Comparison of NWP wind speeds and directions to measured wind speeds and directions

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Publication date:
2010

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

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Risø-R-Report

Poul Astrup and Torben Mikkelsen
Risø-R-1715(EN)
September 2010

Risø DTU
National Laboratory for Sustainable Energy

Author: Poul Astrup and Torben Mikkelsen
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Division: Wind Energy Division

Abstract (max. 2000 char.):
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ISSN 0106-2840
ISBN 978-87-550-3791-5

Contract no.:
EURANOS project.
Contract No: FI6R-CT-2004-508843.

Group's own reg. no.:
1130505-2

Sponsorship:
This work has received partial financial support from the European Commission Sixth Framework Programme (Nuclear Fission/Radiation Protection) under the EURANOS integrated project: European approach to nuclear and radiological emergency management and rehabilitation strategies (Contract No: FI6R-CT-2004-508843).

Cover :

Pages: 34
Tables: 8
References: 0

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Introduction

Numerical Weather Predictions (NWP) of wind speed and direction has been compared to measurements for seven German sites for nuclear power plants, and for Risø, the site of the Danish nuclear research reactors now being decommissioned . For the German sites the data cover approximately three month, the NWP data from Austrian Meteorological and Geophysical Office, AMGO, cover 5th January to 31st March 2009 with two daily sets of analysis and 1 to 48 hours forecasts, the measured data cover the full three month, i.e. from 1st January, with 10 minute resolution. For the Risø site NWP results of the HIRLAM code from Danish Meteorological Institute were once stored for two thirds of a year, i.e. 1017 times analysis and 1 to 5 hour forecast within the period 21st October 1998 to 30th September 1999, and 10 minute averaged measured data are available since November 1995.

For each site the comparison consists of scatter plots of NWP versus measured data for wind speeds and directions at each measurement height, the direction plots for some sites using different symbols for measured wind speed at lowest measurement level being above or below a set threshold given in the legend. The plots are followed by tables of means and standard deviations of the differences NWP minus measured data.

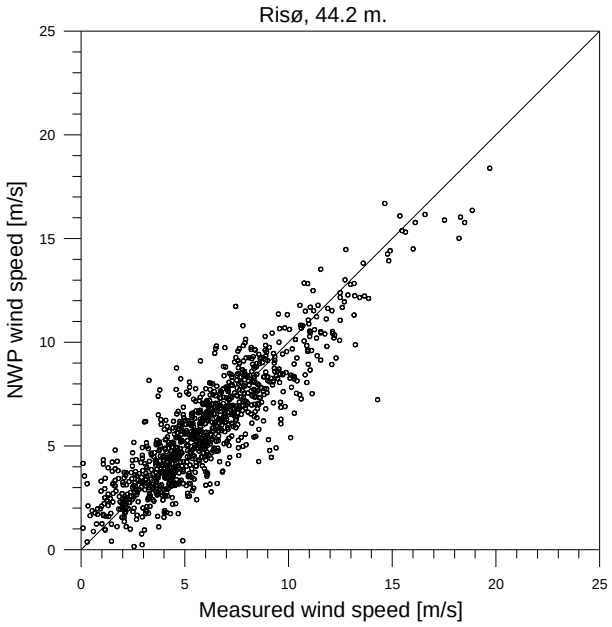
The NWP results are referred to the measurement sites by so called inverse square distance interpolation between the 4 nearest NWP points and to the measurement heights by vertical interpolation following similarity theory, van Ulden and Holtslag (1985). Speed and direction differences are taken as NWP minus measured, the direction difference normalized to stay within plus and minus 180 degree.

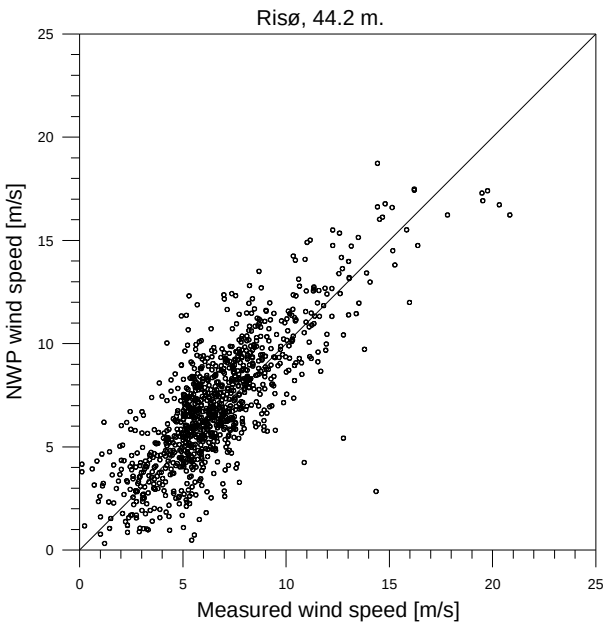
The order of the sites in this report is geographically from north to south. Figure 11 points out the sites on a map.

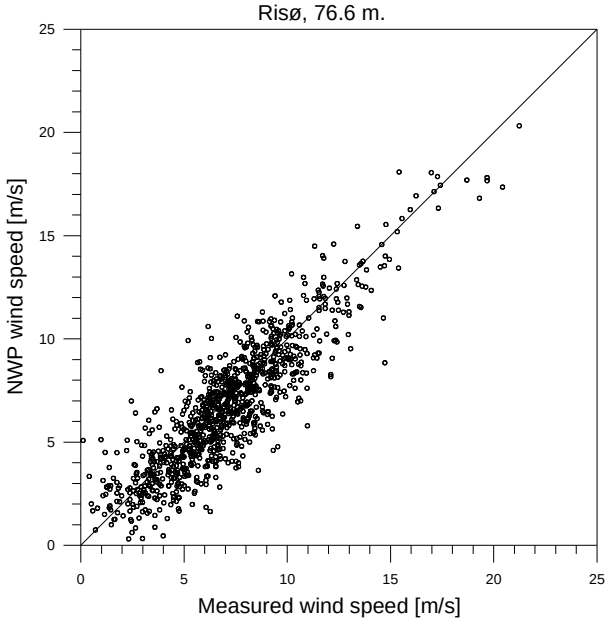
Danish research site Risø

The Risø site has the geographical coordinates 55.694° N, 12.088° E and is situated on a small peninsula in the Roskilde Fjord. The comparison NWP to mast data has been done for the analysis time and for the 5 hour forecast, for wind speed for three heights: 44.2 m, 76.6 m, and 125.2 m above ground, and for wind direction for 76.6 m and 125.2 m. Wind direction is not measured at 44.2 m. The wind direction comparison is further split on measured wind speed at 44.2 m being above or below 5 m/s. Figure 1 left column shows plots for the analysis hours, right column for 5 hour forecasts.

The NWP data for wind speed are as an average slightly under predicted and increasingly so with height, while the mean direction difference NWP minus measured is pretty low, below 5° at analysis time, but with a standard deviation of approximately 25° which however reduces to 15° if only times with wind speeds above 5 m/s at 44.2 m is taken into account. The 5 hour forecasts behave expectedly, both speed and direction standard deviations increase, although very little, and the 5 hour forecasts compare to data almost as well as the analysed NWP. Means and standard deviations for speed and direction differences are listed in table 1.


Risø, 44.2 m.
NWP wind speed [m/s]
Measured wind speed [m/s]
0
5
10
15
20
25


Risø, 44.2 m.
NWP wind speed [m/s]
Measured wind speed [m/s]
0
5
10
15
20
25


Risø, 76.6 m.
NWP wind speed [m/s]
Measured wind speed [m/s]
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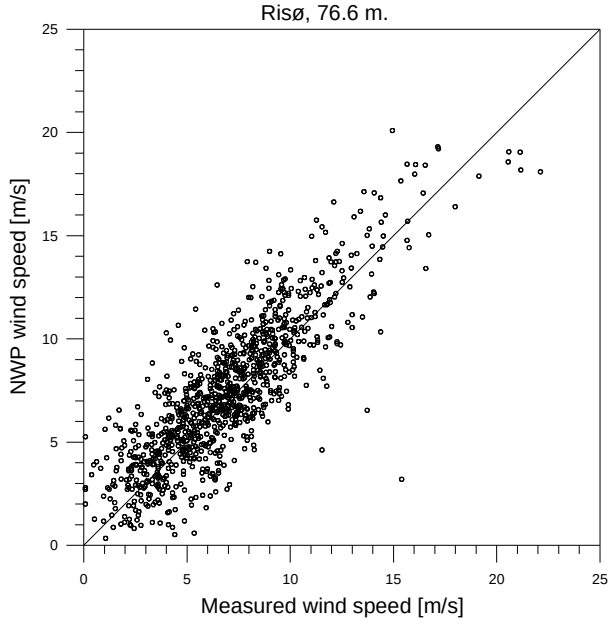
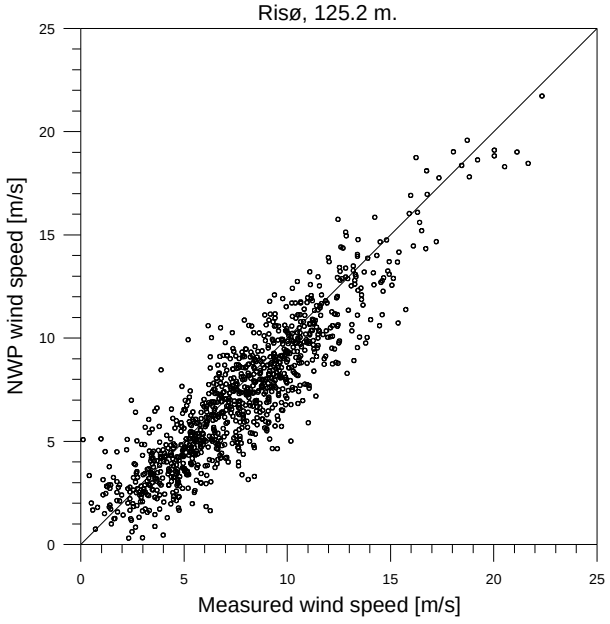
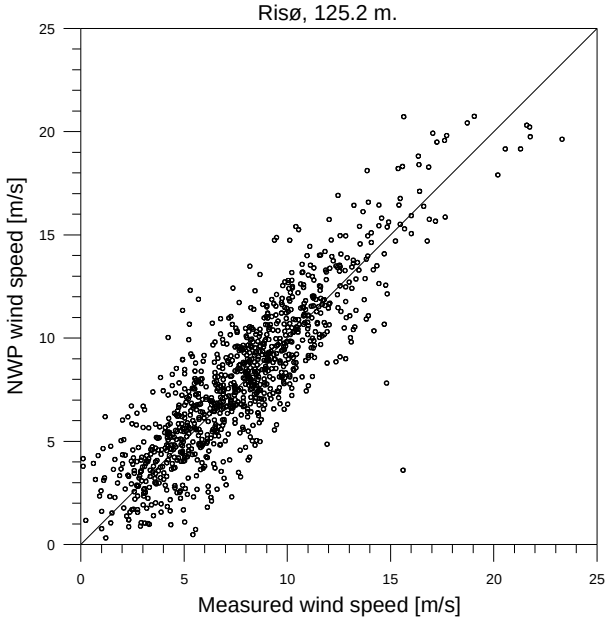
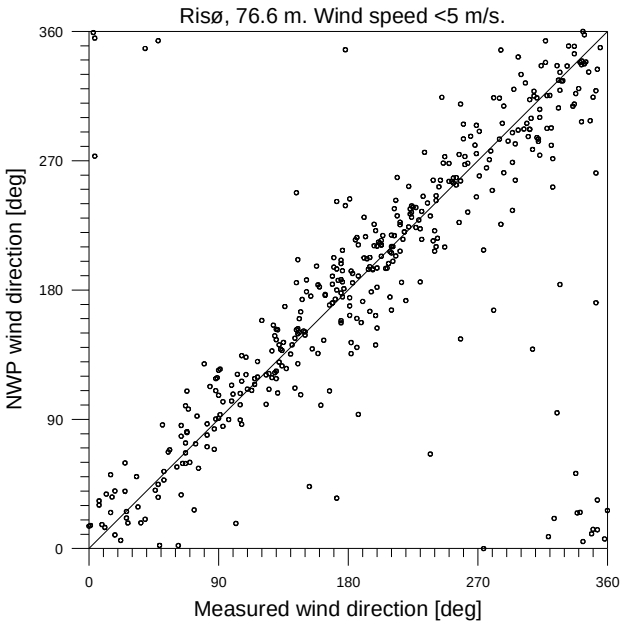
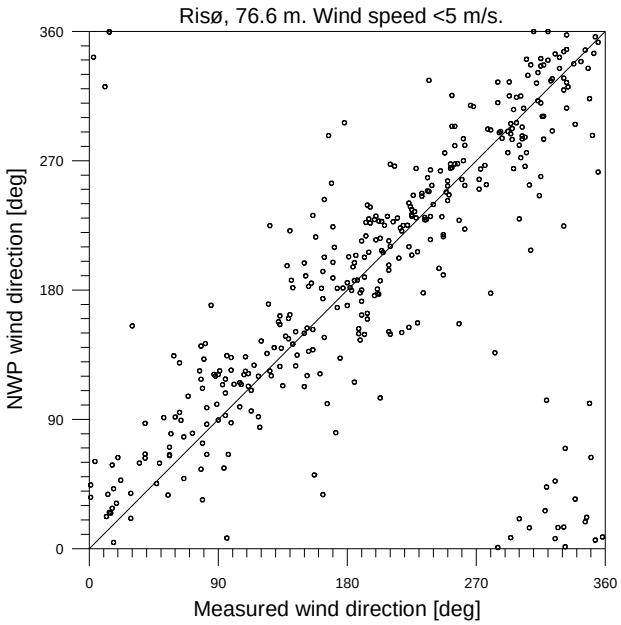
5
10
15
20
25

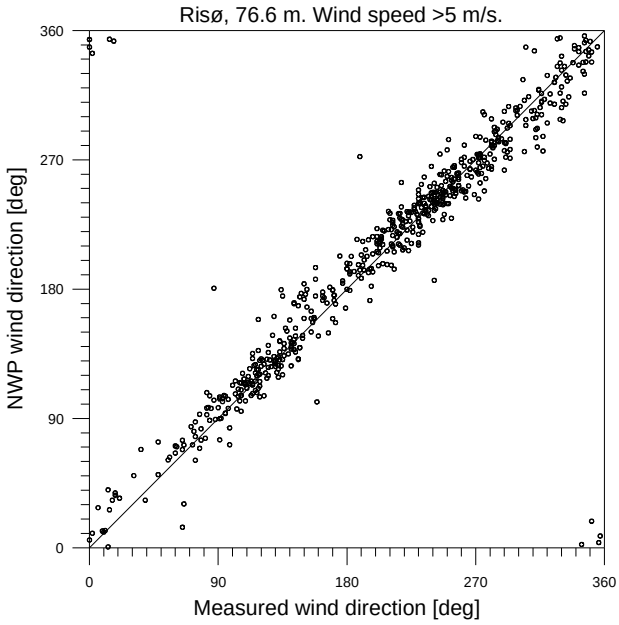

Risø, 76.6 m.
NWP wind speed [m/s]
Measured wind speed [m/s]
0
5
10
15
20
25

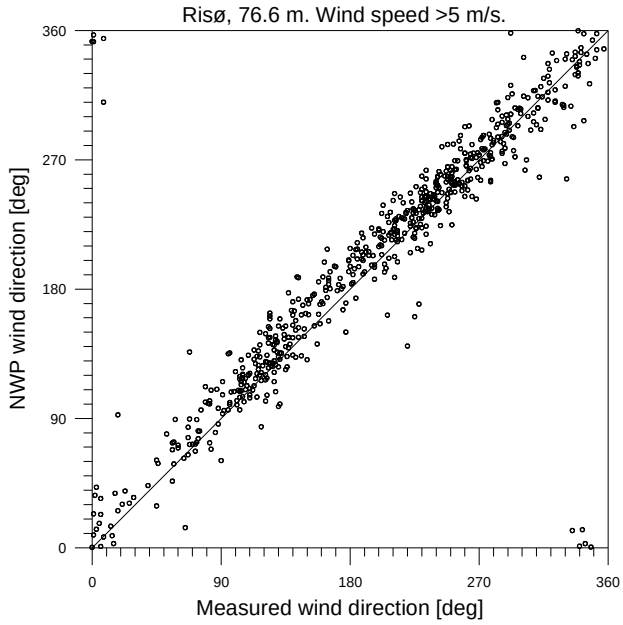

Risø, 125.2 m.
NWP wind speed [m/s]
Measured wind speed [m/s]
0
5
10
15
20
25

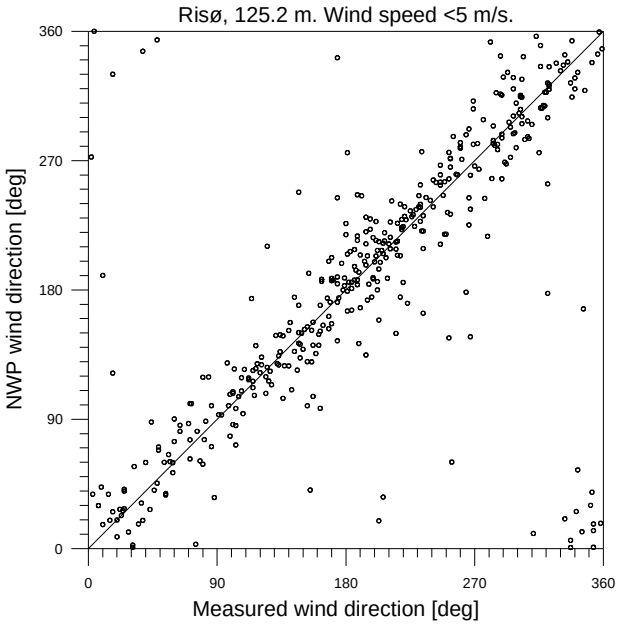

Risø, 125.2 m.
NWP wind speed [m/s]
Measured wind speed [m/s]
0
5
10
15
20
25

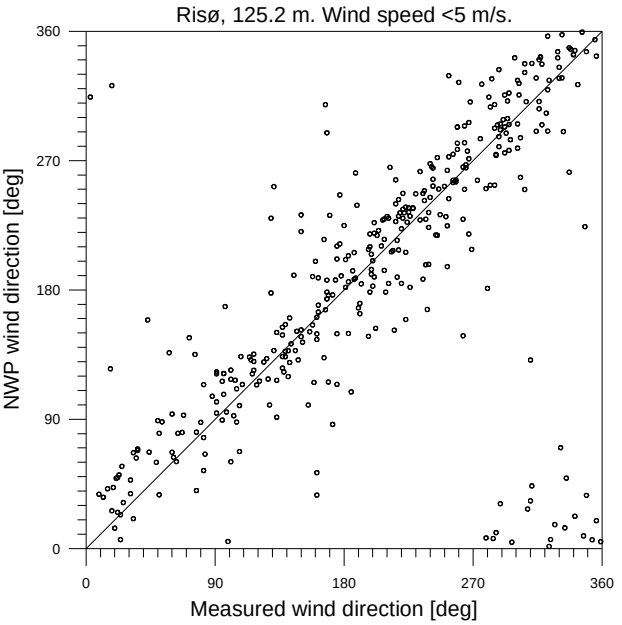

Risø, 76.6 m. Wind speed <5 m/s.
NWP wind direction [deg]
Measured wind direction [deg]
0
90
180
270
360


Risø, 76.6 m. Wind speed <5 m/s.
NWP wind direction [deg]
Measured wind direction [deg]
0
90
180
270
360


Risø, 76.6 m. Wind speed >5 m/s.
NWP wind direction [deg]
Measured wind direction [deg]
0
90
180
270
360


Risø, 76.6 m. Wind speed >5 m/s.
NWP wind direction [deg]
Measured wind direction [deg]
0
90
180
270
360


Risø, 125.2 m. Wind speed <5 m/s.
NWP wind direction [deg]
Measured wind direction [deg]
0
90
180
270
360


Risø, 125.2 m. Wind speed <5 m/s.
NWP wind direction [deg]
Measured wind direction [deg]
0
90
180
270
360

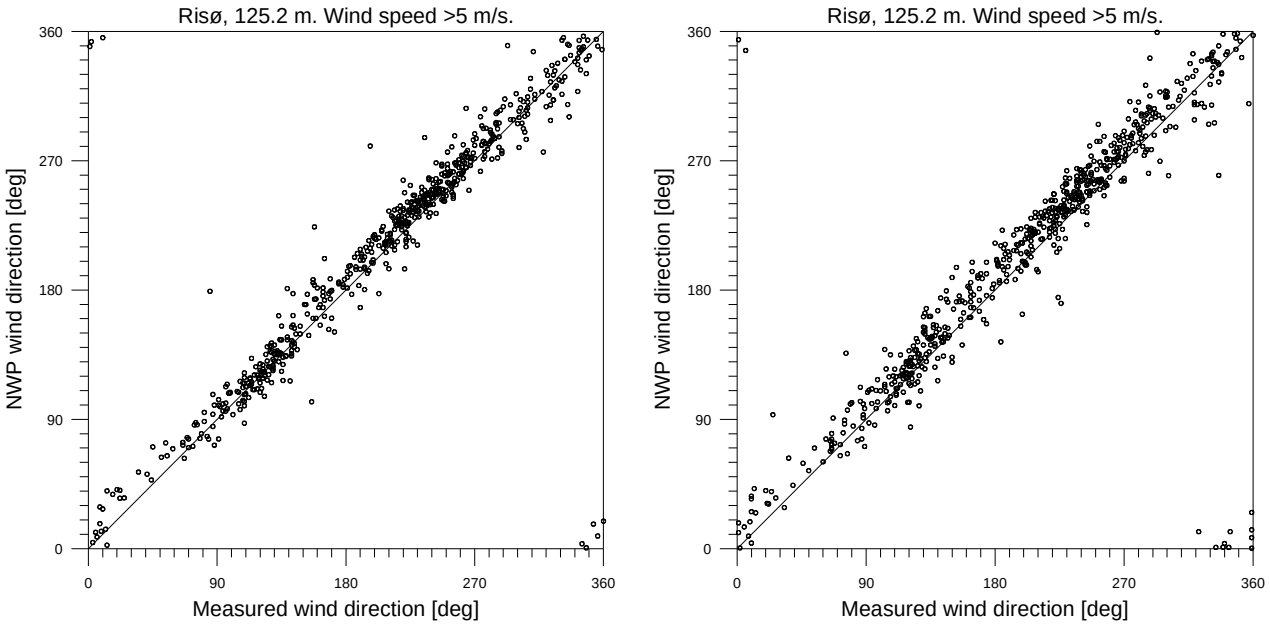


Figure 1. 1017 sets of DMI HIRLAM results for Risø compared to measured data.
Left column: analysis hours; right column: 5 hour forecasts.

Height [m]	speed diff [m/s] mean	std.dev	count
44.2	-0.167	1.375	1017
76.6	-0.223	1.456	1010
125.2	-0.579	1.553	1017

Height [m]	speed diff [m/s] mean	std.dev	count
44.2	0.568	1.755	1015
76.6	0.527	1.869	1008
125.2	0.221	1.903	1015

Height [m]	direction diff [deg] mean	std.dev	count
76.6	1.4	24.6	1017
125.2	4.0	24.3	1017

Height [m]	direction diff [deg] mean	std.dev	count
76.6	6.4	27.0	1015
125.2	7.9	25.4	1015

Measured wind speed at 44.2 m < 5 m/s

Height [m]	direction diff [deg] mean	std.dev	count
76.6	0.3	34.8	406
125.2	1.4	35.1	406

Height [m]	direction diff [deg] mean	std.dev	count
76.6	6.6	38.7	375
125.2	6.6	37.3	375

Measured wind speed at 44.2 m > 5 m/s

Height [m]	direction diff [deg] mean	std.dev	count
76.6	2.1	14.2	611
125.2	5.7	12.5	611

Height [m]	direction diff [deg] mean	std.dev	count
76.6	6.3	16.6	640
125.2	8.7	14.3	640

Table 1. Statistics of differences between DMI HIRLAM results and Risø data.
Left columns: analysis hours; right columns: 5 hour forecasts.

German nuclear power plant sites

Ten minute resolution measurements of wind speed and direction, temperature and other meteorological parameters have been made available by Bundesamt für Strahlenschutz (BsF), the German Federal Office for Radiation Protection, for the period 1st January to 31st March 2009 for the following German nuclear power plant sites: Neckarwestheim, Obrigheim, Philippsburg, Isar, Brokdorf, Brunsbüttel, and Krümmel.

Numerical weather predictions (NWP) for areas covering these plant sites and for almost the full mentioned period, i.e. from 5th January, have been made available by AMGO, the Austrian Meteorological and Geophysical Office. These predictions consist of two daily sets with analysis (0 hour forecast) and hourly forecasts until 48 hour.

Comparisons of NWP to measured wind speed and direction have been made for all measurement heights at all seven plant sites, for the analysis time and for the 48 hour forecast, the reported site order being from north to south, i.e. Brunsbüttel, Brokdorf, Krümmel, Obrigheim, Philippsburg, Neckarwestheim, and Isar.

Brunsbüttel

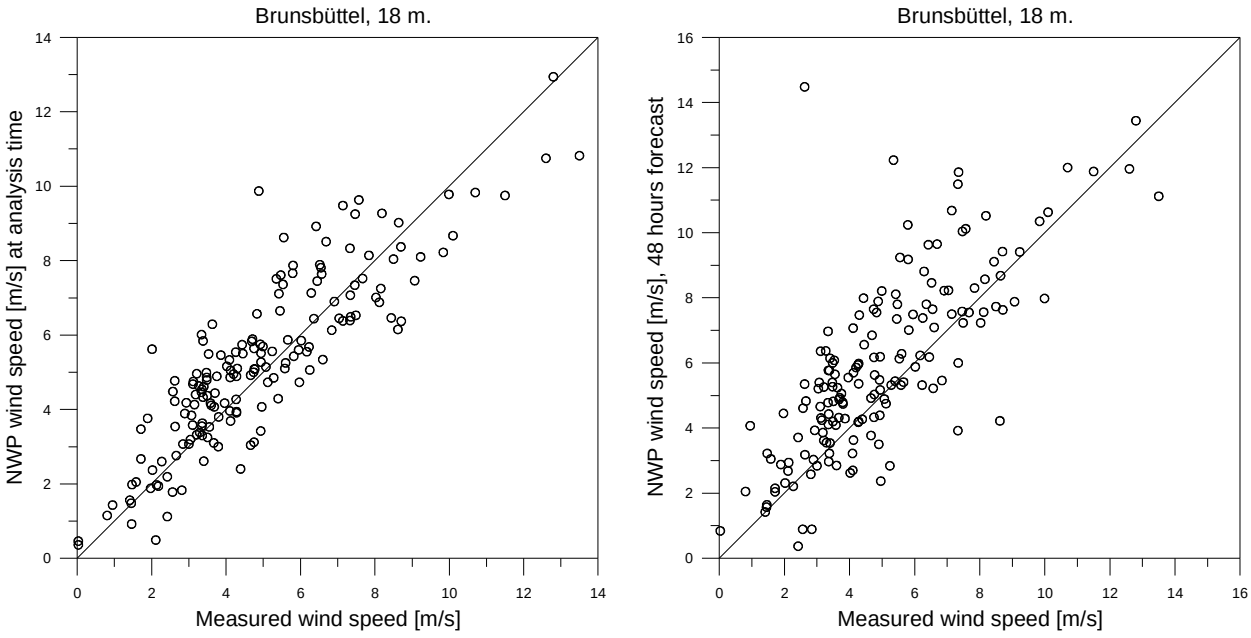
Brunsbüttel at 53.891° N, 9.202° E is situated at the river Elbe in north western Germany very close to the North Sea.

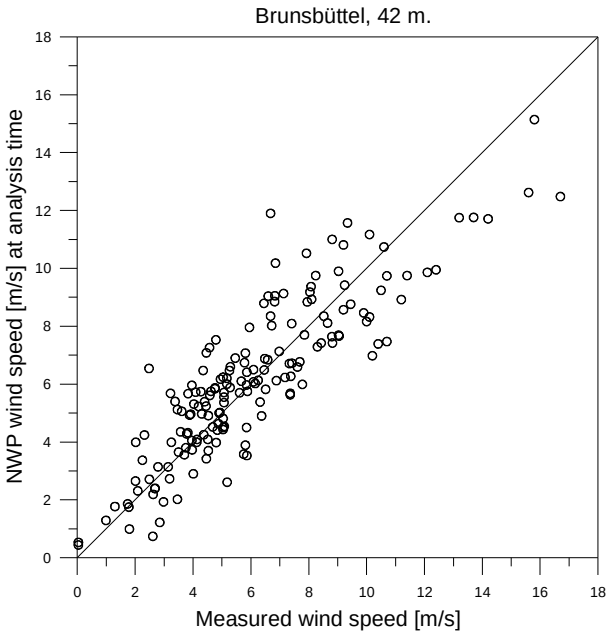
At Brunsbüttel there are three measurement heights, 18 m, 42 m and 102 m. Figure 2 shows the scatter plots of the numerical weather predictions versus the measured data, and table 2 lists means and standard deviations of their differences.

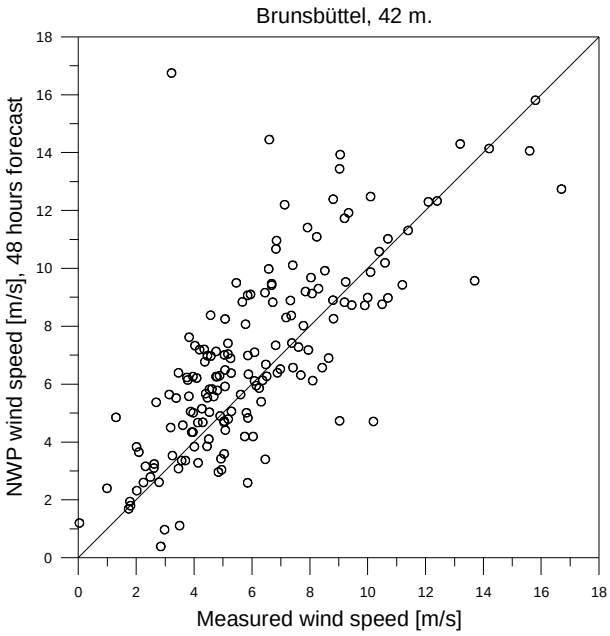
The NWP wind speeds are on average pretty close to the measured, both at analysis time and at 48 hours forecast, the scatter growing reasonably with time. For higher wind speeds at 102 m the NWP tends towards under prediction.

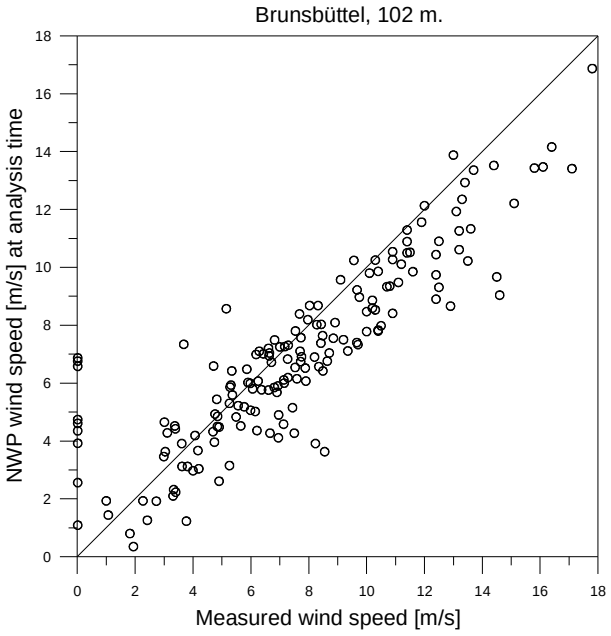
There are some instances of almost zero measured wind speed, especially at 102 m. It looks like measurement errors but as they due to their small number only affect the statistics marginally and as it seems that errors have already been filtered out, they are kept in.

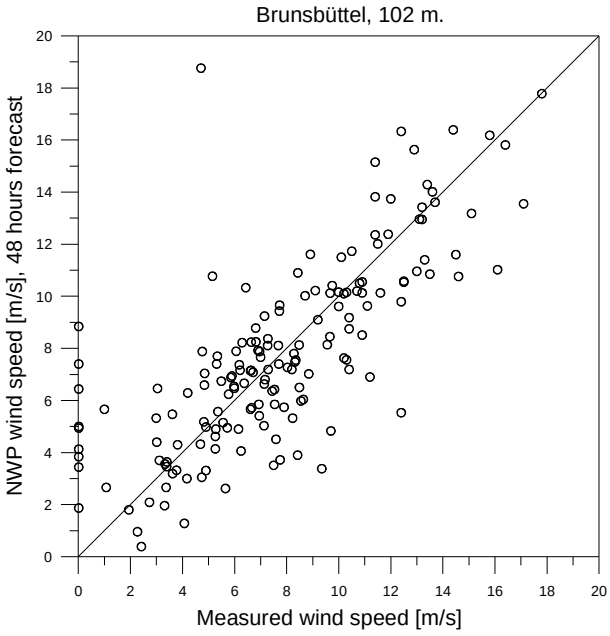
The wind directions are slightly over predicted at the two lower heights, but good at 102 m. Again, as reasonable, scatter, i.e. standard deviation, is higher at 48 hours forecast than at analysis time.

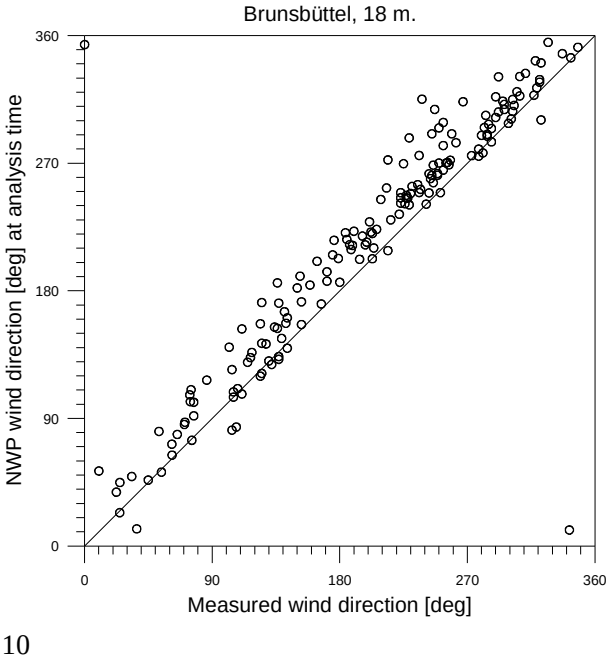


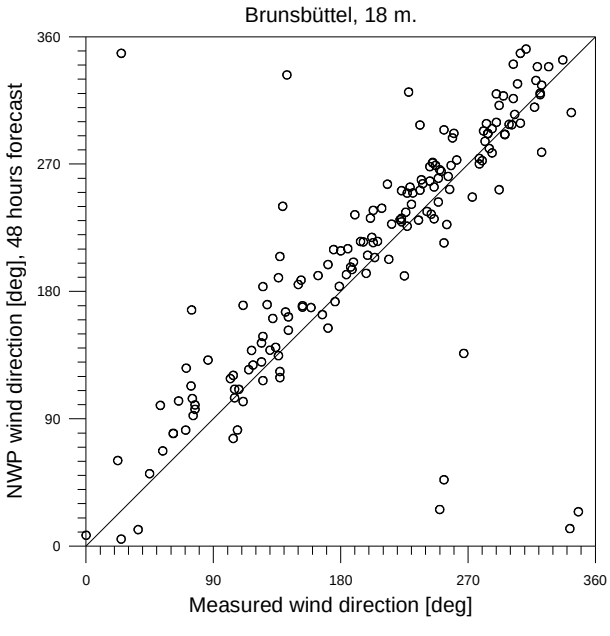

Brunsbüttel, 42 m.
NWP wind speed [m/s] at analysis time
Measured wind speed [m/s]
0 2 4 6 8 10 12 14 16 18


Brunsbüttel, 42 m.
NWP wind speed [m/s], 48 hours forecast
Measured wind speed [m/s]
0 2 4 6 8 10 12 14 16 18


Brunsbüttel, 102 m.
NWP wind speed [m/s] at analysis time
Measured wind speed [m/s]
0 2 4 6 8 10 12 14 16 18


Brunsbüttel, 102 m.
NWP wind speed [m/s], 48 hours forecast
Measured wind speed [m/s]
0 2 4 6 8 10 12 14 16 18 20


Brunsbüttel, 18 m.
NWP wind direction [deg] at analysis time
Measured wind direction [deg]
0 90 180 270 360


Brunsbüttel, 18 m.
NWP wind direction [deg], 48 hours forecast
Measured wind direction [deg]
0 90 180 270 360

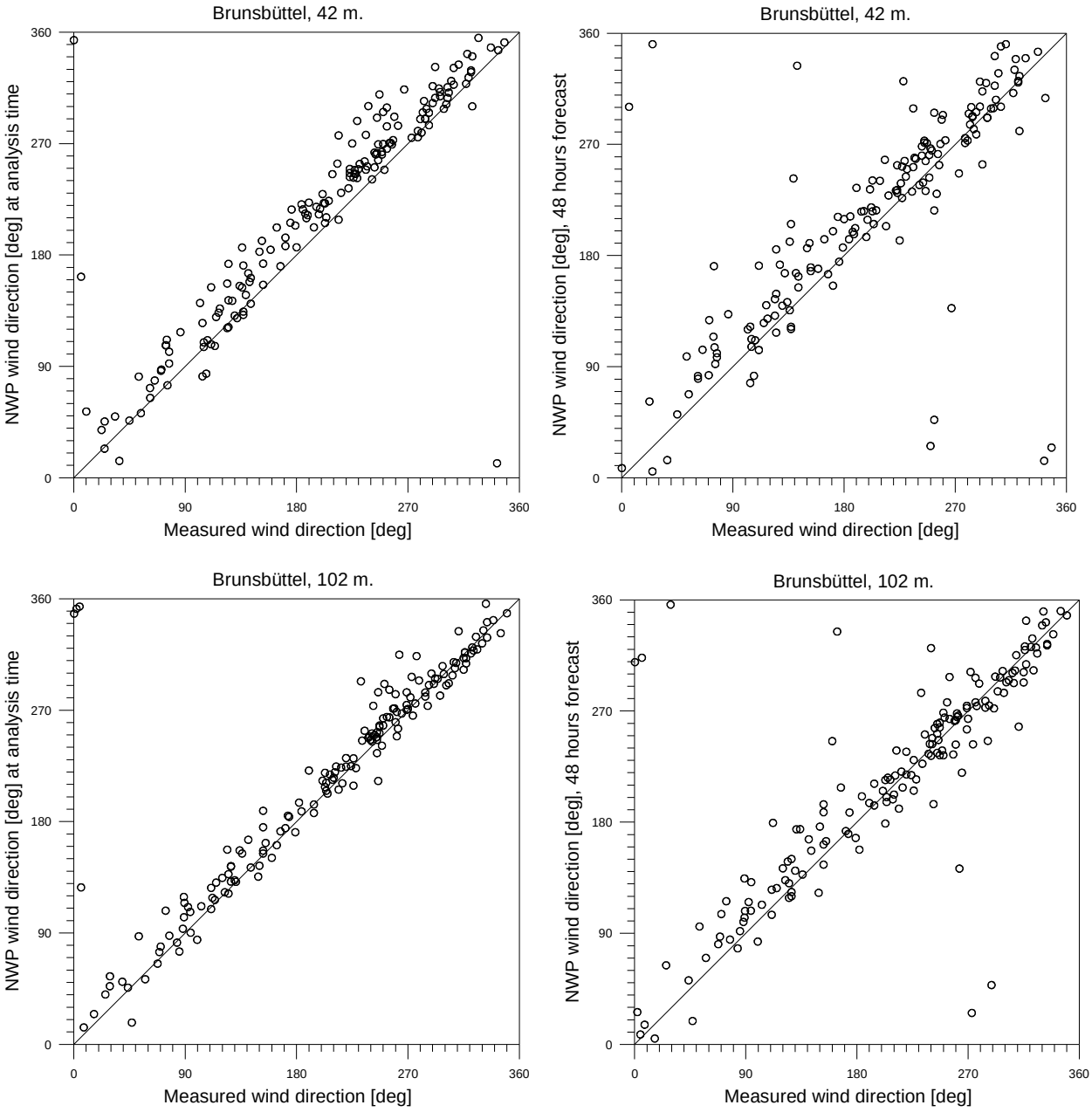


Figure 2. NWP results for Brunsbüttel compared to measured data.
Left column: analysis time; right column: 48 hour forecast.

Height	speed diff [m/s]		
[m]	mean	std.dev	count
18.0	0.350	1.22	171
42.0	0.109	1.47	171
102.0	-0.633	1.89	171

Height	direction diff [deg]		
[m]	mean	std.dev	count
18.0	16.958	16.06	169
42.0	18.109	19.18	171
102.0	6.742	16.20	171

Height	speed diff [m/s]		
[m]	mean	std.dev	count
18.0	0.955	1.81	167
42.0	0.786	2.17	167
102.0	0.089	2.59	167

Height	direction diff [deg]		
[m]	mean	std.dev	count
18.0	13.081	32.76	166
42.0	13.850	33.25	167
102.0	5.797	29.54	167

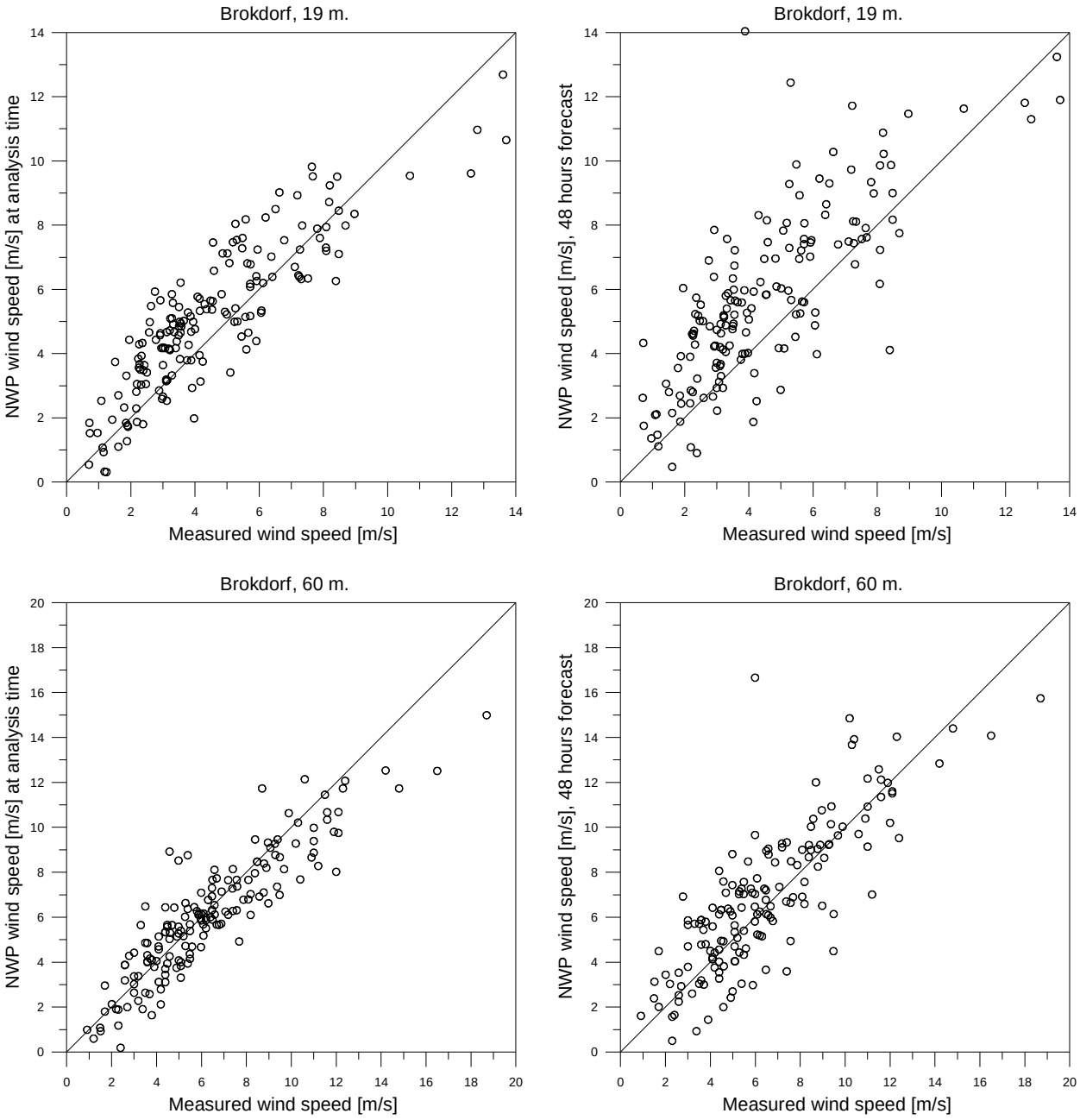
Table 2. Statistics of differences between NWP results and Brunsbüttel data.
Left columns: analysis time; right columns: 48 hour forecast.

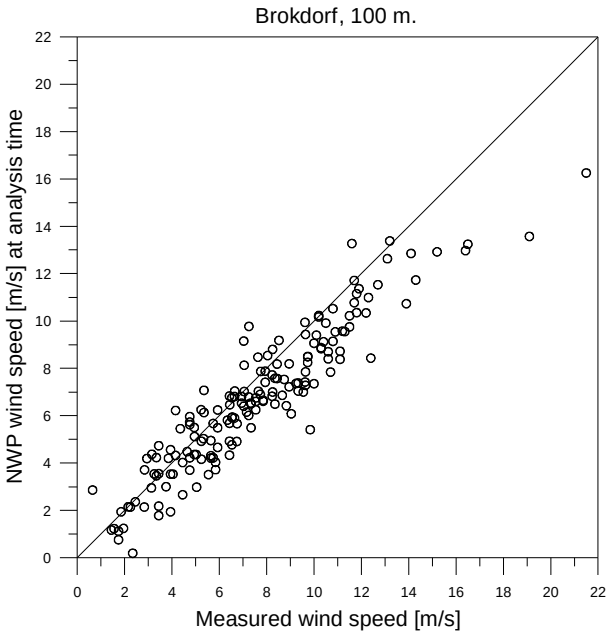
Brokdorf

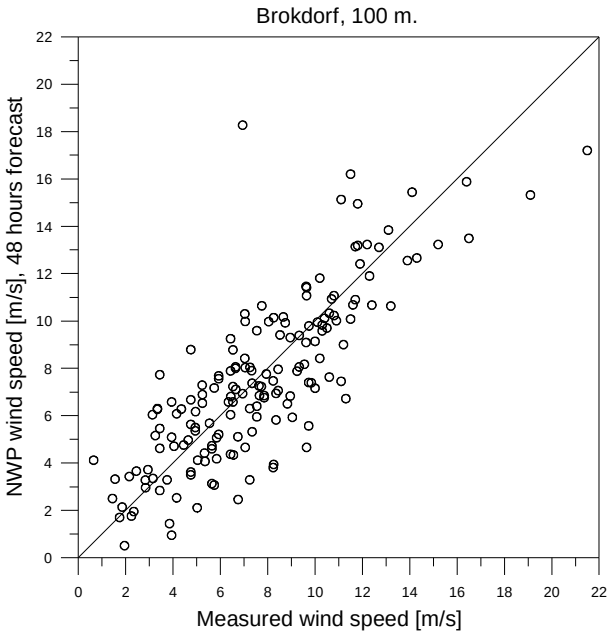
The Brokdorf plant at 53.851° N, 9.346° E is situated in flat terrain on the bank of river Elbe approximately 10 km upstream from the Brunsbüttel plant for which reason neither NWP nor measured data can be very different from those for that plant.

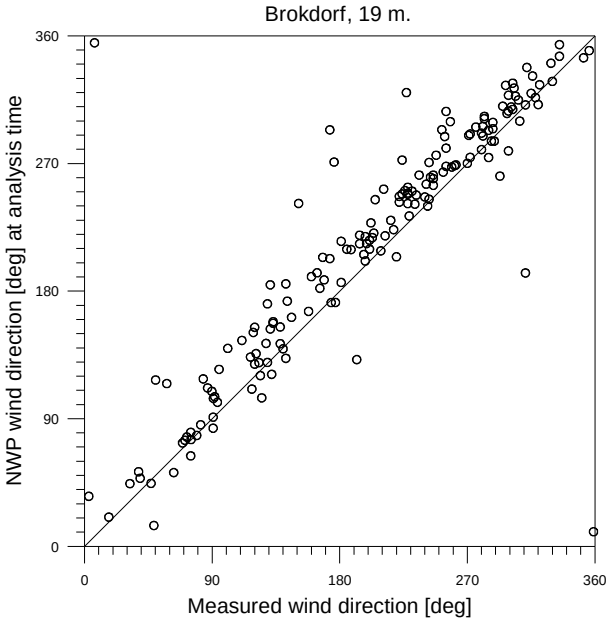
There are three measurement heights at Brokdorf: 19 m, 60 m and 100 m. Figure 3 shows the scatter plots of the numerical weather predictions versus the measured data, and table 3 lists means and standard deviations of their differences.

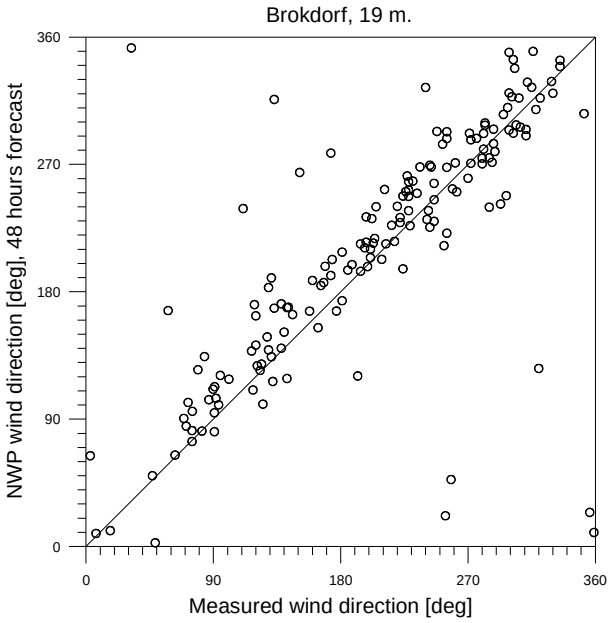
The NWP results for Brokdorf and for Brunsbüttel are as identical as they can be, and the same is true for the measurement, so the comments written for Brunsbüttel is valid here too except that there seems to be no erroneous next to zero wind speeds here.

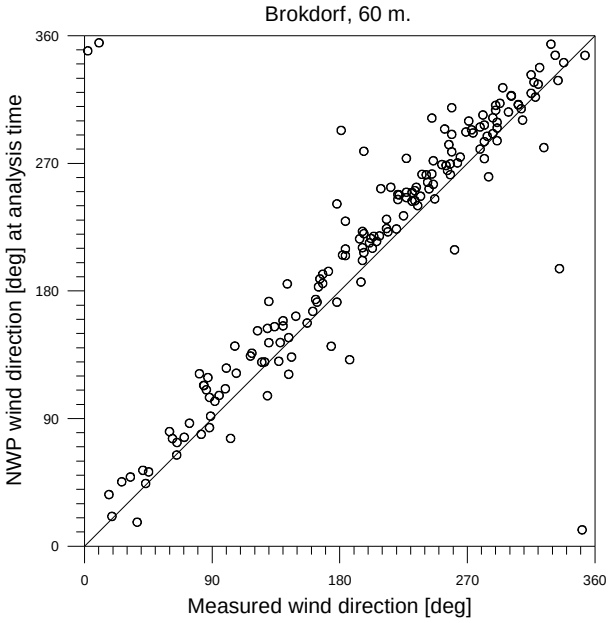


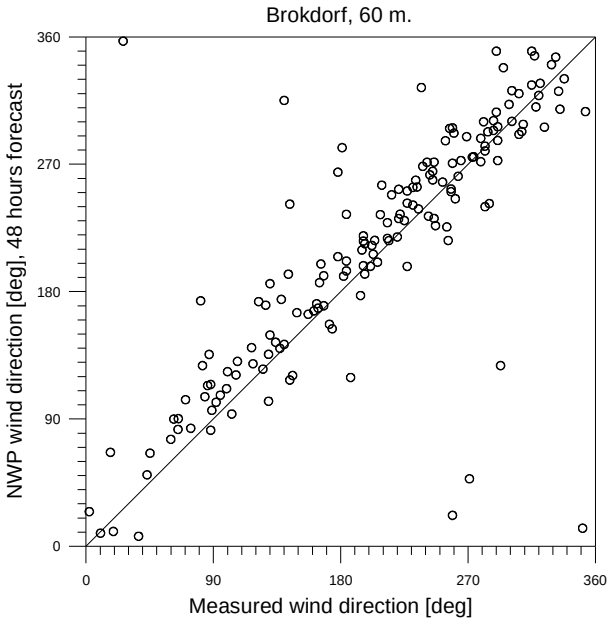

Brokdorf, 100 m.
NWP wind speed [m/s] at analysis time
Measured wind speed [m/s]


Brokdorf, 100 m.
NWP wind speed [m/s], 48 hours forecast
Measured wind speed [m/s]


Brokdorf, 19 m.
NWP wind direction [deg] at analysis time
Measured wind direction [deg]


Brokdorf, 19 m.
NWP wind direction [deg], 48 hours forecast
Measured wind direction [deg]


Brokdorf, 60 m.
NWP wind direction [deg] at analysis time
Measured wind direction [deg]


Brokdorf, 60 m.
NWP wind direction [deg], 48 hours forecast
Measured wind direction [deg]

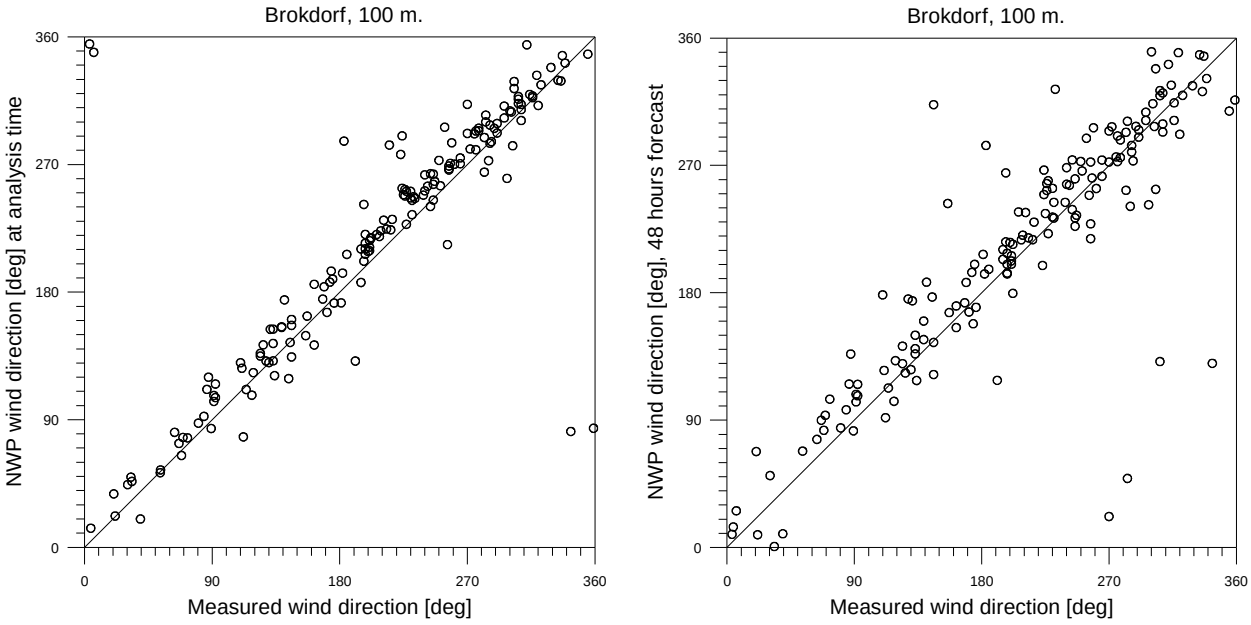


Figure 3. NWP results for Brokdorf compared to measured data.
Left column: analysis time; right column: 48 hour forecast.

Height	speed diff [m/s]		
[m]	mean	std.dev	count
19.0	0.643	1.20	170
60.0	-0.274	1.34	167
100.0	-0.819	1.29	171

Height	direction diff [deg]		
[m]	mean	std.dev	count
19.0	14.299	23.67	170
60.0	12.321	22.77	167
100.0	10.848	19.67	171

Height	speed diff [m/s]		
[m]	mean	std.dev	count
19.0	1.295	1.75	166
60.0	0.392	1.91	163
100.0	-0.099	2.14	167

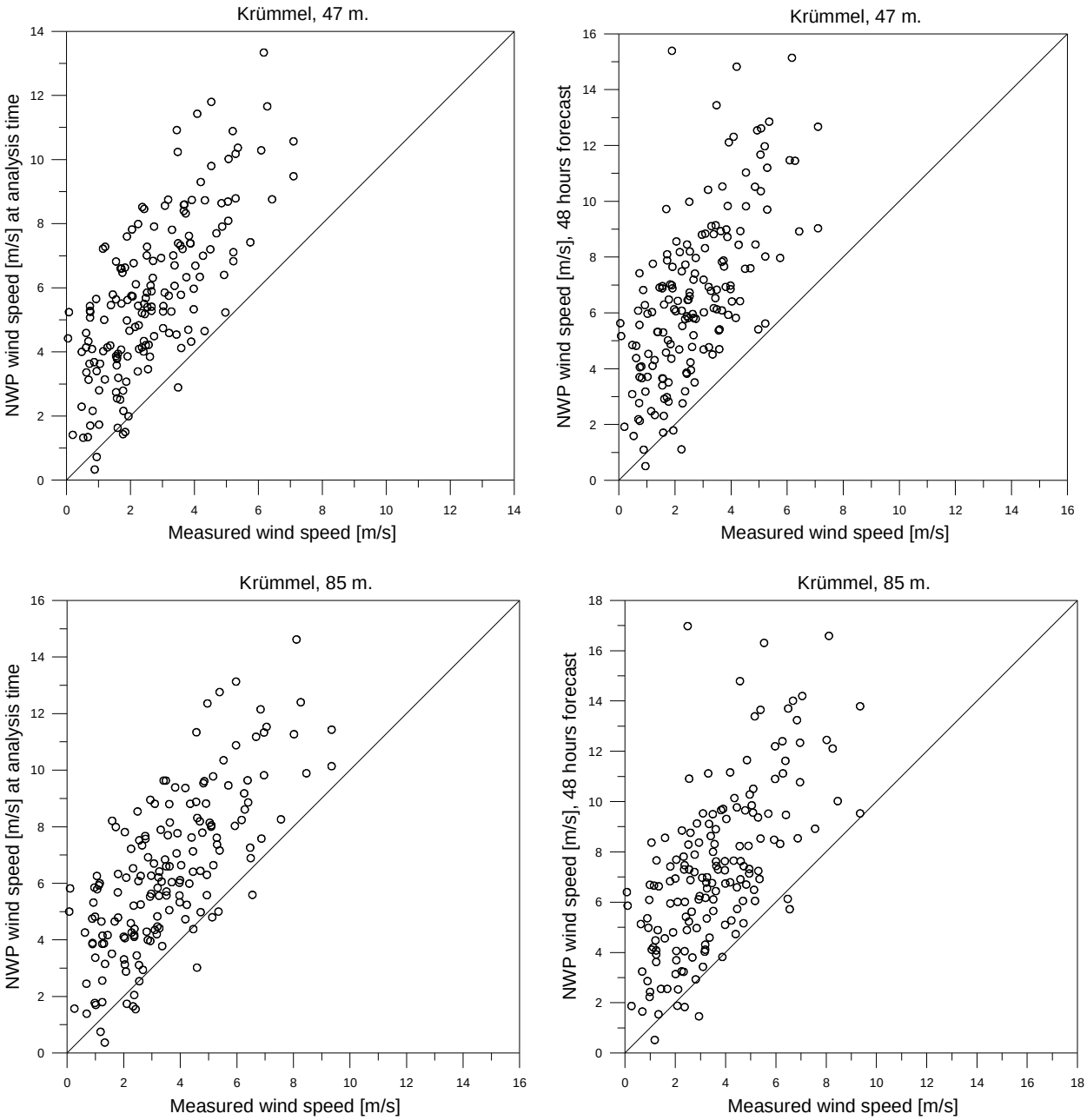
Height	direction diff [deg]		
[m]	mean	std.dev	count
19.0	13.253	36.31	166
60.0	13.040	34.34	163
100.0	10.495	34.59	167

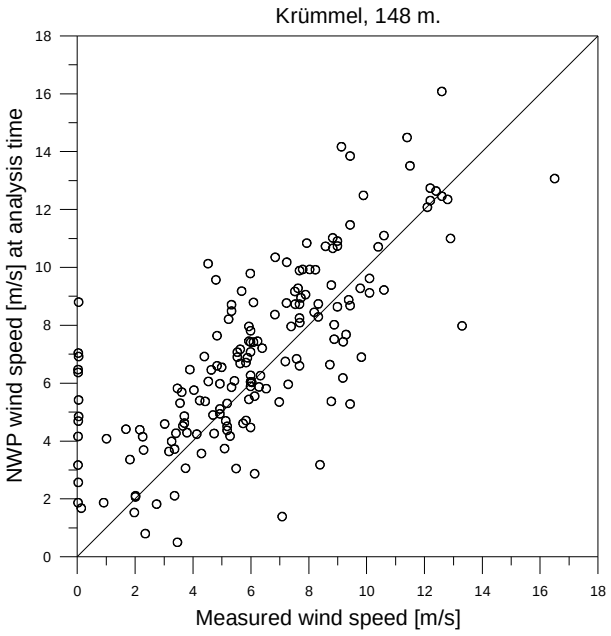
Table 3. Statistics of differences between NWP results and Brokdorf data.
Left columns: analysis time; right columns: 48 hour forecast.

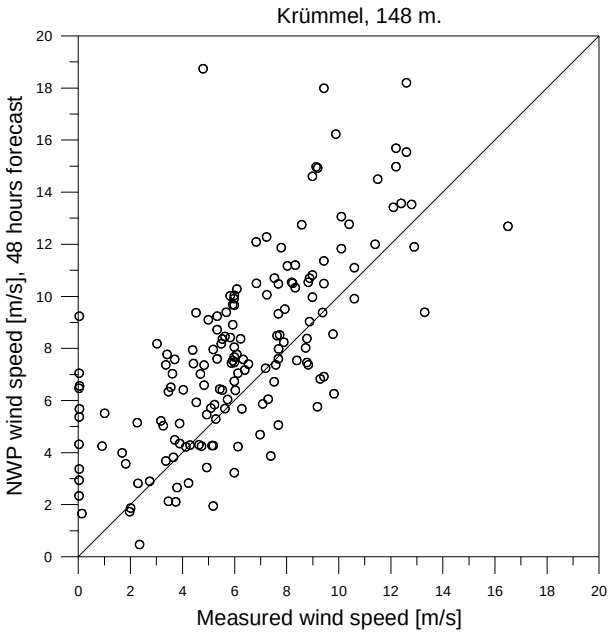
Krümmel

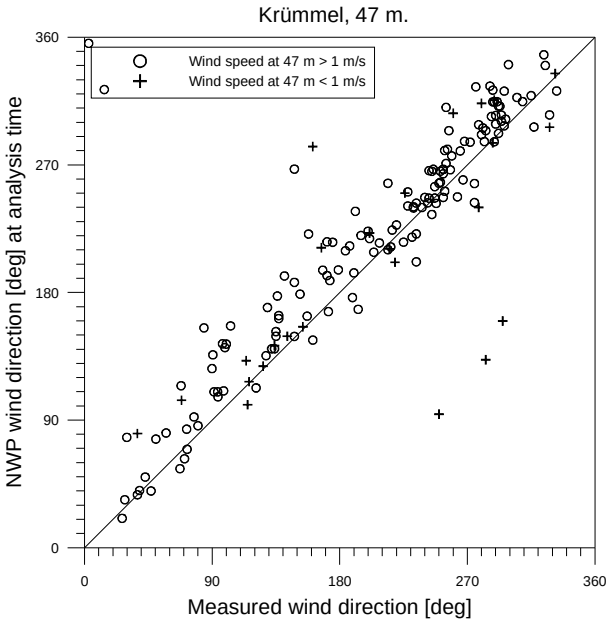
The Krümmel plant at 53.411° N, 10.410° E is situated at the river Elbe approximately 85 km southeast of the Brokdorf plant and 30 km southeast of Hamburg and so somewhat more inland than the coastal plants. There are three measurement heights at Krümmel: 47 m, 85 m and 148 m. Figure 4 shows the scatter plots of the numerical weather predictions versus the measured data, and table 4 lists means and standard deviations of their differences.

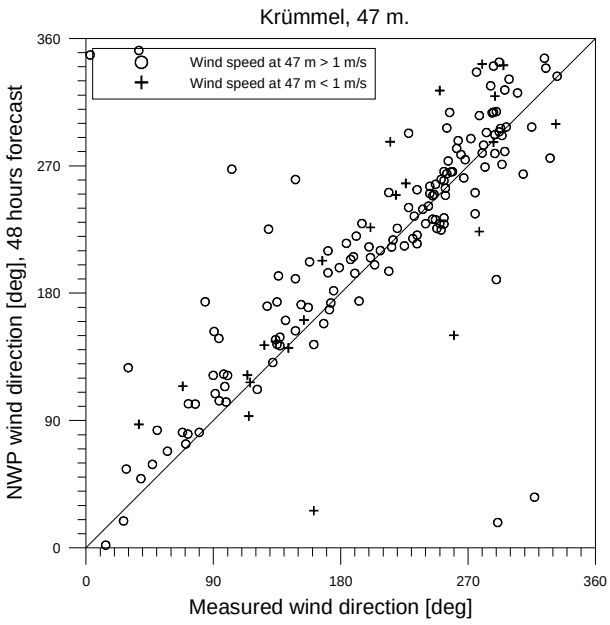
The NWP results for Krümmel show very much over predicted wind speeds at the two lower heights while wind directions are pretty good with some, but not all of the worst outliers corresponding to very low wind speeds. Only looking at wind speed above 1 m/s reduces the wind direction scatter somewhat for the analysis times but not much for the 48 hours forecast.

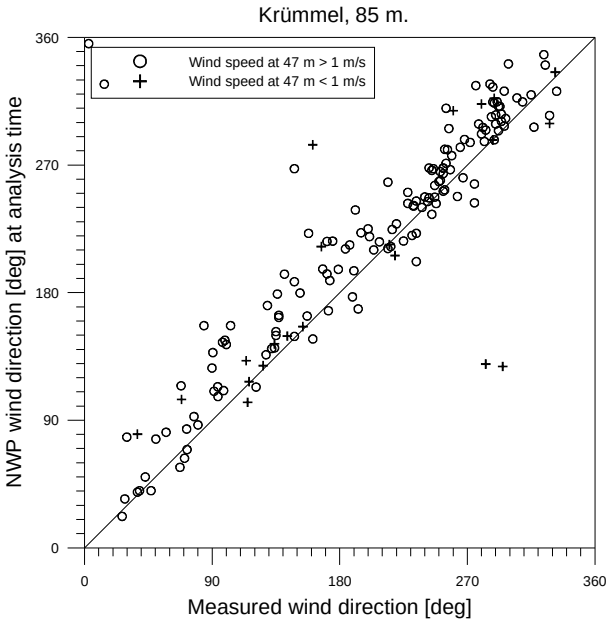


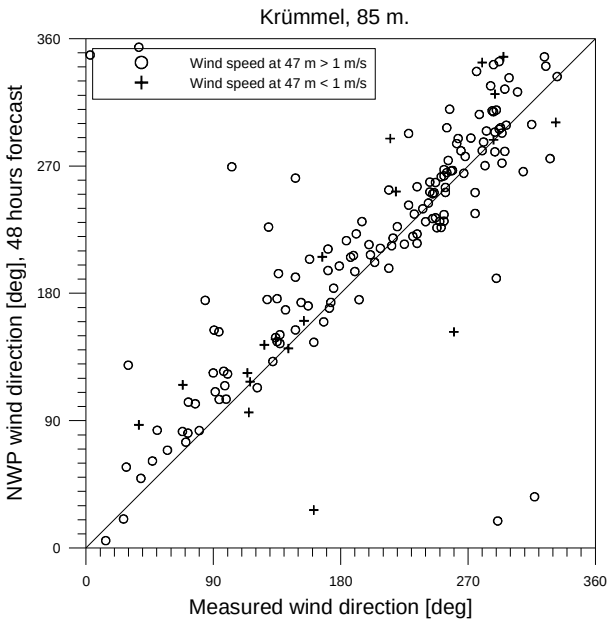

Krümmel, 148 m.
NWP wind speed [m/s] at analysis time
Measured wind speed [m/s]


Krümmel, 148 m.
NWP wind speed [m/s], 48 hours forecast
Measured wind speed [m/s]


Krümmel, 47 m.
Wind speed at 47 m > 1 m/s
Wind speed at 47 m < 1 m/s
NWP wind direction [deg] at analysis time
Measured wind direction [deg]


Krümmel, 47 m.
Wind speed at 47 m > 1 m/s
Wind speed at 47 m < 1 m/s
NWP wind direction [deg], 48 hours forecast
Measured wind direction [deg]


Krümmel, 85 m.
Wind speed at 47 m > 1 m/s
Wind speed at 47 m < 1 m/s
NWP wind direction [deg] at analysis time
Measured wind direction [deg]


Krümmel, 85 m.
Wind speed at 47 m > 1 m/s
Wind speed at 47 m < 1 m/s
NWP wind direction [deg], 48 hours forecast
Measured wind direction [deg]

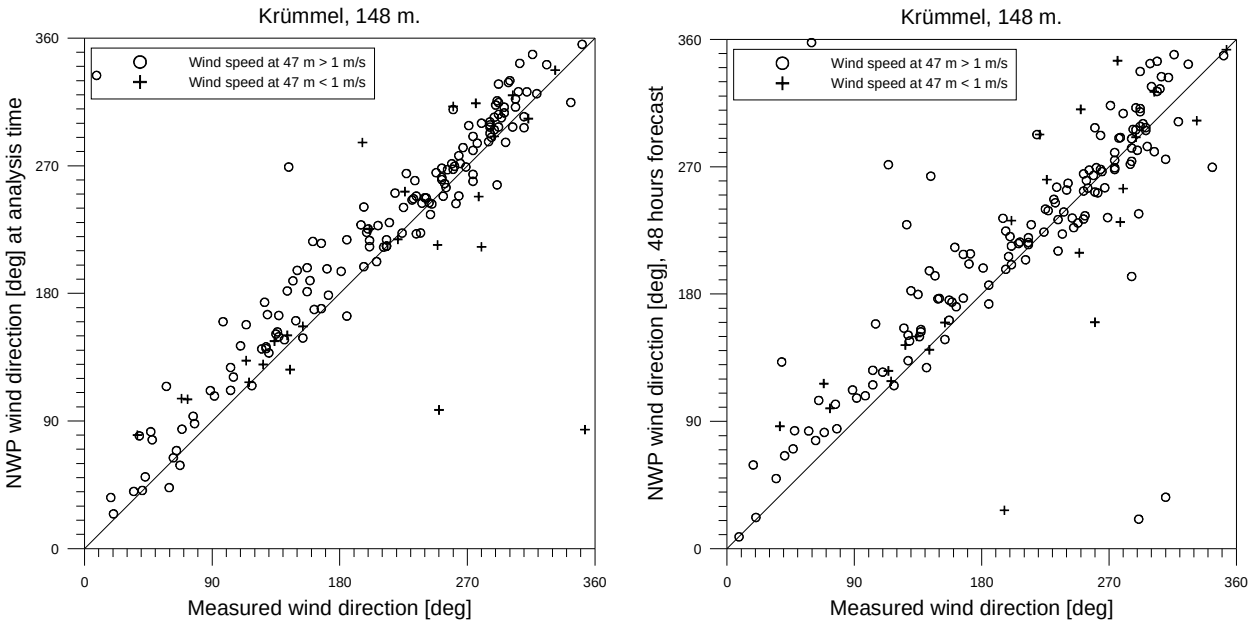


Figure 4. NWP results for Krümmel compared to measured data.
Left column: analysis time; right column: 48 hour forecast.

Height	speed diff [m/s]			Height	speed diff [m/s]		
[m]	mean	std.dev	count	[m]	mean	std.dev	count
47.0	3.091	1.72	169	47.0	3.913	2.24	165
85.0	2.824	1.90	169	85.0	3.686	2.43	165
148.0	0.875	2.25	169	148.0	1.689	2.62	165

Height	direction diff [deg]			Height	direction diff [deg]		
[m]	mean	std.dev	count	[m]	mean	std.dev	count
47.0	11.359	31.54	169	47.0	12.228	35.05	165
85.0	13.136	30.06	165	85.0	13.543	34.80	161
148.0	13.011	25.86	169	148.0	12.266	35.13	165

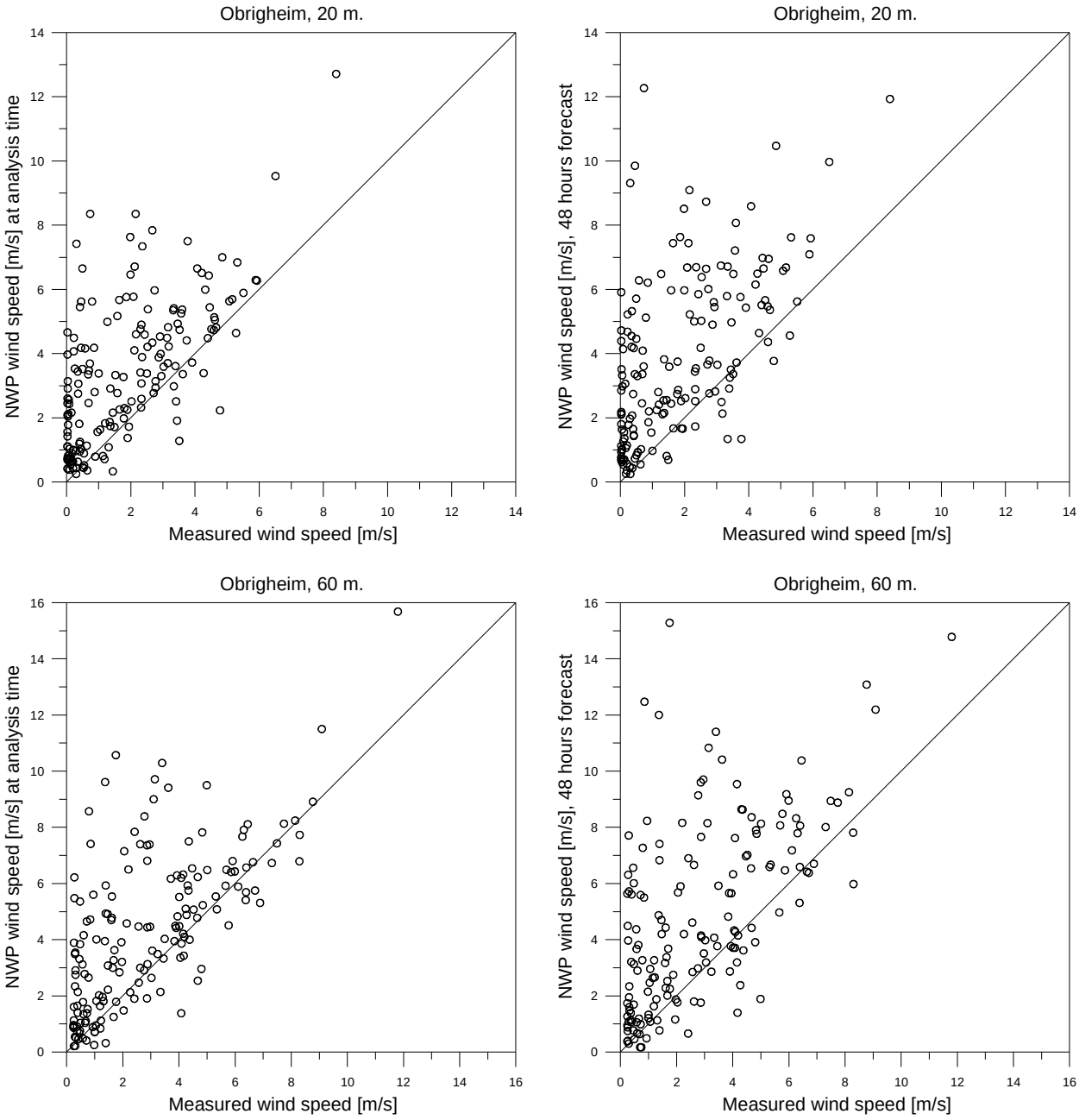
Measured wind speed at 47 m > 1 m/s

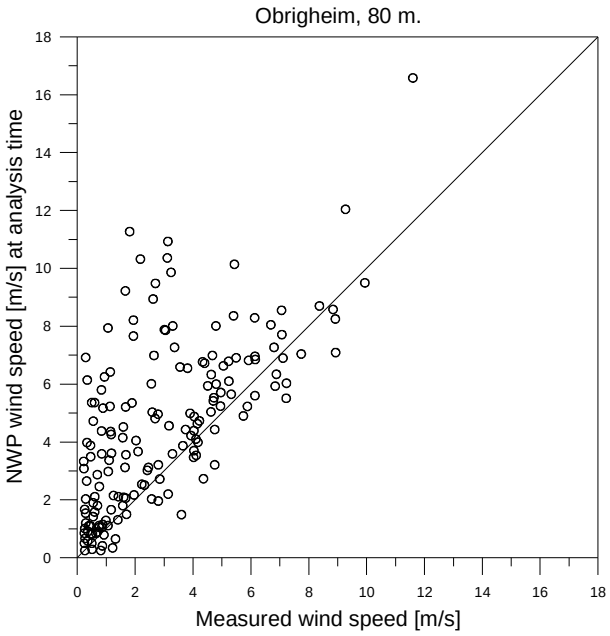
Height	direction diff [deg]			Height	direction diff [deg]		
[m]	mean	std.dev	count	[m]	mean	std.dev	count
47.0	14.117	21.68	144	47.0	12.864	31.71	142
85.0	14.881	21.72	144	85.0	14.335	31.78	142
148.0	13.957	19.78	144	148.0	13.873	30.83	142

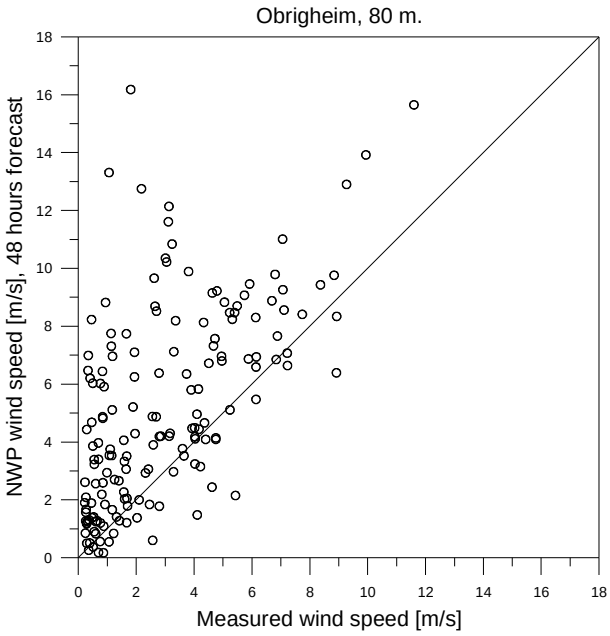
Table 4. Statistics of differences between NWP results and Krümmel data.
Left columns: analysis time; right columns: 48 hour forecast.

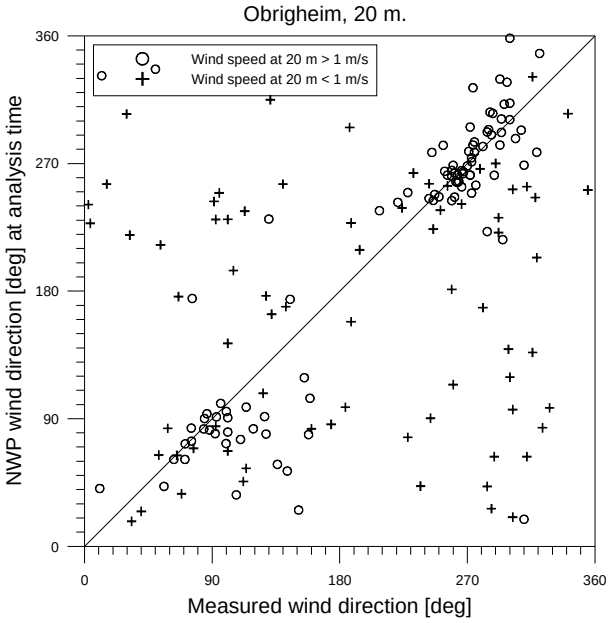
Obrigheim

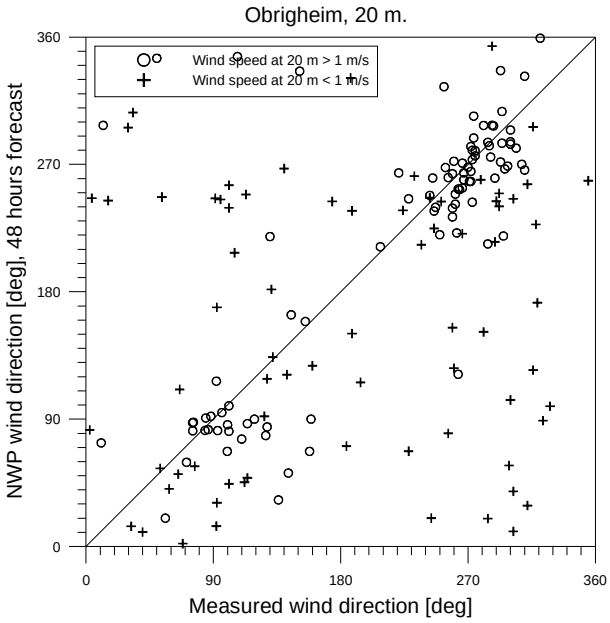
The Obrigheim plant is situated at 49.364° N, 9.076° E at the river Neckar, a tributary to the Rhine river. The meteorological measurements here are at 20 m, 60 m, and 80 m above ground. Figure 5 shows the scatter plots of the numerical weather predictions versus the measured data, table 5 gives the statistics.
The wind speeds are generally very low at Obrigheim, 45% of the measurements at 20 m are below 1 m/s. The NWP wind speeds are over predicted at all heights, and the direction difference standard deviation is very high, 55° to 85°. Only looking at sets where the 20m wind speed exceeds 1 m/s the direction difference standard deviation reduces to between 30° and 65°. The 60 m direction difference average is 30°, far from the 3° and 8° at 20 and 80 m. Figure 6 shows scatter plots of the measured directions at 60 and 80 m against those at 20 m, plus the equivalent figures for the NWP results. Although with great scatter, the 60 m measured directions do seem to some extent to cluster approximately 30° below the 20 and 80 m directions.

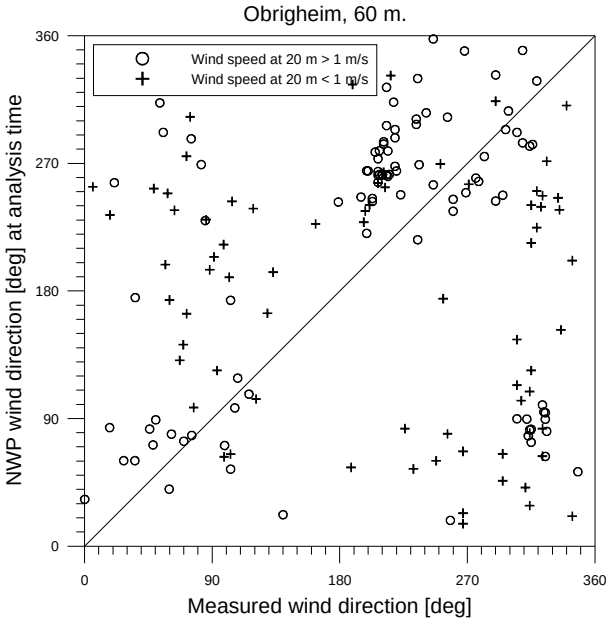


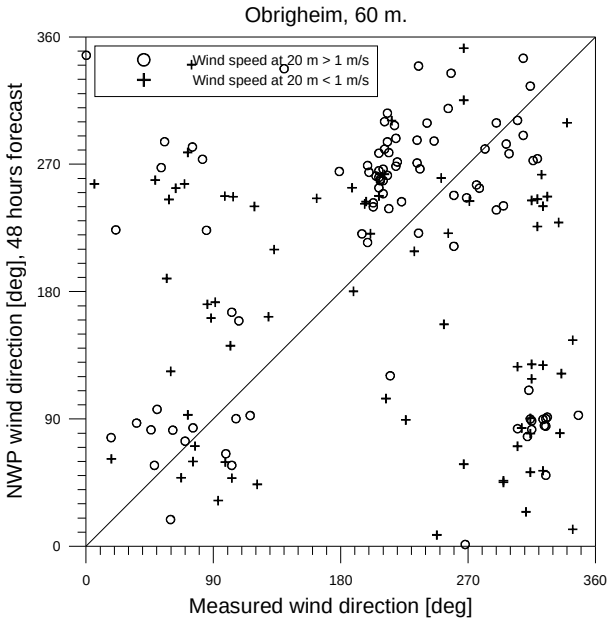

Obrigheim, 80 m.
NWP wind speed [m/s] at analysis time
Measured wind speed [m/s]


Obrigheim, 80 m.
NWP wind speed [m/s], 48 hours forecast
Measured wind speed [m/s]


Obrigheim, 20 m.
Wind speed at 20 m > 1 m/s
Wind speed at 20 m < 1 m/s
NWP wind direction [deg] at analysis time
Measured wind direction [deg]


Obrigheim, 20 m.
Wind speed at 20 m > 1 m/s
Wind speed at 20 m < 1 m/s
NWP wind direction [deg], 48 hours forecast
Measured wind direction [deg]


Obrigheim, 60 m.
Wind speed at 20 m > 1 m/s
Wind speed at 20 m < 1 m/s
NWP wind direction [deg] at analysis time
Measured wind direction [deg]


Obrigheim, 60 m.
Wind speed at 20 m > 1 m/s
Wind speed at 20 m < 1 m/s
NWP wind direction [deg], 48 hours forecast
Measured wind direction [deg]

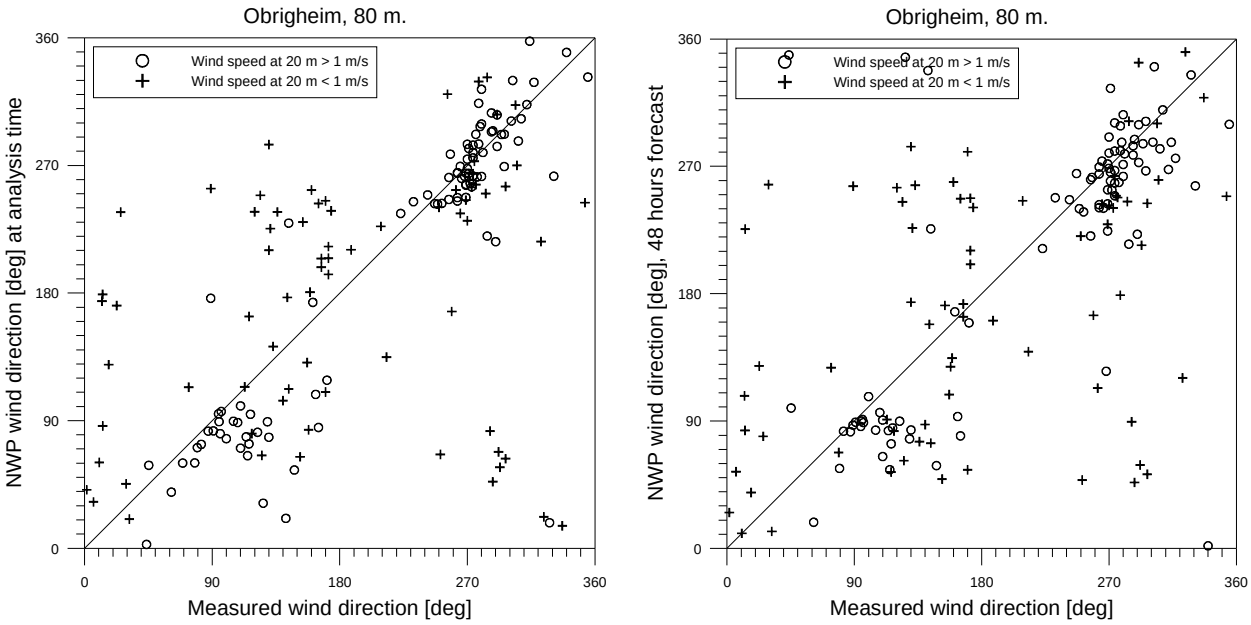


Figure 5. NWP results for Obrigheim compared to measured data.
Left column: analysis time; right column: 48 hour forecast.

Height	speed diff [m/s]		
[m]	mean	std.dev	count
20.0	1.543	1.72	170
60.0	1.467	2.11	169
80.0	1.660	2.24	170

Height	speed diff [m/s]		
[m]	mean	std.dev	count
20.0	2.053	2.13	166
60.0	2.022	2.63	165
80.0	2.223	2.76	166

Height	direction diff [deg]		
[m]	mean	std.dev	count
20.0	-3.492	69.04	170
60.0	31.256	86.79	169
80.0	8.002	57.90	170

Height	direction diff [deg]		
[m]	mean	std.dev	count
20.0	-8.538	68.60	166
60.0	24.783	84.84	165
80.0	-4.714	61.75	166

Measured wind speed at 20 m > 1 m/s

Height	direction diff [deg]		
[m]	mean	std.dev	count
20.0	-5.041	34.65	97
60.0	37.408	65.69	97
80.0	-9.368	32.00	97

Height	direction diff [deg]		
[m]	mean	std.dev	count
20.0	-13.737	40.27	93
60.0	29.468	71.26	93
80.0	-17.343	37.60	93

Table 5. Statistics of differences between NWP results and Obrigheim data.
Left columns: analysis time; right columns: 48 hour forecast.

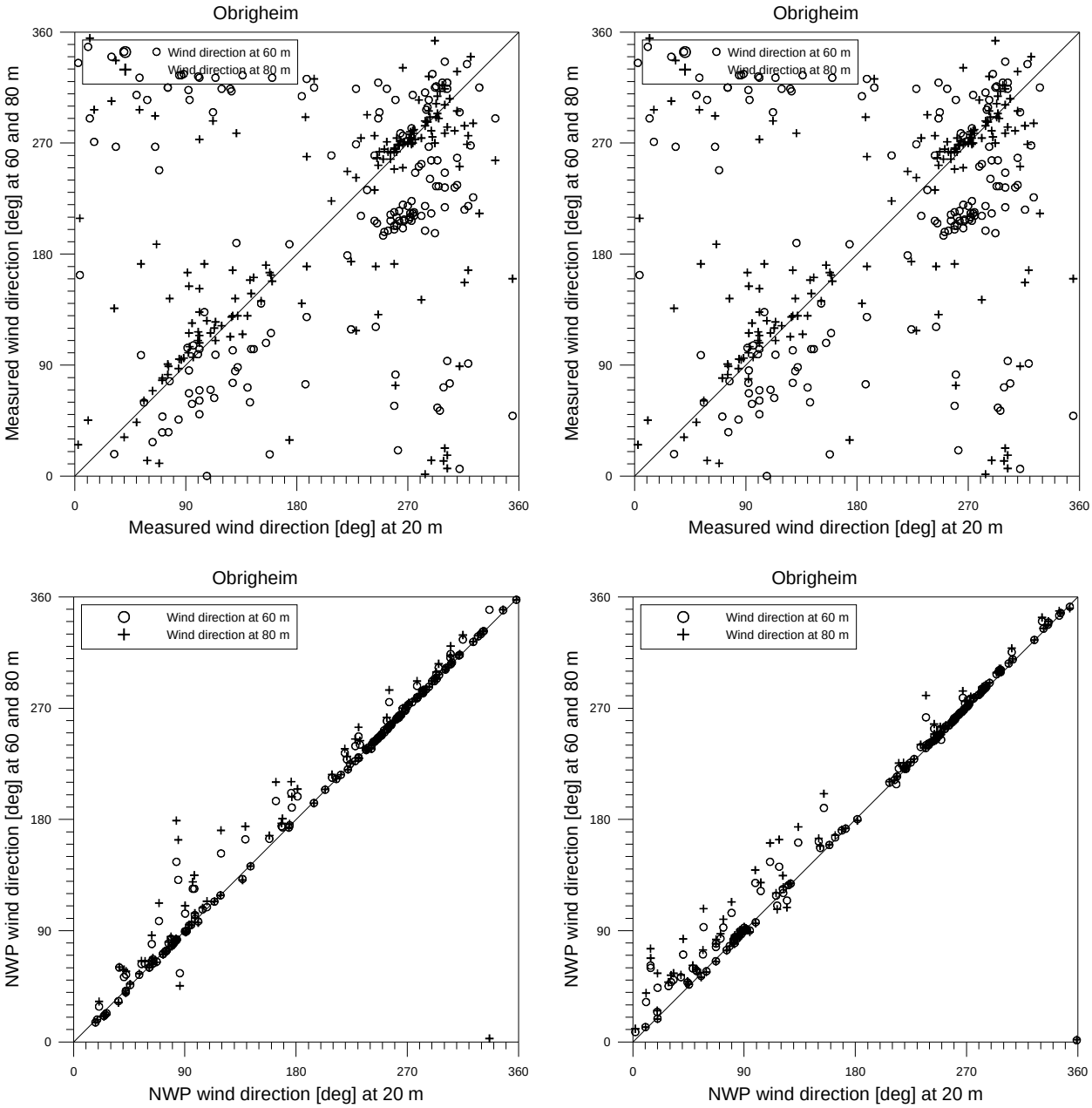
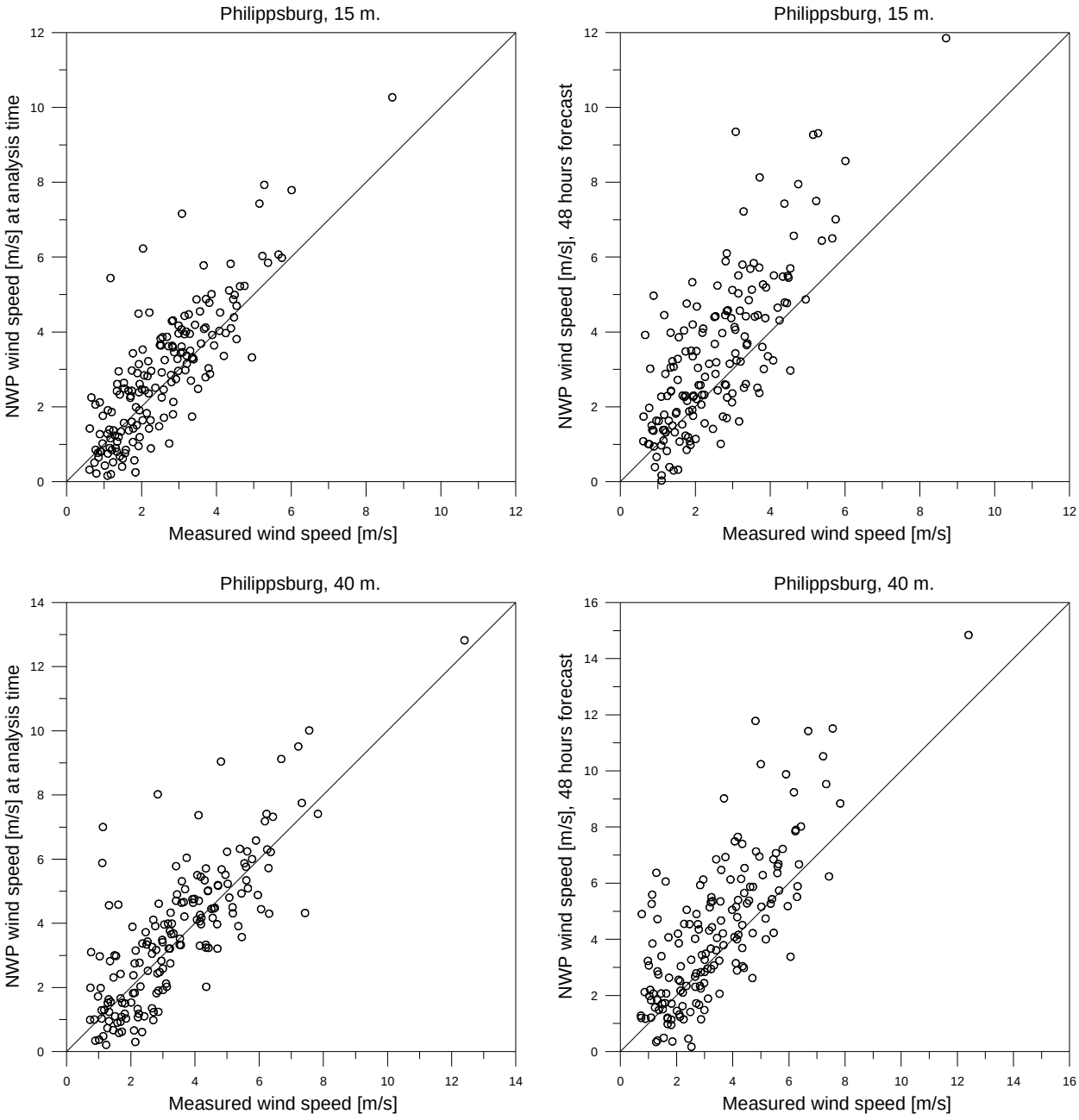


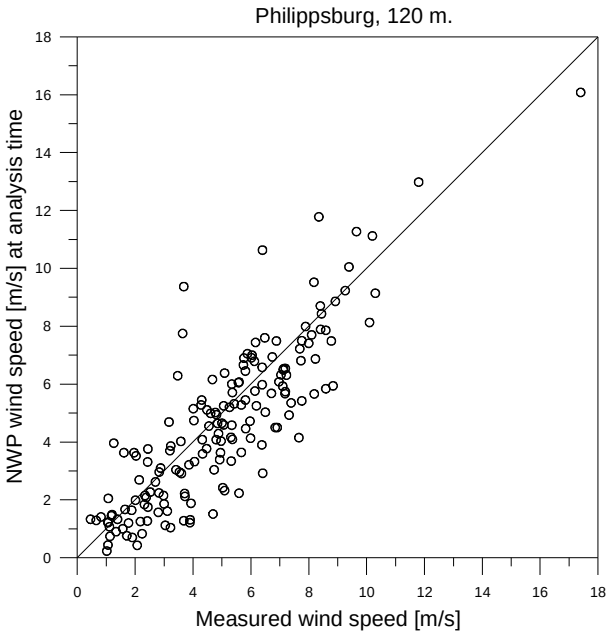
Figure 6: Comparison of measured and predicted wind directions at 60 and 80 m to those at 20 m. Left column: analysis time; right column: 48 hour forecast.

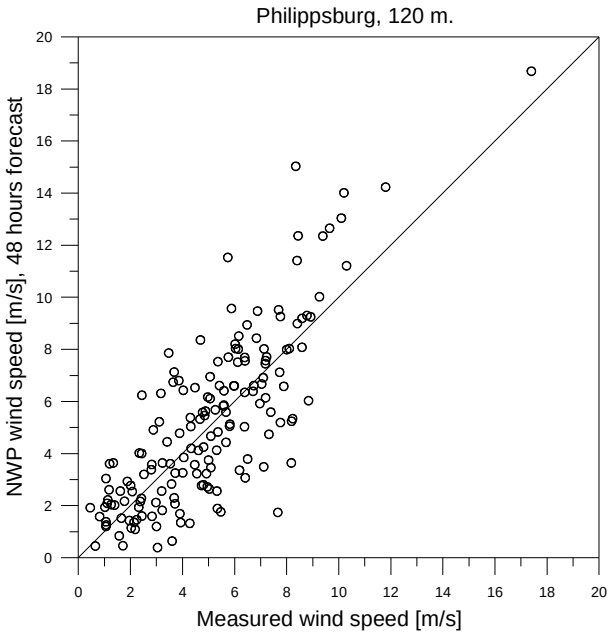
Philippsburg

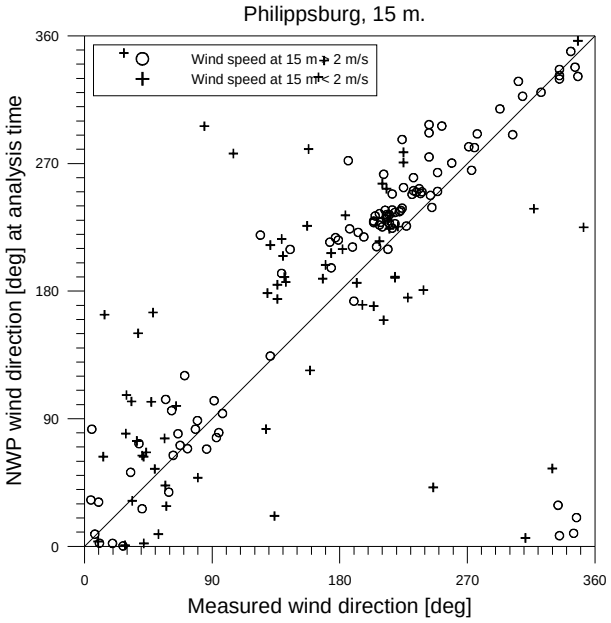
Philippsburg at 49.2520° N, 8.4350° E, is situated at the Rhine river approximately midway between Karlsruhe and Mannheim. Wind speeds and directions are measured at three heights: 15 m, 40 m, and 120 m. Figure 7 shows the scatter plots of the numerical weather predictions versus the measured data, and table 6 lists means and standard deviations of their differences.

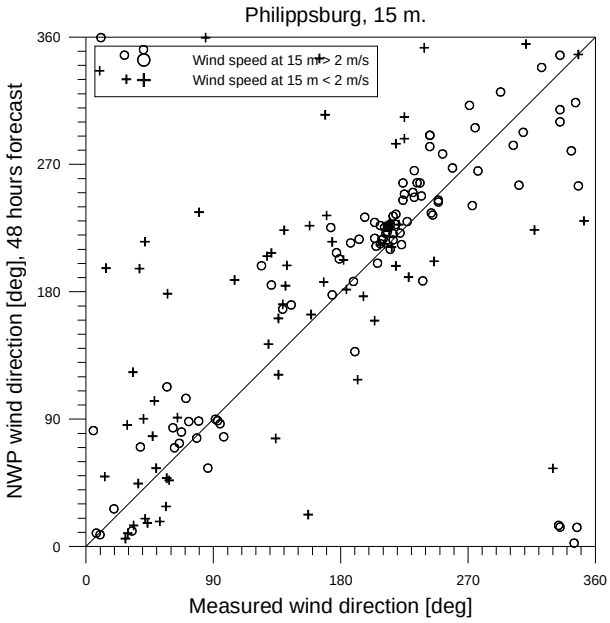
The NWP wind speeds compare pretty well with the measurements although the lowest speeds are slightly under predicted. The wind mean direction differences are small, around 7°, except at 15 m where it is 12°, but the standard deviations are large, up to 45°, but for winds above 2 m/s at 15 m this standard deviation is just around 20°.

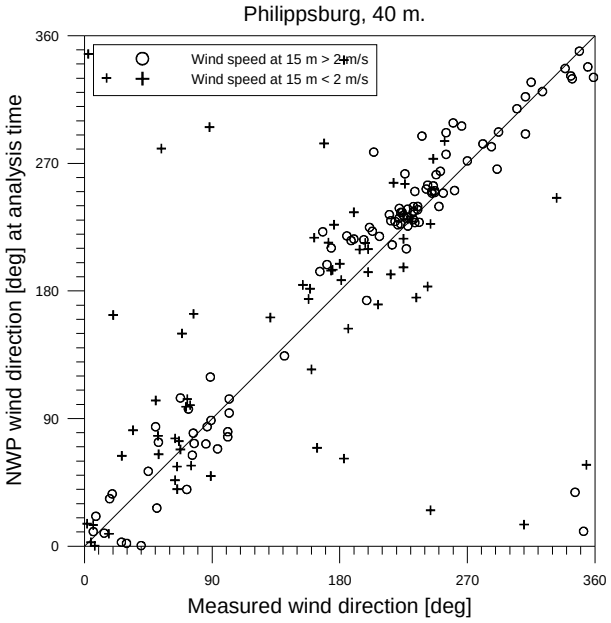


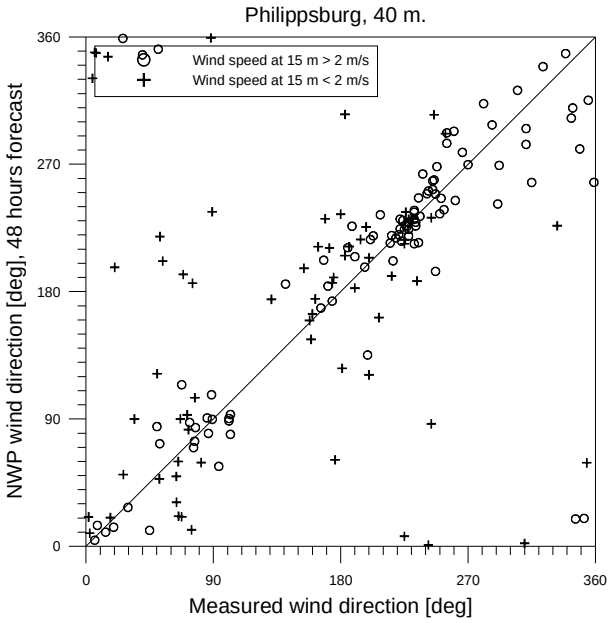

Philippsburg, 120 m.
NWP wind speed [m/s] at analysis time
Measured wind speed [m/s]


Philippsburg, 120 m.
NWP wind speed [m/s], 48 hours forecast
Measured wind speed [m/s]


Philippsburg, 15 m.
Wind speed at 15 m > 2 m/s
Wind speed at 15 m < 2 m/s
NWP wind direction [deg] at analysis time
Measured wind direction [deg]


Philippsburg, 15 m.
Wind speed at 15 m > 2 m/s
Wind speed at 15 m < 2 m/s
NWP wind direction [deg], 48 hours forecast
Measured wind direction [deg]


Philippsburg, 40 m.
Wind speed at 15 m > 2 m/s
Wind speed at 15 m < 2 m/s
NWP wind direction [deg] at analysis time
Measured wind direction [deg]


Philippsburg, 40 m.
Wind speed at 15 m > 2 m/s
Wind speed at 15 m < 2 m/s
NWP wind direction [deg], 48 hours forecast
Measured wind direction [deg]

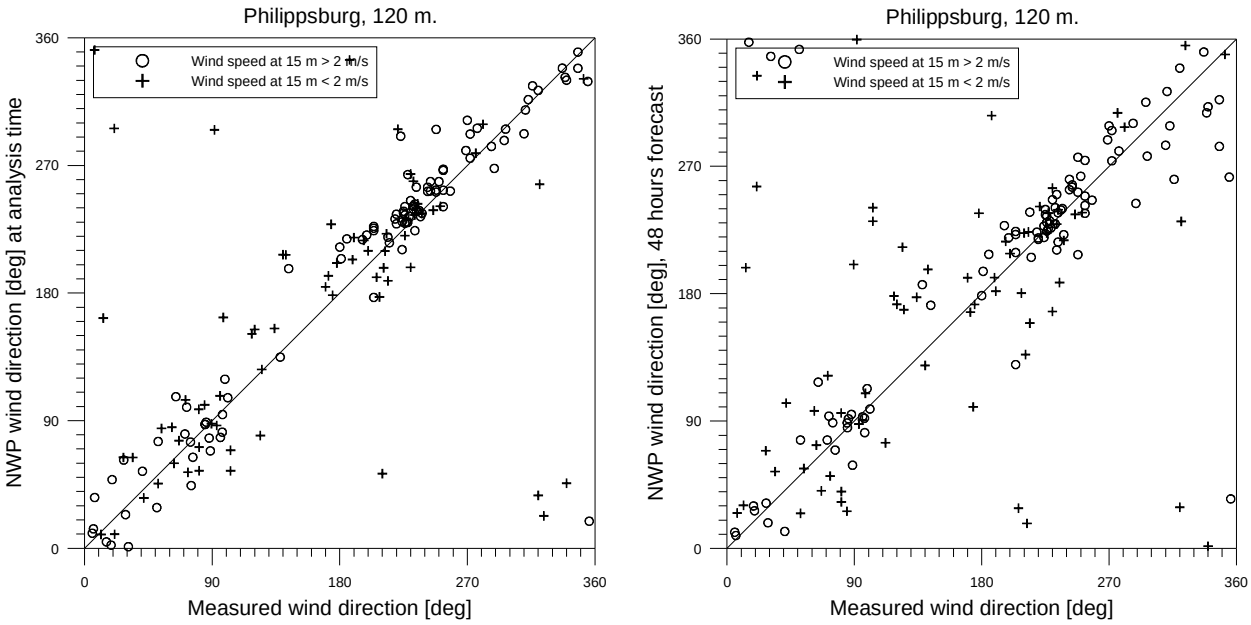


Figure 7. NWP results for Philippsburg compared to measured data.
Left column: analysis time; right column: 48 hour forecast.

Height	speed diff [m/s]			Height	speed diff [m/s]		
[m]	mean	std.dev	count	[m]	mean	std.dev	count
15.0	0.334	1.00	170	15.0	0.854	1.37	166
40.0	0.256	1.32	170	40.0	0.862	1.69	166
120.0	-0.357	1.42	170	120.0	0.210	1.95	166

Height	direction diff [deg]			Height	direction diff [deg]		
[m]	mean	std.dev	count	[m]	mean	std.dev	count
15.0	20.124	45.46	170	15.0	12.269	49.63	166
40.0	7.450	38.76	170	40.0	5.154	46.97	166
120.0	7.076	33.79	170	120.0	1.361	43.97	166

Measured wind speed at 15 m > 2 m/s

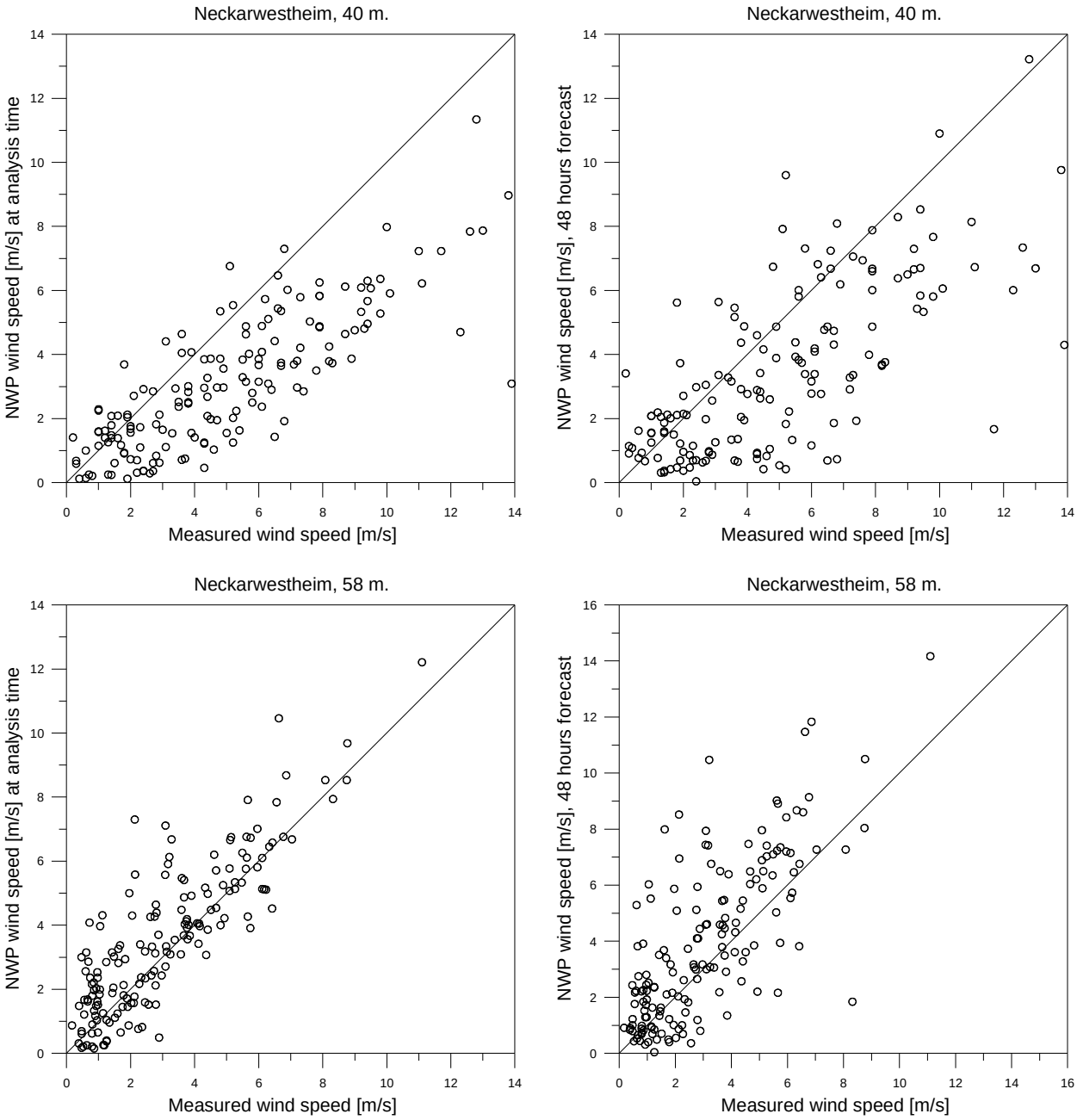
Height	direction diff [deg]			Height	direction diff [deg]		
[m]	mean	std.dev	count	[m]	mean	std.dev	count
15.0	17.702	22.77	101	15.0	7.775	28.17	97
40.0	6.481	20.08	101	40.0	-2.357	26.07	97
120.0	6.794	17.47	101	120.0	-0.343	24.34	97

Table 6. Statistics of differences between NWP results and Philippsburg data.
Left columns: analysis time; right columns: 48 hour forecast.

Neckarwestheim

The Neckarwestheim plant at 49.040° N, 9.174° E is situated at river Neckar approximately 35 km (straight line distance) upstream of the Obrigheim plant. There are only two measurement heights: 40 m and 58 m, the 40 meter instrument being a SODAR, the 58 m a normal mast mounted instrument. Figure 8 shows the scatter plots of the numerical weather predictions versus the measured data, and table 7 lists means and standard deviations of their differences.

The NWP wind speed results are clearly low at 40 m and somewhat high at 58 m. Wind direction scatter is large at both 40 and 58 m and the average direction difference is 20° at 40 m and 5° at 58 m. Screening away 40 m winds below 2 m/s the direction scatter reduces somewhat but the mean direction difference does not.



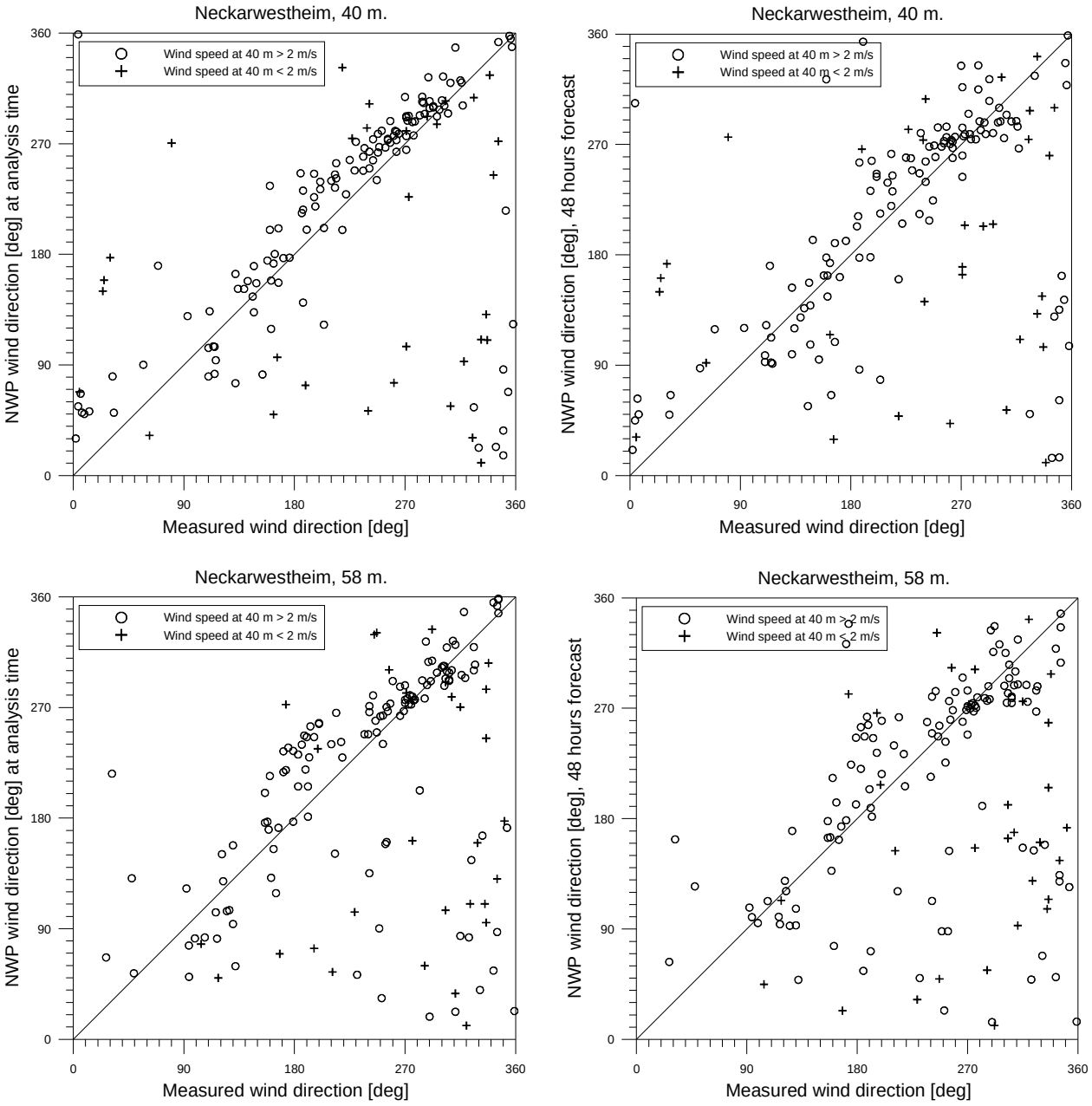


Figure 8. NWP results for Neckarwestheim compared to measured data.
Left column: analysis time; right column: 48 hour forecast.

Height	speed diff [m/s]			Height	speed diff [m/s]		
[m]	mean	std.dev	count	[m]	mean	std.dev	count
40.0	-1.877	1.88	162	40.0	-1.506	2.27	158
58.0	0.519	1.23	167	58.0	0.855	1.91	163

Height	direction diff [deg]			Height	direction diff [deg]		
[m]	mean	std.dev	count	[m]	mean	std.dev	count
40.0	18.943	52.76	162	40.0	11.997	62.72	158
58.0	5.456	65.16	167	58.0	3.945	75.15	163

Measured wind speed at 40 m > 2 m/s

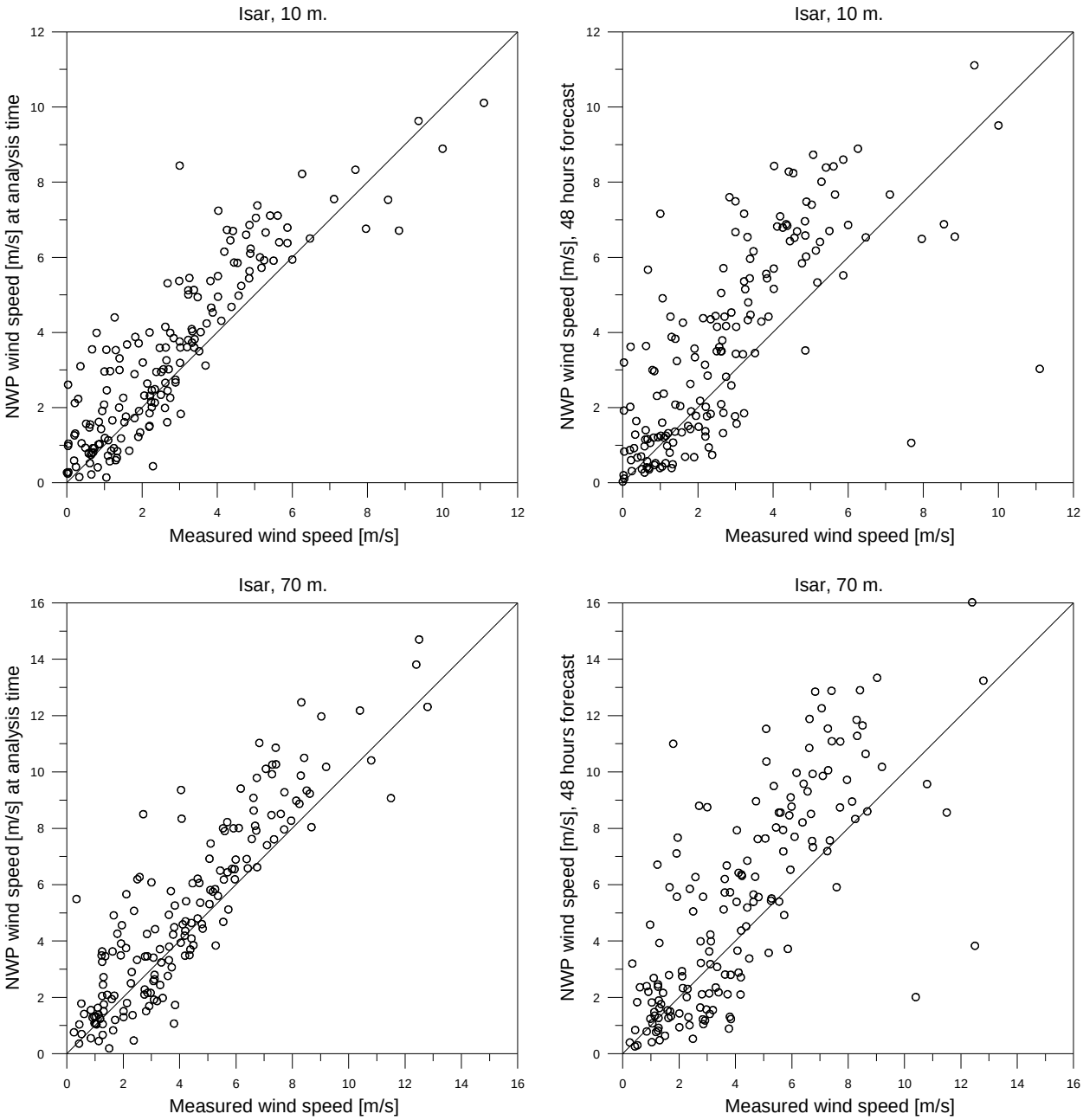
Height	direction diff [deg]			Height	direction diff [deg]		
[m]	mean	std.dev	count	[m]	mean	std.dev	count
40.0	16.302	31.75	130	40.0	12.340	47.69	126
58.0	7.114	55.26	128	58.0	4.065	64.68	124

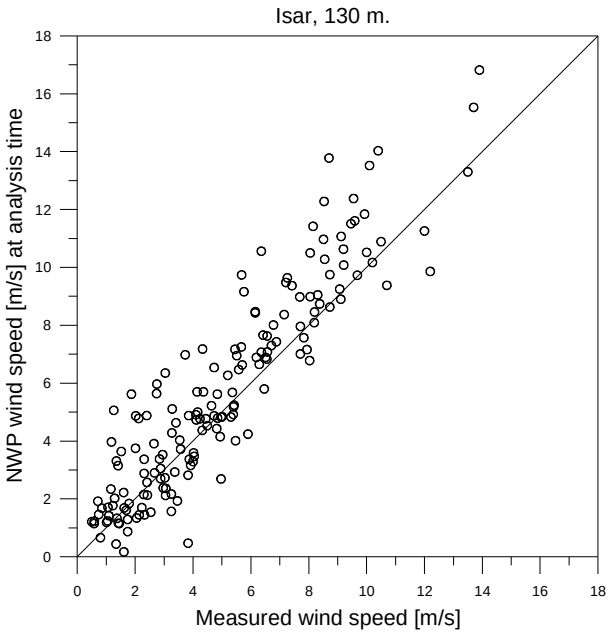
Table 7. Statistics of differences between NWP results and Neckarwestheim data.
Left columns: analysis time; right columns: 48 hour forecast.

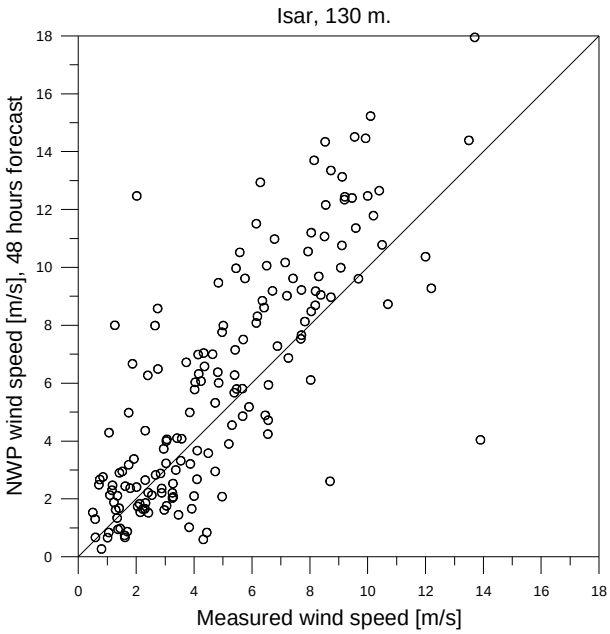
Isar

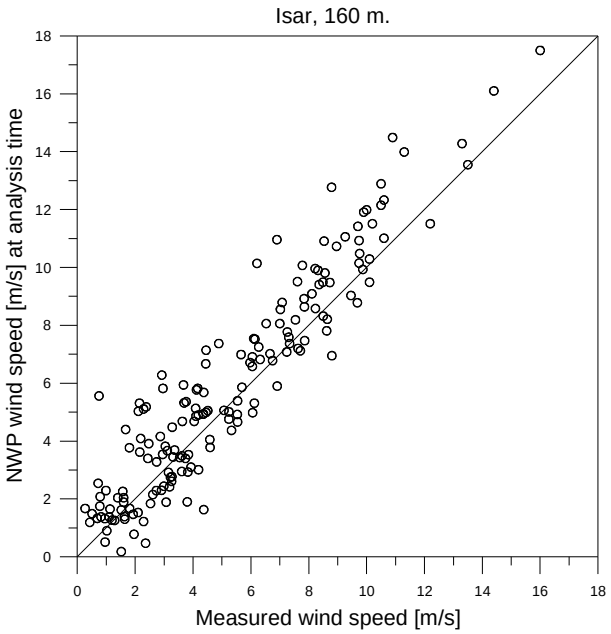
Isar at 48.605° N, 12.295° E is the south-eastern most plant treated, and the wind is here measured at five heights: 10 m, 70 m, 130 m, 160 m, and 220 m. Figure 9 shows the scatter plots of the numerical weather predictions versus the measured data, and table 8 lists means and standard deviations of their differences.

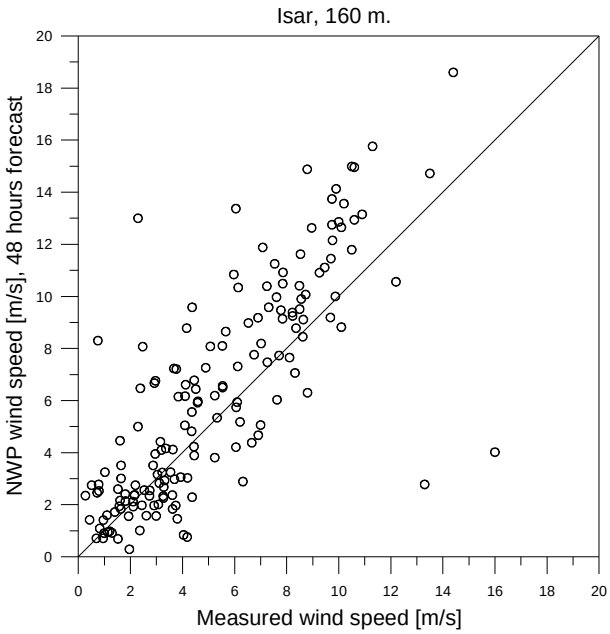
At the lower heights the NWP wind speeds compare rather well at low speeds but generally over predicts at higher speeds. The over prediction however diminishes with height. The mean wind direction difference is around 25 degrees, the standard deviation decreasing with height from 54° to 27°, these last numbers being halved if only looking at data sets where the 10 m wind speed exceeds 2 m/s. For the 48 hour forecast speed and direction scatter is somewhat higher but the average results not much different.

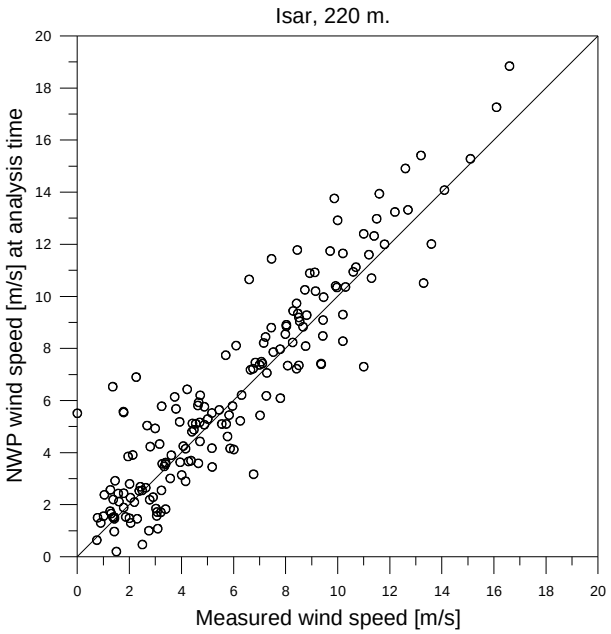


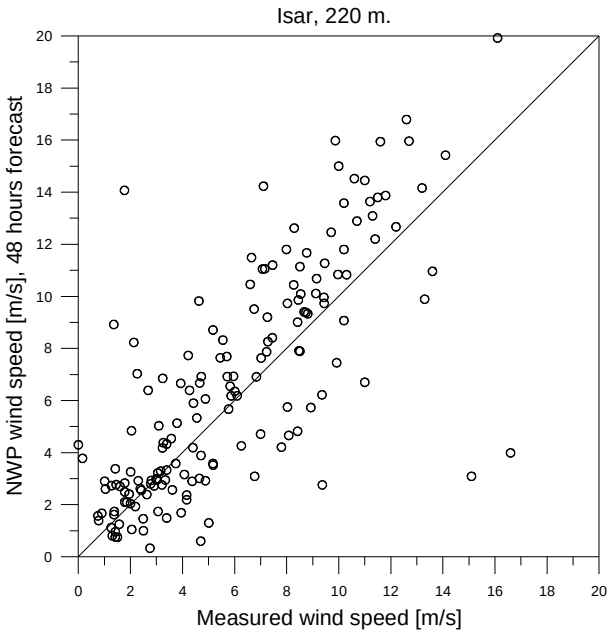

Isar, 130 m.
NWP wind speed [m/s] at analysis time
Measured wind speed [m/s]

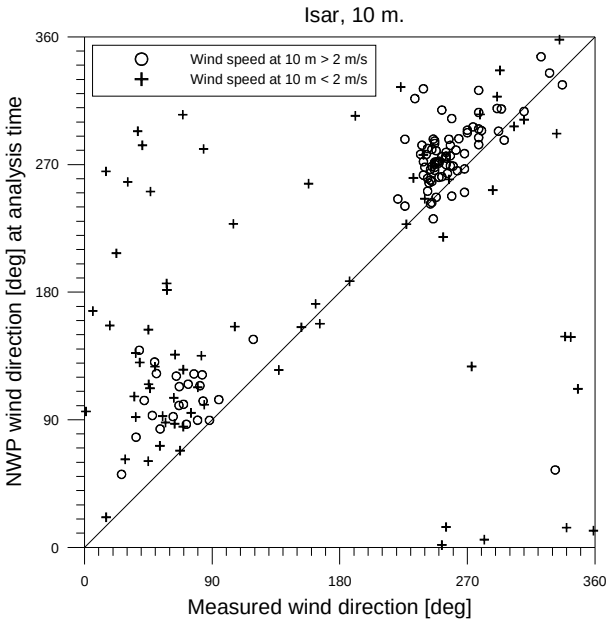

Isar, 130 m.
NWP wind speed [m/s], 48 hours forecast
Measured wind speed [m/s]

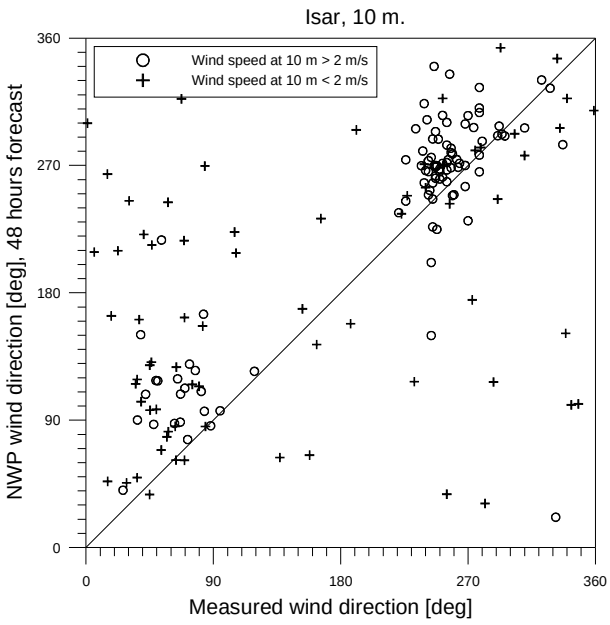

Isar, 160 m.
NWP wind speed [m/s] at analysis time
Measured wind speed [m/s]

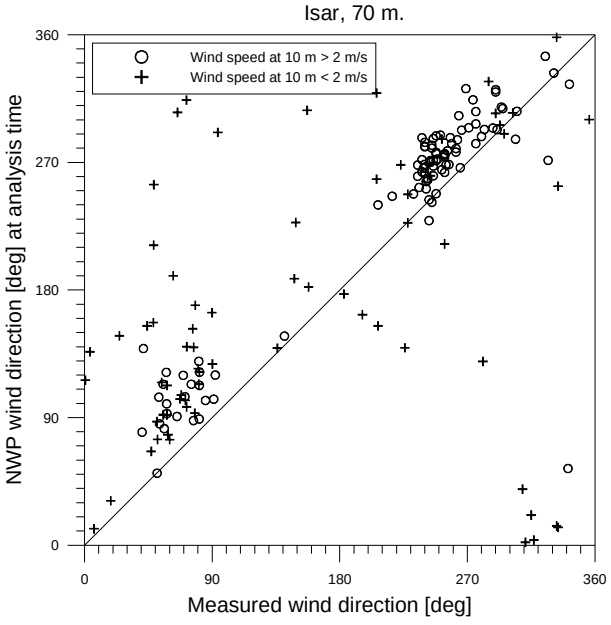

Isar, 160 m.
NWP wind speed [m/s], 48 hours forecast
Measured wind speed [m/s]

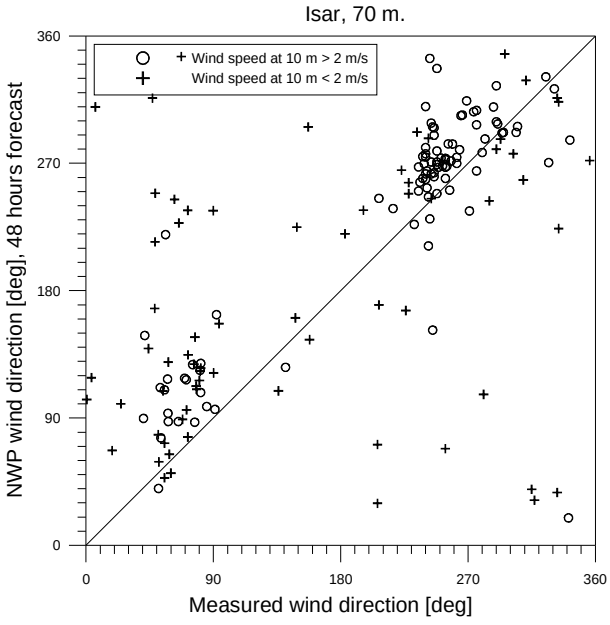

Isar, 220 m.
NWP wind speed [m/s] at analysis time
Measured wind speed [m/s]

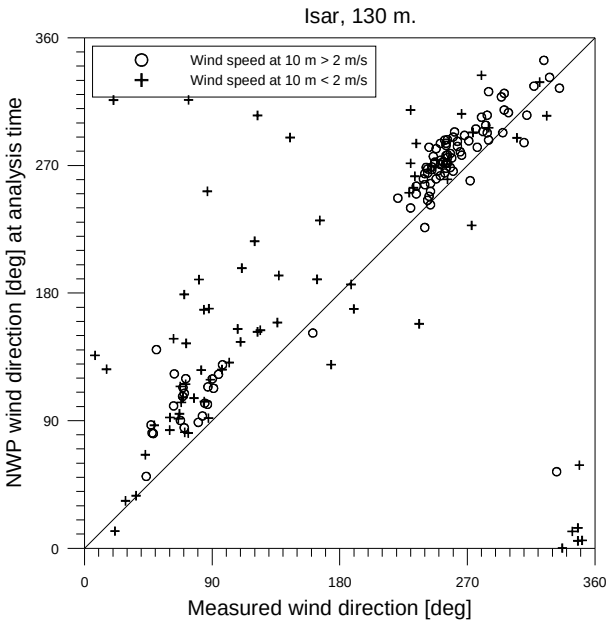

Isar, 220 m.
NWP wind speed [m/s], 48 hours forecast
Measured wind speed [m/s]

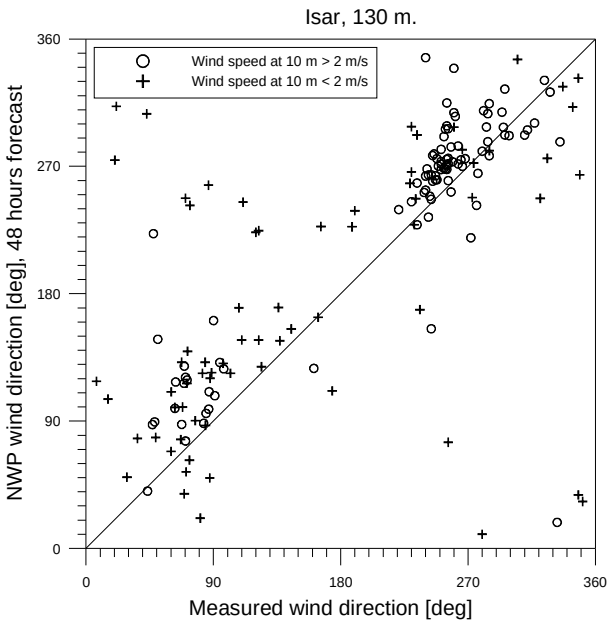

Isar, 10 m.
Wind speed at 10 m > 2 m/s
Wind speed at 10 m < 2 m/s
NWP wind direction [deg] at analysis time
Measured wind direction [deg]

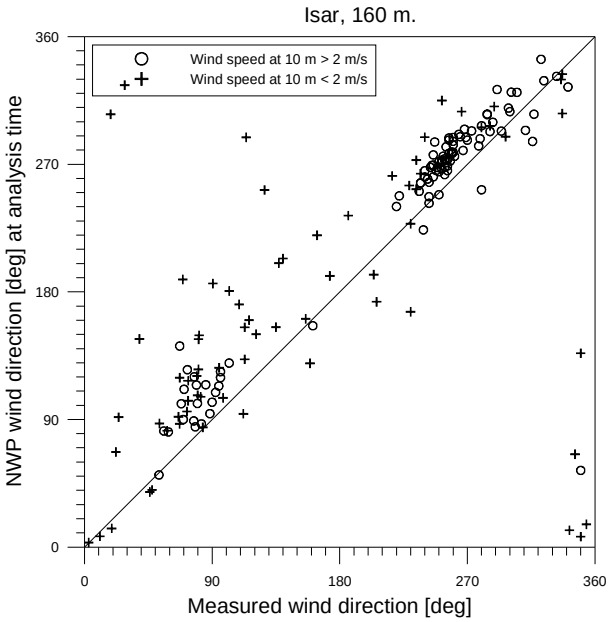

Isar, 10 m.
Wind speed at 10 m > 2 m/s
Wind speed at 10 m < 2 m/s
NWP wind direction [deg], 48 hours forecast
Measured wind direction [deg]

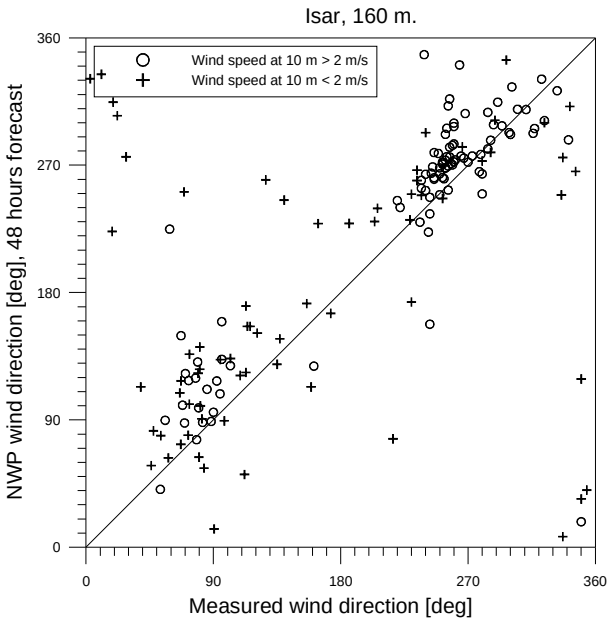

Isar, 70 m.
Wind speed at 10 m > 2 m/s
Wind speed at 10 m < 2 m/s
NWP wind direction [deg] at analysis time
Measured wind direction [deg]


Isar, 70 m.
Wind speed at 10 m > 2 m/s
Wind speed at 10 m < 2 m/s
NWP wind direction [deg], 48 hours forecast
Measured wind direction [deg]


Isar, 130 m.
Wind speed at 10 m > 2 m/s
Wind speed at 10 m < 2 m/s
NWP wind direction [deg] at analysis time
Measured wind direction [deg]
0
90
180
270
360


Isar, 130 m.
Wind speed at 10 m > 2 m/s
Wind speed at 10 m < 2 m/s
NWP wind direction [deg], 48 hours forecast
Measured wind direction [deg]
0
90
180
270
360


Isar, 160 m.
Wind speed at 10 m > 2 m/s
Wind speed at 10 m < 2 m/s
NWP wind direction [deg] at analysis time
Measured wind direction [deg]
0
90
180
270
360


Isar, 160 m.
Wind speed at 10 m > 2 m/s
Wind speed at 10 m < 2 m/s
NWP wind direction [deg], 48 hours forecast
Measured wind direction [deg]
0
90
180
270
360

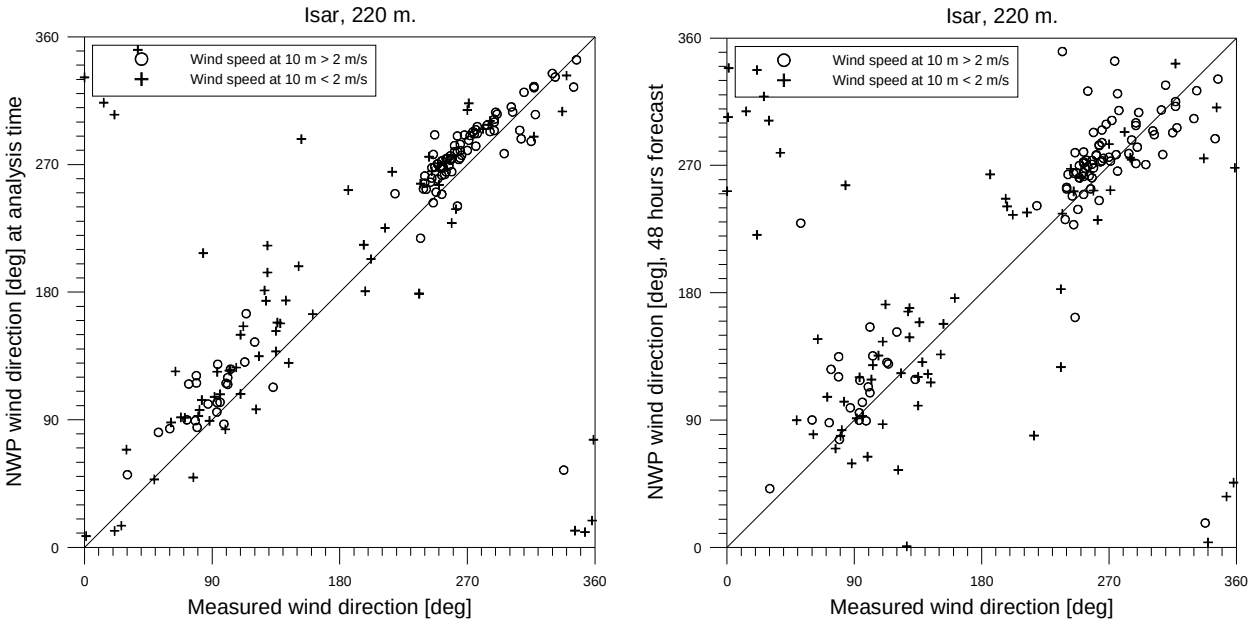


Figure 9. NWP results for Isar compared to measured data.
Left column: analysis time; right column: 48 hour forecast.

Height	speed diff [m/s]			Height	speed diff [m/s]		
[m]	mean	std.dev	count	[m]	mean	std.dev	count
10.0	0.684	1.08	170	10.0	0.930	1.77	166
70.0	0.809	1.48	170	70.0	1.121	2.43	166
130.0	0.701	1.42	170	130.0	1.012	2.44	166
160.0	0.658	1.27	170	160.0	0.955	2.55	166
220.0	0.388	1.50	170	220.0	0.707	2.85	166

Height	direction diff [deg]			Height	direction diff [deg]		
[m]	mean	std.dev	count	[m]	mean	std.dev	count
10.0	26.224	53.94	170	10.0	17.794	63.31	166
70.0	24.959	45.54	170	70.0	21.116	57.23	166
130.0	24.245	36.65	170	130.0	22.354	46.41	166
160.0	22.820	31.36	170	160.0	11.407	44.72	166
220.0	13.804	26.78	170	220.0	4.000	43.82	166

Measured wind speed at 10 m > 2 m/s

Height	direction diff [deg]			Height	direction diff [deg]		
[m]	mean	std.dev	count	[m]	mean	std.dev	count
10.0	25.583	21.79	100	10.0	23.236	33.56	96
70.0	23.922	19.45	100	70.0	22.853	32.75	96
130.0	20.310	16.35	100	130.0	19.631	31.96	96
160.0	17.429	15.34	100	160.0	16.743	30.43	96
220.0	13.283	15.44	100	220.0	12.748	30.20	96

Table 8. Statistics of differences between DWD results and Isar data.
Left columns: analysis time; right columns: 48 hour forecast.

Brokdorf-Krümmel, Obrigheim-Philippsburg
The NWP wind speeds at Brokdorf are very much the same as those at Krümmel, and those at Obrigheim very much the same as those at Philippsburg, see figure 10. This leaves the different discrepancies between measured and predicted values at the sites two and two to be caused by local circumstances not resolved by the NWP.

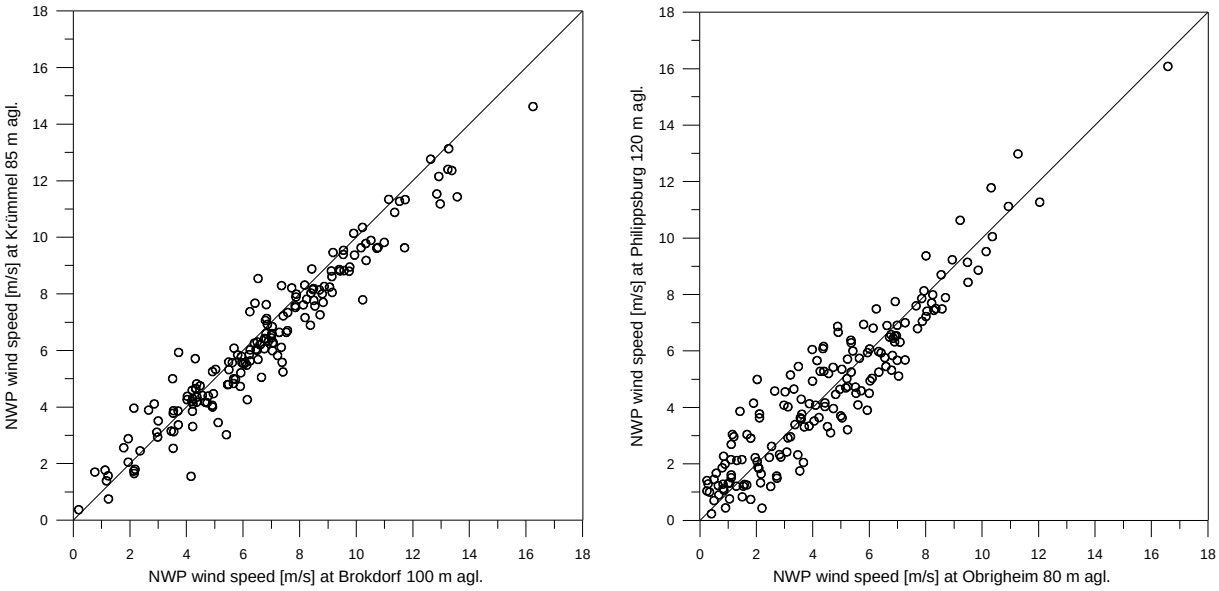


Figure 10. Brokdorf to Krümmel and Obrigheim to Philippsburg NWP wind speed comparison.

Conclusion

Three month of wind speed and direction from twice daily numerical weather predictions have for analysis time and 48 hours forecast been compared to measurements at seven German nuclear power plant sites. For the sites close to the North Sea and for the inland site Philippsburg the predictions of wind speed are on average rather close to the measured, but for sites not far from these, Krümmel respectively Obrigheim, the discrepancies are much larger. Concerning the wind directions the predicted values are on average almost everywhere larger than the measured, typically 15° to 20°, Obrigheim being the only place with smaller predicted values than measured. The direction scatter is pretty large at most sites, but looking only at data sets for which the wind speed exceeds some limit, the scatter reduces somewhat while the average discrepancies don't really change. The relative large wind speed discrepancies at Krümmel and Obrigheim seem to be due to local circumstances not resolved by the NWP.

The 125 m mast at the Danish Risø site is placed on relative flat terrain just east of a reasonable large body of water and so equals in terrain complexity the German sites near the North Sea coast, and the NWP results for Risø show equally good or perhaps slightly better correspondence with the measured data than what is seen at the mentioned German sites.

References

van Ulden A.P. and Holtslag A.A.M:
Estimation of Atmospheric Boundary Layer Parameters for Diffusion Applications.
Journal of Climate and Applied Meteorology, vol. 24, pp. 1196-1207, 1985.

Figure 11. Google Earth map with the comparison sites pointed out.

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