

CHALLENGES AND EXPERIENCES WITH WIND MEASUREMENTS AT AERODROMES

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ABSTRACT

Wind measurements are crucial for the operations at an aerodrome and as a result the measurements must meet strict aeronautical requirements. For landing operations the wind must be representative for the conditions at touchdown and for take-off for the conditions along the runway. Hence wind measurements are performed relatively close to the runway and sometimes even with obstructions in the vicinity. Although these wind measurements meet the aeronautical requirements, as they measure the local conditions, there is still a need to address specific issues. This includes not only issues that are relevant for users in the aviation community since the wind measurements are generally also used for synoptic and climate purposes.

In this paper 2 issues will be addressed: (1) aircraft induced wake vortices affecting the wind measurements along the runway, and (2) wind measurements on the vent stack of production platforms in the North Sea. In the first situation KNMI performs specific processing of the wind data to detect and reduce the wake vortices. In the latter situation a pair of wind sensors is installed at opposite sides of the vent stack and an algorithm selects the sensor to be used, based on the existent conditions. For both issues the KNMI approach will be presented, operational experiences will be shown and pending issues will be discussed. For example it will be shown that the wind measurements along the two main runways at Schiphol are affected by wake vortices, but the current vortex detection algorithm is sometimes also triggered by natural turbulence. The wind sensor selection applied at gives realistic results when events are studied, but specific wind directions are hardly ever reported by the selected sensor.

A. ANALYSIS OF “DETECTIONS” OF AIRCRAFT INDUCED WAKE VORTICES

A.1. INTRODUCTION

Wind measurements have to be performed along runways at airports where they can be affected by aircraft induced vortices. Generally wind measurements close to and downwind of the runway are most exposed to wake vortices. The strongest wake vortices are generally produced by heavy aircraft, but other factors such as the aircrafts speed, wingspan and angle of attack as well as ambient conditions also affect the occurrence and strength of the vortices (CAA, 2008; NATS, 2009). Wake vortices are made up of two counter-rotating cylindrical air masses trailing the aircraft. The air speed in the outer core of the vortex can be as large as 30 m/s and decreases with distance and over time. The wake vortices move slowly downwards and spread sideways with a speed of about 2 m/s. In stable atmospheric conditions the vortices can persist for several minutes and drift with the wind. Hence the upwind vortex can even remain on the runway in situations with of a cross wind of about 2 m/s.

Although the wind measurement in the presence of wake vortices is in principle correct, as the sensor reports the conditions it experiences, the users (ATC) require the wind without the disturbance of wake vortices. Naturally wake vortices need to be considered in aircraft operations (aircraft separation, pilot awareness and aircraft handling). The reported surface wind at airports should be representative of the conditions at touchdown or along the runway (ICAO, 2010). However, ICAO (2011) concerning the location of meteorological instruments at aerodromes

mentions that buildings or constructions may prevent adequate instrument exposure and the effects of aircraft movement and exhausts (particularly during taxiing and turning operations) may be considerable. Hence reporting the wind without the disturbance of wake vortices as requested by the user seems valid. Especially since otherwise wind gusts induced by wake vortices will be reported for 10 minutes, which is longer than the typical duration of wake vortices. Furthermore it should be noted that even when wind measurements along the runway are not affected by wake vortices that does not mean that wake vortices are not present on the runway, and vice versa, when the measurements are affected by vortices that does not necessarily mean that vortices are on the runway.

Van der Meulen (1998) developed an algorithm that detects and reduces the wind speed measurements that are affected by aircraft induced wake vortices. The wake vortex algorithm is based on the fact that the normalized extreme wind, $u_n = (v_{\max} - \bar{v}) / \sigma_v$, is typically within the range -1.5 to $+2.5$ in undisturbed situations. Here v_{\max} denotes the wind gust, \bar{v} the time-averaged wind speed, and σ_v the corresponding standard deviation. The wake vortex algorithm assumes that an instantaneous wind speed measurement v is affected when $v > \bar{v} + 4 \cdot \sigma_v + 0.5$ m/s, in which case the measurements are limited to the maximum natural value $v = \bar{v} + 2 \cdot \sigma_v + 0.5$ m/s. The anti-vortex algorithm is only applied when $\bar{v} > 0.5$ m/s and $\sigma_v > 0.5$ m/s and when $v < 15$ m/s. The first two criteria are required since the normalized extreme wind is undefined at low wind speeds. The latter is used to avoid any risk at high wind speeds, although it is unclear whether 15 m/s is a suitable limit. The wake vortex algorithm is implemented in the measurement network of KNMI and applied to the data of selected wind sensors installed along the runways of civil airports. These are mainly locations at Amsterdam Airport Schiphol that are most susceptible to wake vortices. It should be noted that application of the wake vortex algorithm should only be considered when no suitable location is available where an undisturbed and representative wind for the conditions at touchdown or along the runway can be measured.

The study of van der Meulen (1998) was based on the results of the wind measurements at one location at Schiphol. Hence the validity of the wake vortex algorithm and the thresholds used have not verified extensively. Sometimes wake vortex detections have been observed at synoptical stations where the wake vortex algorithm was activated by mistake. Furthermore, wake vortex events have sometimes been investigated on request of ATC the Netherlands (LVNL) when there was doubt whether spikes in the reported wind gust should have been reduced by the wake vortex algorithm. The KNMI practice regarding the usage of wake vortex detection and reduction for wind speed measurements at civil airports is not properly documented. Furthermore there is no insight in the number of vortex events that are reported at various locations and their relation with aircraft operations. Lastly, field tests with collocated cup anemometers and ultrasonic wind sensors allowed the verification of any possible sensor artefacts in the wake vortex algorithm. Some countries reported a higher sensitivity of ultrasonic wind sensors to aircraft turbulence than their conventional cup anemometers. Hence a study was performed into the occurrence of wake vortex detections using the wind measurement data that was readily available. Results of this study have also been published in a technical report (Wauben, 2014).

A.2. WAKE VORTEX ALGORITHM

The wake vortex algorithm is applied in the SIAM sensor interface of KNMI which is used to connect any sensor to the measurement network. The operational cup anemometer of KNMI is used in combination with the DW0 sensor interface (Bijma, 2009). This wind SIAM samples the wind sensor at 4 Hz and calculates 4 Hz 3-second running averages in order to be able to determine the wind gust according to specifications (WMO, 2008). Time averaging is performed over 10-minutes (2400 samples), but in case of a so-called marked discontinuity the averaging interval is reduced to 2-minutes following ICAO requirements (ICAO, 2010). The extremes and standard deviation use the same averaging interval. The SIAM updates the output every 12 seconds and provides:

- WSs, the highest 3-second averaged wind speed in the last 12-seconds;
- WSm, the 1-minute averaged wind speed;

- WS_x, the 10-minute wind gust, i.e. the highest 3-second averaged wind speed in the last 10-minutes or shorter in case of a marked discontinuity;
- WS_n, the 10-minute wind lull, i.e. the lowest 3-second averaged wind speed in the last 10-minutes or shorter in case of a marked discontinuity;
- WS_a, the 10-minute averaged wind speed, i.e. the averaged wind speed in the last 10-minutes or shorter in case of a marked discontinuity;
- WS_d, the 10-minute standard deviation, i.e. the standard deviation of the wind speed in the last 10-minutes or shorter in case of a marked discontinuity;
- MIS, the percentage of invalid or missing data in the last 10-minutes or shorter in case of a marked discontinuity;
- status information from sensor or sensor interface.

At locations where the wake vortex algorithm is activated the SIAM first checks if any of the 48 4 Hz 3-second averaged samples in the last 12-second interval meets all vortex criteria:

- $\text{sample} > \text{WS}_a + 4 * \text{WS}_d + 0.5 \text{ m/s}$;
- $\text{WS}_a > 0.5 \text{ m/s}$;
- $\text{WS}_d > 0.5 \text{ m/s}$;
- $\text{sample} < 15 \text{ m/s}$;
- $\text{MIS} \leq 10 \%$;

where WS_a, WS_d and MIS are taken from the previous processing step reported 12 second earlier by the SIAM. If one of the 48 samples meets the criteria all 48 samples are limited to $\text{WS}_a + 2 * \text{WS}_d + 0.5 \text{ m/s}$ (WS_a and WS_d again from previous 12 second interval). The new 1-minute and 10-minute output variables are calculated after this reduction has been applied to the samples of the past 12-seconds. The highest 3-second averaged sample in the last 12-seconds is reported as WS_s, hence in case of a wake vortex detection it will equal $\text{WS}_a + 2 * \text{WS}_d + 0.5 \text{ m/s}$ of the previous 12-second interval. The status “y” is reported when the vortex criteria are met. Note that older DW0 SIAM versions (1.5 and lower) indicated a wake vortex by status “c”. The previous XW0 SIAM did also detect and reduce wake vortices using the same wake vortex algorithm, but it did not indicate whether vortex reduction was applied.

The DW0 SIAM reports the highest 3-second averaged sample in the last 12-seconds as WS_s. Hence the occurrence of wake vortex detections can be determined off-line from the reported wind SIAM data when wake vortex filtering is not activated. For that purpose it is checked whether $\text{WS}_s > \text{WS}_a + 4 * \text{WS}_d + 0.5 \text{ m/s}$ and $\text{WS}_s < 15 \text{ m/s}$ as well as $\text{WS}_a > 0.5 \text{ m/s}$, $\text{WS}_d > 0.5 \text{ m/s}$ and $\text{MIS} \leq 10 \%$, where WS_a, WS_d and MIS are taken from the previous processing step. Note that the samples are not limited for these off-line derived vortex events. The threshold for subsequent detections will therefore be higher than when filtering is active, so that the number of derived wake vortex events will be less than when filtering would have been active. Also note that this determination is not conclusive for the XW0 SIAM as it reports the last 3-second averaged sample value of the 12-second interval as WS_s instead of the highest 3-second averaged wind speed in the last 12-seconds which is reported by the DW0 SIAM.

When wake vortex detection was determined off-line wake vortex events were also found at wind measurements locations where the wake vortex algorithm was active. The additional wake vortex also included cases where all vortex criteria were amply met and therefore could not be caused by the resolution. It turned out that the DW0 SIAM sensor interface used an additional wake vortex criterion namely that the cycle counter should exceed 1. This criterion was used to disable filtering during start-up when the number of samples was too small to determine the standard deviation. However, the validity of the standard deviation is now handled by the $\text{MIS} \leq 10 \%$ criterion and the cycle counter is now used in the calculation of the hours of operation of the sensor interface and is therefore reset every hour. Hence, in 2 out of every 300 cycles (0.7 %) vortex detection is incorrectly disabled in the sensor interface. At all locations the fraction of additionally detected vortices is larger. For example for both wind measurement locations at Beek nearly 6 % additional detection are reported, but only about 1 % exceed the thresholds by more than the SIAM output resolution of 0.01 m/s. Furthermore, not all significant additional vortex events are separated by the expected hourly intervals. The obsolete wake vortex criterion using

the cycle counter in the sensor interface has corrected in DW0 SIAM version 2.0, which was introduced after completion of this evaluation.

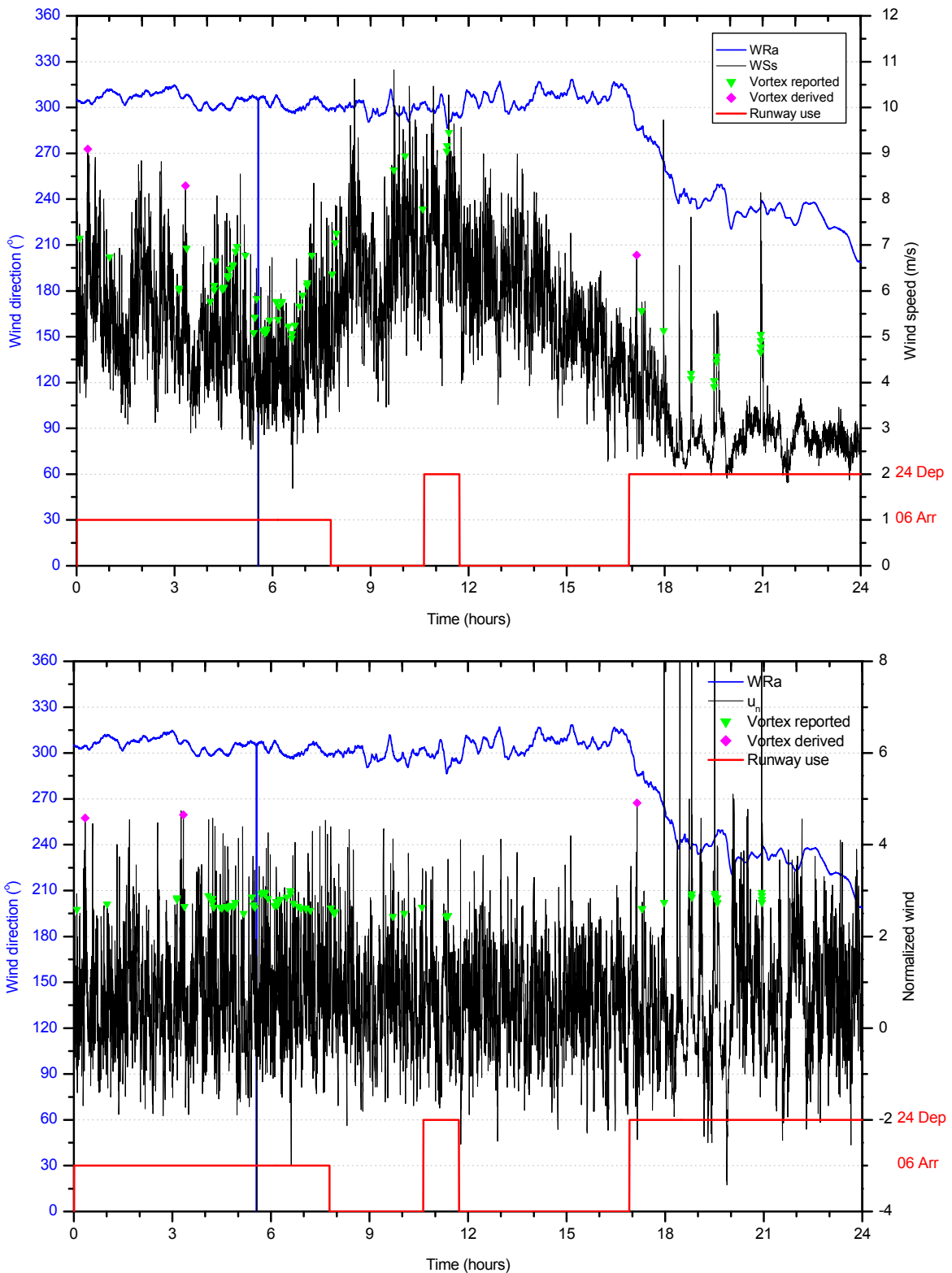


Figure 1: Illustration of the observed wind direction (WRa) and the wind speed (WSs, top panel) and the normalized wind (u_n , bottom panel) at Schiphol 06 touchdown on March 8, 2012 with indication of the reported and derived wake vortices and runway usage.

Figure 1 serves as an illustration of the observed wind, the normalized wind and the wake vortex detection. Figure 1 shows the wind speed (WSs, the highest 3-second averaged wind speed in each 12-second interval) and direction (WRa, 10-minute average updated every 12 seconds) observed on March 8, 2012 near 06 touchdown at Amsterdam Schiphol Airport. The wake vortices reported by and derived from the data of the sensor interface are also indicated in the figure as is the usage of the runway. The lower panel shows the normalized wind $(WSs-WSa)/WSd$. The normalized wind speed during reported wake vortex events is reduced to about 2.5 and the derived wake vortex events have a normalized wind of about 4.5. Figure 1 shows that the wake vortex events generally occur when the wind sensor near 06 touchdown is exposed to arriving and departing aircraft. The north-westerly wind places the measurement location downwind of the touchdown / take-off area. The 2 events around 10 UT occur when the runway is not in use. Some extremes in the normalized wind after 18 UT do not trigger a wake vortex because the standard deviation of the 10-minute averaged wind speed does not meet the 0.5 m/s threshold.

At some locations the output of the sensor interface is not only fed into the measurement network (MetNet) systems but it is also put on the network and made available at the central facilities of KNMI in De Bilt for test purposes. This SIAM data is archived non-operationally, meaning that the data-acquisition is not continuously monitored. As a result the archived data contains some gaps. The archived SIAM data has been used for this analysis since it is readily available. The stations for which data is available include the civil airports Amsterdam Airport Schiphol (EHAM, since April 11, 2009), Rotterdam - The Hague Airport (EHRD, since January 29, 2010), Maastricht - Aachen Airport (EHBK, since July 15, 2009) and Groningen - Eelde Airport (EHGG, since July 14, 2009) and the automatic weather stations De Bilt (operational, since March 21, 2008), De Bilt Test (since January 8, 2008) and Cabauw (including measurements on the 213 m meteorological mast, since November 19, 2009). The periods considered vary per station since the archiving of SIAM data started at different moments.

KNMI performed field tests with 3 different types of ultrasonic wind sensors. At De Bilt and near 18R touchdown at Schiphol a Thies 2D was installed next to the KNMI cup anemometer and wind vane and at Cabauw a Thies 2D, Thies 3D and Gill Windmaster Pro was evaluated between 2009 and 2011. The Thies 2D, Thies 3D and Gill Windmaster Pro was used in combination with the DW1, DW2 and DW3 SIAM sensor interface, respectively. The sensor interface requested 1-second averaged wind data at 4 Hz from the Thies 2D and instantaneous wind data at 10 Hz from the 3D sonics. The latter was required since the sensor data of the 3D sonics was also used off-line to derived turbulence parameters. The sensor interface for all ultrasonic wind sensors calculates 4 Hz 3-second running averages of the horizontal wind, which is then processed identically as in the DW0 SIAM.

A.3. ANALYSIS OF REPORTED AND DERIVED WAKE VORTICES

The total number of wake vortices reported by all wind sensors contained in the archived data from the commencement of the archiving up to October 31, 2012 is given in Table 1. For that purpose all wind SIAM strings with status "y" or "c" was counted. In addition the number of derived wake vortex detections and the number of wake vortex detections without the 15 m/s limit and the total number (reported, derived and ≥ 15 m/s) are given. The first two columns give a description of the wind measurement location, and the abbreviation of the location used in this report. The last two columns give the averaged daily number of total wake vortex events, and the number of days for which wind data was available for this study.

Table 1: Wind measurement locations used in the analysis and the number of reported and derived wake vortices and the daily average.

<i>Location description</i>	<i>Code</i>	<i>Reported</i>	<i>Derived</i>	<i>≥15m/s</i>	<i>Total</i>	<i><Total></i>	<i>Days</i>
EHAM runway 18C touchdown	AM18C	9603	454	339	10396	8.04	1293
EHAM runway 06 touchdown	AM06	27707	891	583	29181	22.57	1293
EHAM runway 36C touchdown	AM36C	7558	389	393	8340	6.45	1293
EHAM runway 18R touchdown	AM18R	20331	956	436	21723	16.80	1293
EHAM runway 18R touchdown Thies 2D	AM18R-T2D	11851	166	224	12241	15.92	769
EHAM runway 36R touchdown	AM36R	515	453	388	1356	1.05*	1293
EHAM runway 27 touchdown, AWS	AM27	0	4754	419	5173	4.00	1293
EHAM runway 22 touchdown	AM22	0	4913	419	5332	4.12	1293
EHAM runway 36L touchdown	AM36L	1	8928	481	9410	7.28	1292
EHAM fog station Assendelft	AMAD	0	5735	462	6199	4.79	1293
EHAM fog station Muiden	AMMU	1	3598	288	3887	3.01	1293
EHAM fog station Nieuwkoop	AMNK	2	4528	283	4813	3.72	1293
EHAM fog station Nieuw Vennepe	AMNV	0	5318	342	5660	4.38	1292
EHBK runway 22 touchdown	BK22	5673	347	245	6265	5.27	1188
EHBK runway 04 touchdown	BK04	6505	410	165	7080	5.96	1188
EHGG runway 23 touchdown	GG23	0	4995	338	5333	4.42	1206
EHGG runway 05 touchdown	GG05	0	5280	260	5540	4.59	1206
EHRD runway 24 touchdown	RD24	0	4690	349	5039	5.03	1001
EHRD runway 06 touchdown	RD06	0	5146	346	5492	5.49	1001
De Bilt 20 m, AWS	DB20	0	6877	264	7141	4.56	1565
De Bilt 1.5 m	DB2	0	14364	13	14377	9.77	1472
De Bilt 20 m Thies 2D	DB20-T2D	0	3694	147	3841	3.48	1105
De Bilt 1.5 m Thies 2D	DB2-T2D	0	6604	4	6608	7.37	897
De Bilt Test 10 m	DBT10	4836	9977	107	14920	9.48	1574
De Bilt Test 1.5 m	DBT2	0	787	0	787	15.43	51
Cabauw 10 m, AWS	CBAWS	0	3275	246	3521	3.27	1078
Cabauw 10 m, mast	CB10M	0	3216	216	3432	3.19	1076
Cabauw 10 m, B mast	CB10B	0	3571	264	3835	3.56	1078
Cabauw 20 m, B mast	CB20B	0	2804	345	3149	2.92	1078
Cabauw 20 m, C mast	CB20C	0	2830	321	3151	2.92	1078
Cabauw mast 40 m north	CB40N	0	2698	430	3128	2.90	1078
Cabauw mast 40 m west-southwest	CB40W	0	2276	366	2642	2.45	1078
Cabauw mast 80 m north	CB80N	0	2151	541	2692	2.50	1078
Cabauw mast 80 m west-southwest	CB80W	0	1935	491	2426	2.25	1078
Cabauw mast 140 m north	CB140N	0	1754	582	2336	2.17	1078
Cabauw mast 140 m west-southwest	CB140W	0	1468	565	2033	1.89	1078
Cabauw mast 200 m north	CB200N	0	2096	679	2775	2.57	1078
Cabauw mast 200 m west-southwest	CB200W	0	1291	662	1953	1.81	1078
Sonic 10 m cup/vane	CB-CV	0	1181	77	1258	3.28	383
Sonic 10 m Thies 2D	CB-T2D	0	1028	66	1094	2.86	383
Sonic 10 m Thies 3D	CB-T3D	0	1008	25	1033	2.70	383
Sonic 10 m Gill 3D	CB-G3D	0	870	2087	2959	7.73	383

* Low number due to use of XW0 SIAM with wake vortex filtering but without corresponding status. The usage of DW0 in the last 55 days gives an averaged daily value of 10.13.

A.3.1. De Bilt Test

Of the two wind measurement locations in De Bilt Test only the 10 m wind measurements are available over the entire evaluation period, except for an extensive period between February 2, and July 15, 2008 when the MUF data was not available. The wind measurements at 1.5 m were terminated in October 2008 when they moved to the operational station in De Bilt. The wake vortex filtering was by mistake enabled between January 8, 2008 and October 21, 2009 for the wind measurements at 10 m in De Bilt Test. During that period vortex detection were reported regularly (cf. Figure 2). The occurrence of wake vortex detections at De Bilt Test shows that wake vortex detections can also be triggered by natural phenomena causing turbulence. The wake vortex filtering was only active for the first part of the evaluation period. Hence the change from reported to derived wake vortices can be analysed. Figure 2 shows a rather smooth transition from reported to derived wake vortex events. The averaged number of reported wake vortices is 10.30 per day during which about 0.63 derived vortices occur. After October 22, 2009 on average about 8.86 derived vortices occur per day. The number of derived vortices is slightly less than the number of reported vortices. This can probably be explained by the fact that when vortex filtering is active the wind samples are limited in case of vortex detections. Therefore the averaged wind and the corresponding standard deviation are reduced so that the criteria for subsequent wake vortex detection are slackened. Hence, more wake vortex detections are to be expected when wake vortex filtering is active.

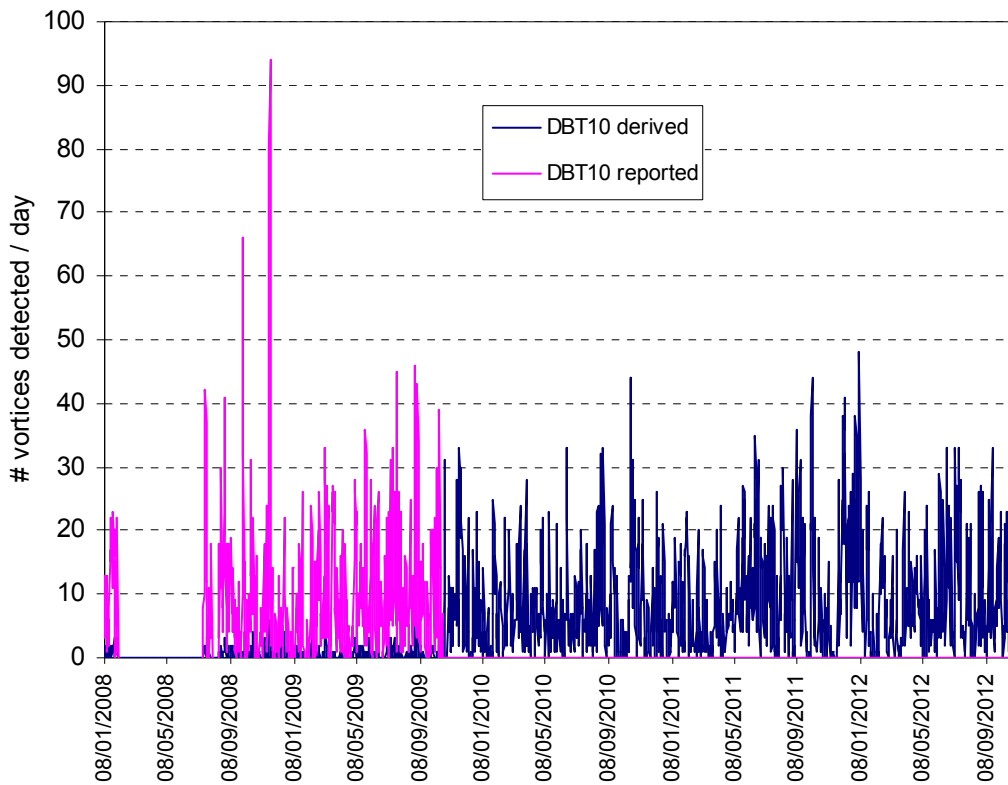


Figure 2: The daily number of reported and derived wake vortices (inclusive ≥ 15 m/s) during the evaluation period for De Bilt Test at 10 m.

A.3.2. De Bilt

The derived wake vortex detections for De Bilt show enhanced values for the measurements at 2 m (on average 9.77 per day) compared to the measurements at 20 m (4.56 per day) while the contribution of events with speeds ≥ 15 m/s is smaller. This could be expected since turbulence is generally higher closer to the surface whereas the wind speed is smaller. The same behaviour can be observed for the 2D sonics at De Bilt and for the wind measurements at De Bilt Test. The Thies 2D sonics in De Bilt give significantly less vortex detections than the collocated KNMI cup anemometers. The reason for this is unclear. Probably this is the result of the fact that the cup anemometer is more susceptible to turbulence because its response is nearly independent to the vertical angle of attack of the wind whereas the sonic only measures the horizontal wind component. The dependency of the derived vortices on wind direction is similar for cup anemometer and sonic and there is no evidence for any disturbance when the sonic is in the wake of the cup anemometer (cf. Figure 3). The distribution of the events with wind direction follows the prevailing southwest wind directions. At De Bilt Test the peak in southwest directions consists of two peaks near south and west directions. This is caused by the turbulence generated by a tree line in that sector. The turbulence induced by the obstructions in the prevailing wind direction are also the reason why the wind measurements in De Bilt Test report nearly twice as many vortices per day as other locations that are also not affected by aviation.

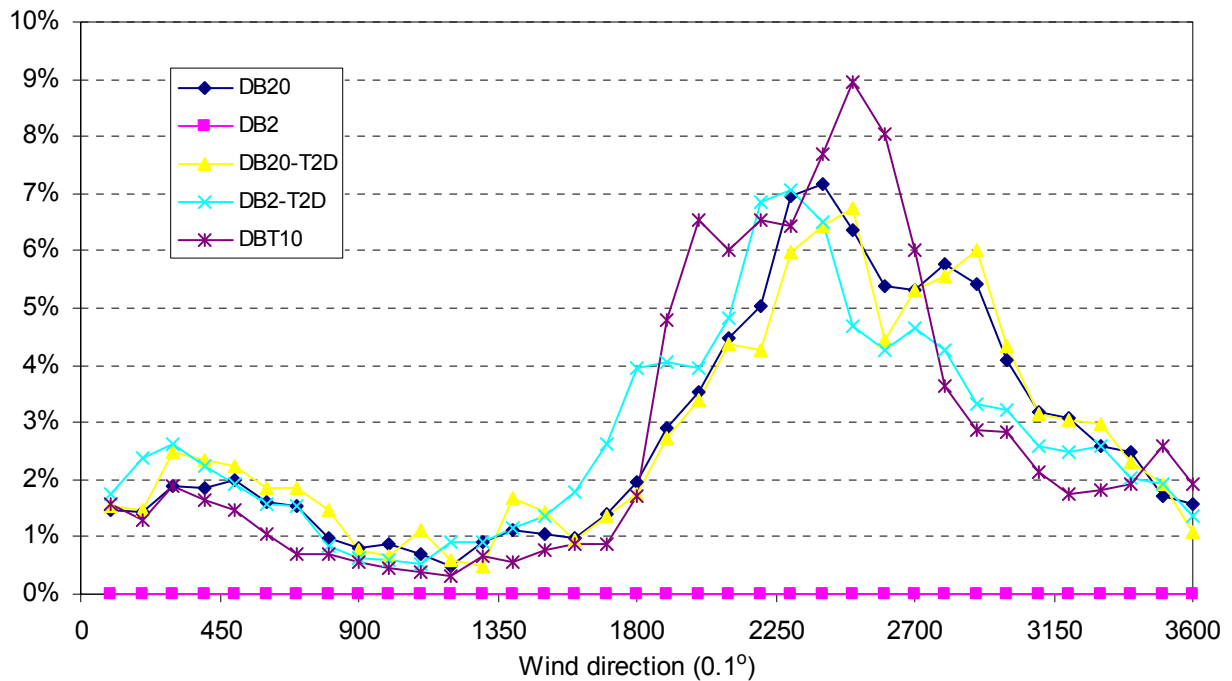


Figure 3: The relative occurrence of derived wake vortices (inclusive ≥ 15 m/s) during the evaluation period at De Bilt and De Bilt Test as a function of 1-minute averaged wind direction (WRm in 10° bins).

A.3.3. Cabauw

The derived wake vortex detections at Cabauw clearly show the expected behaviour with the largest number of detections near the surface where turbulence is highest and decreasing numbers with height, whereas the corresponding wind speed (and the number of detections with speed ≥ 15 m/s) increases with height (cf. Table 1). The distribution of the vortices with wind direction is very smooth at 10 and 20 m (cf. Figure 4) reflecting the good measurements conditions, except for the northwest direction of the B-mast at 10 m. The number of vortices obtained in the meteorological mast is affected by the mast. The measurements on the north side of the mast give more wake vortex events than those on the south-southwest side, since the north side is often in the wake of the mast during the prevailing southwest wind. The disturbance for south-southwest wind directions clearly shows up in Figure 5 and increases with height when the

wind speed and the induced turbulence increase. The measurements south-southwest of the mast show a less significant disturbance for east-northeast wind directions.

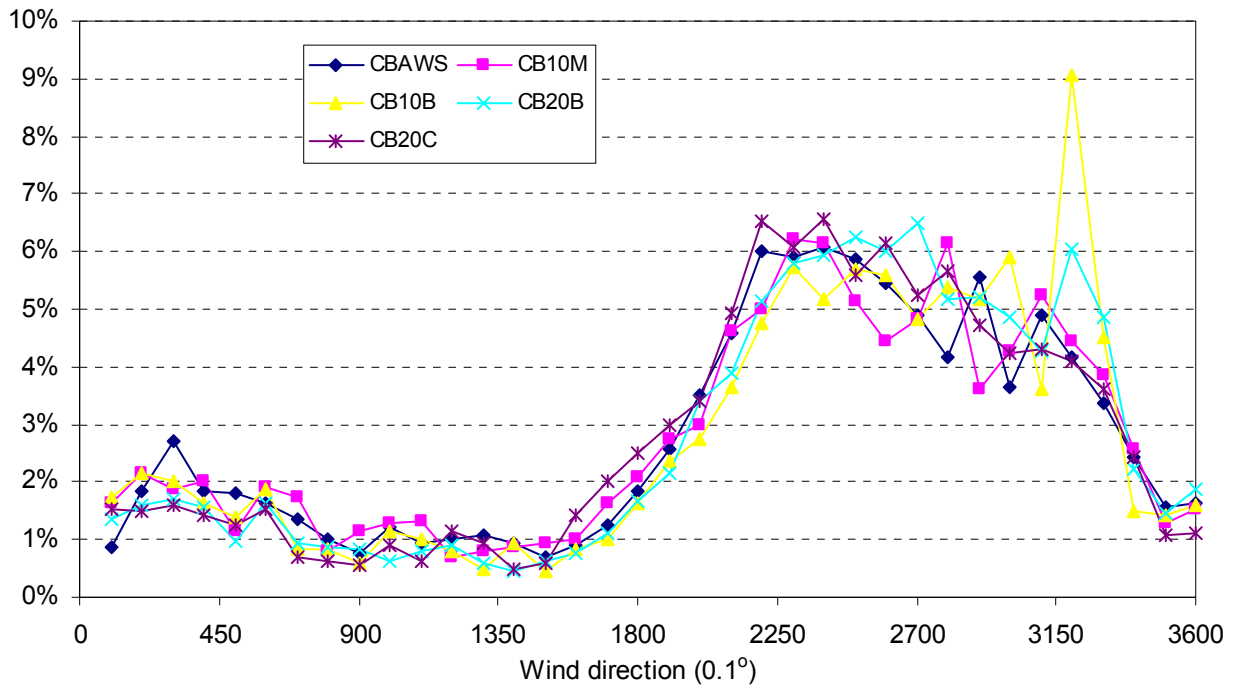


Figure 4: The relative occurrence of derived wake vortices (inclusive ≥ 15 m/s) at Cabauw as a function of 1-minute averaged wind direction (WRm in 10° bins).

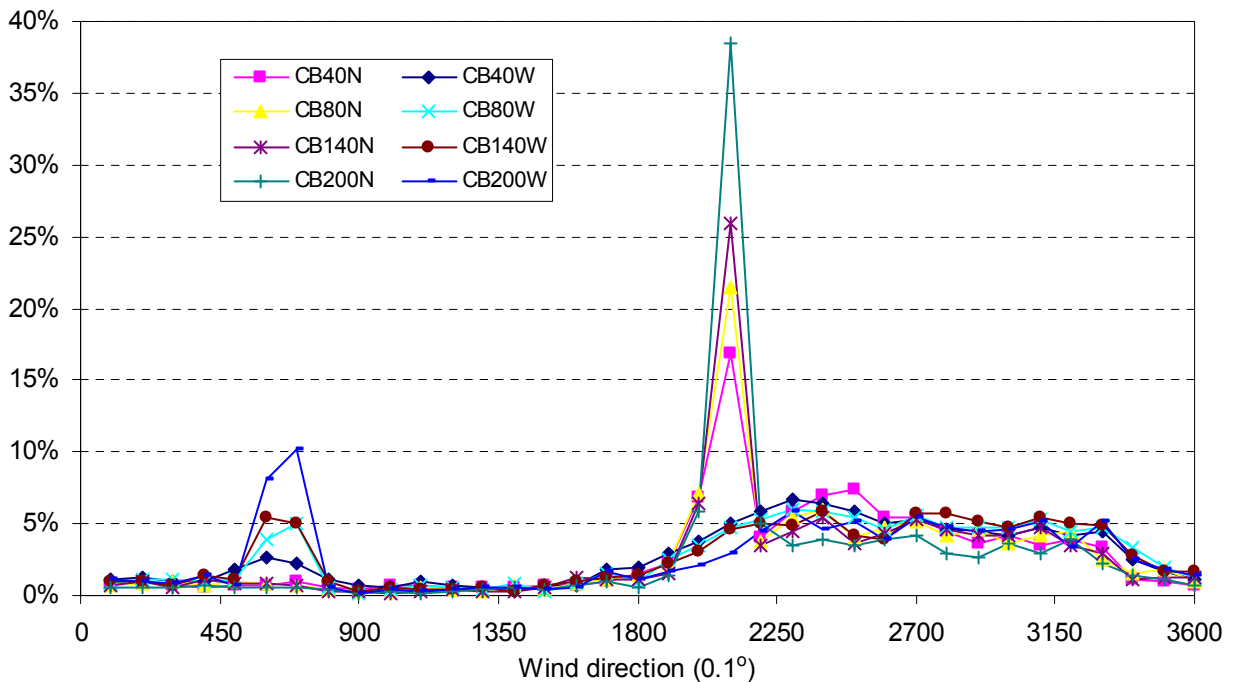


Figure 5: The relative occurrence of derived wake vortices (inclusive ≥ 15 m/s) in the meteorological mast at Cabauw as a function of 1-minute averaged wind direction (WRm in 10° bins).

The Thies 2D at Cabauw shows again less derived wake vortex detections than the collocated cup anemometer although the difference is less than for De Bilt. The numbers reported by the Thies 2D and Thies 3D sonics are very similar. The Gill 3D gives a very large number of derived vortices, but most of them are related to situations when faulty high wind speeds are reported by the Gill 3D.

A.3.4. Schiphol

A total of 13 wind measurements locations exist at Schiphol including the 4 so-called fog stations located at a distance of about 15 to 20 km from the airport. The layout of the runways at Schiphol and the location of the wind masts are given in Figure 6. The wind measurements near 06 and 18R touchdown report a large number of wake vortices (27707 and 20331, respectively) and to a lesser degree the measurements at 18C and 36C touchdown (9603 and 7558). At these locations vortices are reported evenly over the entire evaluation period. The 2D sonic at 18R reported 11851 vortices. It should be noted that the lower number of wake vortices reported by the 2D sonic at 18R touchdown compared to the collocated cup anemometer is caused by the shorter period of operation. When only the period with overlapping 2D sonic and cup anemometer measurements is considered the total number of wake vortices reported at 18R touchdown is 12745 vortices. The wind measurements at 36R reported 515 wake vortices. There was one isolated event reported on September 30, 2011 (probably during maintenance), but the other vortices occurred from September 6, 2012 onwards. Hence it seems that the wake vortex algorithm was activated at 36R touchdown on September 6, 2012. The averaged number of wake vortex detections reported at AM36R (1 per day) is low compared to that of other locations even for those not affected by aviation. The number of derived vortices is comparable to those of other Schiphol locations where wake vortex filtering was active. Since the results for AM36R show no increase prior to September 6, 2012 after which vortices are reported by the sensor interface, it is expected that wake vortex filtering was also active beforehand, but probably the old XW0 sensor interface was used that did not indicate when vortex filtering occurred. The other wind measurements at Schiphol (27 and 22 touchdown) report no vortices or only 1 (at 36L touchdown) which is probably related to maintenance.

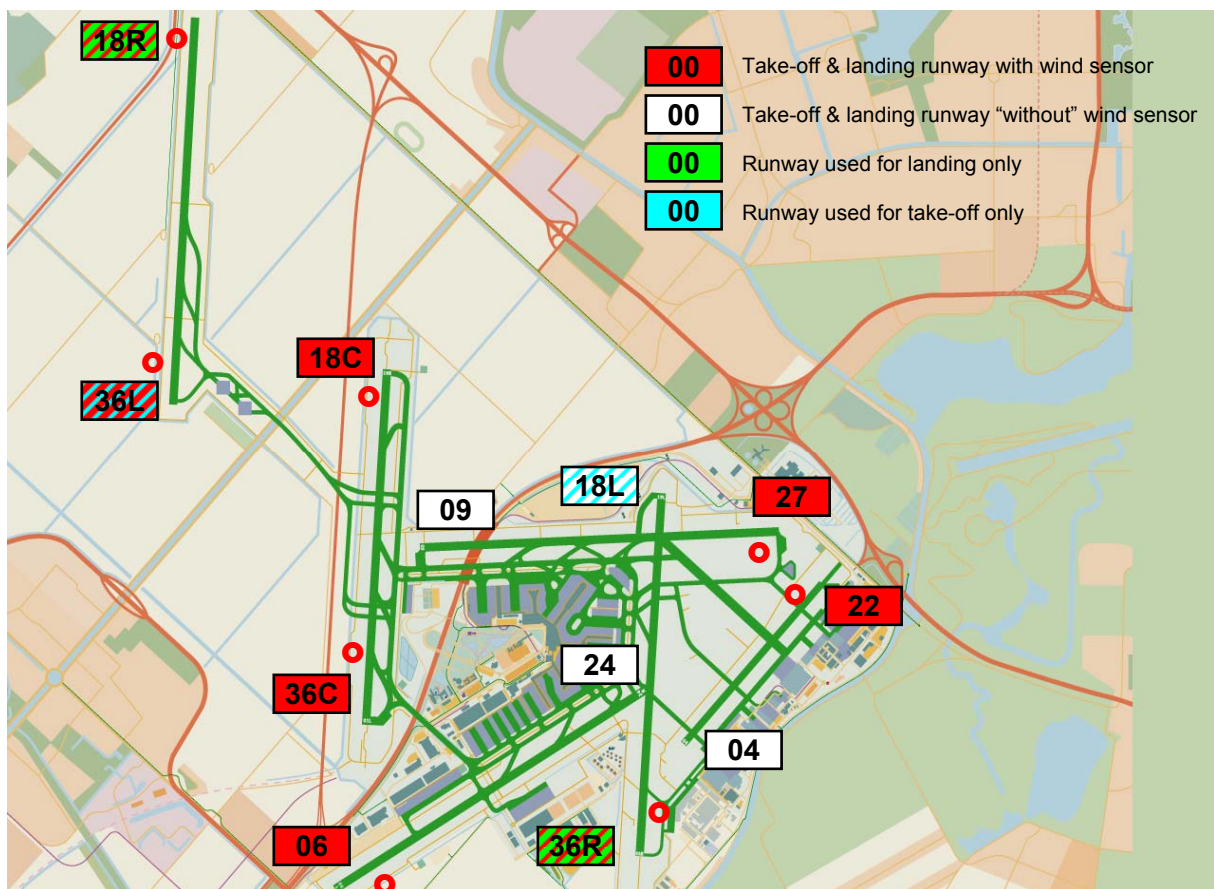


Figure 6: The runway system at Schiphol with indication of all possible touchdown and take-off positions and the wind measurements locations.

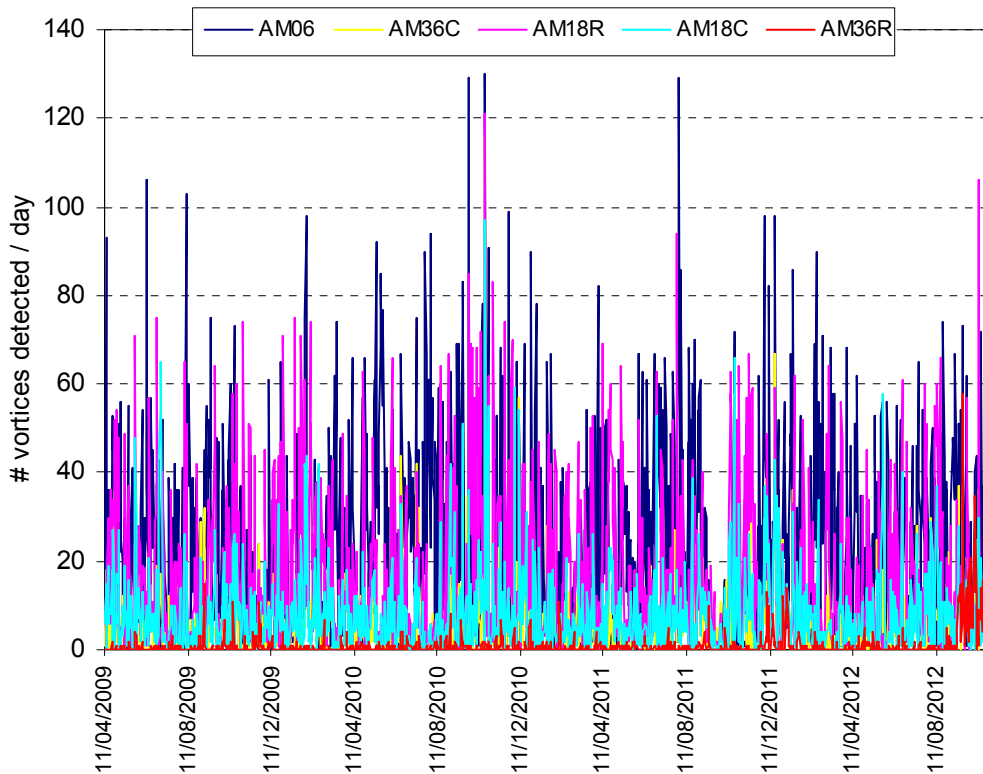


Figure 7: The daily number of wake vortices detections (reported and derived inclusive $\geq 15\text{m/s}$) during the evaluation period for five wind measurement locations at Schiphol.

Figure 7 shows that wake vortex detections (total of reported and derived inclusive $\geq 15\text{ m/s}$) occur regularly at 06, 18R, 18C and 36C (and 36R once activated) with large day-to-day variations. The maximum number of daily detections is 130, 121, 116 and 97 for 06, 18R, 36C and 18C touchdown, respectively, and 58 for 36R touchdown. The averaged number of vortices per day is 22.57, 16.80, 6.45 and 8.04 for 06, 18R, 36C and 18C touchdown, respectively, and 1.05 for 36R touchdown. When only the last 55 days are considered the averaged daily number of total wake vortex events at 36R is 10.13. The correspondence of the wake vortices reported for the cup anemometer and 2D sonic at 18R touchdown is given in Figure 8. The daily number of vortices reported by both types of sensors is close and they show nearly identical day-to-day variations. The maximum number of daily detections for the 2D sonic at 18R touchdown is 115 with an averaged number of 15.92 vortex events reported per day.

The occurrence of the vortex detections with wind direction at Schiphol deviates from the general distribution of the wind direction (cf. Figure 9). Both measurements at 18R touchdown, and to a lesser degree also the wind measurements at 18C and 36C, have enhanced vortex detections for northeast and southeast wind directions. The peak around the prevailing wind direction is less pronounced at 18C and 36C, and is hardly noticeable for 18R touchdown. Wake vortex detections at 06 touchdown occur mainly for northwest winds while detections at 36R touchdown occur around southwest wind directions. Note that the peak in the distribution for 06 and 36R also indicates a bimodal distribution with peaks at west and north-northwest wind directions at 06 touchdown and at south-southwest and west-northwest wind directions at 36R touchdown. The wind direction distribution for vortex detections at 36R touchdown is not as smooth as for the other locations since the number of vortex detections was smaller due to the shorter period that the DW0 SIAM was in use. The general wind direction at the maximum of vortex detections (east for 18R, 18C and 36C, northwest for 06 and west for 36R) puts the wind measurements at these locations downwind of the touchdown area (cf. Figure 6). Hence, the distributions suggest that the wake vortices reported at Schiphol are, at least partly, caused by aircraft.

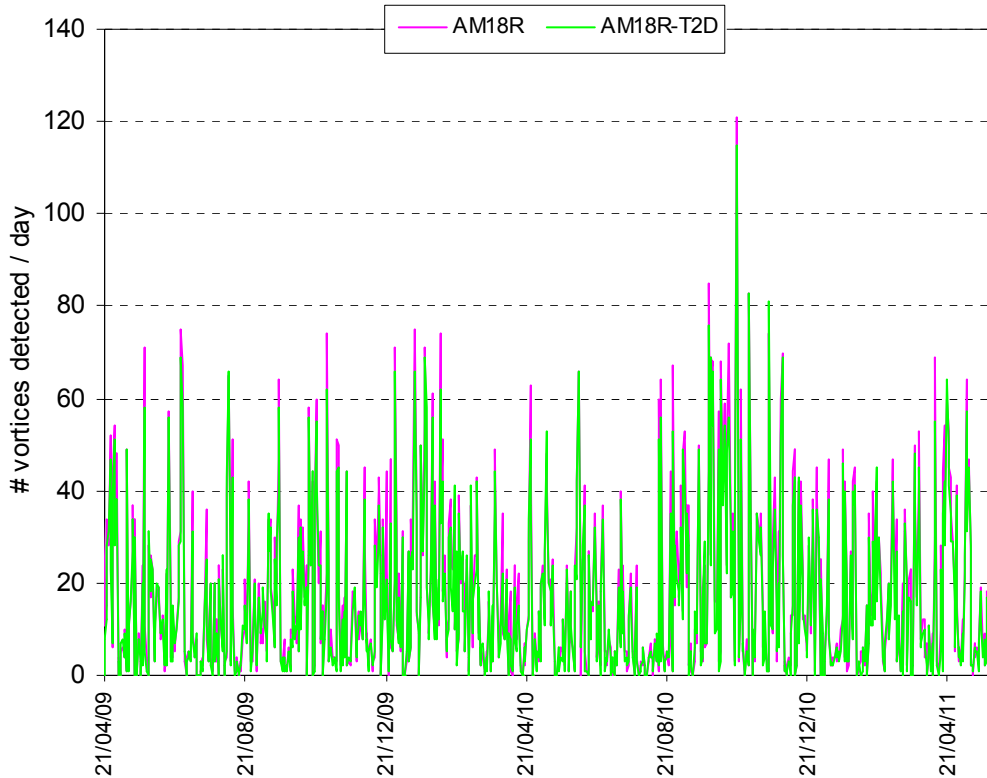


Figure 8: The daily number of wake vortices detections (reported and derived inclusive $\geq 15\text{m/s}$) during the evaluation period at 18R touchdown by cup anemometer and 2D sonic.

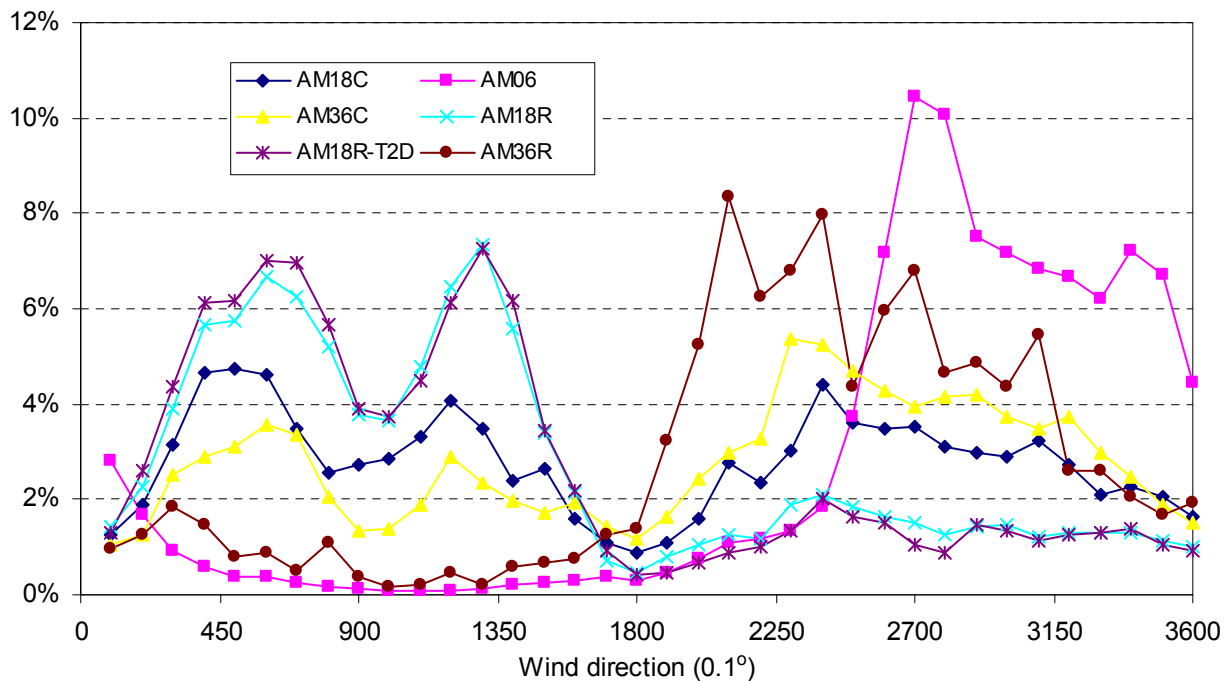


Figure 9: The relative occurrence of wake vortex detections (reported and derived inclusive $\geq 15\text{m/s}$) during the evaluation period for six wind measurement locations at Schiphol as a function of 1-minute averaged wind direction (WRm in 10° bins).

The runway system at Schiphol consists of six runways, most of which can be used from both directions and for landing and take-off operations (cf. Figure 6). There are 10 possible runways for landing and 10 for take-off, but at most 2 landing and 2 take-off runways are in use at any time. The usage of runways is determined by Air Traffic Control the Netherlands (LVNL) and is based on e.g. meteorological conditions, periodical runway maintenance, and noise limits. The actual runway usage is provided automatically to KNMI and enters the meteorological server systems as a SIAM string. The availability of the runway usage allows verification whether wake vortex detections occur when the runway is in use. Wake vortex detections at for example 06 touchdown are expected during landing on runway 06 (10003 events or 34 %) and take-off from runway 24 (17227 events or 59 %). There were only 47 vortex detections when runway 06 was used for take-off and during 45 of these events runway 06 was also used for landing simultaneously. Hence take-off from 06 seems to cause almost no vortex detections at 06 touchdown, probably because start for take-off at runway 06 occurs further along the runway. The same holds for the wind at other measurement locations. Only at 36C touchdown a large fraction of vortex detections occur when 36C is used for take-off (10 %), probably because of the location of the wind measurements at the displaced threshold. 93 % of the vortex detections at 06 touchdown occur when the wind measurement location is exposed to aircraft during landing on runway 06 or take-off from runway 24. Similarly the detections at 18R occur mainly (95 %) occur when the runway is used for landing or take-off. However, the correspondence between vortex detections and runway usage is less for the measurements at 18C (39 % +2 % for take-off on 18C), 36R (32 %) and 36C (19 % +10 % for take-off on 36C). The correspondence of the occurrence of vortex detections with runway usage is generally higher for take-off than for landing, typically 60:40%, except for 36C where number are roughly equal. The lower correspondence of vortex detections with runway usage at some measurement locations suggests that aircrafts are not the main source of the vortex detections at these locations. For these locations the peaks in the number of vortex detections when the location is downwind of touchdown (cf. Figure 9) are consequently less pronounced.

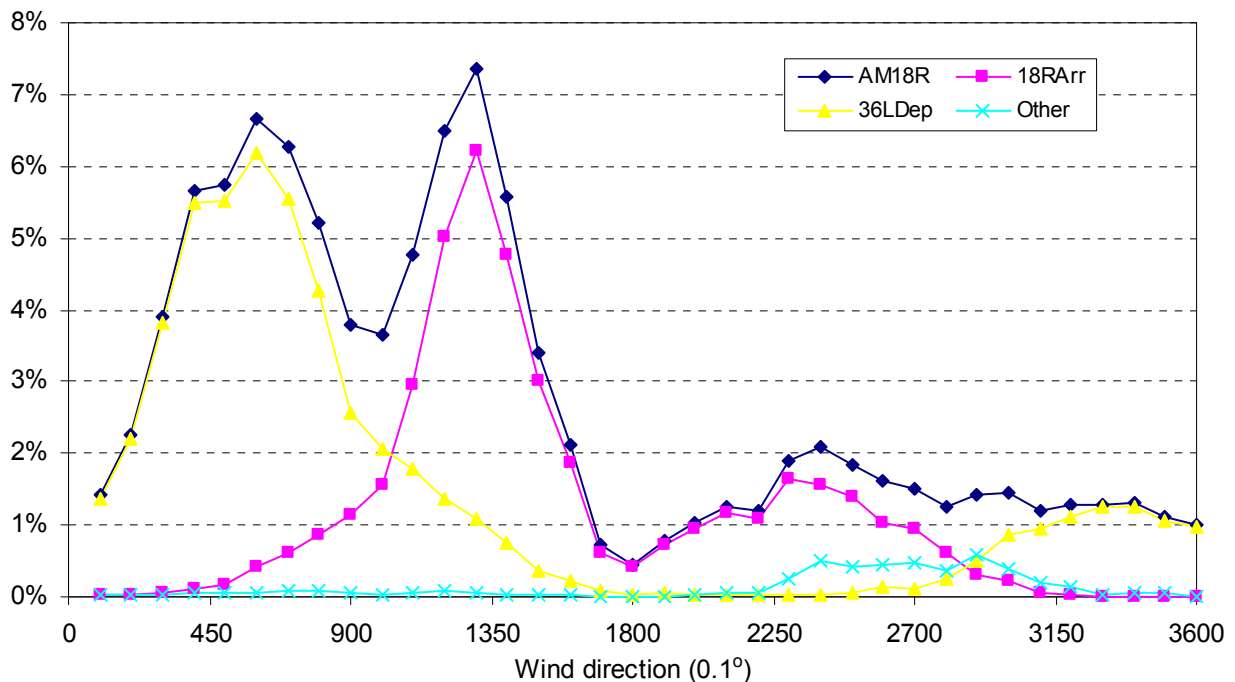


Figure 10: The relative occurrence of wake vortex detections (reported and derived inclusive $\geq 15\text{m/s}$) at 18R touchdown as a function of 1-minute averaged wind direction (WRm in 10° bins) and the runway usage.

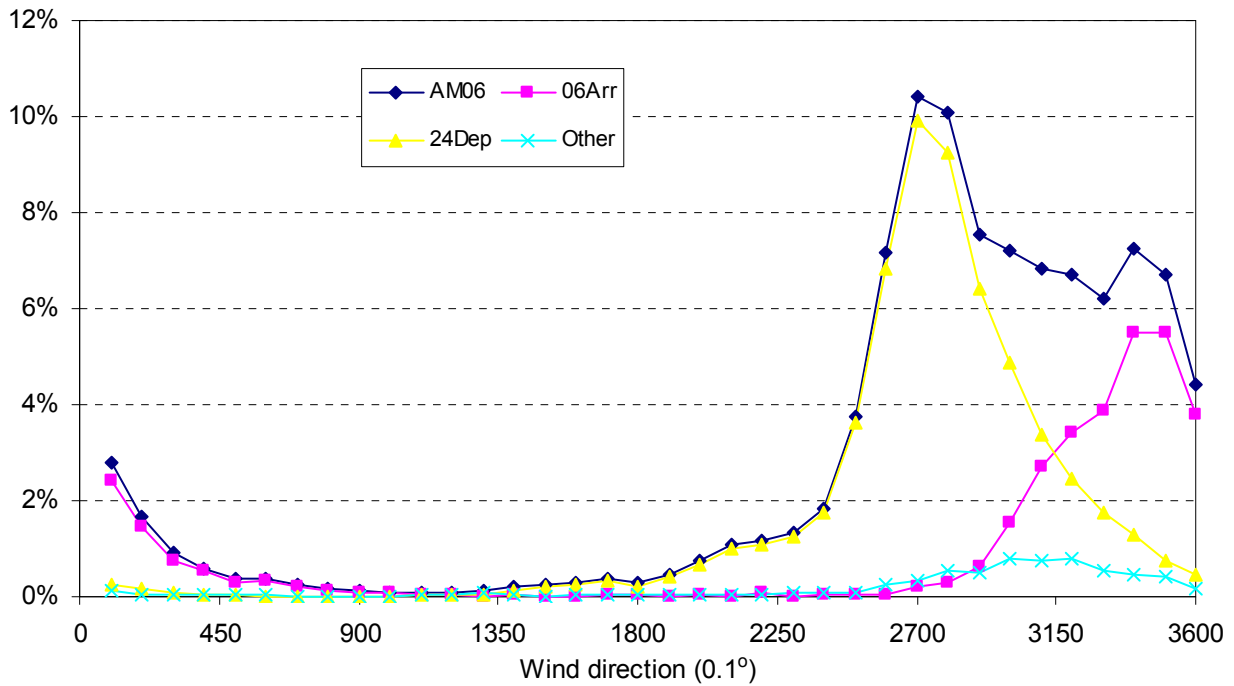


Figure 11: The relative occurrence of wake vortex detections (reported and derived inclusive $\geq 15\text{m/s}$) at 06 touchdown as a function of 1-minute averaged wind direction (WRm in 10° bins) and the runway usage.

The occurrence of wake vortex detections with wind direction can also be investigated as a function of the runway usage. Figure 10 clearly shows that the peaks in detections around northeast and southeast wind occur when the runway is in use for take-off and landing operations, respectively. The difference in direction is influenced by the fact that the runway usage depends on the wind conditions since head winds are preferred in aircraft operations, whereas cross winds tend to be avoided. The distribution of the detections when the runway is not in use gives maximum values near the prevailing southwest wind direction. Although the peaks around northeast and southeast direction at 36C and 18C are less pronounced, they are still largely related to the runway usage. Figure 11 shows the good correspondence of the 2 peaks in detections at 06 touchdown when the runway is in use for take-off and landing operations. Again the wind direction for the peaks is affected by the preferred conditions for using the runway. The distribution of the detections when runway 06/24 is not in use gives maximum values for northwest directions. In about half of these cases runway 36C is used for landing. It could be possible that aircrafts landing on 36C cause turbulence at 06 touchdown although it seems unlikely.

The number of derived wake vortices at AM27 and AM22 (4 per day) show comparable numbers as obtained for the Schiphol fog stations (AMAD, AMMU, AMNK, AMNV, 3 to 5 per day), and their distribution with wind direction follow the prevailing wind direction (cf. Figure 12). The number of derived wake vortices shows some variations for the fog stations and some minor features as a function of the wind direction, but that is probably related to local surface roughness conditions. The number of derived wake vortices at AM36L (7 per day), however, is enhanced and shows a prominent peak around northeast wind directions. 36L touchdown at Schiphol is not exposed during landing or take-off since the runway is not available for 36L arrival and 18R departure operations. However, the detections at 36L occur mainly (92 %) occur when the runway 18R is in use. Actually nearly all vortex events at 36L between north and east wind directions occur when 36L is used for departure (see Figure 13). Hence the wind measurements at 36L seem to be affected by aircrafts when they start accelerating at the end of the runway during departure.

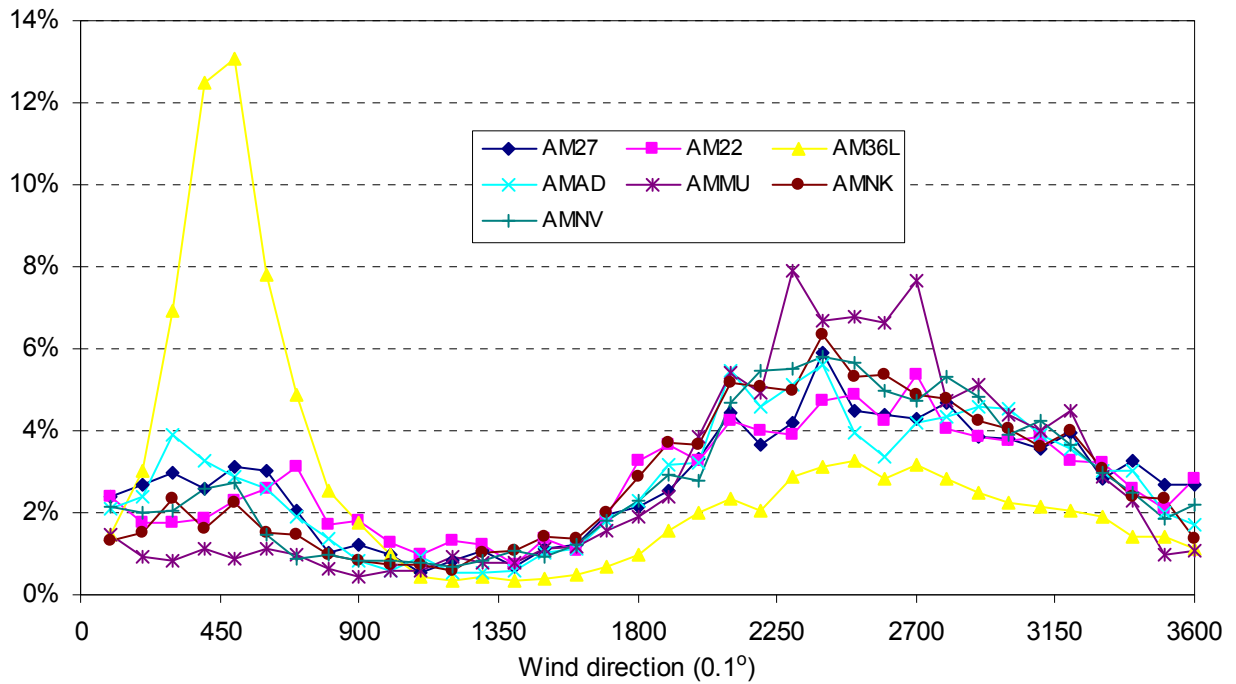


Figure 12: The relative occurrence of derived wake vortices (inclusive ≥ 15 m/s) for seven wind measurement locations at Schiphol as a function of 1-minute averaged wind direction (WRm in 10° bins).

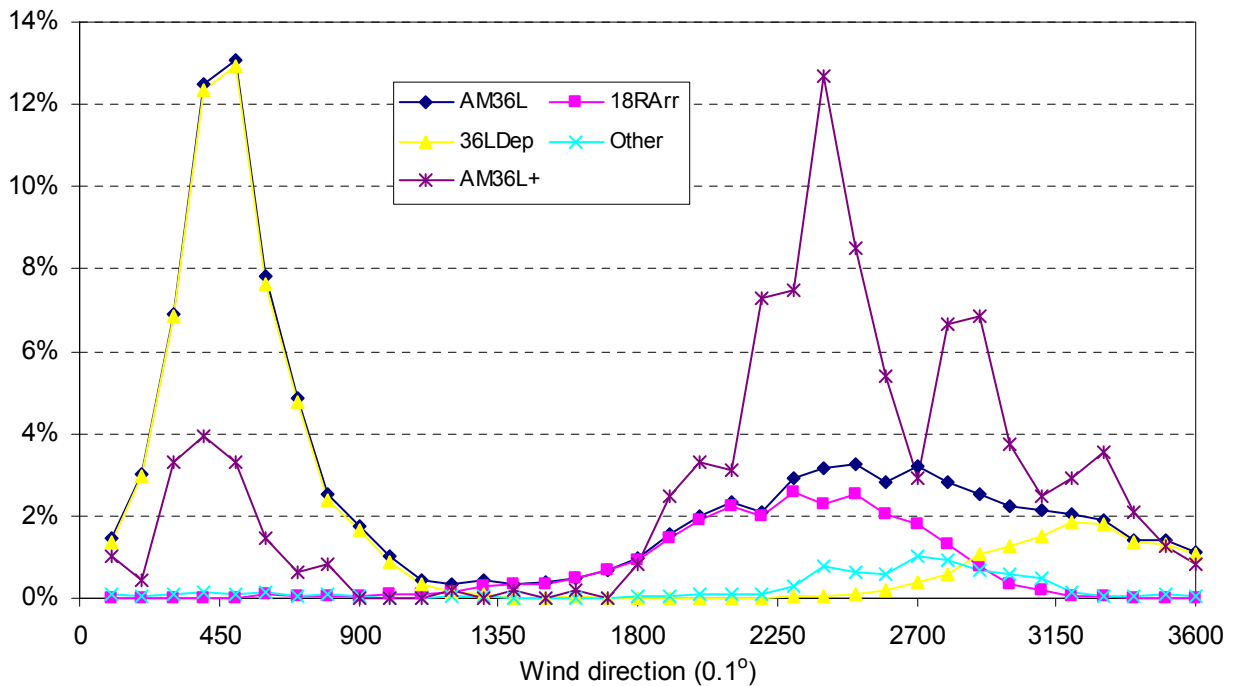


Figure 13: The relative occurrence of derived wake vortices (inclusive ≥ 15 m/s) at 36L touchdown as a function of 1-minute averaged wind direction (WRm in 10° bins) and the runway usage. The relative occurrence of derived wake vortices with speeds ≥ 15 m/s is given by AM36L+.

When vortex filtering is active the highest 3-second averaged wind speed in the last 12-seconds (WSs) is reduced during vortex events. Therefore the 12-second gust corresponding with the wake vortex event is only available for the derived events. When the derived wake vortex detections for speeds ≥ 15 m/s are plotted as a function of the wind direction (curve labelled

AM36L+ in Figure 13) most events occur for the prevailing wind directions although the number of detections are slightly enhance when the measurement location is downwind of the runway. The same holds for the other Schiphol wind measurements locations that are affected by aircraft vortices. Hence aircraft induced wake vortex detections with speeds exceeding 15 m/s occur, but the fraction of vortex detections due to natural turbulence is higher in these conditions.

A.3.5. Beek, Eelde and Rotterdam

The regional airports Beek, Eelde and Rotterdam are all equipped with two wind sensors, i.e. a sensor at each end of the runway. The wind sensors at the two touchdown positions at Beek report a similar number of wake vortex events (7080 at 04 touchdown and 6265 at 22 touchdown). Note that at the other regional airports the southwest wind sensor also reports more wake vortices than the northeast sensor. Figure 14 shows that wake vortices are detected regularly throughout the entire evaluation period, but days without vortices also occur regularly. Figure 14 illustrates that the daily number of wake vortices reported by the wind sensors at Beek has large day-to-day variations with a maximum daily value of 50. The averaged number of vortices per day is 5.96 and 5.27 for 04 and 22 touchdown, respectively. For Eelde (4.59 and 4.42 for 05 and 23 touchdown) and Rotterdam (5.45 and 5.03 for 06 and 24 touchdown) the number of vortices is slightly less.

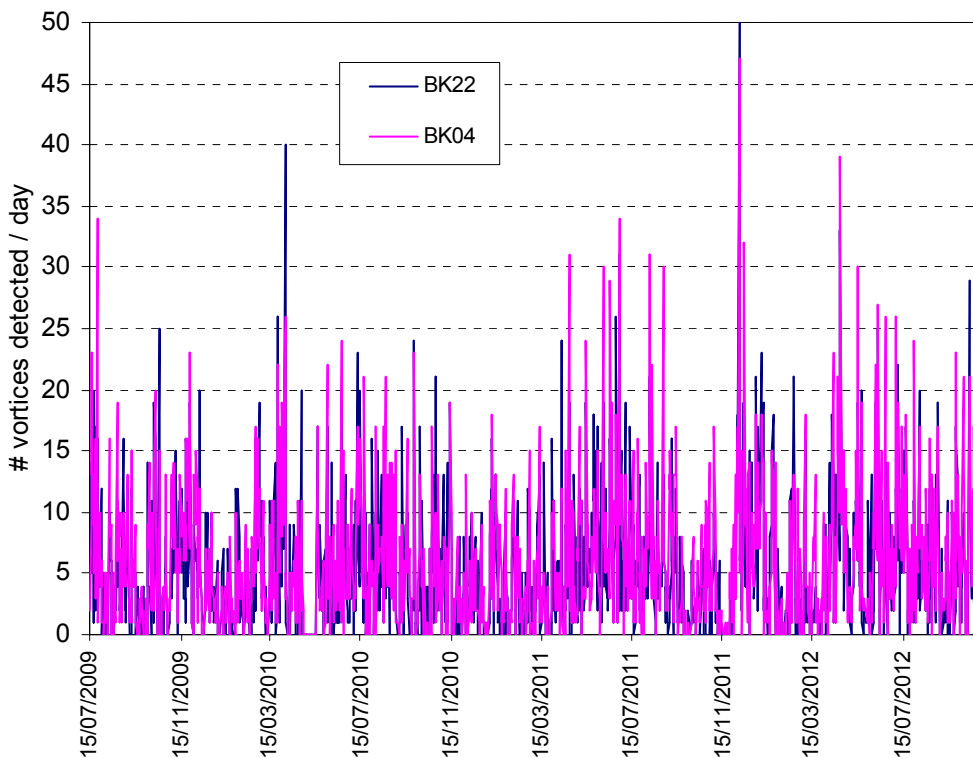


Figure 14: The daily number of wake vortices detections (reported and derived inclusive $\geq 15\text{m/s}$) for the two wind measurement locations at Beek.

The occurrence of the vortex detections with wind direction (cf. Figure 15) shows generally the same behaviour as for De Bilt (Figure 3). However, at Beek the peak in southwest directions is more pronounced, or the number of vortices for west wind directions is suppressed. This is not the case for the relative occurrence of wake vortex detections as a function wind direction at Eelde and Rotterdam (cf. Figure 16). Figure 15 and Figure 16 show that most wake vortex detections occur when the wind comes from the southwest, which is the prevailing wind direction. Although the wind sensors are located northwest of the touchdown area, wake vortices can still affect the wind measurements when the wind speed is small. However, this is generally not the case.

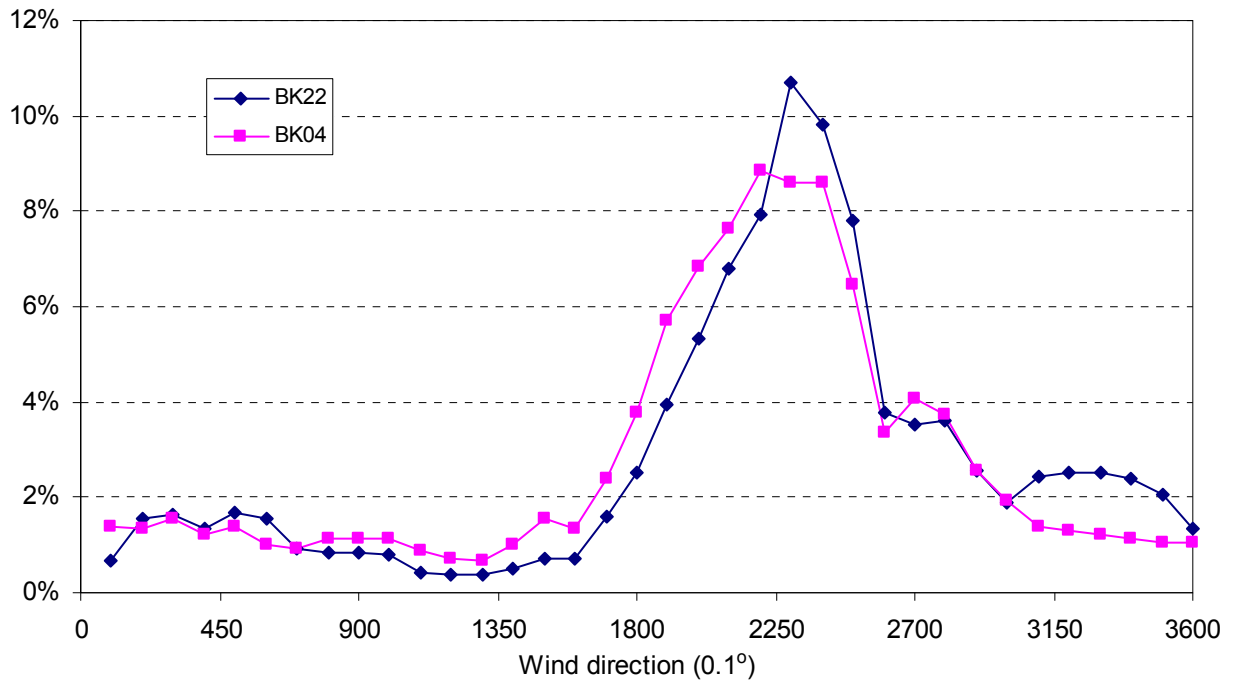


Figure 15: The relative occurrence of wake vortex detections for the two wind measurement locations at Beek as a function of 1-minute averaged wind direction (WRm in 10° bins).

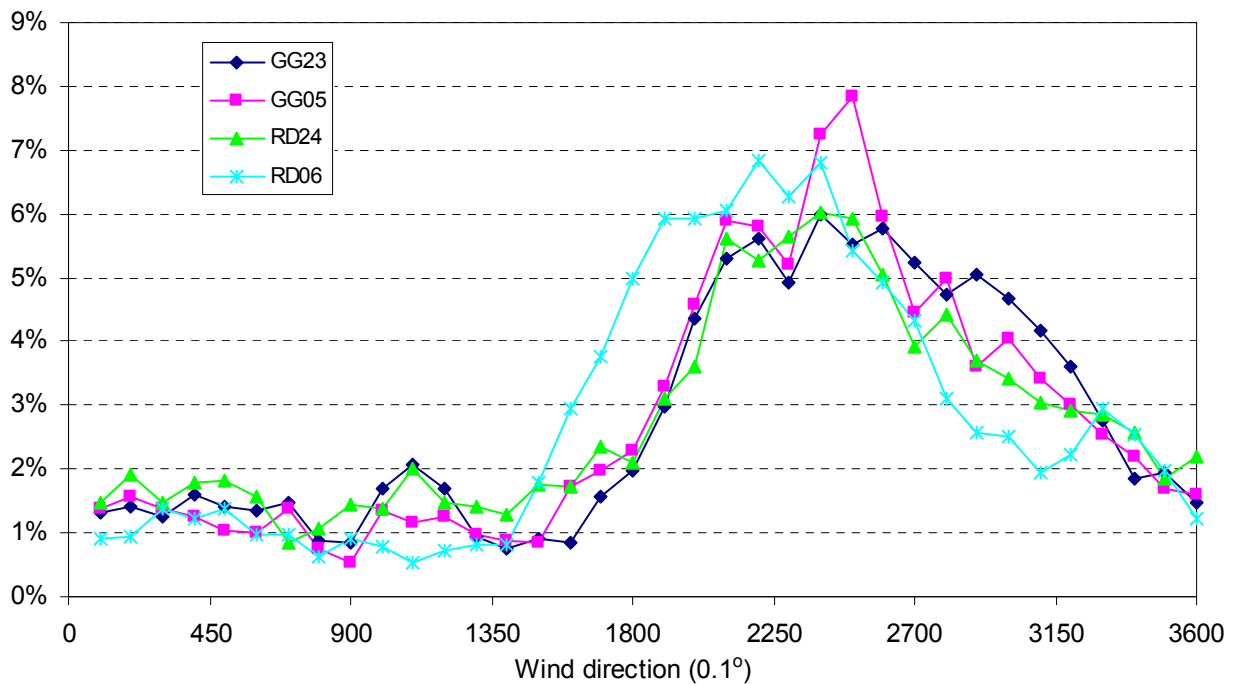


Figure 16: The relative occurrence of wake vortex for the two wind measurement locations at Eelde and Rotterdam as a function of 1-minute averaged wind direction (WRm in 10° bins).

Note that an analysis of the vortex detections as a function of runway in use is not useful for the regional airports since they have only one runway that is used for landing and take-off operations. Since no distinction is made between landing and take-off operations of the runway and the runway closed indicator is not used at Beek no relation to runway usage can be established. For example at Beek either runway 04 or runway 22 is in use and in any of these conditions both wind measurement locations at opposite ends of the runway can be exposed to aircraft. For example the wind measurements at 22 touchdown might be affected during landing

operations on runway 22 or during take-off operations of runway 04. For both measurements locations at 04 and 22 touchdown most vortex detections occur (85 %) when runway 22 is in use. However, this only reflects the preferred runway usage due to the prevailing south-westerly wind.

The wake vortex detections for Beek, Eelde and Rotterdam have averaged numbers of 4 to 6 per day, similar to other measurement locations that are not affected by aviation. The distribution of the events with wind direction follows the prevailing wind directions. There are no clear features around southeast directions that would be indicative of influence by aircraft, since for these wind directions the measurement location is downwind of the touchdown / take-off area.

A.4. SUMMARY AND CONCLUSIONS OF WAKE VORTEX FILTERING

All wind measurement locations report wake vortices when the current wake vortex algorithm is applied to the measurements. The averaged daily number of vortices is between 3 and 6 per day for non-aeronautical locations and depends on the local surface roughness conditions. In the sheltered conditions at De Bilt Test the averaged number is as high as 9 per day. The number of vortices increases when wind measurements are performed closer to the ground and decreases with measurement altitude. The distribution of the vortices with wind direction reflects the prevailing wind direction, but turbulence introduced by local obstructions can lead to enhanced values for specific directions.

Wake vortex detection and reduction is currently active in the SIAM sensor interface for the wind measurements near 06, 18R, 18C, 36C and 36R touchdown at Schiphol and near 22 and 04 touchdown at Beek.

The wind measurements near 06 and 18R touchdown at Schiphol are affected by wake vortices most frequently (on average 23 and 17 events per day). At these two locations vortex detections occur mainly (about 95 %) when the runway is used for touchdown or take-off operations and the wind direction is such that the wind measurement location is downwind of the touchdown or take-off area. This analysis has to be treated with care because runway usage is dependent on the wind conditions since head winds are preferred and significant cross wind components are avoided in aircraft operations. However, the increased number of wake vortex detections; their principal occurrence when the runway is in use; and the general occurrence of the wake vortex detections when the location is downwind of the touchdown zone of the runway in use suggests non-natural causes. Hence most wake vortex detections at 06 and 18R touchdown seem related to aviation. The measurements at 18C, 36C and 36R touchdown are also affected by wake vortices (on average 8, 6 and 9 per day), but their correspondence with runway usage (30 to 40%) and wind direction is less. Hence a large fraction of the wake vortex detections at these locations seem not related to aviation.

The wind measurements near 36L touchdown are also affected by aviation although 36L is not available for arrival or 18R for departure. The wind measurements are mainly affected when 18R is used for departure. The averaged number of derived wake vortex detections is about 7 per day, their correspondence to runway usage is 92 % and the wind direction is such that the wind measurement location is downward of end of the runway. Therefore it is recommended that wake vortex detection and reduction should be enabled for the wind measurements near 36L touchdown at Schiphol.

The wind measurements near 22 and 04 touchdown at Beek report wake vortices (on average 5 per day). A correspondence with the runway usage cannot be made. The wind direction associated with wake vortex detections reflects the prevailing wind direction during which the wind measurement location is upwind of the touchdown or take-off area. Hence the wake vortex detections at Beek are probably not related to aviation. Therefore it is recommended that wake vortex detection and reduction should be disabled for the wind measurements at Beek.

The derived vortex detections for the wind measurements at Groningen and Rotterdam show averaged values of about 5 per day and no enhanced values when the measurement location is

downwind of the runway. Hence wake vortex detections at Groningen and Rotterdam airport seems not to be an issue.

Wake vortex detections induced by aviation can also occur for wind speeds exceeding 15 m/s, but the detections at these higher speeds are mostly caused by other phenomena. Hence the < 15 m/s criterion for wake vortex detection seems valid.

The KNMI cup anemometer and the Thies 2D ultrasonic wind sensor show good agreement with regards to the occurrence of wake vortex detections. Hence the individual sensor characteristics, particularly their response time to sudden changes in the wind, are such that the running 3-second averages are not affected. The Thies 2D sonic generally reports less wake vortices than the collocated KNMI cup anemometer. This underestimation is probably caused because the sonic measures only the horizontal wind component in turbulent conditions.

A study on the optimization of the wake vortex detection algorithm is required since the current criteria are also triggered by natural phenomena causing turbulence. A wind direction criterion which places the measurement location downwind of the touchdown/take-off area seems to be a good candidate, although not conclusive for low wind speeds. For the multi-runway system at Schiphol the combination with runway usage seems an obvious choice. The wind speed threshold of 15 m/s should not be relaxed, but the duration of the turbulence events might be considered as a criterion. However, the requisite for a (near) real-time utilization and the available wind measurement data will put operational constraints on the wake vortex detection algorithm. Note that the availability of the raw unfiltered 4 Hz wind data used in the SIAM processing, which is currently not available, is essential for such a study. Additional information on runway usage, specifically time and type of aircraft on the runway and distinction between landing and take-off, is required at regional airports to allow the verification of the wake vortex detections. This additional information also improves the analysis of Schiphol wind measurements and would be very useful for the optimization. Such information can for example be obtained from Mode S / ADS-B data (ICAO, 2004) that is available at KNMI.

Apart from the optimization of the current wake vortex detection and reduction algorithm KNMI in collaboration with ATC should consider using other mitigating measures. The main issue for LVNL is not only that a wake vortex leads to a wind gust, but also that this induced gust is persisted for 10 minutes. Hence a possible solution could be to reduce the default 10 minutes interval for reporting the wind extremes to 2 minutes in case of a wake vortex event. Thus, similarly to the handling of marked discontinuity, when a wake vortex detection occurred in the last 10 minutes but not in the last 2 minutes, consider using only the wind data after the wake vortex detection for the calculation of the 10-minute averages, extremes and standard deviation of wind speed and direction.

B. WIND MEASUREMENTS ON PRODUCTION PLATFORMS IN THE NORTH SEA

B.1. INTRODUCTION

KNMI runs a network of 13 automatic weather stations on the North Sea in collaboration with the Dutch civil water and road authorities (RWS) and the Netherlands Oil and Gas Exploration and Production Association (NOGEP). The purpose of the measurement is not only meteorology and climatology, but also aeronautics due to the helicopter flights to the production platforms. Performing meteorological measurements on production platform is difficult, not only due to the harsh conditions, but also the lack of good locations for installing the instruments particularly for wind measurements. At some production platforms the location of the wind sensors is quite good, for example at F3-FB-1 platform wind is measured on a 10 m mast that is located near the helideck. At other platforms such a setup is not possible and wind is measured on the vent stack which comes in various sizes (see Figure 17). The vent stack is the highest location on a production platform so that the wind is not disturbed by other constructions, except the vent stack itself. To overcome this problem the wind is measured on both sides of the vent stack and the

suitable sensor is selected for use. For that purpose the sensor set (direction and speed) which reports the highest 1-minute averaged wind speed is used.



Figure 17: The wind measurements near the helideck of platform F3 (top left) and on the vent stack of K14 (top right) and AWG (bottom right).

B.2. CHARACTERISTICS OF THE WIND MEASURED ON THE HELIDECK

The wind measurements on platform F3 are performed near the helideck on a 10 m mast with no nearby obstructions. Hence they serve as an example of good quality wind measurements on North Sea platforms. In this situation wind sensor set 1 is used as the primary sensor and the other sensor is the backup and is only used when the primary sensor fails. Figure 18 shows that the distribution of the wind direction reported by each sensor is nearly identical except near north. The sensor selection (although not used in this situation) alters the wind direction distribution and introduces features in the distribution when the standard deviation of the wind direction is used for selecting the sensor. The differences between the 1-minute averaged wind directions reported by both sensors are shown as a histogram in Figure 19. The distribution, which has an offset of 3° , is very narrow. The full width at half maximum is 2° and the standard deviation is about 7° . The differences are generally largest for wind coming from the north. Differences in wind direction exceeding $\pm 30^\circ$ hardly occur even when all wind speeds are considered. The ratios of the 1-minute averaged wind speeds reported by both sensors are shown as a scatter plot in Figure 20 as a function of the wind direction. The wind speeds are typically within $\pm 3\%$, except when one cup anemometer is in the wake of the other. The wind speed is affected over a wind direction range of about 40° . In these situations the speed reported by the shaded anemometer is reduced up to about 20% .

The wind speed measurements at F3 are affected by the nearby backup sensor when the primary anemometer is in the wake of the backup sensor. The wind directions reported by the primary and of the backup vane are very close and can be used to determine which anemometer should be used.

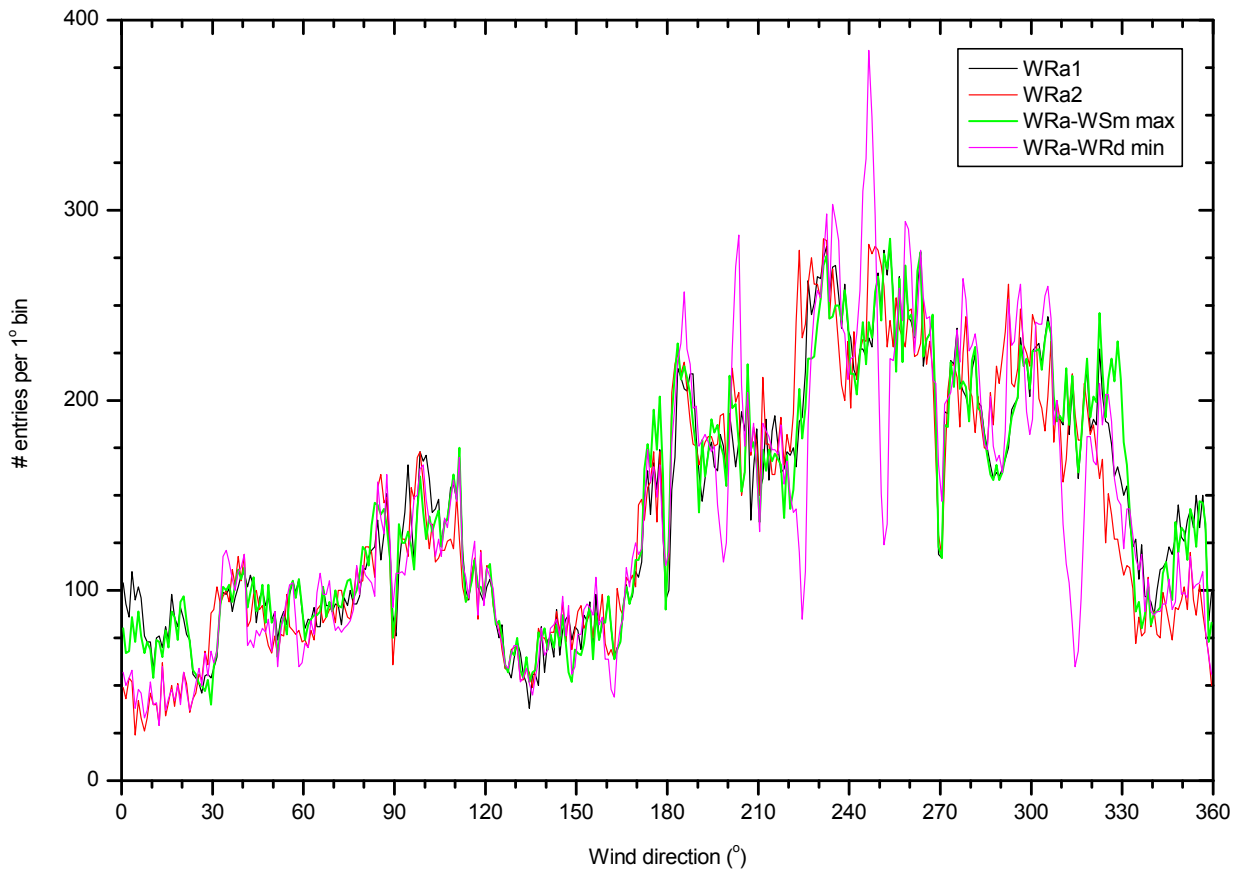


Figure 18: Distributions of the 10-minute averaged wind directions observed at platform F3 in 2012.

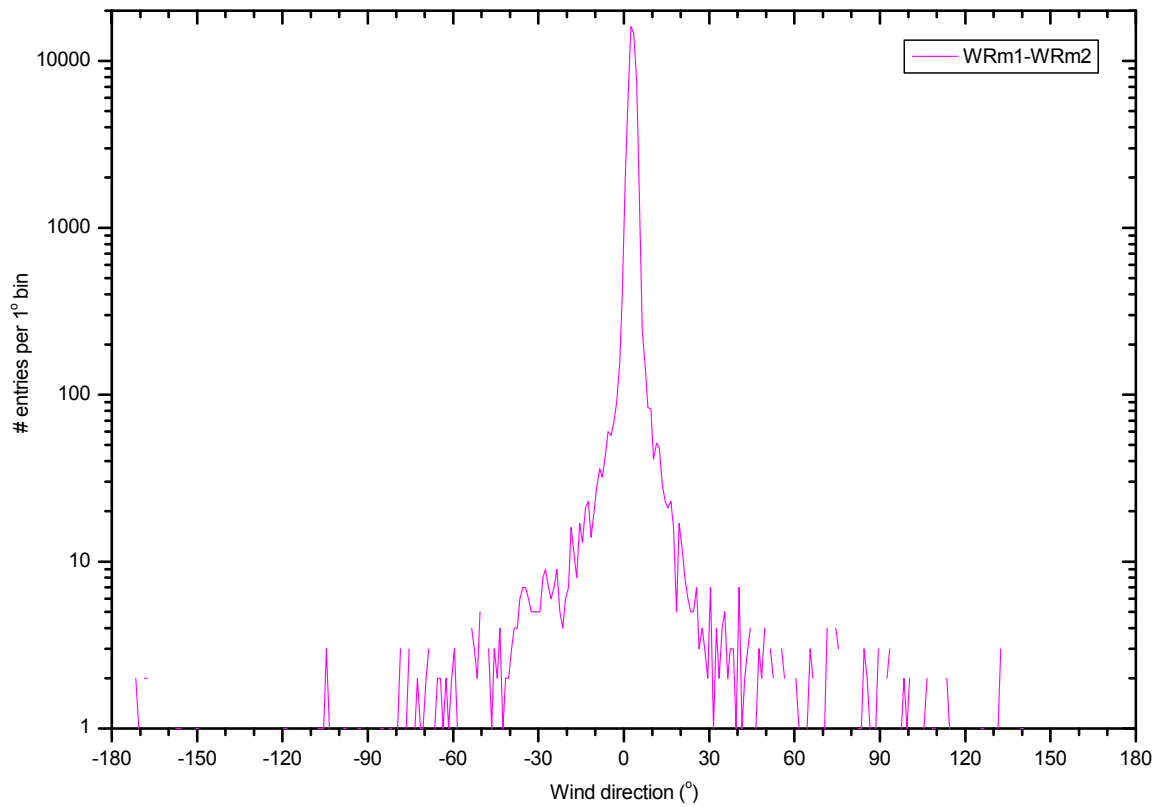


Figure 19: A histogram of the differences of the 1-minute averaged wind directions measured by the two wind vanes at platform F3 in 2012.

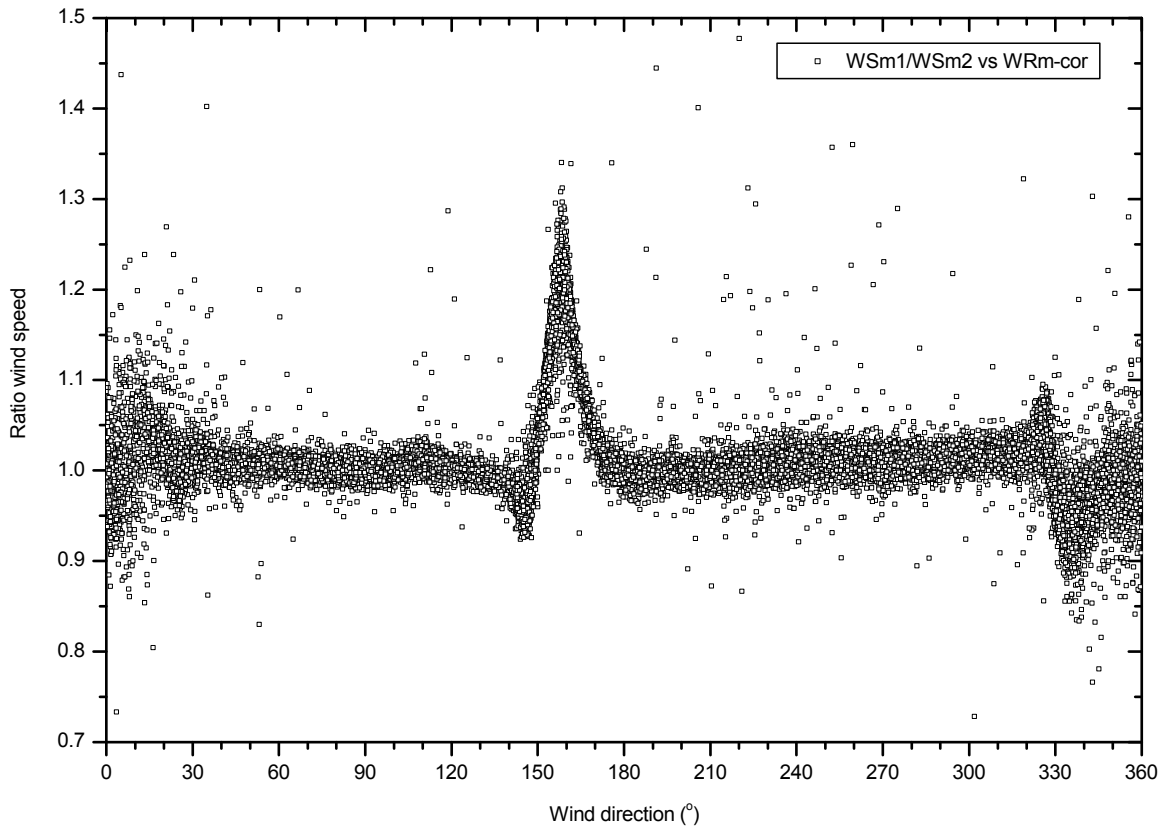


Figure 20: Scatter plot of the ratio of the 1-minute averaged wind speeds measured by the two cup anemometers at platform F3 in 2012 as a function of the wind direction.

B.3. CHARACTERISTICS OF WIND MEASURED ON THE VENT STACK

Platform AWG is one of the worst examples encountered on North Sea with regard to wind measurements because the diameter of the vent stack is large and the wind sensors are located close to it. Figure 21 shows a scatter plot of the 10-minute averaged wind vector measured at AWG in 2012. The individual sensors show that wind directions that place the sensor downwind of the vent stack - i.e. northeast and southwest, respectively - do hardly occur. The wind sector that is blocked by the vent stack covers about 70° since the sensors are located close to the mast. The 10-minute averaged wind vector of the selected wind sensor shows a better coverage of the wind directions, but the directions perpendicular to the orientation of the wind sensors (directions 150 and 330°) hardly occur. The occurrence of wind directions is shown as a histogram in Figure 22. This graph clearly shows the sectors blocked by the vent stack with reduced occurrences and bounded by regions with enhanced occurrences. When the wind sensor reporting the maximum 1-minute averaged wind speed is selected, the directions upwind of the vent stack are filled in by the sensor exposed to the wind. The distribution of the selected wind direction shows, however, not only reduced values near 150 and 330°, but also many features that are not consistent with the expected distribution of wind directions. Clearly the resulting wind direction distribution is not realistic. Also when the wind sensor selection is determined by the sensor reporting the smallest standard deviation of the 10-minute wind direction, as suggested by De Haij (2009), the resulting distribution is unrealistic.

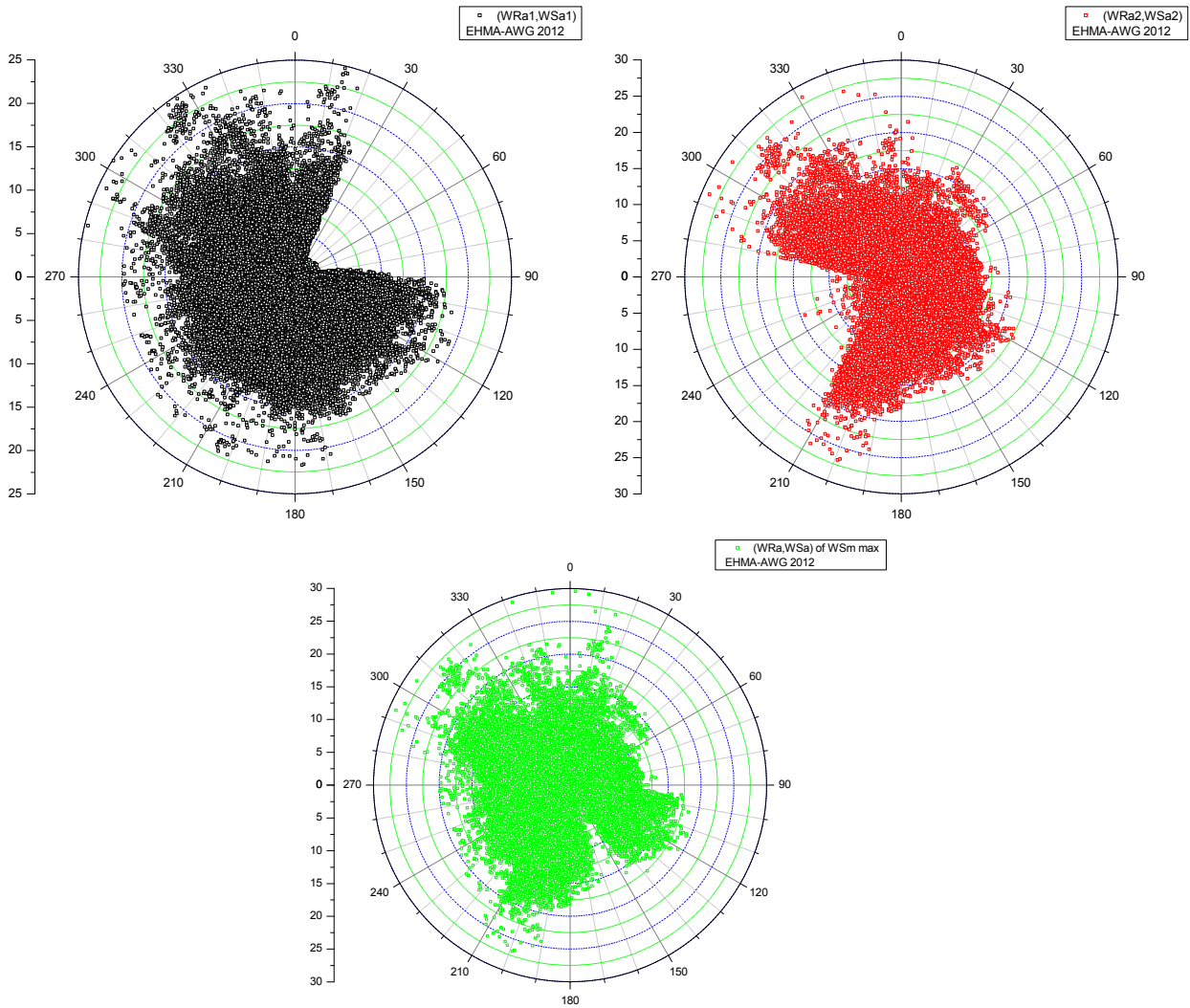


Figure 21: The 10-minute averaged wind vectors observed at platform AWG in 2012 showing the individual measurements of the dual sensor set (top) and the selected sensor (bottom).

Another selection mechanism that has been considered uses the wind direction to determine which sensor set should be used. Consider for example the 1-minute averaged wind direction reported by sensor 2. When the direction indicates that the sensor 1 is upwind of the vent stack the measurements of sensor 1 are used, otherwise sensor 2 is used. The wind sector that is used to determine whether sensor 1 can be used can be varied from small ($\pm 45^\circ$), extended ($\pm 60^\circ$), to full ($\pm 90^\circ$). Increasing the wind sector reduces the enhanced occurrence of directions around the blocked area, but again the resulting distribution is not smooth (cf. Figure 23). Furthermore the distribution deviates from the one that is obtained when sensor 1 is used to determine when sensor 2 can be used (dashed curves in Figure 23).

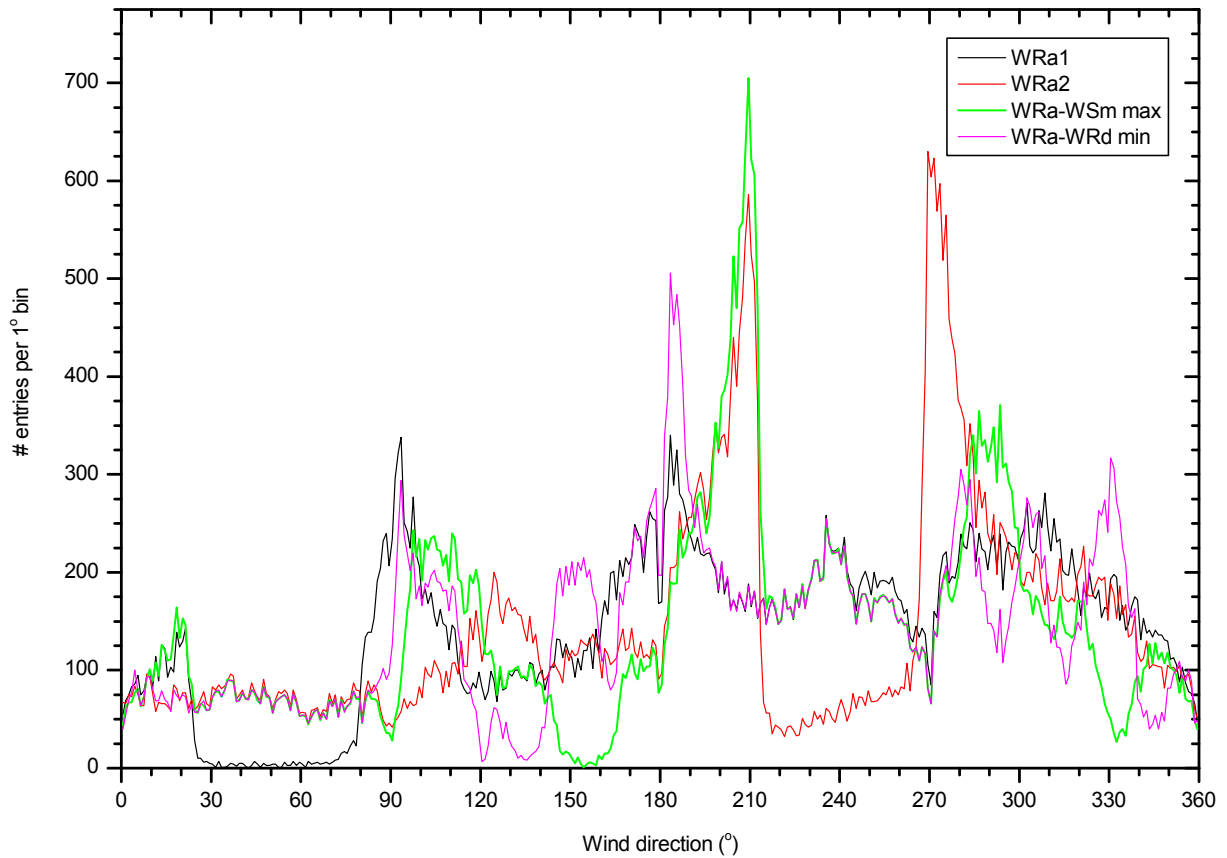


Figure 22: Distributions of the 10-minute averaged wind directions observed at platform AWG in 2012 showing the individual and the selected measurements.

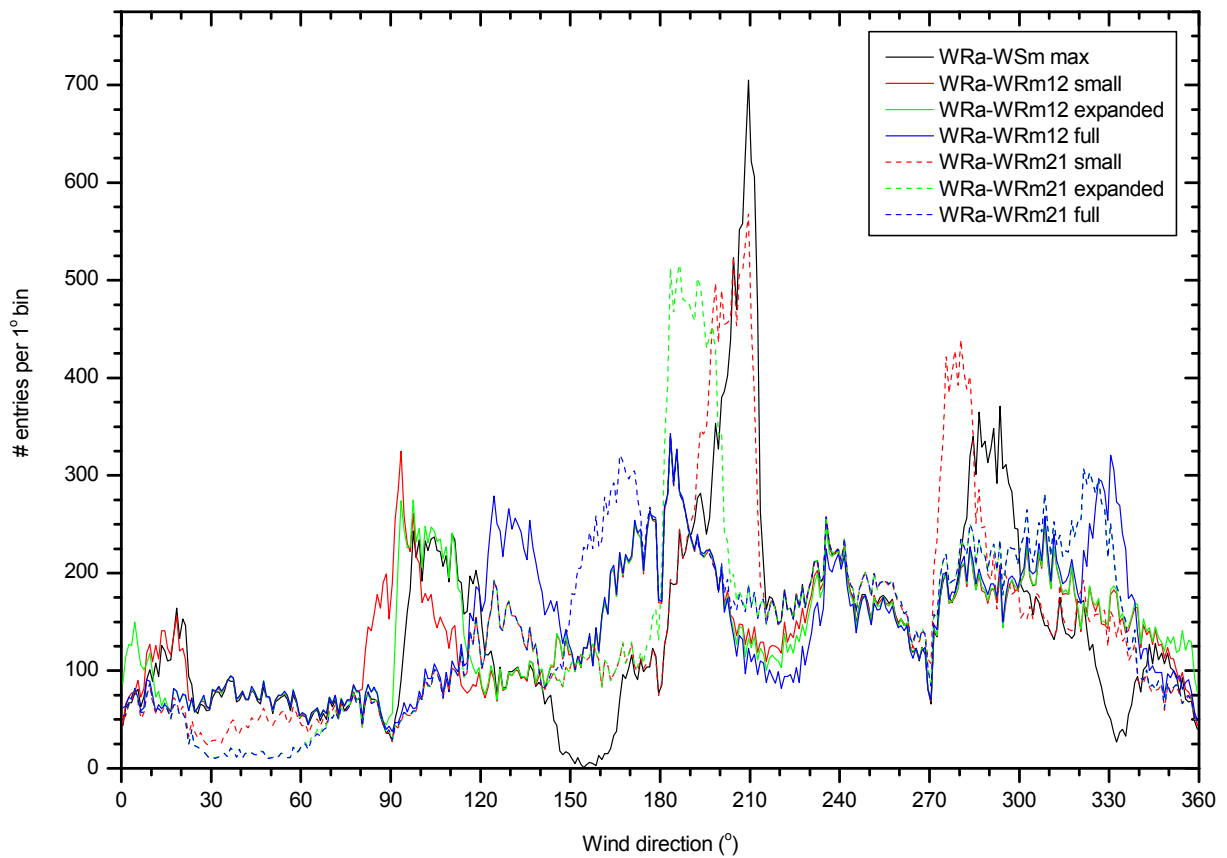


Figure 23: Distributions of the 10-minute averaged wind directions observed at platform AWG in 2012 showing results of various selection methods.

The differences between the 1-minute averaged wind directions reported by both sensors on platform AWG are shown as a histogram in Figure 24. The distribution is much broader than for platform F3 and differences in direction up $\pm 180^\circ$ occur. The distribution has an offset of -12° , the full width at half maximum is 44° and the standard deviation is 44° . Most noticeably the distribution is bi-modal with peaks at -22 and $+12^\circ$. Figure 25 shows a scatter plot of the differences in wind direction as a function of the wind direction. The graph shows all entries (black symbols); the entries when the wind speed of sensor 1 exceeds 5 m/s (red); and when the wind speeds of both sensors exceed 5 m/s (blue). The data on the slant lines are the situations when the direction of sensor 1 varies, but sensor 2 is fixed, while the data on vertical lines pertains to situations with sensor 1 fixed and sensor 2 varying. In these situations the wind vane that is in the wake of the vent stack is varying. Situations with a wind vane in the wake of the vent stack rotating over 360° have been observed. The bi-modal behaviour of the differences in wind direction is related to different wind sectors between 90 and 190° and 270 and 10° . The ratios of the 1-minute averaged wind speeds reported by both sensors are shown as a scatter plot in Figure 26 as a function of the wind direction. The wind speeds of both sensors are nearly identical between 110 and 190° and between 300 and 20° but the ratio decreases with direction in the first region and increases in the second. For the other directions one of the wind sensors is affected by the vent stack and the ratio can increase to a factor of 5 or more.

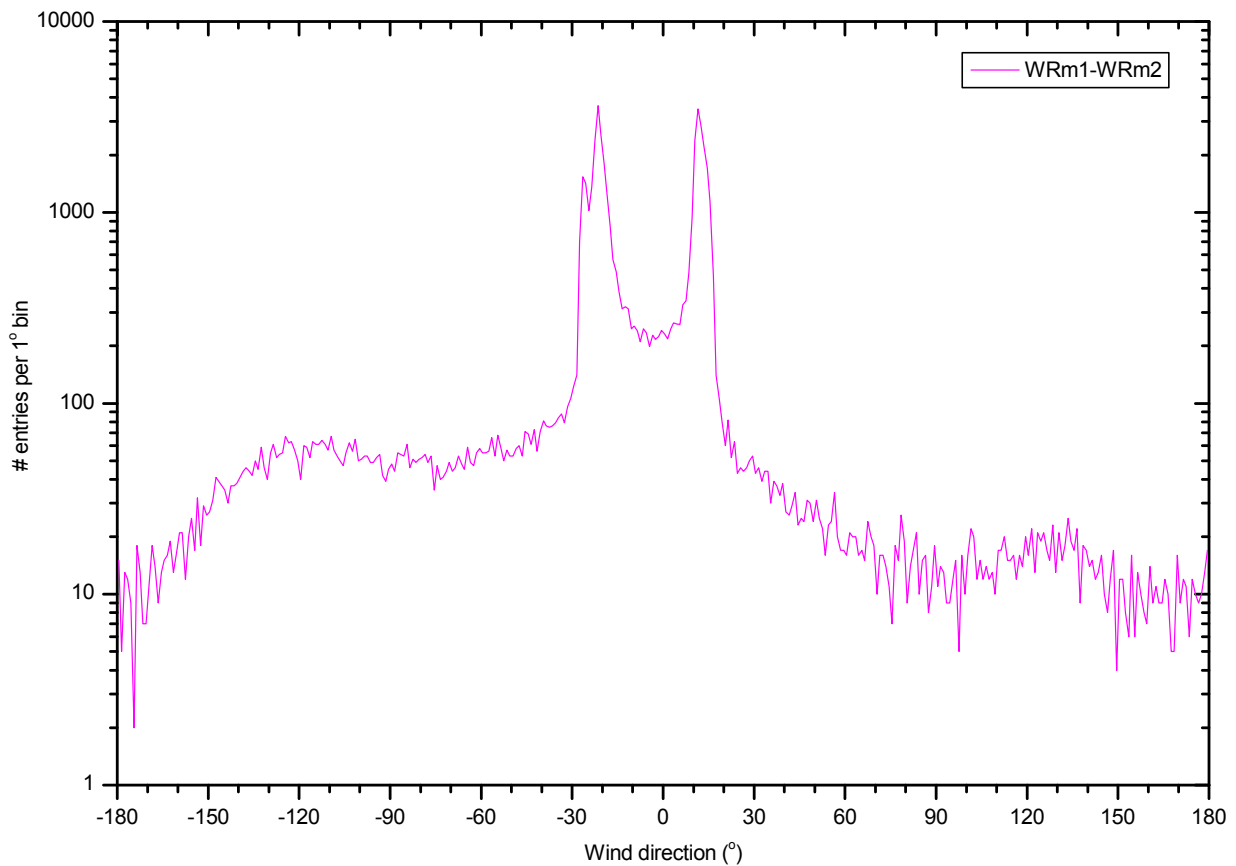


Figure 24: A histogram of the differences of the 1-minute averaged wind directions measured by the two wind vanes at platform AWG in 2012.

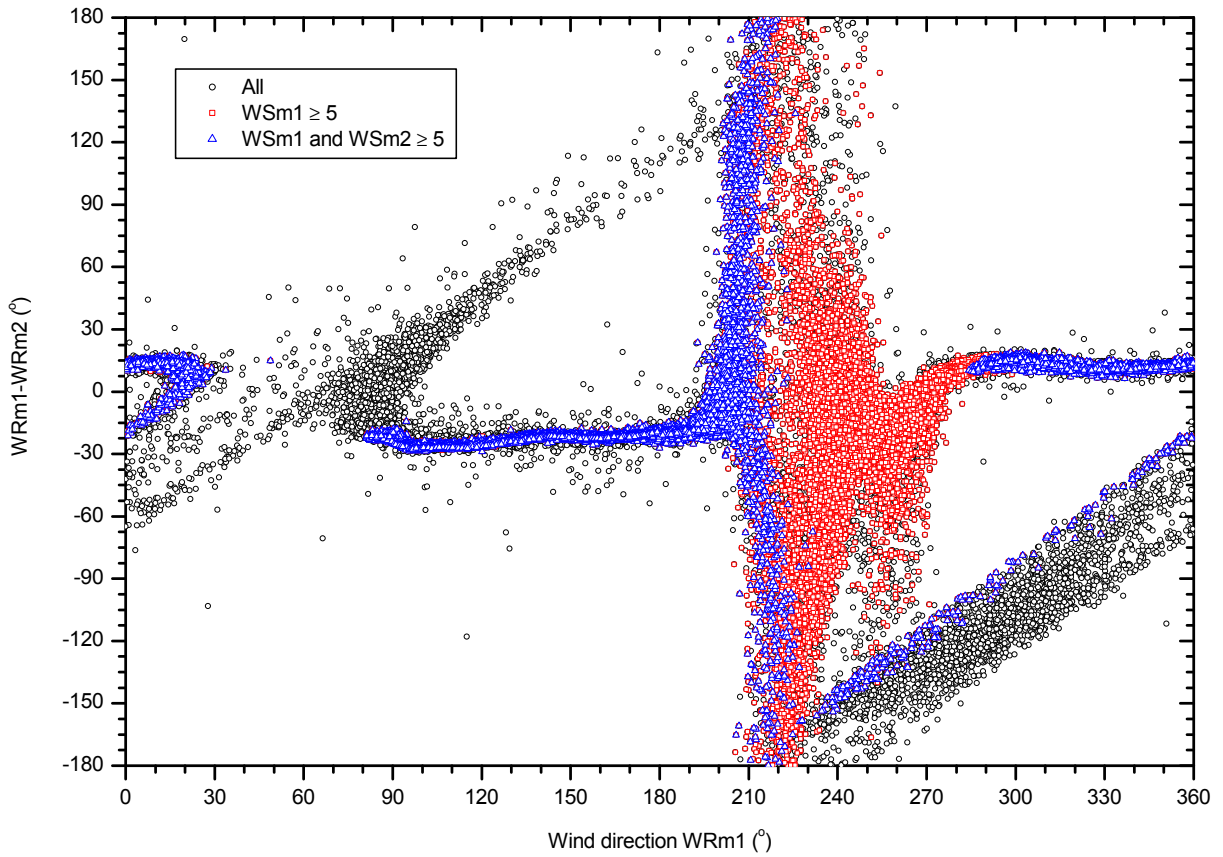


Figure 25: Scatter plot of the ratio of the 1-minute averaged wind directions measured by the two wind vanes at platform AWG in 2012 as a function of the wind direction.

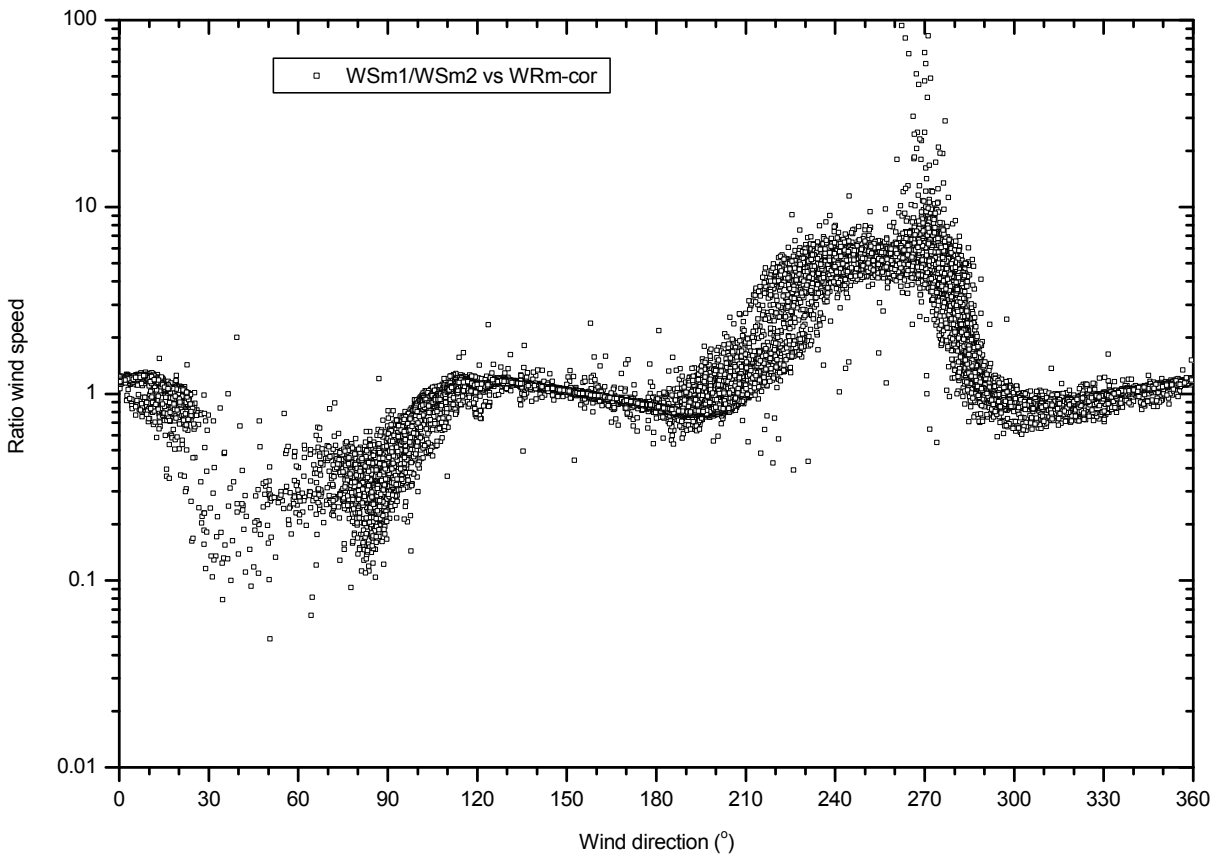


Figure 26: Scatter plot of the ratio of the 1-minute averaged wind speeds measured by the two cup anemometers at platform AWG in 2012 as a function of the wind direction.

It can be expected that the wind measurements on the vent stack are affected by the vent stack, even the upwind sensor. In case of laminar flow the expected wind field is given by the potential flow around a circular cylinder. Figure 27 shows the potential flow around a circular cylinder and the expected deviations in wind direction and speed as a function of the relative distance from the circular cylinder and the direction. The wind is coming from the left. The differences are symmetric. Hence when the wind sensors are mounted at exactly opposite sides of the mast (180° apart) their deviations are identical and the differences in speed and direction are zero. Differences occur when the sensors are not installed symmetrically on the vent stack. Figure 28 shows the differences in wind speed and direction that occur between sensors at a relative distance of 1.5 when they are 180° (at opposite sides of the vent stack) to 90° apart. The wind direction and speed show large differences when the sensors are not exactly opposite and the differences vary with the orientation of the sensor with respect to the wind direction. Note that the vent stack at AWG has a diameter of nearly 2 m, the platform on which the sensor are mounted has a diameter of about 4 m while the sensors are 6 m apart. Hence the relative distance of the sensors to the mast is 3, and 1.5 with respect to the platform.

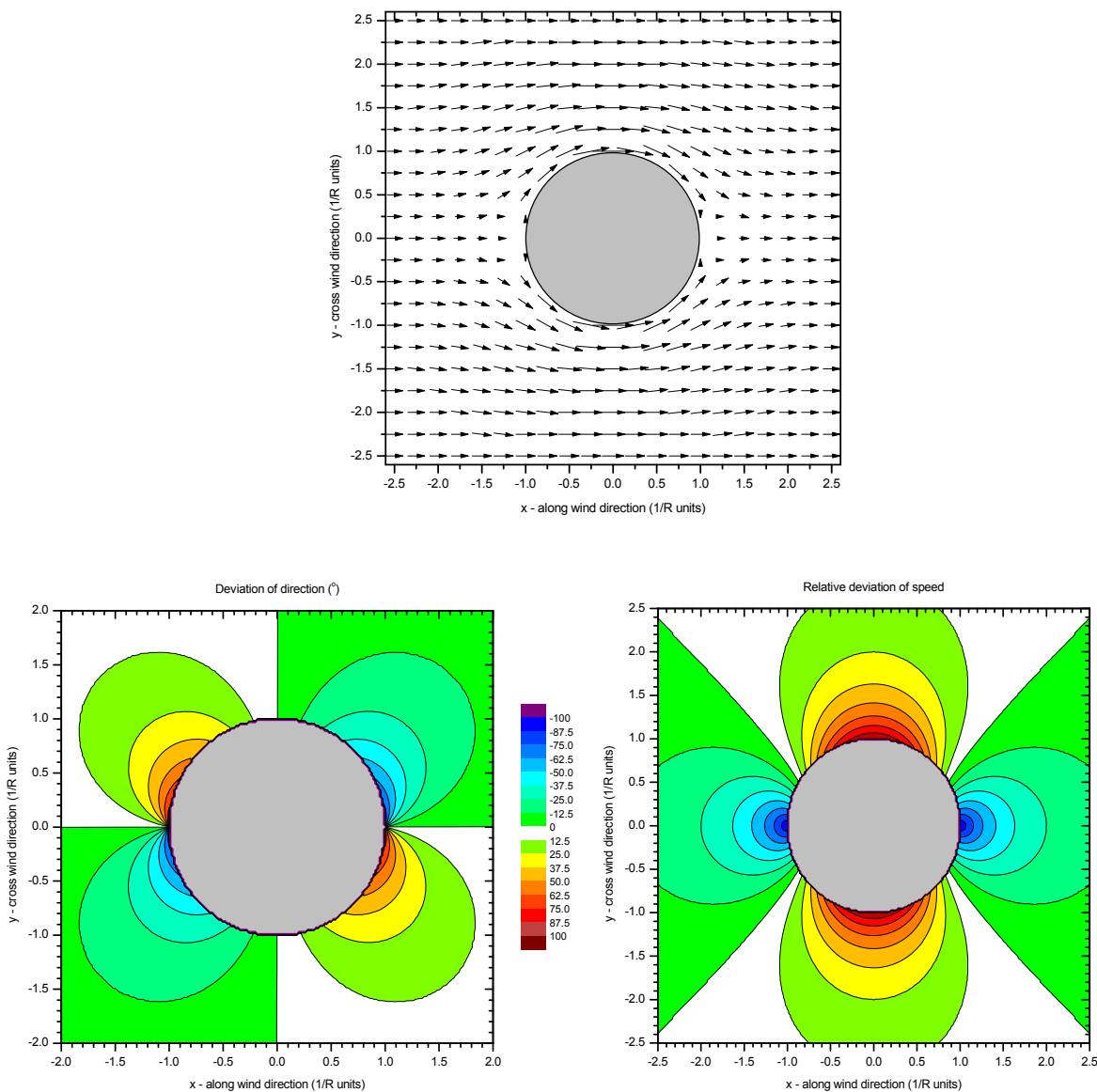


Figure 27: Potential flow around a circular cylinder (top) and the resulting change in wind direction (bottom left) and speed (bottom right).

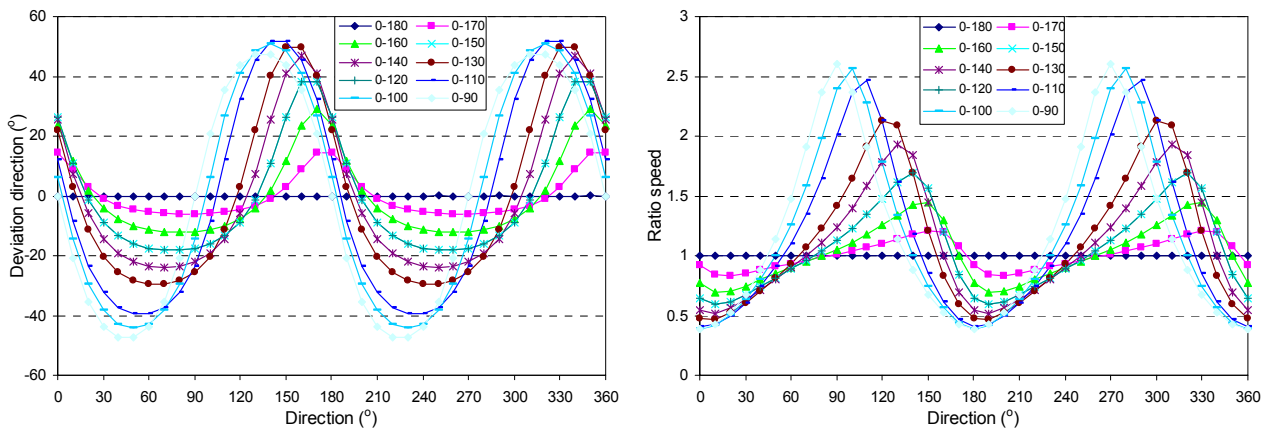


Figure 28: The differences in wind direction and speed between sensors mounted directly opposite and at other angles in a potential flow around a circular cylinder at $r/R = 1.5$.

B.4. SUMMARY AND CONCLUSIONS OF WIND MEASUREMENTS ON PLATFORMS

The wind measurement on platforms can be of good quality when there are no obstructions nearby. This is for example the case when the wind is measured on a 10 m mast on the helideck. In case a double wind sensor set is used, the primary cup anemometer is disturbed by the nearby backup sensor when it is in its wake. In these situations the wind speed is affected over a wind direction range of about 40° and the speed reported by the shaded anemometer is reduced up to about 20 %. The wind directions reported by the primary and of the backup vane are always very close. In these situations the wind direction should be used to determine which anemometer should be used.

Measuring the wind on a vent stack ensures that there are no obstructions except the vent stack itself. KNMI currently uses a dual wind sensor setup and a sensor selection to determine which sensor set should be used. The selected sensor gives an unrealistic distribution of wind directions with peaks and dips. The differences between the two wind direction measurements show a bi-modal distribution and the ratio of the wind speeds varies over the full angular range. The observed differences cannot be explained a laminar flow around a circular cylinder. The assumption of laminar flow is generally not the case expect for very low wind speeds. Also the assumption that the vent stack is a perfect circular cylinder is not always valid. Hence a more sophisticated description of the potential flow around the vent stack should be used to determine the deviations introduced by the vent stack. Wessels 1985 used such an approach to correct the wind measurements obtained form the 213 m meteorological tower at Cabauw, but there the relative distance to the mast was 10 r/R and three wind vanes, 120° apart, are used to select one of the two cup anemometers. This approach will probably not work in the setup using only 2 wind sensors very close to the mast. Possibly CFD calculations or wind tunnel measurements are required to get accurate estimations of the deviations in wind speed and direction that can be used to select and correct the measured wind on the vent stack.

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