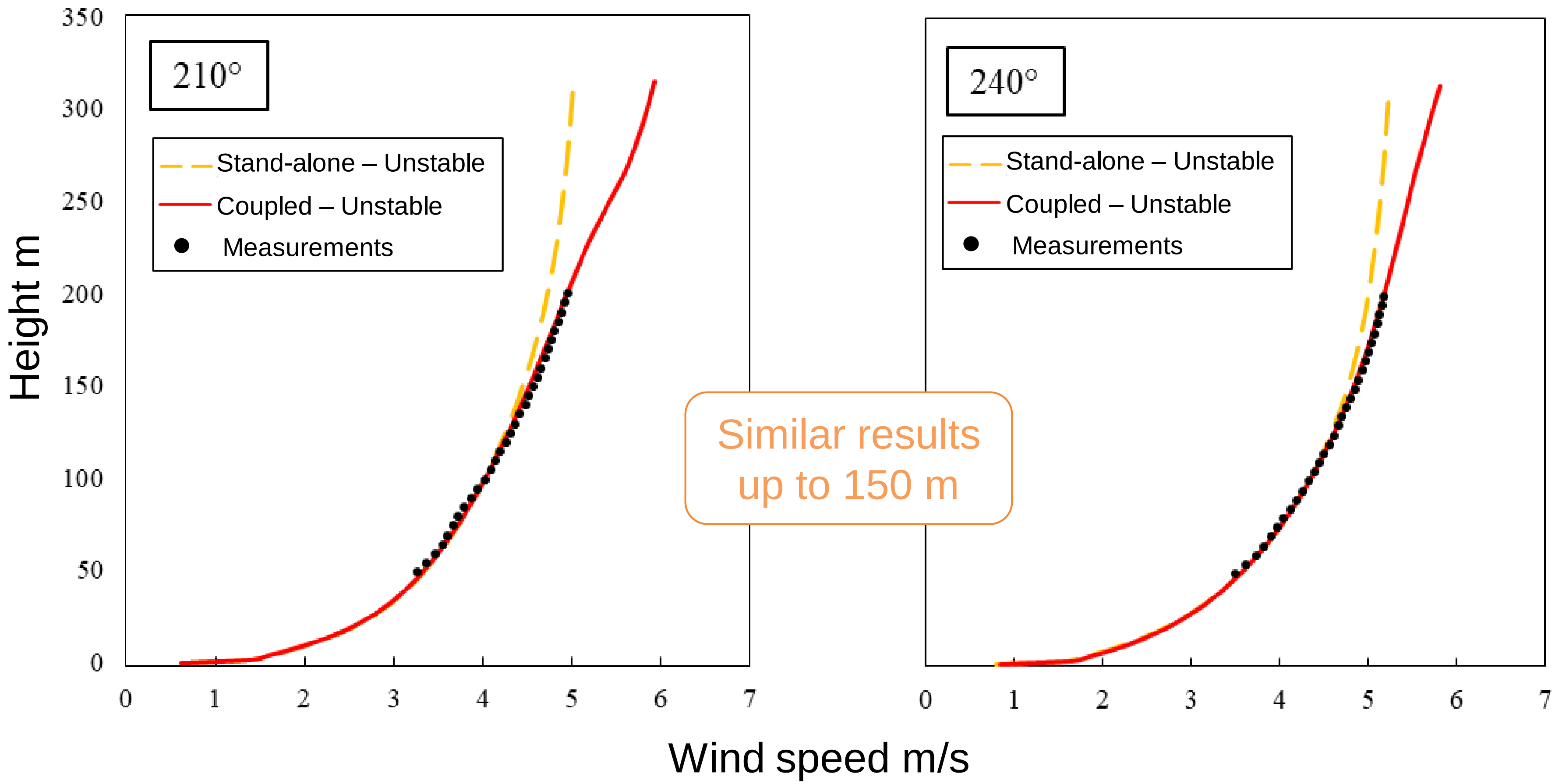

Validation study – Honkajoki wind farm

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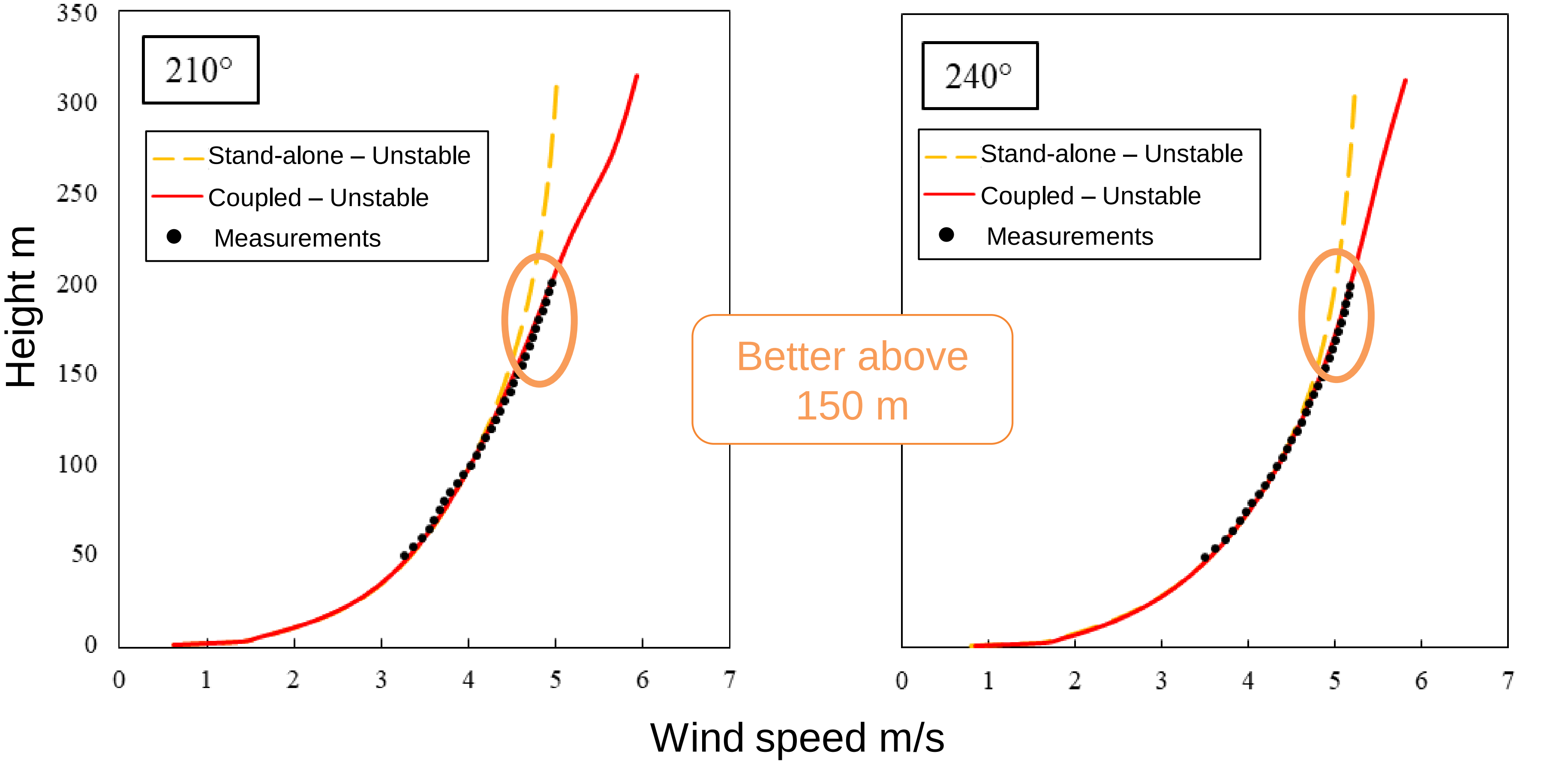
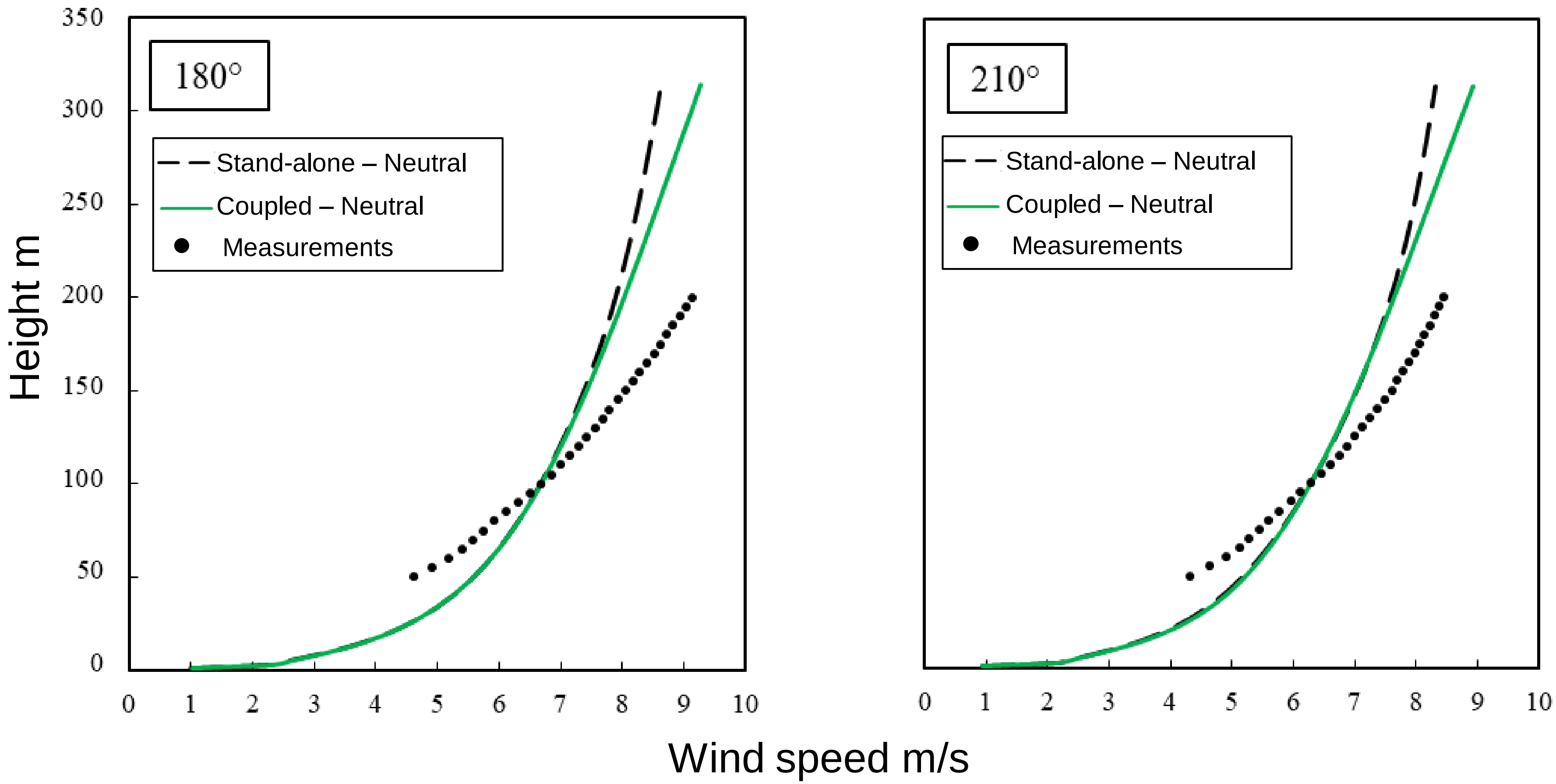


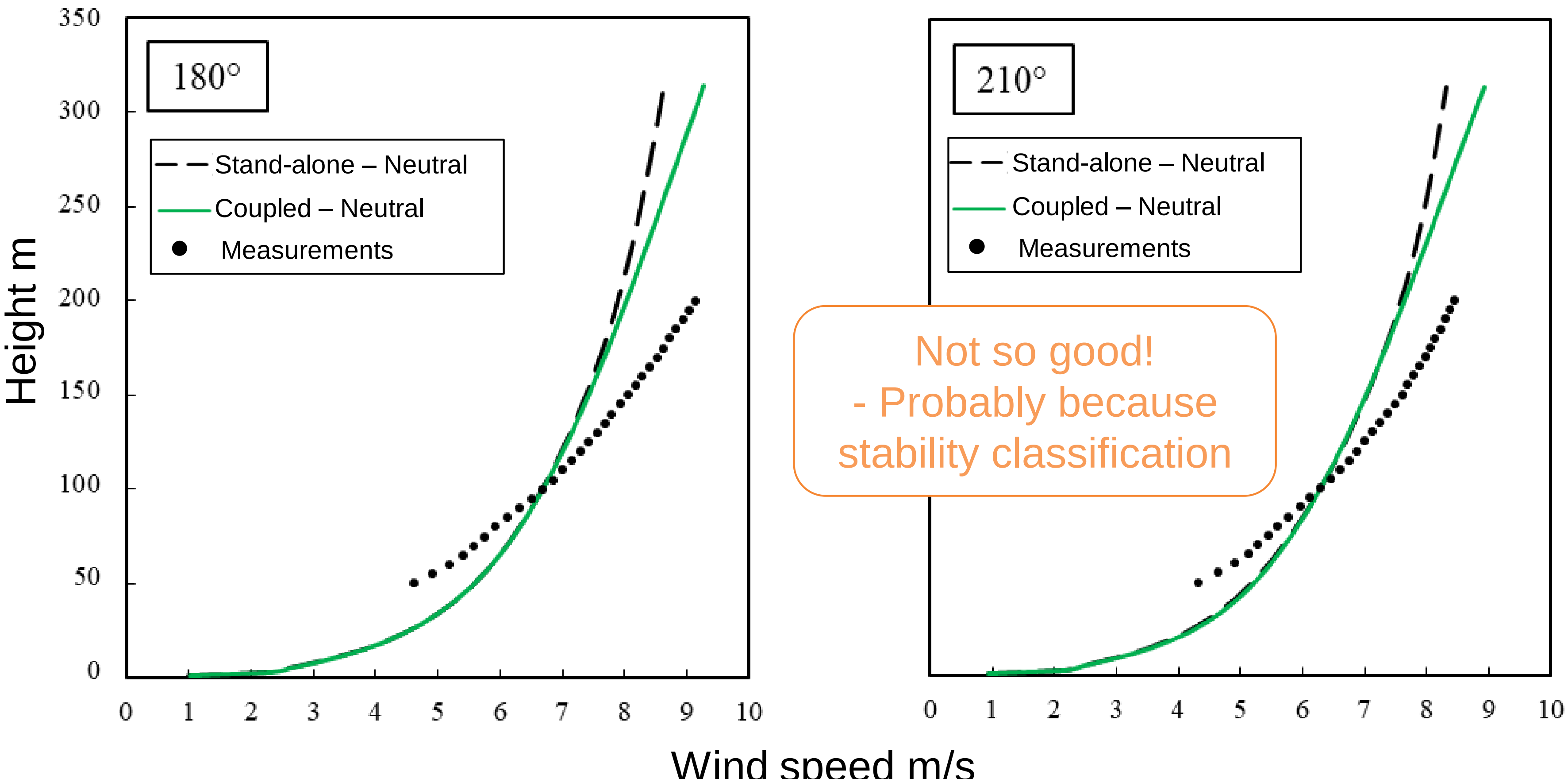
Validation study – Honkajoki wind farm

- Neutral case: **Coupled** v/s **Stand-alone**



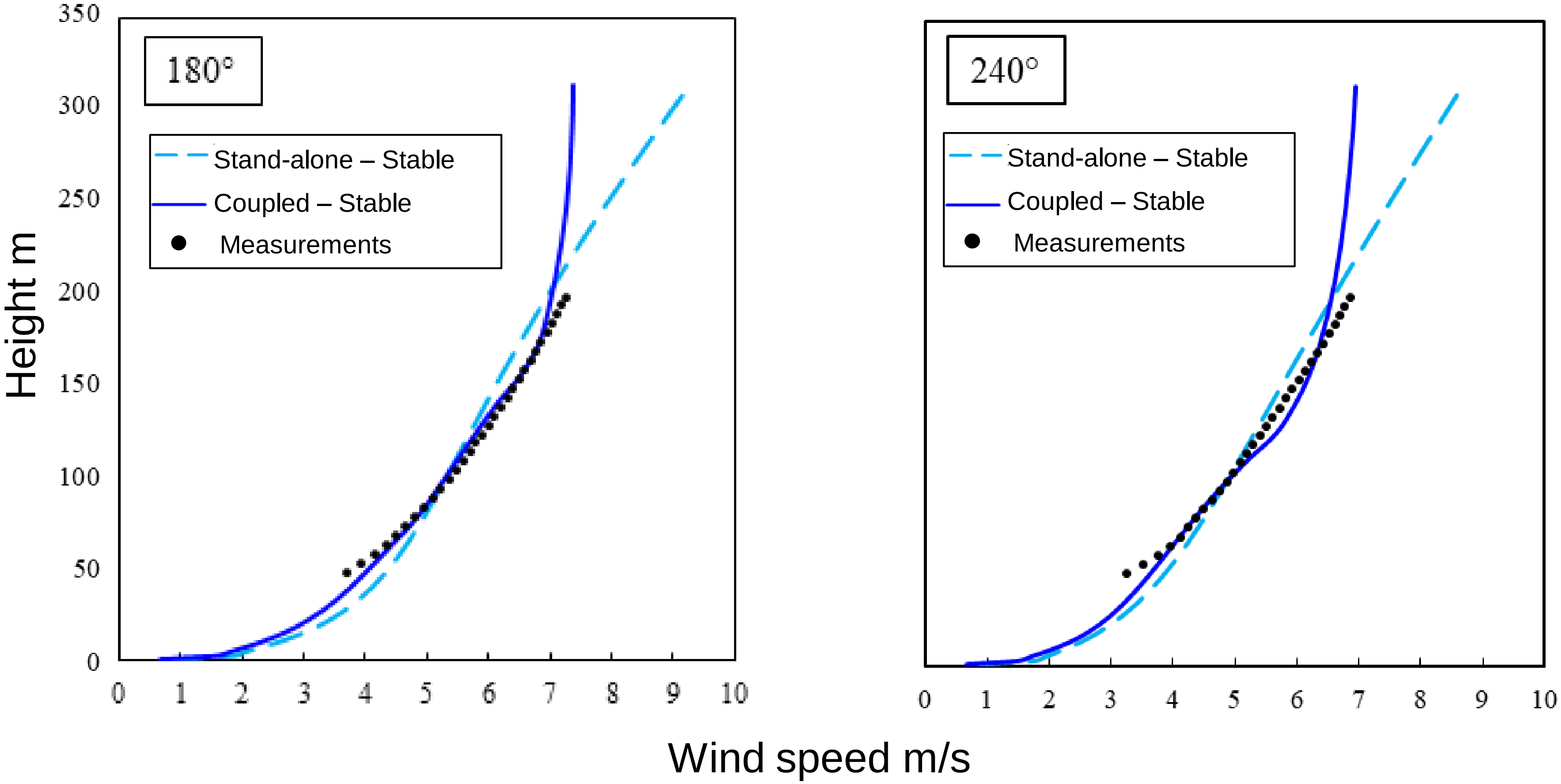
Validation study – Honkajoki wind farm

- Neutral case: **Coupled** v/s **Stand-alone**



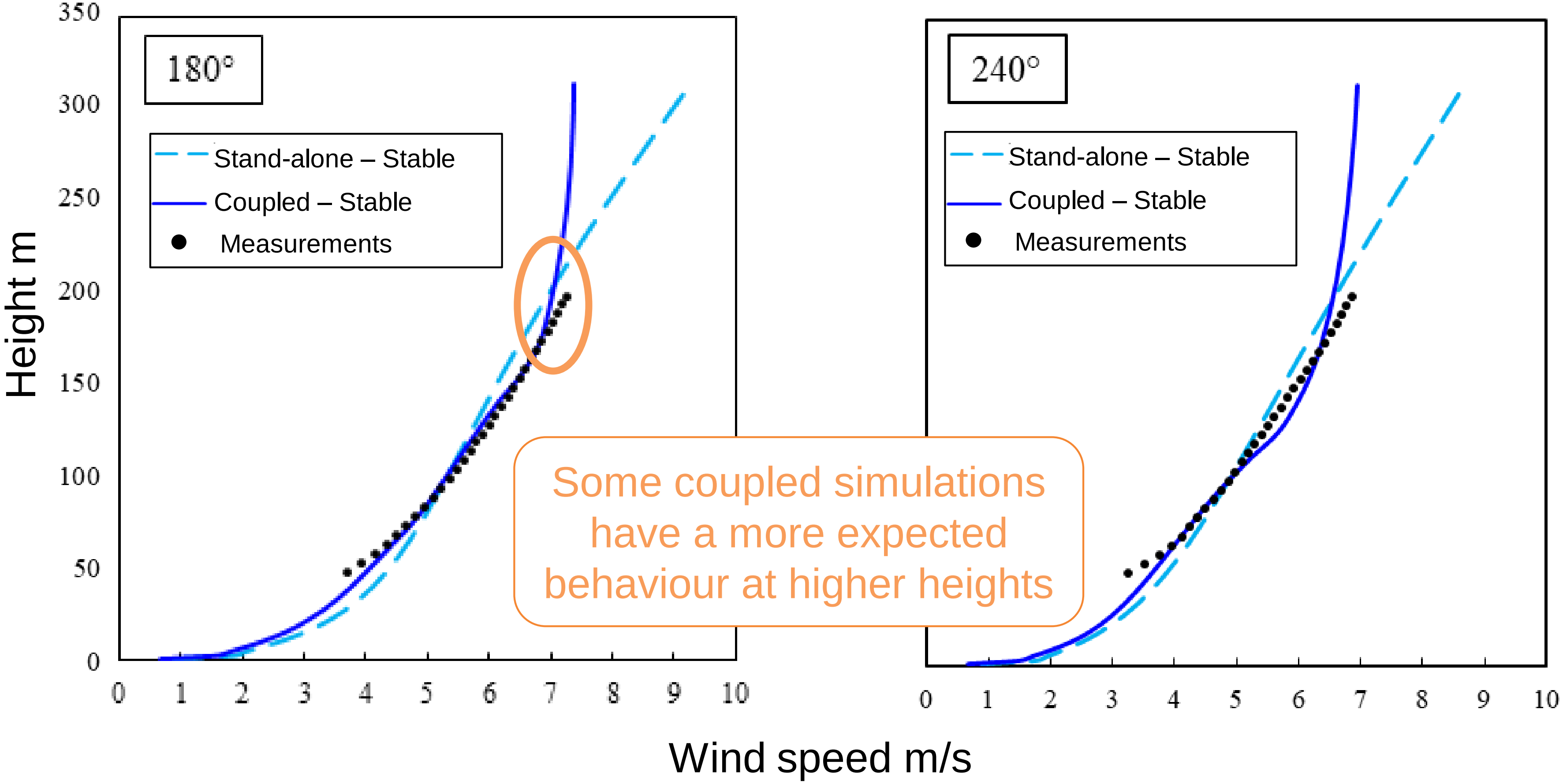
Validation study – Honkajoki wind farm

- Stable case: **Coupled** v/s **Stand-alone**



Validation study – Honkajoki wind farm

- Stable case: **Coupled** v/s **Stand-alone**



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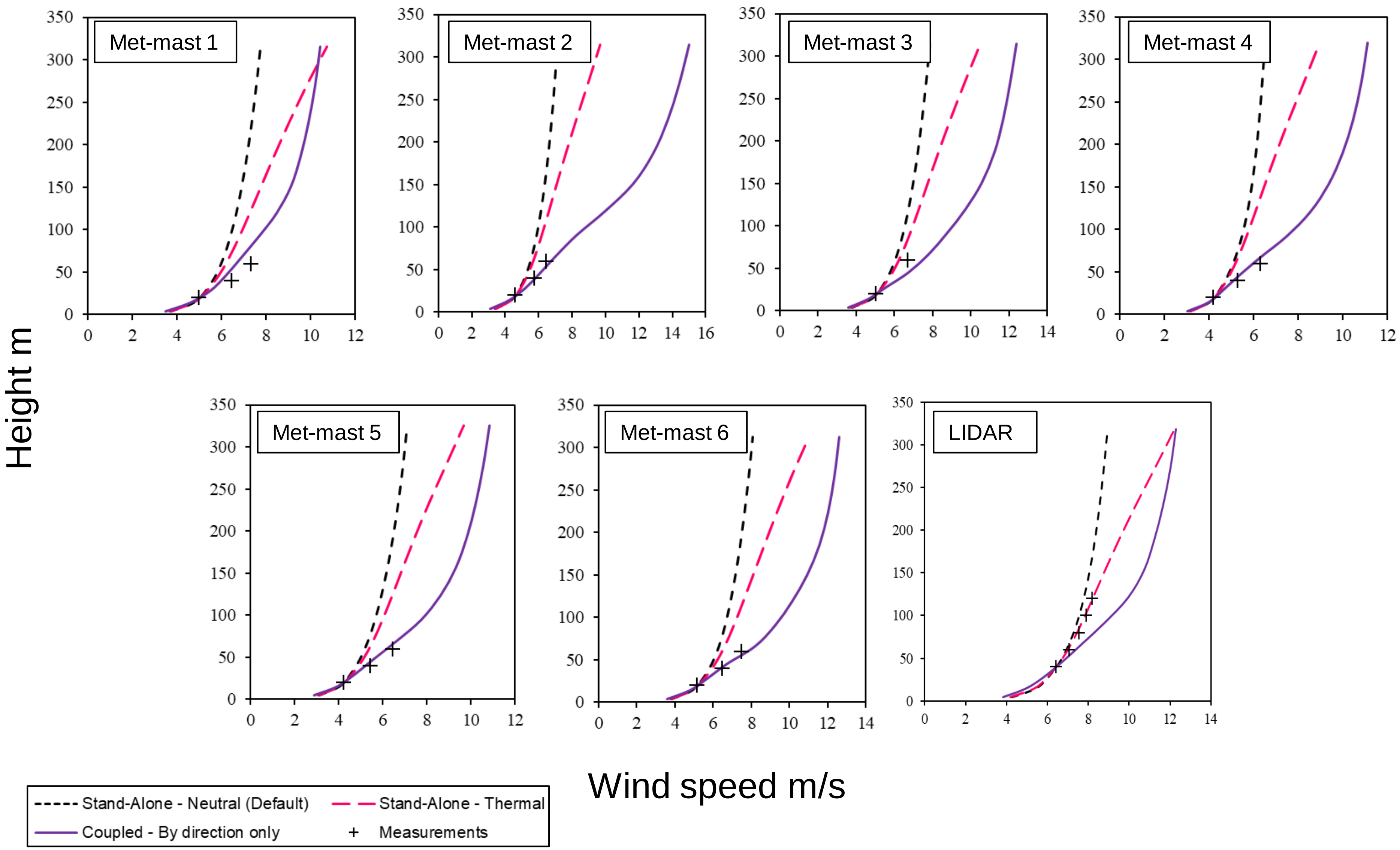
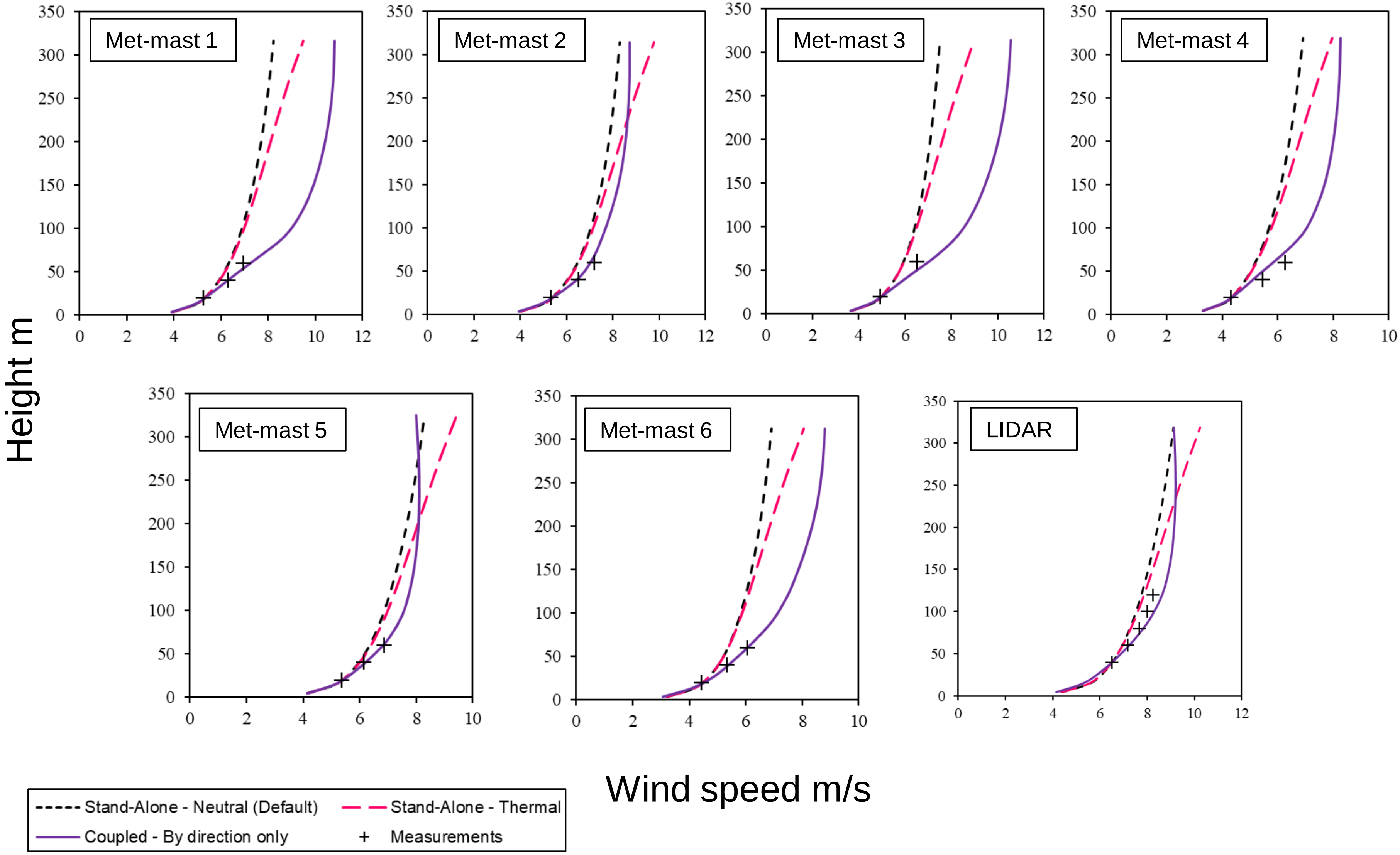
Validation study – Site 2 – Sector 270°



Validation study – Site 2 – Sector 180°



Validation study – Site 2 – Vertical cross-prediction error

Stand-alone Neutral

Ref.	Targ.	Sectors											
		0	30	60	90	120	150	180	210	240	270	300	330
M1-20	M1-40	-1.9	-6.4	-2.9	-0.8	-5.1	-10.5	-6.2	-9.7	-13.3	-13.0	-8.4	-5.0
M1-20	M1-60	-2.9	-8.2	-4.7	-2.1	-8.5	-15.8	-10.1	-14.5	-19.3	-18.2	-11.5	-6.8
M1-40	M1-20	2.1	7.3	2.6	1.1	5.2	11.5	6.8	10.2	13.1	16.0	9.6	5.4
M1-40	M1-60	-0.8	-2.3	-1.7	-1.5	-3.7	-6.0	-3.8	-5.4	-6.1	-6.6	-3.7	-1.9
M1-60	M1-20	3.4	9.2	4.6	2.8	9.6	18.2	11.0	16.3	19.0	23.0	15.9	7.9
M1-60	M1-40	0.8	2.3	2.1	1.6	4.0	6.3	3.8	5.9	5.7	6.8	4.6	2.0
M2-20	M2-40	-6.5	-6.0	-4.9	-0.8	-3.8	-6.3	-8.0	-9.5	-12.0	-10.2	-10.1	-9.0
M2-20	M2-60	-7.9	-6.7	-5.9	-1.4	-5.7	-9.4	-11.0	-13.1	-17.7	-15.0	-14.7	-13.3
M2-40	M2-20	7.3	7.7	4.4	1.0	4.2	6.8	8.5	10.4	14.3	11.0	10.7	10.1
M2-40	M2-60	-1.4	-1.8	-1.0	-0.6	-2.2	-3.5	-2.7	-4.2	-6.5	-5.3	-4.9	-4.5
M2-60	M2-20	9.7	7.3	4.8	3.9	7.1	11.3	11.0	14.5	22.6	17.0	16.4	14.8
M2-60	M2-40	1.5	0.9	1.1	1.3	2.5	3.9	2.5	4.1	6.7	5.3	5.5	4.5
M3-20	M3-60	0.9	-3.0	-2.3	-4.2	-9.2	-9.6	-8.7	-7.4	-10.7	-12.0	-7.9	-1.2
M3-60	M3-20	-0.2	3.8	2.5	3.9	8.6	10.4	10.2	8.4	11.4	11.3	9.5	1.5
M4-20	M4-40	-1.9	-1.3	-0.8	-3.0	-7.4	-10.3	-13.1	-16.2	-16.6	-8.1	-5.2	-4.0
M4-20	M4-60	-3.2	-1.8	-1.7	-6.5	-11.7	-16.3	-19.0	-23.7	-24.8	-15.4	-9.3	-6.4
M4-40	M4-20	2.6	2.0	0.5	2.8	7.3	10.8	13.6	19.2	19.5	10.3	5.9	4.4
M4-40	M4-60	-1.8	-0.6	-0.7	-3.4	-4.4	-6.3	-6.5	-7.5	-11.0	-8.5	-4.6	-2.5
M4-60	M4-20	5.2	3.5	1.9	5.8	11.3	17.0	21.1	27.4	29.0	24.1	11.7	7.9
M4-60	M4-40	2.2	0.9	1.0	3.2	4.3	6.2	7.5	6.6	10.0	11.0	5.2	2.8
M5-20	M5-40	0.9	2.2	3.2	0.8	0.9	-0.7	-5.0	-11.0	-13.5	-11.4	-6.9	-1.2
M5-20	M5-60	-0.4	0.6	3.3	0.8	0.4	-4.3	-11.1	-19.4	-23.4	-18.6	-10.3	-2.2
M5-40	M5-20	-0.7	-2.1	-3.3	-0.8	-0.9	0.3	4.1	10.4	14.3	13.3	8.2	1.8
M5-40	M5-60	-1.1	-1.6	0.1	-0.2	-0.5	-3.1	-5.4	-9.7	-9.5	-9.2	-4.0	-1.2
M5-60	M5-20	0.7	-0.7	-3.3	-0.9	-0.4	3.2	8.2	18.2	24.2	24.7	14.3	4.7
M5-60	M5-40	1.1	1.5	0.1	0.2	0.3	2.9	5.1	9.7	9.7	10.1	5.1	1.7
M6-20	M6-40	-1.7	-5.0	-7.8	-7.8	-11.3	-7.7	-5.5	-10.8	-11.4	-10.5	-8.5	-1.4
M6-20	M6-60	-3.0	-6.2	-9.8	-11.2	-16.2	-13.1	-10.9	-17.5	-18.0	-16.9	-13.1	-2.9
M6-40	M6-20	1.8	5.8	9.1	8.3	12.5	7.6	5.9	12.0	12.8	11.8	8.9	1.4
M6-40	M6-60	-1.4	-1.3	-2.5	-3.2	-5.6	-5.7	-5.7	-7.9	-7.3	-7.3	-4.8	-1.4
M6-60	M6-20	3.3	7.7	12.5	11.7	18.1	13.8	13.1	21.0	20.8	21.2	13.7	3.1
M6-60	M6-40	1.5	1.5	2.7	3.1	5.7	6.2	6.2	8.5	7.8	8.2	4.7	1.4

Stand-alone thermal

Ref.	Targ.	Sectors											
		0	30	60	90	120	150	180	210	240	270	300	330
M1-20	M1-40	-1.7	-5.3	-1.9	-0.8	-5.3	-10.6	-6.0	-8.3	-11.5	-11.6	-8.3	-5.0
M1-20	M1-60	-2.5	-6.2	-2.9	-2.1	-8.8	-15.8	-9.7	-12.1	-16.1	-15.7	-11.3	-6.8
M1-40	M1-20	1.9	6.1	1.5	1.1	5.4	11.6	6.5	8.5	10.7	14.2	9.5	5.4
M1-40	M1-60	-0.7	-1.4	-0.9	-1.5	-3.8	-5.9	-3.6	-4.2	-4.4	-5.2	-3.6	-1.9
M1-60	M1-20	3.1	6.9	2.7	2.8	10.0	18.2	10.5	13.0	14.4	19.3	15.8	7.9
M1-60	M1-40	0.7	1.3	1.2	1.6	4.1	6.3	3.6	4.5	3.8	5.3	4.5	2.0
M2-20	M2-40	-6.3	-5.0	-3.9	-0.8	-4.0	-6.6	-8.0	-8.2	-10.4	-9.0	-10.1	-9.0
M2-20	M2-60	-7.5	-4.7	-4.0	-1.4	-5.9	-9.9	-10.8	-10.6	-14.7	-12.7	-14.6	-13.3
M2-40	M2-20	7.1	6.6	3.3	1.0	4.4	7.3	8.5	8.9	12.2	9.5	10.6	10.1
M2-40	M2-60	-1.1	-0.7	0.0	-0.6	-2.3	-3.6	-2.5	-2.8	-4.9	-4.0	-4.9	-4.5
M2-60	M2-20	9.1	5.1	2.7	3.9	7.4	11.8	10.7	11.3	18.4	13.9	16.3	14.8
M2-60	M2-40	1.3	-0.2	0.1	1.3	2.6	4.0	2.3	2.6	5.0	4.0	5.4	4.5
M3-20	M3-60	1.7	-1.3	-0.2	-4.2	-9.6	-10.5	-8.5	-4.9	-7.5	-9.2	-7.8	-1.2
M3-60	M3-20	-0.9	2.1	0.4	3.9	9.1	11.5	10.0	5.6	7.6	7.8	9.4	1.5
M4-20	M4-40	-1.8	-0.2	0.4	-2.9	-7.4	-10.2	-12.8	-14.2	-14.5	-7.3	-5.2	-4.0
M4-20	M4-60	-3.0	0.2	0.6	-6.4	-11.7	-16.0	-18.5	-20.2	-21.3	-13.9	-9.3	-6.4
M4-40	M4-20	2.4	1.0	-0.7	2.8	7.4	10.6	13.2	16.4	16.7	9.4	5.9	4.4
M4-40	M4-60	-1.7	0.3	0.4	-3.4	-4.4	-6.1	-6.2	-5.5	-9.2	-7.7	-4.6	-2.5
M4-60	M4-20	4.9	1.5	-0.4	5.8	11.4	16.6	20.3	21.8	23.4	22.0	11.6	7.9
M4-60	M4-40	2.1	-0.1	0.0	3.2	4.3	6.0	7.2	4.4	7.8	10.0	5.2	2.8
M5-20	M5-40	0.9	3.8	4.3	0.8	0.8	-0.4	-4.6	-9.2	-11.0	-9.6	-6.7	-1.2
M5-20	M5-60	-0.2	3.1	5.3	0.8	0.3	-3.7	-10.4	-16.3	-19.3	-15.8	-9.9	-2.2
M5-40	M5-20	-0.8	-3.6	-4.4	-0.8	-0.7	0.0	3.6	8.2	11.2	11.1	8.0	1.8
M5-40	M5-60	-1.0	-0.7	0.9	-0.1	-0.4	-2.9	-5.1	-8.2	-7.3	-7.9	-3.9	-1.2
M5-60	M5-20	0.5	-3.1	-5.1	-0.9	-0.3	2.5	7.4	14.1	17.9	20.6	13.9	4.7
M5-60	M5-40	1.0	0.6	-0.7	0.2	0.3	2.6	4.7	7.9	7.1	8.5	5.0	1.7
M6-20	M6-40	-1.3	-4.3	-7.1	-7.8	-11.7	-8.1	-5.4	-9.5	-9.7	-8.8	-8.4	-1.4
M6-20	M6-60	-2.2	-4.7	-8.7	-11.1	-16.7	-13.5	-10.7	-15.2	-14.9	-13.9	-12.9	-2.9
M6-40	M6-20	1.4	5.0	8.3	8.3	12.9	8.1	5.7	10.4	10.6	9.7	8.7	1.4
M6-40	M6-60	-1.0	-0.6	-2.0	-3.2	-5.7	-5.7	-5.6	-6.6	-5.7	-5.8	-4.7	-1.4
M6-60	M6-20	2.4	6.1	11.0	11.7	18.8	14.3	12.8	17.7	16.5	17.0	13.5	3.1
M6-60	M6-40	1.1	0.8	2.2	3.0	5.8	6.2	6.0	7.0	6.0	6.4	4.6	1.4

Coupled – By direction only

Ref.	Targ.	Sectors											
		0	30	60	90	120	150	180	210	240	270	300	330
M1-20	M1-40	6.5	-4.5	0.0	4.3	-1.0	-6.2	-0.1	2.8	2.7	-7.4	-2.7	1.7
M1-20	M1-60	12.8	-2.0	1.8	6.6	-1.9	-6.6	2.8	6.2	3.7	-9.5	-0.3	5.1
M1-40	M1-20	-6.0	5.3	-0.4	-3.8	0.9	6.4	0.6	-2.3	-5.0	8.9	3.1	-1.6
M1-40	M1-60	6.1	2.1	2.0	2.1	-0.9	-0.4	3.1	3.2	2.0	-2.9	2.1	3.3
M1-60	M1-20	-10.7	2.5	-2.1	-5.6	2.2	6.6	-1.9	-4.5	-9.3	11.1	2.9	-4.4
M1-60	M1-40	-5.7	-2.2	-1.6	-2.0	1.1	0.5	-3.0	-2.9	-3.1	2.8	-1.3	-3.2
M2-20	M2-40	-3.4	-0.1	0.1	0.8	-0.9	-2.1	-2.3	10.2	7.1	-0.6	-6.0	-4.9
M2-20	M2-60	-1.2	9.1	6.1	2.2	0.0	-1.5	-3.3	17.9	14.5	2.5	-6.3	-5.3
M2-40	M2-20	3.9	1.3	-0.8	-0.6	1.1	2.3	2.5	-5.4	-8.4	0.2	5.8	5.3
M2-40	M2-60	2.4	8.1	6.1	1.5	0.6	0.6	-0.6	2.8	7.9	3.3	-0.2	-0.3
M2-60	M2-20	2.2	-8.4	-7.1	0.2	1.0	2.2	2.9	-6.1	-16.8	-3.6	5.9	5.1
M2-60	M2-40	-2.3	-8.4	-5.7	-0.8	-0.4	-0.3	0.4	-1.8	-8.2	-3.6	0.4	0.0
M3-20	M3-60	7.7	6.1	4.0	-1.5	-3.8	6.4	7.3	12.6	8.3	8.8	1.9	4.2
M3-60	M3-20	-6.4	-5.1	-3.6	1.1	2.7	-6.2	-6.2	-11.2	-7.7	-10.0	-0.4	-3.8
M4-20	M4-40	1.2	6.2	1.2	-0.7	-5.7	-4.6	-8.1	-7.7	-3.4	-1.4	-1.4	0.6
M4-20	M4-60	0.9	14.5	4.7	-1.4	-7.8	-4.7	-9.7	-10.1	3.5	-1.1	-2.8	2.2
M4-40	M4-20	-0.7	-5.6	-1.5	0.5	5.4	4.1	7.7	8.6	2.8	2.9	1.8	-0.4
M4-40	M4-60	-0.6	7.9	3.7	-0.6	-2.0	0.3	-1.1	-1.8	6.2	-0.5	-1.8	1.8
M4-60	M4-20	0.8	-11.8	-4.6	0.4	6.6	2.8	8.3	11.1	-8.1	6.6	4.4	-1.7
M4-60	M4-40	1.1	-7.1	-3.4	0.2	1.7	-0.7	1.2	1.5	-8.4	2.1	2.2	-1.9
M5-20	M5-40	13.0	25.5	12.2	4.7	4.8	4.3	-1.7	-1.1	-2.9	-3.4	-1.0	4.5
M5-20	M5-60	23.9	47.9	19.8	5.9	7.4	5.6	-5.0	-1.1	-3.6	-3.3	1.4	9.5
M5-40	M5-20	-12.4	-30.5	-10.5	-4.7	-4.7	-4.5	0.6	0.9	1.5	4.0	1.8	-3.5
M5-40	M5-60	10.7	27.3	6.1	1.1	2.7	1.8	-2.5	-1.9	1.9	-1.1	1.9	4.5
M5-60	M5-20	-20.3	-51.3	-15.8	-5.9	-7.3	-6.6	1.4	1.5	-2.9	4.9	1.2	-5.9
M5-60	M5-40	-9.5	-24.4	-5.7	-1.1	-2.8	-2.1	2.0	2.1	-3.0	1.0	-1.0	-3.8
M6-20	M6-40	2.9	5.1	-4.6	-6.4	-8.3	-3.0	0.9	0.0	5.2	-1.9	-5.0	2.5
M6-20	M6-60	7.7	11.6	-3.4	-8.1	-10.7	-5.1	0.2	2.6	7.8	2.5	-7.1	4.6
M6-40	M6-20	-2.7	-4.4	5.4	6.6	8.7	2.5	-0.7	0.2	-4.9	1.9	4.8	-2.5
M6-40	M6-60	4.6	6.1	1.0	-1.4	-2.7	-1.9	-0.8	2.3	2.6	4.3	-2.0	2.2
M6-60	M6-20	-6.8	-9.6	4.7	7.9	10.7	4.1	1.0	-2.4	-8.1	-2.1	6.1	-4.3
M6-60	M6-40	-4.2	-5.6	-0.9	1.2	2.5	2.1	1.0	-2.4	-2.6	-3.8	1.6	-2.2

Validation study – Site 2 – Vertical cross-prediction error

Stand-alone Neutral

		Sectors											
Ref.	Targ.	0	30	60	90	120	150	180	210	240	270	300	330
100 m	40 m	-0.8	-2.5	-1.0	-1.0	-1.8	-3.6	-3.5	-6.3	-4.9	-2.1	0.5	0.6
100 m	60 m	-1.0	-3.2	-1.3	-1.9	-3.1	-5.9	-5.6	-10.3	-8.2	-3.5	0.7	1.2
100 m	80 m	-1.5	-4.5	-1.9	-2.6	-3.9	-6.9	-6.5	-12.0	-10.1	-4.3	0.8	1.2
100 m	120 m	-1.9	-5.7	-2.8	-3.4	-3.7	-7.0	-6.2	-12.2	-10.6	-4.8	0.7	0.8
120 m	40 m	0.7	2.8	1.1	0.7	1.8	3.8	3.6	5.8	5.5	2.3	-0.2	-0.2
120 m	60 m	-0.2	-0.8	-0.3	-0.4	-1.3	-2.2	-1.9	-3.9	-4.2	-1.6	0.1	0.5
120 m	80 m	-0.8	-1.9	-1.0	-1.2	-2.3	-3.4	-2.6	-5.8	-6.6	-2.6	0.0	0.5
120 m	100 m	-1.5	-3.1	-1.9	-2.1	-2.5	-3.8	-2.5	-6.5	-7.4	-3.2	-0.1	0.1
40 m	60 m	0.8	4.0	1.6	0.5	3.1	6.0	5.9	8.8	10.4	4.0	0.1	-0.1
40 m	80 m	0.0	1.1	0.4	0.0	1.2	2.3	2.0	3.4	4.7	1.7	0.0	-0.3
40 m	100 m	-0.8	-1.3	-0.8	-0.5	-1.2	-1.3	-0.7	-1.7	-3.0	-1.1	-0.2	0.0
40 m	120 m	-1.9	-2.4	-1.7	-1.2	-1.9	-1.8	-0.8	-2.0	-4.7	-1.8	-0.4	-0.3
60 m	40 m	1.4	4.5	2.9	0.2	3.6	7.5	7.0	9.5	13.2	5.0	0.9	0.3
60 m	80 m	0.6	1.9	1.5	0.1	1.9	3.9	2.9	4.3	7.5	3.0	0.6	-0.1
60 m	100 m	0.7	1.2	0.9	0.2	1.0	1.6	0.7	1.4	3.1	1.2	0.4	0.1
60 m	120 m	-1.2	-1.2	-1.0	-0.6	-0.9	-0.9	0.0	-0.5	-2.0	-0.9	-0.4	-0.3
80 m	40 m	2.5	4.0	4.0	0.1	3.8	7.6	7.1	8.7	12.9	5.8	1.4	0.8
80 m	60 m	1.7	2.1	2.5	0.2	2.6	4.6	3.0	4.0	8.1	4.0	0.9	0.4
80 m	100 m	1.9	2.0	1.9	0.5	1.9	2.6	0.7	1.3	4.5	2.2	0.7	0.5
80 m	120 m	1.2	1.2	1.0	0.4	1.0	1.1	-0.1	0.3	2.0	1.0	0.4	0.3

Stand-alone thermal

		Sectors											
Ref.	Targ.	0	30	60	90	120	150	180	210	240	270	300	330
100 m	40 m	0.3	1.9	-0.3	0.2	3.4	6.2	5.7	3.0	8.0	1.2	0.9	0.3
100 m	60 m	-0.4	0.1	-0.7	0.1	1.8	3.0	2.1	0.1	4.2	0.3	0.6	-0.1
100 m	80 m	0.1	0.3	-0.1	0.2	0.9	1.1	0.3	-0.7	1.4	-0.2	0.3	0.1
100 m	120 m	-0.4	-0.2	0.1	-0.6	-0.7	-0.3	0.5	1.6	-0.3	0.7	-0.4	-0.3
120 m	40 m	0.6	0.4	-0.4	0.1	3.5	5.7	5.4	0.2	5.9	0.3	1.4	0.8
120 m	60 m	-0.1	-0.6	-0.7	0.2	2.3	3.1	1.7	-2.3	3.0	-0.4	0.9	0.4
120 m	80 m	0.4	0.1	-0.3	0.5	1.7	1.5	-0.2	-2.8	1.1	-0.9	0.6	0.5
120 m	100 m	0.4	0.2	-0.1	0.4	0.9	0.5	-0.6	-1.8	0.3	-0.6	0.4	0.3
40 m	60 m	-0.7	-1.7	0.0	-1.0	-1.8	-3.3	-3.2	-4.5	-3.4	-1.1	0.5	0.6
40 m	80 m	-0.5	-1.6	0.8	-1.9	-3.0	-5.2	-4.9	-6.6	-5.4	-1.3	0.8	1.2
40 m	100 m	-0.4	-2.0	1.2	-2.6	-3.8	-5.8	-5.4	-6.5	-5.8	-0.8	0.8	1.2
40 m	120 m	0.0	-2.4	1.3	-3.4	-3.4	-5.4	-4.6	-4.7	-4.7	0.3	0.7	0.8
60 m	40 m	0.6	1.9	0.1	0.7	1.8	3.5	3.2	3.8	3.9	1.3	-0.2	-0.2
60 m	80 m	0.2	0.1	0.8	-0.4	-1.2	-1.8	-1.5	-1.9	-2.7	-0.4	0.2	0.5
60 m	100 m	0.2	-0.2	1.1	-1.2	-2.1	-2.6	-1.8	-1.8	-3.6	-0.1	0.0	0.5
60 m	120 m	0.2	-0.4	1.2	-2.1	-2.2	-2.4	-1.2	-0.5	-2.8	1.0	-0.1	0.1
80 m	40 m	0.3	2.3	-0.5	0.5	3.0	5.3	5.2	4.6	7.1	1.7	0.1	-0.1
80 m	60 m	-0.3	0.2	-0.7	0.0	1.2	1.9	1.6	1.3	3.1	0.5	0.0	-0.3
80 m	100 m	-0.2	-0.4	0.3	-0.5	-1.1	-0.8	-0.3	0.4	-1.5	0.3	-0.2	0.0
80 m	120 m	-0.5	-0.6	0.5	-1.2	-1.6	-0.8	0.2	2.2	-1.5	1.2	-0.4	-0.3

Coupled – By direction only

		Sectors											
Ref.	Targ.	0	30	60	90	120	150	180	210	240	270	300	330
100 m	40 m	-0.6	-0.7	2.9	2.1	0.3	-0.1	0.3	2.2	1.4	4.1	4.8	5.1
100 m	60 m	-1.4	-0.7	6.0	5.2	1.7	2.7	0.4	1.4	1.8	10.1	9.8	9.4
100 m	80 m	-2.0	-1.1	7.7	8.3	4.1	7.1	0.4	0.7	2.5	16.7	15.0	13.0
100 m	120 m	-1.9	-1.5	8.0	11.1	8.1	11.9	0.6	1.1	3.9	23.5	20.5	16.4
120 m	40 m	0.6	0.9	-2.8	-2.4	-0.3	0.1	-0.4	-3.2	-1.0	-3.8	-4.2	-4.6
120 m	60 m	-0.8	0.1	3.0	3.4	1.4	3.0	0.4	-0.5	-0.4	5.7	4.6	4.1
120 m	80 m	-1.5	-0.3	4.6	6.6	3.6	7.4	0.6	-1.2	-0.4	12.0	9.5	7.6
120 m	100 m	-1.8	-0.6	4.9	9.1	7.1	12.0	0.8	-1.4	0.6	18.4	14.8	10.9
40 m	60 m	1.5	1.4	-5.4	-6.2	-1.7	-3.2	-0.6	-4.1	-0.2	-9.2	-8.0	-8.1
40 m	80 m	0.8	0.3	-2.9	-3.7	-1.5	-3.1	-0.5	-0.1	0.9	-5.4	-4.3	-3.9
40 m	100 m	-1.0	-0.5	1.5	3.4	2.0	4.3	0.4	-0.5	-0.7	6.0	4.5	3.5
40 m	120 m	-1.6	-0.8	1.8	6.0	5.0	8.6	0.5	-0.3	-0.9	12.0	9.5	6.9
60 m	40 m	2.6	1.1	-6.3	-9.9	-4.4	-7.3	-1.0	-4.1	0.5	-14.9	-11.5	-11.4
60 m	80 m	1.7	0.3	-3.9	-7.2	-3.9	-6.9	-1.0	-0.2	1.7	-10.9	-8.2	-7.2
60 m	100 m	1.0	0.4	-1.3	-3.5	-2.2	-3.9	-0.5	0.3	0.9	-5.7	-4.3	-3.4
60 m	120 m	-0.7	-0.3	0.3	2.7	2.7	3.9	0.3	-0.1	-0.7	5.4	4.6	3.3
80 m	40 m	3.5	-0.2	-6.4	-12.9	-7.5	-11.4	-1.8	-4.4	-0.3	-18.8	-15.3	-14.5
80 m	60 m	2.4	-0.3	-4.1	-10.1	-6.6	-10.6	-1.7	-0.7	1.6	-14.8	-12.3	-10.4
80 m	100 m	1.7	0.3	-1.5	-6.3	-4.7	-7.4	-1.3	-0.1	1.5	-10.1	-8.6	-6.7
80 m	120 m	0.7	0.3	-0.3	-2.9	-2.5	-3.5	-0.6	0.0	0.9	-4.9	-4.4	-3.3

windsim

Conclusions of the validation study

- The proposed MMC methodology **captures the average atmospheric stability** of the site by producing more realistic boundary conditions. This resulted in an **overall improvement** of the modelled vertical wind speed profiles

- The coupled simulations have **more realistic wind speeds at higher heights** compared to analytical profiles.

- Results depend on **proper WRF modeling** (rubbish in, rubbish out)

Conclusions of the validation study – Follow up study

- Further validation study:
  - Understand the physics behind the differences of coupled and stand-alone simulations
  - Study of horizontal wind flow patterns
- Test of the methodology in complex terrain

Content

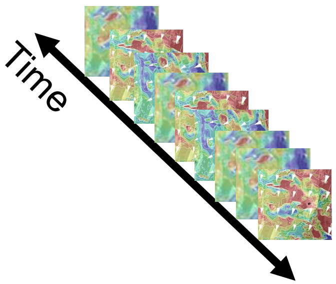
- What is meso-microscale coupling?
- Meso-microscale coupling in WindSim
- A first approach…
- Proposed coupling methodologies
    - Averaged conditions per sector
    - Averaged conditions per sector + per atmospheric stability
- Validation study
    - Validation sites
    - Validation methodology
    - Boundary conditions
    - Site 1: Honkajoki wind farm
    - Site 2: North America
    - Conclusions of the validation study
- Future work: A new approach

Future work: A new approach

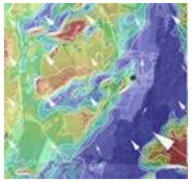
1 year of mesoscale model output

Automated classification of most common weather patterns

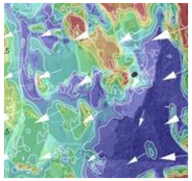
Transfer WRF data to WindSim model



Class 1



Class 2



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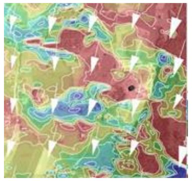
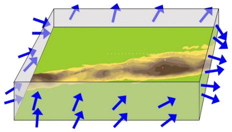
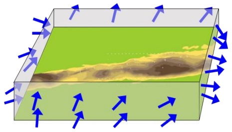
Class N







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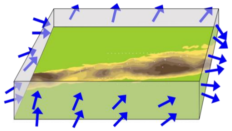

1 CFD Boundary condition per class

*Processes
*Data


Thank you
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