RUNE benchmarks

Pena Diaz, Alfredo

Publication date:
2017

Document Version
Publisher's PDF, also known as Version of record

RUNE benchmarks

DTU Wind Energy
E-Report

Alfredo Peña

DTU Wind Energy-E-Report-0134 (EN)
January 2017

DTU Wind Energy
Department of Wind Energy

DTU Wind Energy-E-Report-0134(EN)

RUNE benchmarks

Alfredo Peña

DTU Wind Energy
Department of Wind Energy

DTU Wind Energy, Risø Campus,
Technical University of Denmark, Roskilde, Denmark

January 2017

Author: Alfredo Peña
Title: RUNE benchmarks
Department: DTU Wind Energy

DTU Wind Energy-E-Report-0134(EN)
January 5, 2017

Abstract (max. 2000 char)

This report contains the description of a number of benchmarks with the purpose of evaluating flow models for near-shore wind resource estimation. The benchmarks are designed based on the comprehensive database of observations that the RUNE coastal experiment established from onshore lidar measurements mostly.

ISSN:
ISBN:
978-87-93549-02-9

Contract no:

Project no:

Sponsorship:
ForskEL and NEWA

Cover:

Pages: 24
Tables: 4
Figures: 15
References: 2

Technical University of Denmark
Frederiksborgvej 399
4000 Roskilde
Denmark
Tel. +4546775024
aldi@dtu.dk
www.vindenergi.dk

Contents

1 Introduction

In order to decrease the uncertainty of models used for wind resource estimation, we need high-quality datasets to, first, evaluate the models abilities and, second, improve the models (if possible) or at least understand their behavior under certain flow and topographical conditions. During the RUNE campaign (Floors et al., 2016b), we gathered a comprehensive database of near-shore wind observations mainly using lidars of different types. A large portion of the data corresponds to measurements performed with DTU's scanning lidars (WindScanners), which acquired radial wind speed measurements over a large area across the west coast of Denmark.

At DTU we think it is beneficial for the wind energy community to have access to the RUNE dataset but, most importantly, to be able to perform an evaluation exercise, where the ability of models of different types in regards to the estimation of the wind near the coast is tested. For such a purpose we propose a series of benchmarks that can aid in understanding the uncertainty of models fairly. The benchmarks are developed to maximize the information regarding winds on the area. All easting and northing coordinates are in UTM 32V, WGS84. All heights refer to the height above mean sea level (AMSL) unless otherwise stated.

1.1 RUNE coastal experiment

Figure 1 illustrates the positions of the different instruments during the RUNE campaign and in Fig. 2 the main scanning configuration of the campaign is shown. Other details regarding the coastal experiment, such as topographical inputs, can be found in Floors et al. (2016a) and Floors et al. (2016b). Detailed data of the terrain are available for download at the Geostyrelsen website: `http://download.kortforsyningen.dk/content/dhm-2007overflade-16-m-grid`.

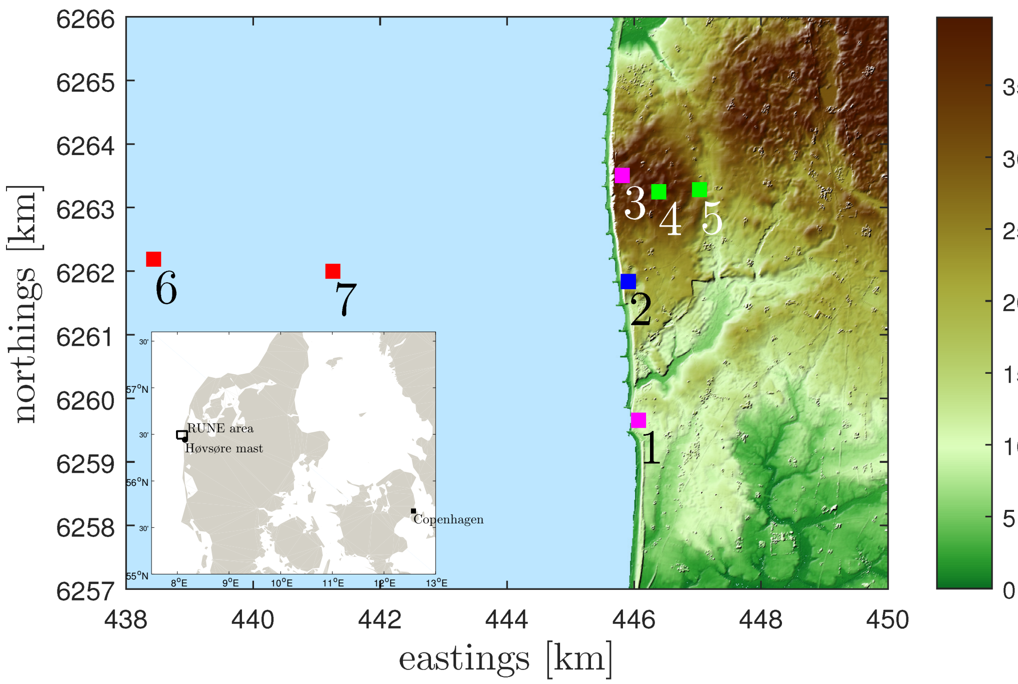

Figure 1: Description of the terrain of the RUNE experimental area (colorbar shows the height in meters) and the positions of the instruments. On the left-bottom, the RUNE experimental area is shown in Denmark

The proposed benchmarks use measurements from the WindScanners (all of the Leosphere-type WLS200S) at positions 1–3 (see Table 1). The instruments performed different scanning

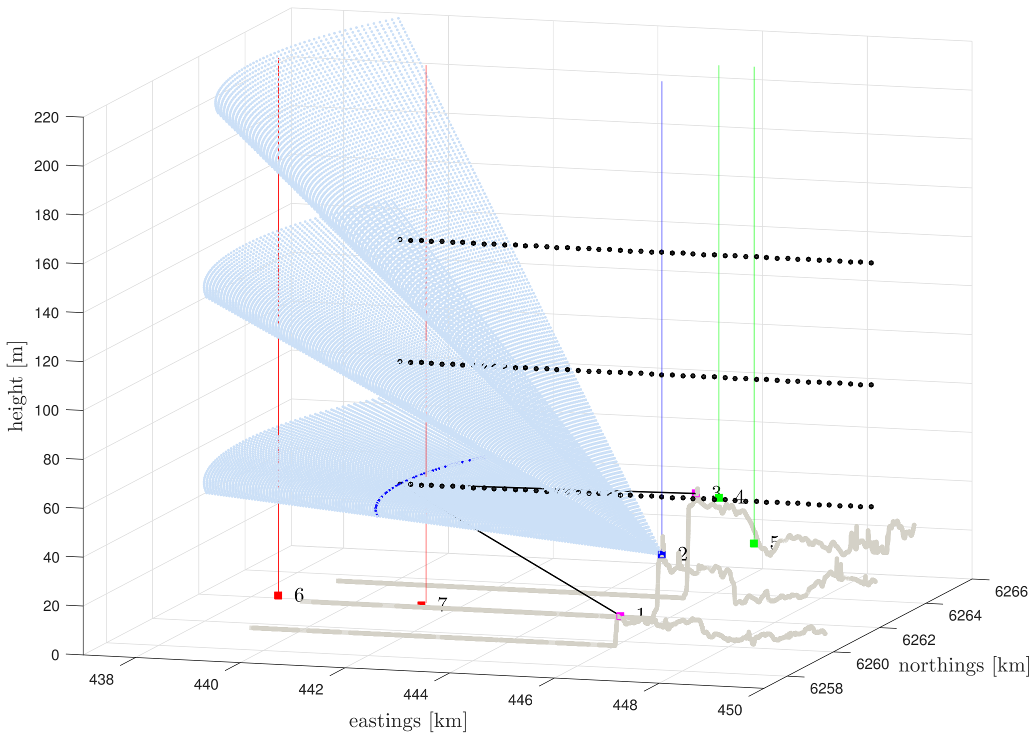

Figure 2: Sketch of the main scanning strategy during the RUNE experiment. PPI scans are shown in light blue and the positions of the reconstructed winds from the dual-setup scans in black circles

strategies and the benchmarks are designed based on:

1. dual-setup scans: both Sterenn and Koshava performed sector scans (i.e. scans over a range of azimuthal positions) so that their measurement volumes overlapped at heights 50, 100 and 150 m on transects aligned with the northing position of Vara from a position 5000 m west to 4000 m east of Vara (see black circles in Fig. 2).

2. Plan position indicator (PPI) scans: Vara performed 60° PPI scans at three elevation angles so that at a distance 5000 m west of Vara the scans had measured ranges at the heights 50, 100 and 150 m (see cyan markers in Fig. 2).

3. Virtual mast scans: both Sterenn and Koshava performed range height indicator (RHI) scans and these scans were setup so that their measurement volumes overlapped at a position 5 km west of Vara at several heights (not shown).

		Position (UTM, WGS84, Zone 32V)		
position	name	easting (m)	northing (m)	height (m)
1	Koshava	446080.03	6259660.30	12.36
2	Vara	445915.64	6261837.49	26.38
3	Sterenn	445823.66	6263507.90	42.97

Table 1: Positions and names of the WindScanners at the RUNE coastal experiment

For the purpose of the benchmarks, the different scanning strategies have advantages and disadvantages regarding data availability and ease to use for model evaluation. The reconstructed wind speeds using the radial velocity measurements of the dual-system scans (on the transect along the Vara position) are model-friendly as the reconstruction is performed at the the same level AMSL. However, the positions on the transect are relatively far from both instruments so the availability of data is low, decreases drastically when moving east or west on the transect, and decreases with overlapping height. PPI scans have higher availability due to, mainly, the relatively short ranges but are not ease to use for model evaluation because the reconstructed wind speeds are not at the same height but vary with range.

1.2 Definitions

The horizontal wind speed components (u, v) are reconstructed from radial velocity measurements that were time-averaged or aggregated over a given period (10-min unless otherwise stated). We choose u to be the west-east and v the south-north wind components; we establish a relative coordinate system (x, y, z) with the x-coordinate aligned with the west-east direction, the y-coordinate with the south-north direction, and z being the vertical coordinate. The origin of the x-y coordinate system is position 2 (6261837 N, 445916 E). The $\langle\rangle$ symbol denotes ensemble averages and the magnitude of the wind is estimated as $U = \sqrt{u^2 + v^2}$ and $\langle U \rangle = \langle \sqrt{u^2 + v^2} \rangle$. The subscript $_o$ denotes the reference and the position of the reference depends on the specific benchmark.

2 Benchmark 1: Coastal wind gradient based on the dual-system scans

2.1 Generalities

Horizontal wind speed components were reconstructed from the dual-system scans along three transects at the heights 50, 100 and 150 m that are perpendicular to the coast (and aligned with the northing of position 2) at positions separated ≈200 m from a distance ≈5000 m west from position 2 up to one 4000 m east from position 2. The easting coordinates of the transect and its positions relative to position 2 are given in Appendix A. The northing coordinate of the transect (and of position 2) is 6261837 m.

The wind speed components were reconstructed every 10 min. However, due to the increase of range with height and with distance from position 2, the amount of 10-min reconstructed winds decrease with distance from position 2 as shown in Fig. 3. For this benchmark (and for Fig. 3), we use 10-min reconstructed winds with 100% availability of measurements of both systems, i.e. Koshava and Sterenn were able to measure radial velocities at the position of wind reconstruction 4 times during the 10-min interval with a carrier-to-noise ratio (CNR) above −26.5 dB.

The following cases are established based on the availability of data with range and wind conditions; we make sure that there are ≈100 10-min per case as a minimum and that all positions and heights included in each of the cases have the same 10-min values. Regarding the wind conditions, Fig. 4 shows the wind rose based on the reconstructed wind speeds at 100 m at a position 903 m west of position 2. Due to NEWA's research interests, we establish benchmarks corresponding to all directions and to easterly, westerly and southwesterly flow.

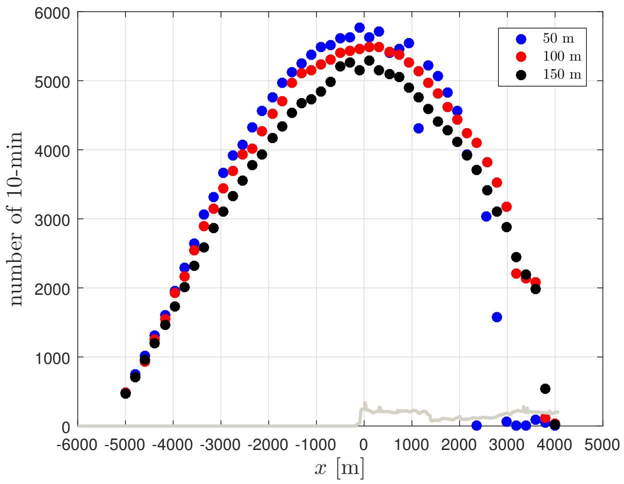

Figure 3: The amount of 10-min reconstructed winds with 100% availability based on the dual-system scans per height and range from position 2

2.2 Case 1: Coastal wind gradient for all directions

This case includes winds from all directions and all positions within the interval $x = [-4994, 2160]$ m in order to increase the amount of 10-min samples. In Fig. 5, we show the horizontal wind speed along the transect normalized with the wind speed magnitude at $(x,z) = (-4994, 150)$ m.

2.3 Case 2: Coastal wind gradient for westerlies

This case includes westerlies only that were 'filtered' from Case 1 using the wind direction θ estimated at the position $(x,z) = (-4381, 150)$ m with the criterion $240° \leq \theta \leq 300°$ (see Fig. 6).

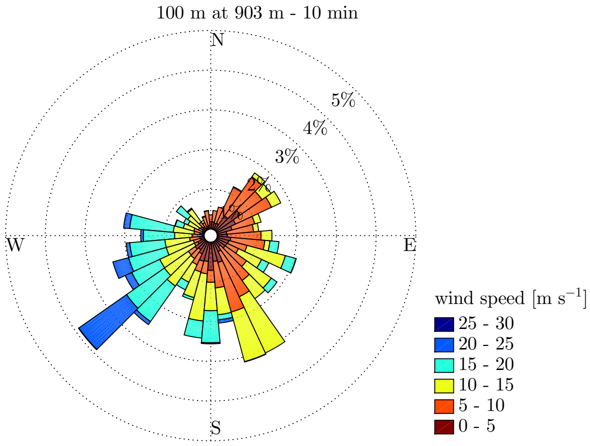

Figure 4: The wind climate based on the reconstructed winds from the dual-system scans at 100 m height at a position 903 m west from position 2

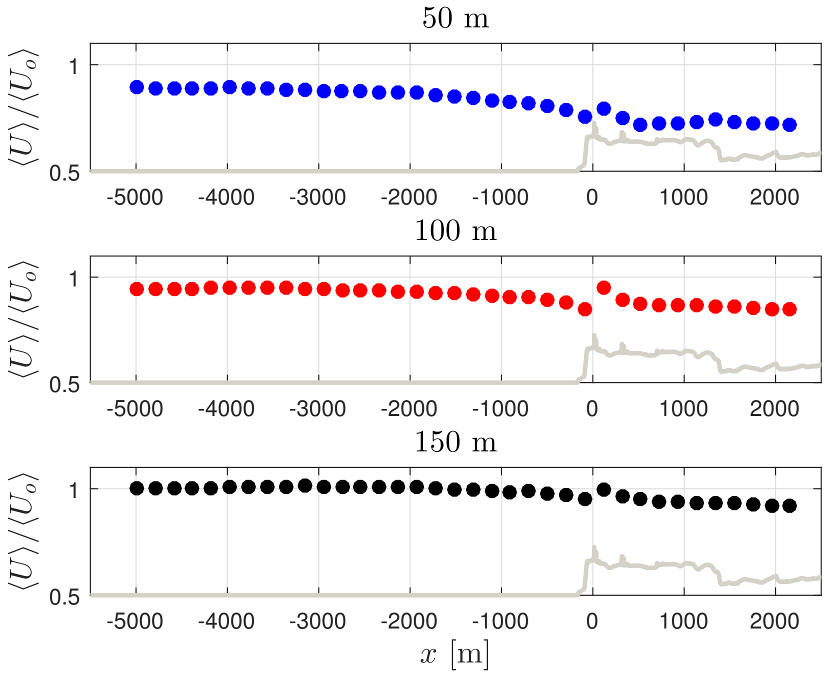

Figure 5: Normalized coastal wind gradient along the dual-setup transect of reconstructed wind speed measurements for all directions for each height. The height of the terrain above the mean sea level is indicated in the grey line (not in scale)

Due to the filtering, the amount of 10-min periods decrease and so we need to reduce the interval of positions for the analysis to $x = [-4381, 2160]$ m.

2.4 Case 3: Coastal wind gradient for southwesterlies

This case is exactly as Case 2 but for southwesterly winds, i.e. $195° \leq \theta \leq 255°$ (see Fig. 7).

2.5 Case 4: Coastal wind gradient for easterlies

This case includes easterlies that were 'filtered' from Case 1 using the wind direction estimated at the position $(x, z) = (1955, 150)$ m with the criterion $60° \leq \theta \leq 120°$ (see Fig. 8).

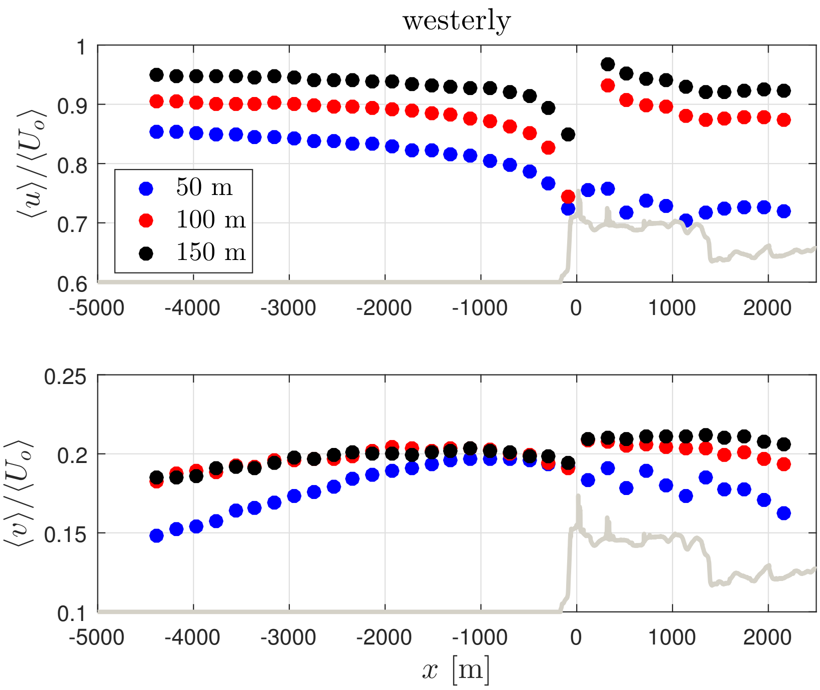

Figure 6: Normalized coastal gradient along the dual-setup transect of reconstructed wind speed measurements for westerly directions and for each height. *u*-component is on the top and the *v*-component on the bottom. The height of the terrain above the mean sea level is indicated in the grey line (not in scale)

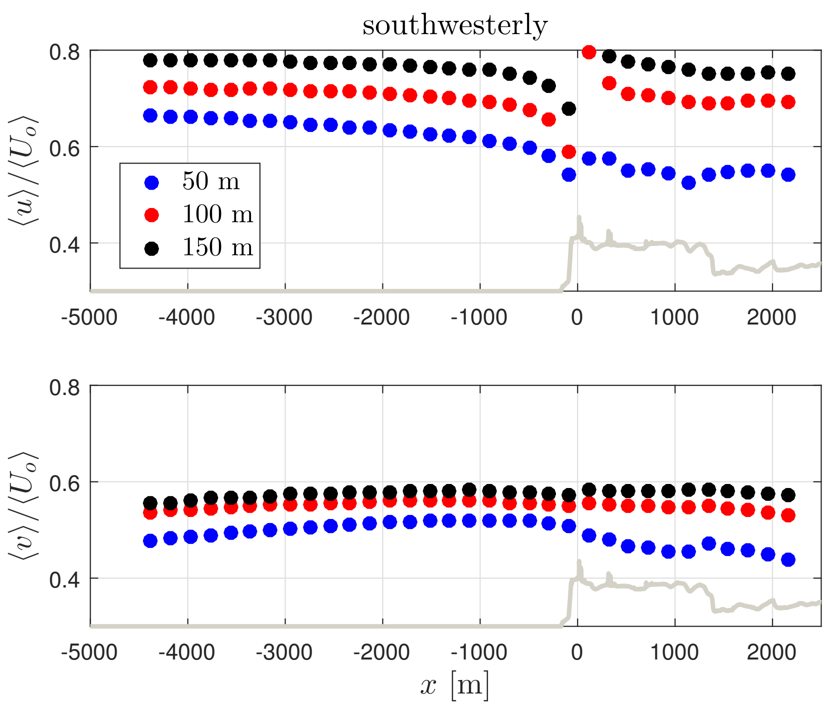

Figure 7: Similar to Fig. 6 but for southwesterly winds

2.6 Specifications and other details for modelers

The period required for the benchmark comparison is between 2015-12-03 00:00 and 2016-02-18 00:00 UTC. When submitting data for this benchmark you agree on evaluating the model results against the 4 cases. Data can be submitted in different file formats and a clear description of the

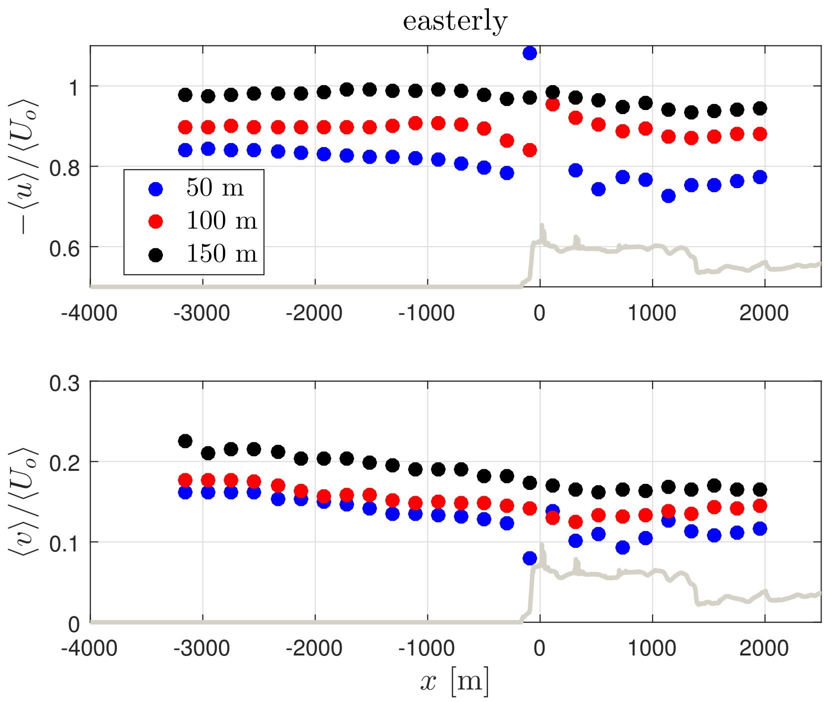

Figure 8: Similar to Fig. 6 but for easterly winds

data format should be included. Time stamps should be in UTC with the format yyyy-mm-dd HH:MM and both u and v wind speed components should be included for the three heights (50, 100 and 150 m) and the positions provided in Appendix A. The data should be in a 10-min time series basis within the above given period. The data of the simulations will be compared to the reconstructed wind speed components of accumulated radial velocities within the 10-min with the starting time as reference, i.e. simulated data with a time stamp such as 2015-12-03 23:30 will be compared with reconstructed winds within the period 2015-12-03 23:30–2015-12-03 23:40.

3 Benchmark 2: Coastal wind gradient based on the 60° PPI scans

3.1 Generalities

Horizontal wind speed components were reconstructed from the three 60° PPIs. As the scans are performed at three elevation angles, the heights vary with range and elevation angle. We will assume that the reconstructed wind speed is a good estimate of the wind speed in the middle of each arc and so the position in the y-coordinate is always the same as position 2 ($y = 0$ m) with northing at 6261837 m.

The wind speed components were reconstructed every time the scanning lidar performed an arc and were averaged within 10-min periods. Due to the increase of range with distance (and elevation angle), the amount of 10-min reconstructed winds decrease with distance from position 2 as shown in Fig. 9. For this benchmark (and for Fig. 9), we use 10-min reconstructed winds with 100% availability of measurements, i.e. Vara was able to measure radial velocities at all positions within the arc 4 times during the 10-min interval with a CNR above -27 dB.

The following cases are established based on the availability of data with range and wind conditions; we make sure that there are at least 100 10-min per case and that all positions and heights included in each case have the same amount of 10-min values. Regarding the wind conditions, Fig. 10 shows the wind rose based on the reconstructed wind speeds at the height 50 m at a position 951 m west of position 2.

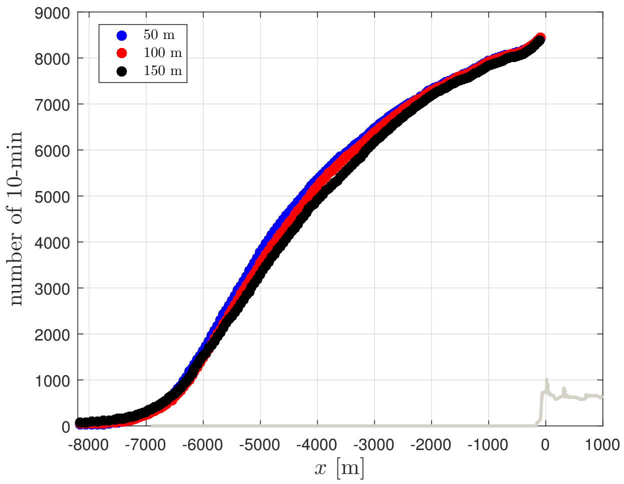

Figure 9: The amount of 10-min reconstructed winds with 100% availability based on the 60° PPI scans per height and range from position 2

3.2 Case 5: Coastal wind gradient for all directions

This case includes winds from all directions at given positions, $x = [-5000, -3000, -1601 - 951]$ m at the heights 50, 100 and 150 m in order to increase the amount of 10-min samples (the availability drastically decreases for $|x| \geq 5000$ m. For completeness we provide all ranges and heights were wind reconstruction was performed in Appendix B. In Fig. 11, we show the horizontal wind speed along the transect normalized with the wind speed magnitude at $(x, z) = (-5000, 150)$ m.

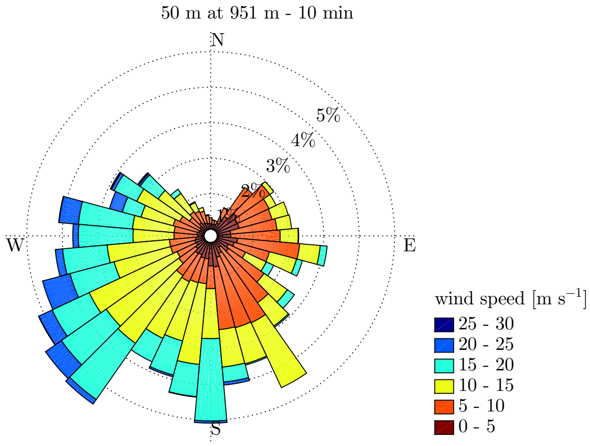

Figure 10: The wind climate based on the 60° PPI scans reconstructed winds at 50 m height at a position 951 m west from position 2

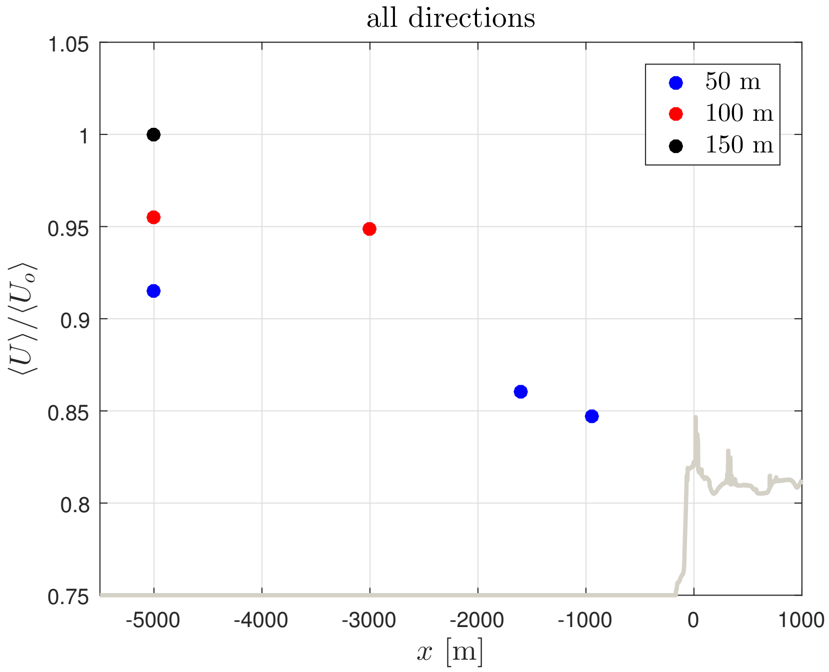

Figure 11: Normalized coastal wind gradient along the 60° PPIs transect of reconstructed wind speed measurements for all directions for each height. The height of the terrain above the mean sea level is indicated in the grey line (not in scale)

3.3 Case 6: Coastal wind gradient for westerlies

This case includes westerlies only that were 'filtered' from Case 5 using the wind direction θ estimated at the position $(x,z) = (-5000, 150)$ m with the criterion $240° \leq \theta \leq 300°$ (see Fig. 12).

3.4 Case 7: Coastal wind gradient for easterlies

This case is exactly as Case 6 but for easterly winds, i.e. $60° \leq \theta \leq 120°$ (see Fig. 13).

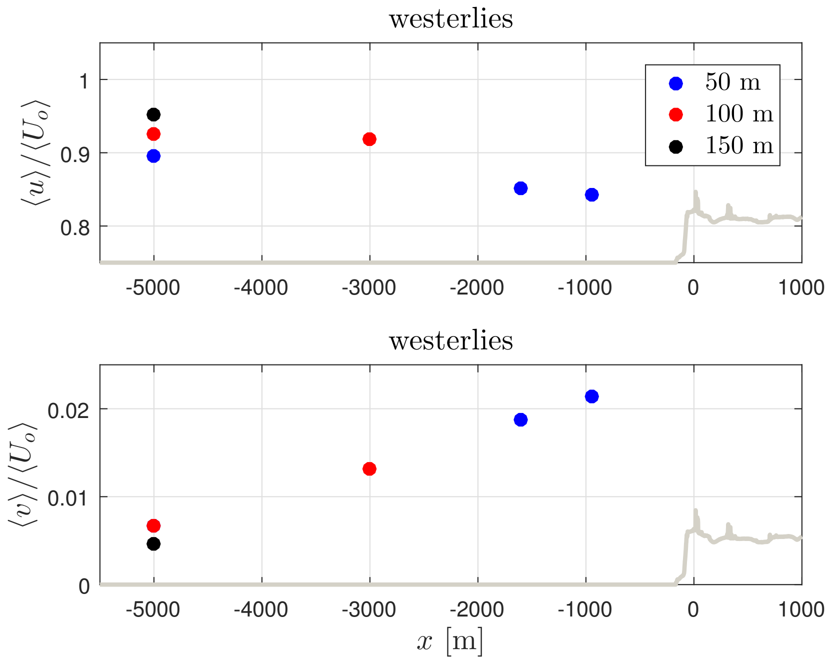

Figure 12: Normalized coastal wind gradient along the 60° PPIs transect of reconstructed wind speed measurements for westerly directions and for each height. *u*-component is on the top and the *v*-component on the bottom panels. The height of the terrain above the mean sea level is indicated in the grey line (not in scale)

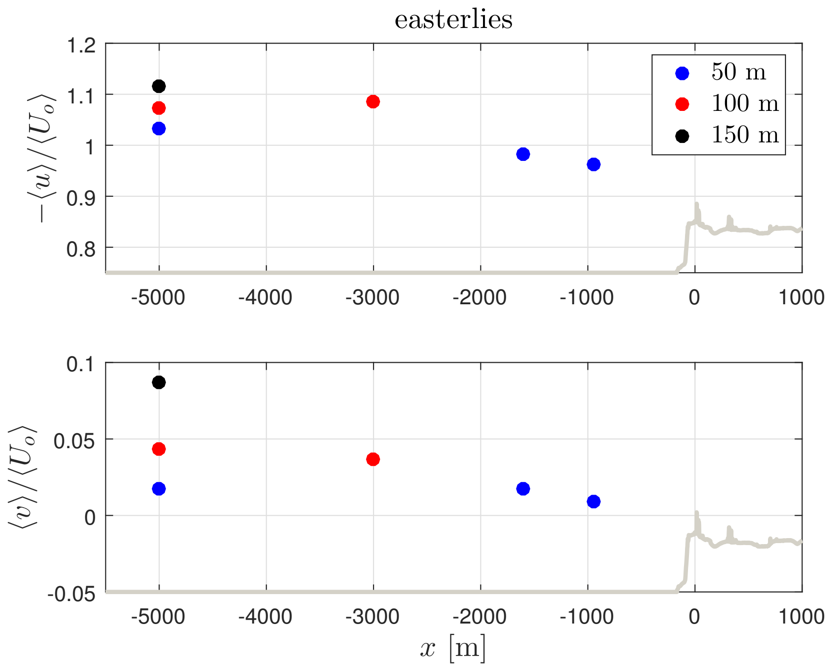

Figure 13: Similar to Fig. 12 but for easterly winds

3.5 Specifications and other details for modelers

The period required for the benchmark comparison is between 2015-11-26 00:00 and 2016-02-18 00:00 UTC. When submitting data for this benchmark you agree on evaluating the model results against the 3 cases. Data can be submitted in different file formats and a clear description of the data format should be included. Time stamps should be in UTC with the format yyyy-mm-dd HH:MM and both *u* and *v* wind speed components should be included for the three heights

(50, 100 and 150 m) and the positions provided in Sect. 3.2 that are also found in red color in Appendix B. The data should be in a 10-min time series basis within the above given period. The data of the simulations will be compared to the reconstructed wind speed components that were averaged within the 10-min with the starting time as reference, i.e. simulated data with a time stamp such as 2015-12-03 23:30 will be compared with reconstructed winds within the period 2015-12-03 23:30–2015-12-03 23:40.

4 Benchmark 3: Virtual mast

4.1 Generalities

Horizontal wind speed components were reconstructed from the RHI scans that overlapped at a position 5 km from position 2, i.e. $(x,y) = (-5000,0)$ m, at a number of heights (see Appendix C). The northing and easting coordinates of such position are 440915 and 6261837 m, respectively.

The wind speed components were reconstructed every 10 min. The amount of 10-min reconstructed winds peak at the height ≈500 m but the number of concurrent 10-min samples at all reconstructed heights is low when using a 100% availability criterion (similar to the previous benchmarks). Therefore, we make a compromise between the amount of vertical levels to study, the amount of 10-min samples and the availability itself. With a minimum 50% availability criterion for both systems (CNRs above -27 dB), we have a good number of 10-min concurrent samples within the range of heights given in Appendix C. Figure 14 illustrates the amount of 10-min reconstructed winds per height.

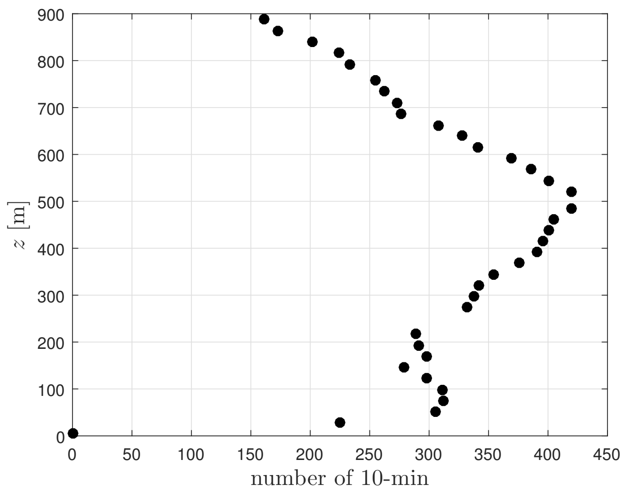

Figure 14: The amount of 10-min reconstructed winds based on the RHI scans per height, where the availability of both Koshava and Sterenn is above (or equal) to 50%

4.2 Case 8: Offshore vertical wind speed profile

This case includes winds from all directions at the reconstructed wind horizontal position $(x,y) = (-5000,0)$ m for the range of heights in Appendix C. Figure 15 illustrates the behavior with height of both wind speed components based on the reconstructed winds from the virtual mast.

4.3 Specifications and other details for modelers

The period required for the benchmark comparison is between 2016-02-17 00:00 and 2016-02-28 23:50 UTC. Data can be submitted in different file formats and a clear description of the data format should be included. Time stamps should be in UTC with the format yyyy-mm-dd HH:MM and both u and v wind speed components should be included for the heights in Appendix C and the position (440915 E, 6261837 N). The data should be in a 10-min time series basis within the above given period. The data of the simulations will be compared to the reconstructed wind speed components that were averaged within the 10-min with the starting time as reference, i.e. simulated data with a time stamp such as 2015-12-03 23:30 will be compared with reconstructed winds within the period 2015-12-03 23:30–2015-12-03 23:40.

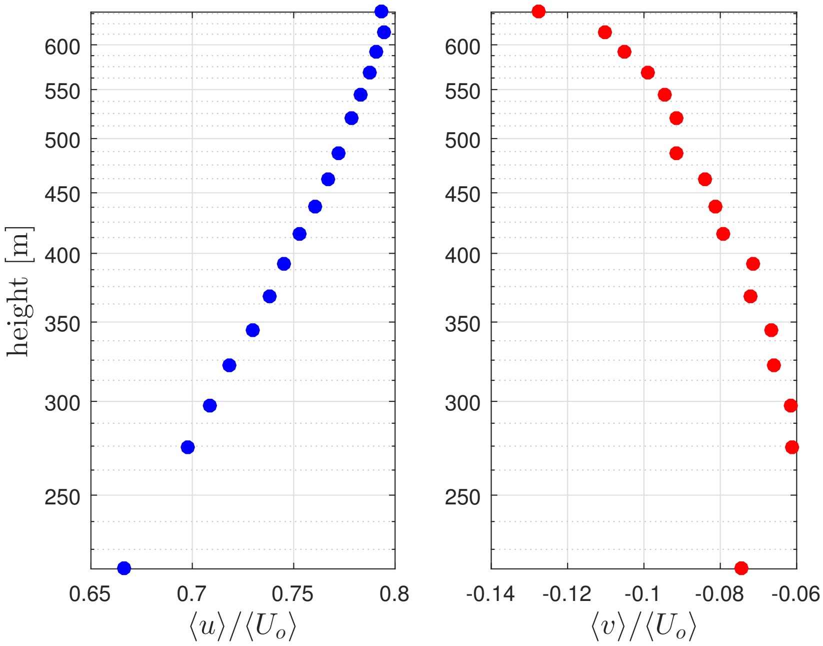

Figure 15: Normalized vertical wind speed components (*u* in the left and *v* in the right panel) as function of height based on the reconstructed wind speed measurements of the RHI scans for all directions

References

Floors, R., G. Lea, A. Peña, I. Karagali, and T. T. Ahsbahs, 2016a: Report on RUNE's coastal experiment and first inter-comparisons between measurements systems. Technical Report DTU Wind Energy-E-Report-0115(EN), Technical University of Denmark.

Floors, R., A. Peña, G. Lea, N. Vasiljevic, E. Simon, and M. Courtney, 2016b: The RUNE experiment–a database of remote-sensing observations of near-shore winds. *Remote Sens.*, **8**, 884–899.

A Appendix A – coordinates of the dual-setup reconstructed winds

x [m]	easting [m]
4000	449916
3796	449712
3592	449507
3387	449303
3183	449098
2978	448894
2773	448689
2569	448485
2364	448280
2160	448075
1955	447871
1751	447666
1546	447462
1342	447257
1137	447053
933	446848
729	446644
523	446439
320	446236
116	446032
-87	445828
-291	445625
-495	445420
-699	445216
-904	445012
-1108	444807
-1313	444603
-1517	444398
-1722	444193
-1927	443989
-2131	443784
-2336	443580
-2540	443375
-2745	443171
-2949	442966
-3154	442762
-3358	442557
-3563	442353
-3767	442148
-3972	441944
-4176	441739
-4381	441535
-4585	441331
-4790	441126
-4994	440921

Table 2: Relative and easting coordinates of the dual-setup reconstructed wind speed components

B Appendix B – coordinates of the 60° PPI scans reconstructed winds

x [m]	easting [m]	z_1 [m]	z_2 [m]	z_3 [m]
-101	445815	27	28	29
-151	445765	27	29	30
-201	445715	27	29	31
-251	445665	28	30	33
-301	445615	28	31	34
-351	445565	28	32	35
-401	445515	28	32	36
-451	445465	29	33	38
-501	445415	29	34	39
-551	445365	29	34	40
-601	445315	29	35	41
-651	445265	29	36	42
-701	445215	30	37	44
-751	445165	30	37	45
-801	445115	30	38	46
-851	445065	30	39	47
-901	445015	31	40	49
-951	444965	31	40	50
-1001	444915	31	41	51
-1051	444865	31	42	52
-1101	444815	32	43	54
-1151	444765	32	43	55
-1201	444715	32	44	56
-1251	444665	32	45	57
-1301	444615	33	46	59
-1351	444565	33	46	60
-1401	444515	33	47	61
-1451	444465	33	48	62
-1501	444415	33	48	64
-1551	444365	34	49	65
-1601	444315	34	50	66
-1651	444265	34	51	67
-1701	444215	34	51	68
-1751	444165	35	52	70
-1801	444115	35	53	71
-1851	444065	35	54	72
-1901	444015	35	54	73
-1951	443965	36	55	75
-2001	443915	36	56	76
-2051	443865	36	57	77
-2101	443815	36	57	78
-2151	443765	37	58	80
-2201	443715	37	59	81
-2251	443665	37	60	82
-2301	443615	37	60	83
-2351	443565	37	61	85

x [m]	easting [m]	z_1 [m]	z_2 [m]	z_3 [m]
-2401	443515	38	62	86
-2451	443465	38	62	87
-2501	443415	38	63	88
-2551	443365	38	64	89
-2601	443315	39	65	91
-2651	443265	39	65	92
-2701	443215	39	66	93
-2751	443165	39	67	94
-2801	443115	40	68	96
-2851	443065	40	68	97
-2901	443015	40	69	98
-2951	442965	40	70	99
-3001	442915	41	71	101
-3051	442865	41	71	102
-3101	442815	41	72	103
-3151	442765	41	73	104
-3201	442715	42	74	106
-3251	442665	42	74	107
-3301	442615	42	75	108
-3351	442565	42	76	109
-3401	442515	42	76	111
-3451	442465	43	77	112
-3501	442415	43	78	113
-3550	442365	43	79	114
-3600	442315	43	79	115
-3650	442265	44	80	117
-3700	442215	44	81	118
-3750	442165	44	82	119
-3800	442115	44	82	120
-3850	442065	45	83	122
-3900	442015	45	84	123
-3950	441965	45	85	124
-4000	441915	45	85	125
-4050	441865	46	86	127
-4100	441815	46	87	128
-4150	441765	46	88	129
-4200	441715	46	88	130
-4250	441665	46	89	132
-4300	441615	47	90	133
-4350	441565	47	90	134
-4400	441515	47	91	135
-4450	441465	47	92	136
-4500	441415	48	93	138
-4550	441365	48	93	139
-4600	441315	48	94	140
-4650	441265	48	95	141
-4700	441215	49	96	143
-4750	441165	49	96	144
-4800	441115	49	97	145
-4850	441065	49	98	146

x [m]	easting [m]	z_1 [m]	z_2 [m]	z_3 [m]
-4900	441015	50	99	148
-4950	440965	50	99	149
-5000	440915	50	100	150
-5050	440865	50	101	151
-5100	440815	50	102	153
-5150	440765	51	102	154
-5200	440715	51	103	155
-5250	440665	51	104	156
-5300	440615	51	104	157
-5350	440565	52	105	159
-5400	440515	52	106	160
-5450	440465	52	107	161
-5500	440415	52	107	162
-5550	440365	53	108	164
-5600	440315	53	109	165
-5650	440265	53	110	166
-5700	440215	53	110	167
-5750	440165	54	111	169
-5800	440115	54	112	170
-5850	440065	54	113	171
-5900	440015	54	113	172
-5950	439965	55	114	174
-6000	439915	55	115	175
-6050	439866	55	116	176
-6100	439816	55	116	177
-6150	439766	55	117	179
-6200	439716	56	118	180
-6250	439666	56	118	181
-6300	439616	56	119	182
-6350	439566	56	120	183
-6400	439516	57	121	185
-6450	439466	57	121	186
-6500	439416	57	122	187
-6550	439366	57	123	188
-6600	439316	58	124	190
-6650	439266	58	124	191
-6700	439216	58	125	192
-6750	439166	58	126	193
-6800	439116	59	127	195
-6850	439066	59	127	196
-6900	439016	59	128	197
-6950	438966	59	129	198
-7000	438916	59	130	200
-7050	438866	60	130	201
-7100	438816	60	131	202
-7150	438766	60	132	203
-7200	438716	60	132	204
-7250	438666	61	133	206
-7300	438616	61	134	207
-7350	438566	61	135	208

x [m]	easting [m]	z_1 [m]	z_2 [m]	z_3 [m]
-7400	438516	61	135	209
-7450	438466	62	136	211
-7500	438416	62	137	212
-7550	438366	62	138	213
-7650	438266	63	139	216
-7750	438166	63	141	218
-7850	438066	64	142	221
-7950	437966	64	143	223
-8050	437866	64	145	225
-8150	437766	65	146	228

Table 3: Relative, easting, and vertical coordinates of the 60° PPI scans reconstructed wind speed components

C Appendix C – heights of the virtual mast

height [m]
217
275
298
322
345
368
392
415
438
461
486
520
544
568
591
615
639

Table 4: Heights of the virtual mast reconstructed wind speed components

DTU Wind Energy
Technical University of Denmark

Frederiksborgvej 399
4000 Roskilde
Denmark
Phone +45 4677 5024

www.vindenergi.dtu.dk