ON THE SPATIAL REPRESENTATIVENESS OF OBSERVATIONS AT SCHIPHOL AIRPORT AND APPLICATION TO PREVAILING VISIBILITY

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ABSTRACT

KNMI employs 24 Vaisala FD12P Present Weather Sensor (PWS) at Amsterdam Airport Schiphol. The differences between the visibility and precipitation intensity measurements of any two of such sensors as a function of distance is analyzed. The standard deviation of the differences or the standard error of the linear fit and the correlation coefficient show a clear dependency on distance. The distance dependency is largest at small distances and decreases with distance. The 10-minute average precipitation intensity shows levelling off at about 15 km. The distance dependency is also evident in the POD and FAR for the occurrence of specific events, but one has to be careful that the results are not affected by local climatological conditions.

The visibility sensors at Schiphol are used to determine the so-called prevailing visibility. This is compared to the visibility reported by the observer in the METAR. This shows that the median visibility of the sensors gives better results than any of the individual sensors. The agreement is further improved by giving each sensor a weight that is the reciprocal of its distance to the observer. Note that although the use of multiple sensors gives better results than using a single sensor, even the median of all available visibility sensors at Schiphol and the application of a weight leaves significant deviations between observed and derived prevailing visibility. Fog indicated by the sensors but not reported as prevailing visibility by the observer is generally reported as shallow or partial fog or fog patches. During these situations the median sensor visibility is probably not considered representative for the conditions at the aerodrome.

1. INTRODUCTION

KNMI employs the Vaisala FD12P Present Weather Sensor (PWS) as visibility sensor along the runways of Amsterdam Airport Schiphol (EHAM). A CAT III runway requires three visibility sensors, near touchdown, the mid- and the end position (ICAO, 2013). Additional visibility sensors are used in case the runway is long, in case of a displaced threshold, or when the meteorological conditions require it. Furthermore, five so-called fog stations at a distance of about 10 to 30 km around Schiphol are equipped with a visibility sensor. Fog station Voorschoten is available from June 13, 2014 onwards and is not considered here. In total, 24 PWSs are in use at Schiphol. An overview of the runway system at Schiphol and the FD12P sensors along the runways is given in Figure 1. The direction and distance to the five fog stations around Schiphol is also indicated. Note that the FD12P Present Weather Sensor measures not only the visibility (specifically the Meteorological Optical Range, MOR), but also the precipitation intensity, the precipitation type and, for each FD12P located at touchdown or end position of the runway and at the fog stations, also the background luminance.

The fact that so many FD12P sensors are located at Schiphol allows studying the differences between the measurements of two such sensors as a function of distance. In addition, the visibility sensors at Schiphol are used to investigate different way to determine the prevailing visibility, i.e. the greatest visibility value that is reached within at least half the horizon circle or within at least half of the surface of the aerodrome. The prevailing visibility obtained from the visibility sensors is compared to that reported by the observer.

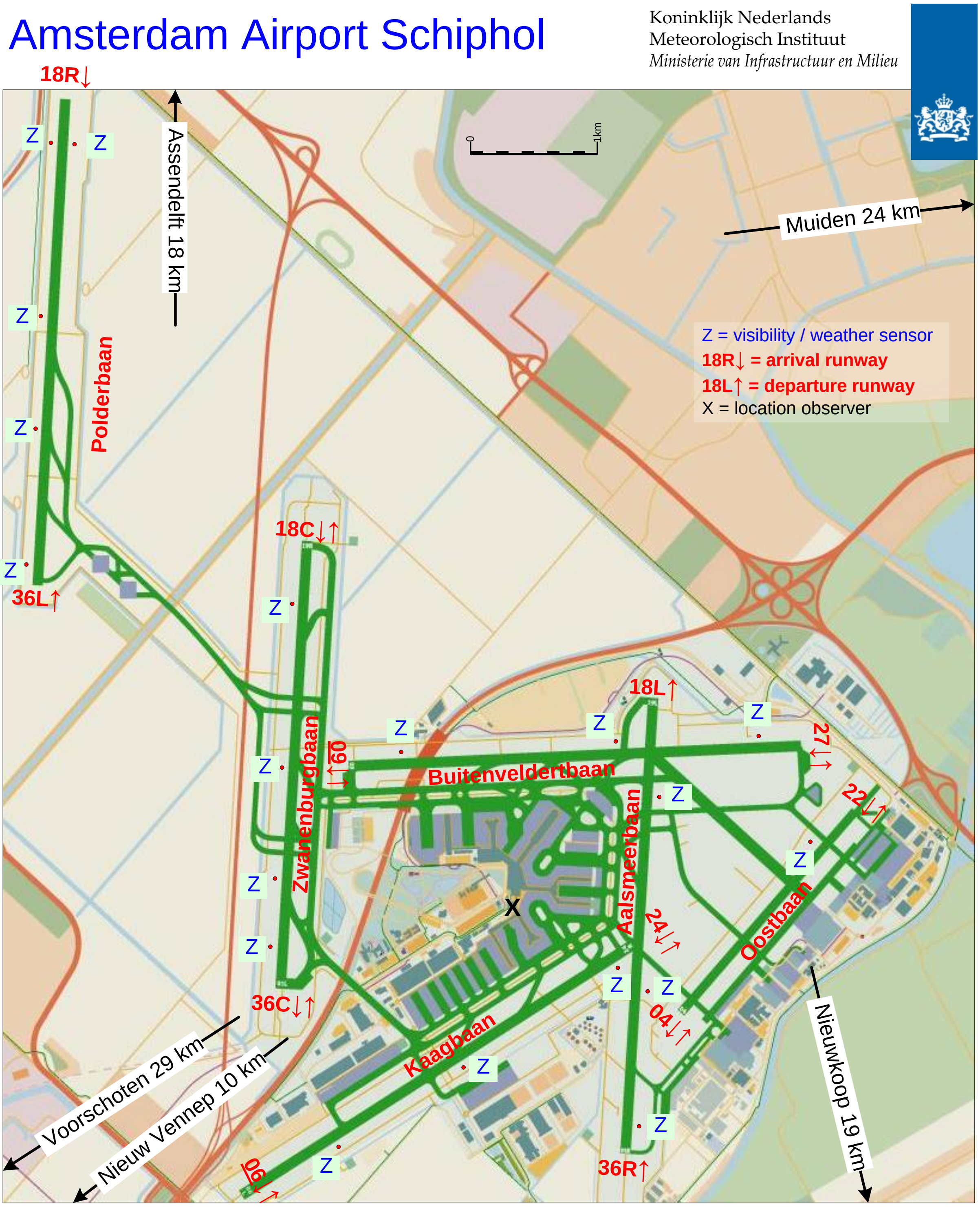


Figure 1: Overview of the available runways at Amsterdam Airport Schiphol and the locations of the FD12P Present Weather Sensors.

2. ANALYSIS OF VISIBILITY (MOR) VERSUS DISTANCE

The 10-minute averaged MOR reported by all FD12P sensors at Schiphol in 2012 is considered. The MOR data can be compared directly to each other or by comparing each to a selected sensor or some suitable "reference". For the latter the median of all individual MOR values at each 10-minute interval is considered. Taking the median of all individual MOR values corresponds to the so-called prevailing visibility. The analysis of the MOR data can be performed by considering the differences between the 10-minute averaged visibility (MOR) of each FD12P sensor and the MEDIAN. Characteristics of these differences for all the FD12P sensors at Schiphol are studied as a function of the distance. The reference point is the median of the locations of the FD12P sensors at the aerodrome itself (excluding the sensors at the fog stations). This reference point is about 375 m east of the FD12P sensor at the mid position along runway 18C-36C and about 535 m west of the sensor near 09 touchdown. The average, standard deviation, median and the skewness of the differences between the 10-minute averaged visibility (MOR) of each FD12P sensor at Schiphol versus their MEDIAN are shown in Figure 2 as a function of the distance. The average, standard deviation and median are reported in m with the scale on the left, the skewness uses the scale on the right. The average, median and skewness show no clear dependency with distance (at 95 % confidence level) and have correlations of 0.05, 0.02 and 0.10, respectively. The variability of these parameters for the sensors at the aerodrome itself is large. This is probably partly caused by differences in local conditions. The results of the standard deviation show a dependency on distance. The standard deviation and thus the width of the frequency distribution of the differences between the 10-minute averaged visibility (MOR) of a FD12P sensor and the MEDIAN generally increases with distance. When all FD12P sensors are considered the slope is 221±16 m/km with the intercept at 3149±129 m and a correlation of 0.90. When only the sensors at aerodrome itself are considered, with distances up to 5 km, the slope is 366±86 m/km with the intercept at 2771±259 m and a correlation of 0.52. The linear regression line is a good fit for the data with a 99.9% confidence level and also for the dependency on the distance.

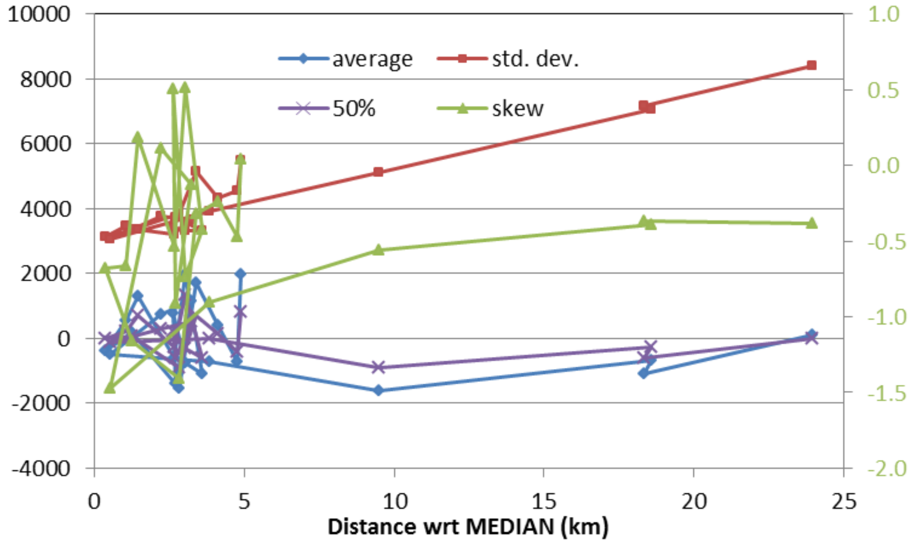


Figure 2: The average, standard deviation, median (50% percentile) and skewness of the differences between the 10-minute averaged visibility (MOR) of each FD12P sensor at Schiphol versus the MEDIAN as a function of the distance.

Another way to compare the MOR data is by comparing the individual 10-minute averaged visibility (MOR) reported by a FD12P sensor with the corresponding MEDIAN. Figure 3 gives the slope of the linear regression, the standard error of the linear fit and the correlation coefficient of the 10-minute averaged visibility (MOR) of each FD12P sensor at Schiphol versus the MEDIAN as a function of the distance. The slope and correlation coefficient are reported with the scale on the left, the standard error uses the scale on the right. The standard error of the linear fit shows a clear dependency on the distance. The values for the standard error of the linear fit are close to the standard deviation of the differences given in Figure 2. When all FD12P sensors are considered the slope is 221±16 m/km with the intercept at 3062±127 m and a correlation of 0.90. When only the sensors at aerodrome itself are considered, with distances up to 5 km, the slope is 340±86 m/km with the intercept at 2756±259 m and a correlation of 0.48. The linear regression line is a good fit for the data with a 99.9% confidence level (99.5% when only the sensors at aerodrome itself are considered) and the dependency on distance is significant. The correlation coefficient also shows a dependency on distance with a 99.9% confidence level. When all FD12P sensors are considered its slope is $-11.5\pm0.5*10^{-3}$/km with the intercept at 0.954±0.004 and a correlation of 0.96. When only the sensors at aerodrome itself are considered, with distances up to 5 km, the slope is $-11.9\pm2.5*10^{-3}$/km with the intercept at 0.958±0.007 and a correlation of 0.57. The slope of the linear regression shows no dependency on the distance (at 95 % confidence level) and the correlation is 0.15.

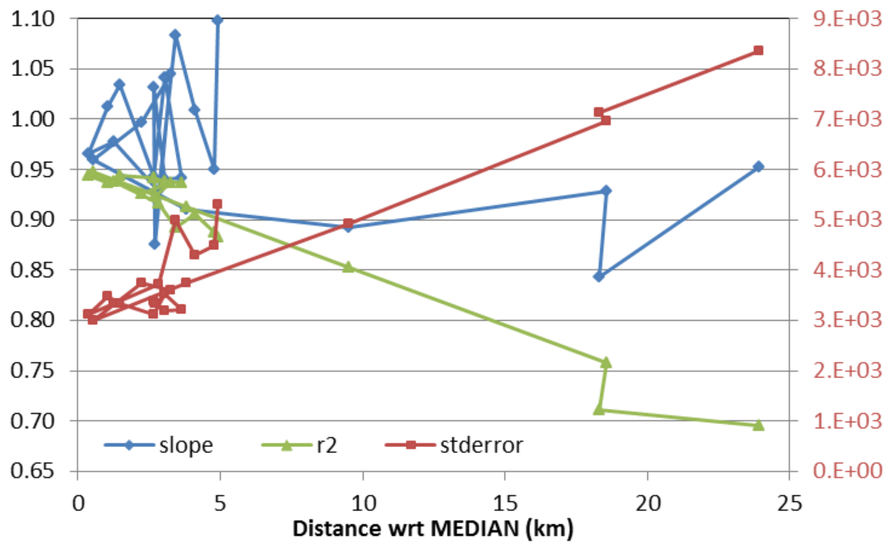


Figure 3: The slope of the linear regression, the standard error of the linear fit and the correlation coefficient of the 10-minute averaged visibility (MOR) of each FD12P sensor at Schiphol versus the MEDIAN as a function of the distance.

The distribution of the differences of the 10-minute averaged visibility reported by the FD12P sensor and the MEDIAN cannot always be adequately expressed in terms of averaged values and the standard deviation. The range of the visibility values in combination with the spatial variability of visibility makes such an approach unsuitable. The aeronautical community is only interested in visibility values up to 10 km. Low visibility values are important since they affect the operations at an airport. The critical aeronautical visibility thresholds are 800, 1500, 3000, 5000 and 8000 m. In addition, the threshold of 1000 m for fog and the reporting threshold of 10 km are considered. The performance in these situations is often expressed in scores such as the probability of detection (POD) and the false alarm rate (FAR) that are related to the occurrence or not of specific events. Figure 4 shows the POD, FAR and BIAS for MOR below 1000 m obtained for each FD12P versus the MEDIAN as a function of the distance. The POD for fog has an intercept of 89 % and decreases by −0.5 % per km, the FAR has an intercept of 16 % and increases by 2.5 % per km and the BIAS has an intercept of 96 % and decreases by −2.6 % per km. The linear fits to all these scores have a 99.9% confidence level. When only the FD12P sensors at the aerodrome itself are considered (distance less than 5 km) the linear fit to the POD has a confidence level of less than 95%. Hence the POD of fog shows no dependency on the distance when only the FD12P sensors at the aerodrome itself are considered. The linear fit to the FAR and BIAS have a confidence level of 99.9 and 99%, respectively. However, the slope of the linear fit is doubled and the correlation is roughly halved for both compared to the results when all sensors are considered. Figure 4 shows that the FAR and BIAS of the FD12P sensors along the Polderbaan (points within red ellipse) deviate largely from those of the other FD12P sensors. The BIAS is much lower, meaning these sensors report more often fog than the MEDIAN, and the FAR for fog is consequently higher.

The results for the MOR range between 5000 and 8000 m is given in Figure 5. The BIAS shows no significant dependency with distance. The POD and FAR show a dependency (with 99.9 % confidence level) when considering all FD12P sensors and when considering only the sensors at the aerodrome itself. The slopes of the linear fits of the latter are steeper.

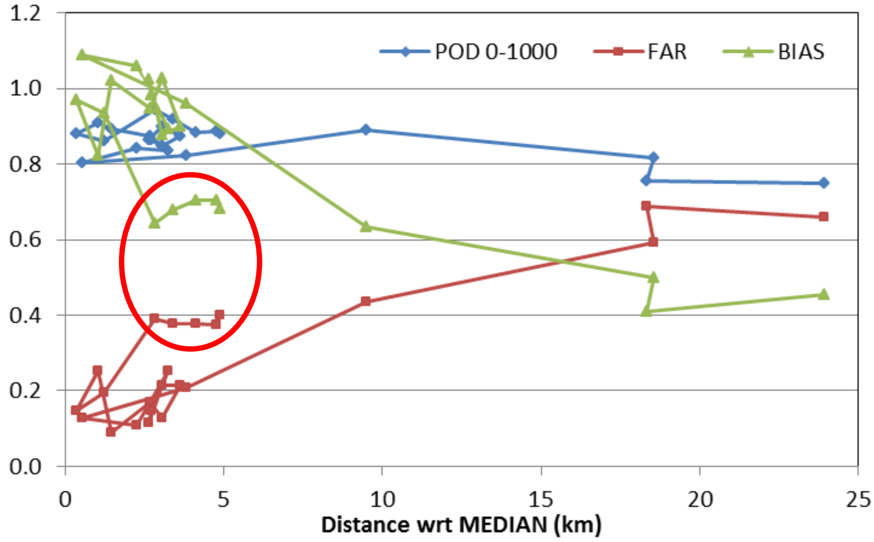


Figure 4: The POD, FAR and BIAS for MOR below 1000 m for the 10-minute averaged visibility (MOR) of each FD12P sensor at Schiphol versus the MEDIAN as a function of the distance.

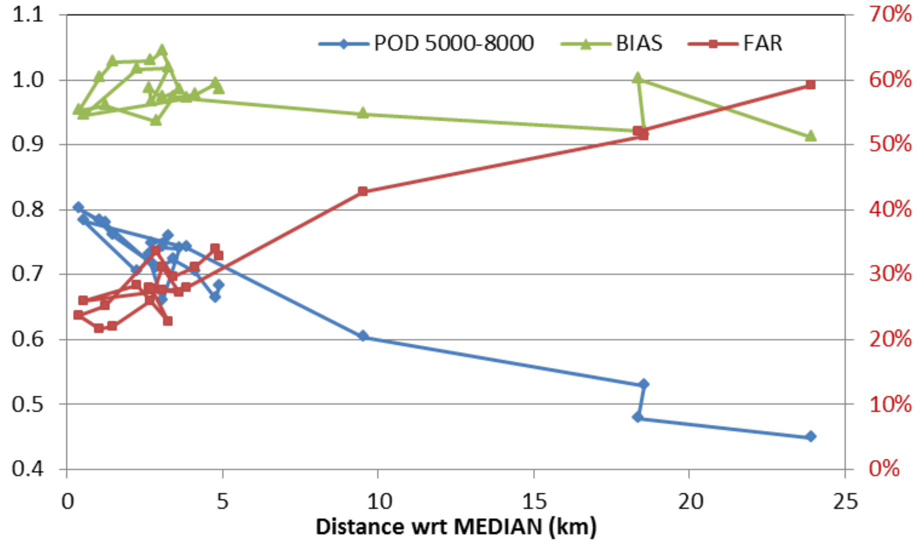


Figure 5: The POD, FAR and BIAS for MOR between 5000 and 8000 m for the 10-minute averaged visibility (MOR) of each FD12P sensor at Schiphol versus the MEDIAN as a function of the distance.

Lastly, the dependency on distance of the standard error of the linear fit, the correlation coefficient and of the POD, FAR and BIAS for MOR below 1000 m and MOR between 5000 and 8000 m are analysed by considering these quantities for each FD12P pair. Hence a total of 23*22 data points is denoted by symbols in Figure 6 for each quantity. The results for the quantities compared to the MEDIAN are given by the corresponding lines. The results obtained by using all FD12P pairs shows the same behaviour as when the MOR of each FD12P is compared to the MEDIAN. Using each FD12P pair shows that the results do not vary linearly with distance, but change more rapidly at small distances. The width of the scatter in the graphs using each FD12P pair can serve as an estimate of the uncertainty. The scatter shows that dependency on distance of the POD and BIAS for MOR below 1000 m is not significant because it is affected by location conditions.

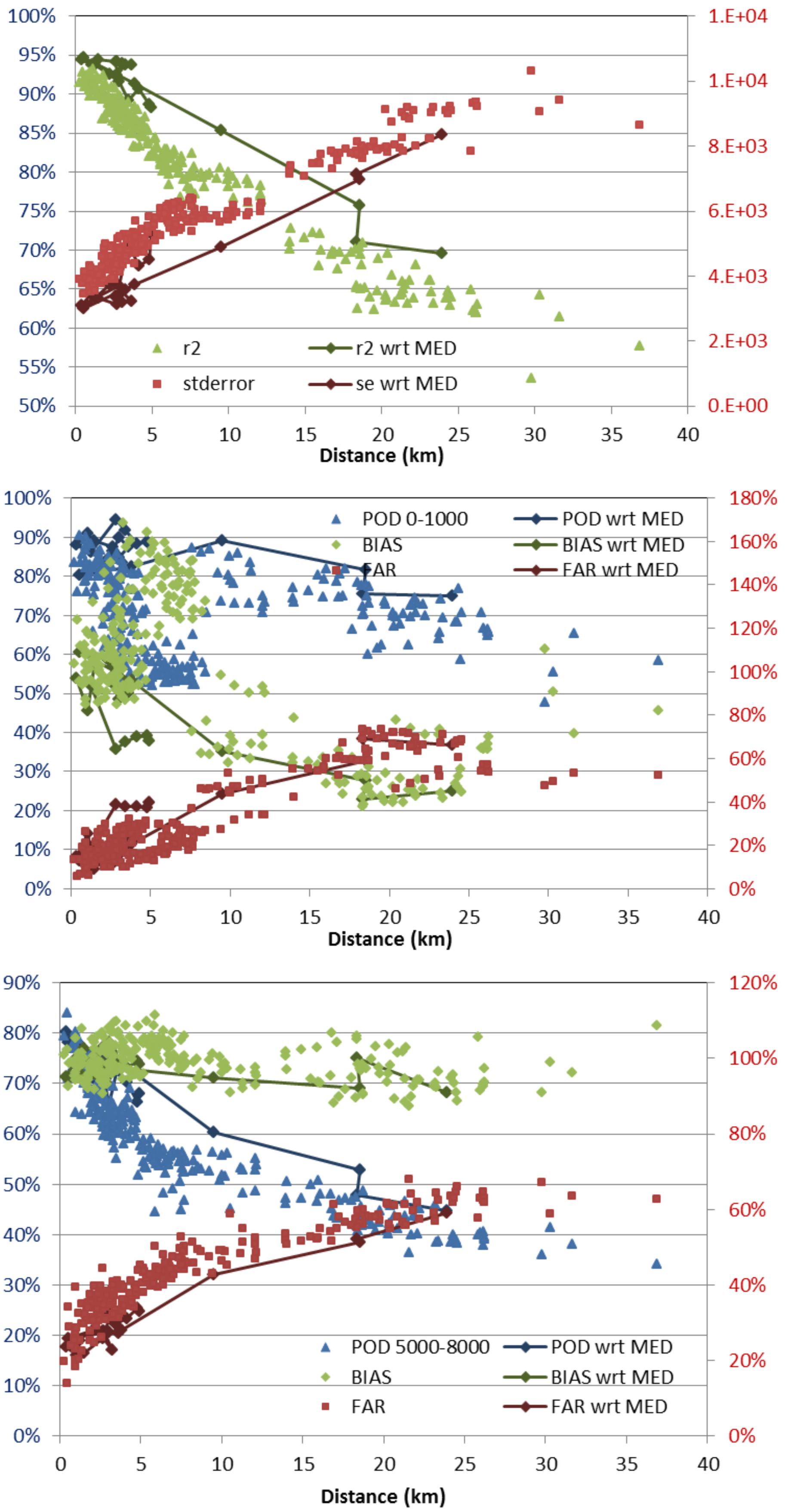


Figure 6: As Figure 3 to Figure 5, but also including the results obtained for each FD12P pair (BIAS now uses the scale on the right).

3. ANALYSIS OF PRECIPITATION INTENSITY VERSUS DISTANCE

Here the 10-minute averaged precipitation intensity reported by all FD12P sensors at Schiphol in 2012 is considered. The precipitation intensity reported by the FD12P cannot easily be calibrated. The manufacturer recommends to place the FD12P in the field next to a calibrated rain gauge and rescale the accumulated precipitation amount of the FD12P to that of the gauge after a suitable amount has been measured. KNMI operates the FD12P without rescaling of the precipitation intensity. The precipitation amounts obtained for the FD12P sensors at Schiphol in 2012 ranges between 510 and 1135 mm with an averaged value of 836 mm and a standard deviation of 144 mm. The precipitation intensity data of each FD12P has been rescaled so that they all give a total amount of 836 mm. Note that in this section only the 10-minute intervals are considered where all FD12P sensors have valid values and at least one of them reports precipitation.

Again the characteristics of the differences between the 10-minute averaged precipitation intensity of the FD12P sensors at Schiphol versus their MEDIAN are studied as a function of the distance. The average, standard deviation, median and the skewness of the differences between the 10-minute averaged precipitation intensity of each FD12P sensor at Schiphol versus the MEDIAN are shown in Figure 7 as a function of the distance. The average, median and standard deviation are reported in mm/h with the scale on the left, the skewness uses the scale on the right. The average and median do not vary between the individual sensors because the intensity has been rescaled. The results of the standard deviation show a dependency on distance. The standard deviation and thus the width of the frequency distribution of the differences between the 10-minute averaged precipitation intensity of a FD12P sensor and the MEDIAN generally increases with distance. When all FD12P sensors are considered the slope is 0.030±0.004 mm/h/km with the intercept at 0.793±0.037 mm/h with a 99.9% confidence level and a correlation of 0.67. When only the sensors at aerodrome itself are considered, with distances up to 5 km, the slope is 0.076±0.020 mm/h/km with the intercept at 0.663±0.059 mm/h with a 99% confidence level and a correlation of 0.47. The skewness also shows a dependency on distance. When all FD12P sensors are considered the skewness decreases by −0.40±0.08 per km with the intercept at 15.1±0.7. The confidence level of the linear fit is 99.9%. The correlation coefficient is 0.53. The skewness has no dependency with distance at the 95% confidence level when only the sensors at aerodrome itself are considered, with distances up to 5 km. The correlation coefficient is 0.14.

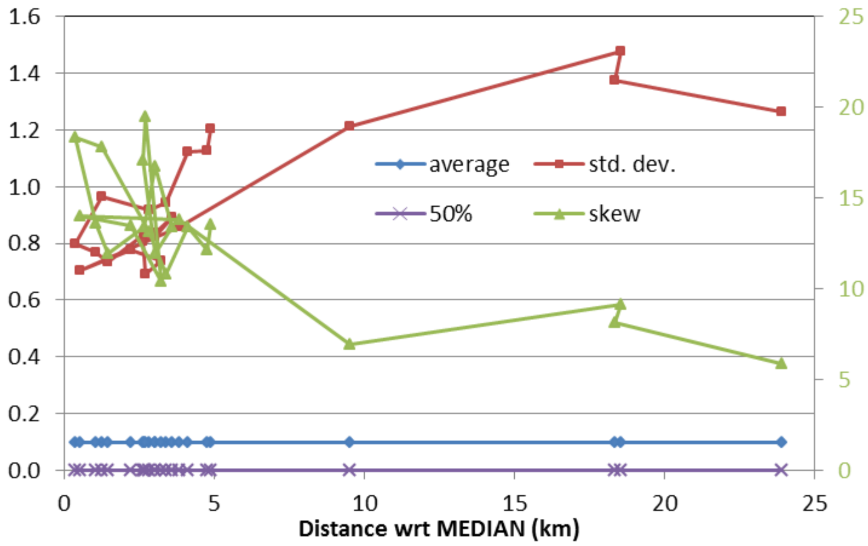


Figure 7: The average, standard deviation, median (50% percentile) and skewness of the differences between the 10-minute averaged precipitation intensity of each FD12P sensor at Schiphol versus the MEDIAN as a function of the distance.

Figure 8 gives the slope of the linear regression, the standard error of the linear fit and the correlation coefficient of the 10-minute averaged precipitation intensity of each FD12P sensor at Schiphol versus the MEDIAN as a function of the distance. The slope and correlation coefficient are reported with the scale on the left, the standard error uses the identical scale on the right. All three variables shows a clear dependency on the distance with a 99.9% confidence level (99% for the slope when only the sensors at aerodrome itself are considered). When all FD12P sensors are considered the slope decreases by −0.04±0.00 (−0.08±0.02) per km with the intercept at 1.31±0.04 (1.40±0.06) and a correlation of 0.82 (0.42). The standard error increases by 0.03±0.00 (0.08±0.02) per km with the intercept at 0.77±0.04 (0.62±0.06) and a correlation of 0.59 (0.48). The correlation coefficient decreases by −0.03±0.00 (−0.08±0.02) per km with the intercept at 0.66±0.03 (0.79±0.05) and a correlation of 0.73 (0.52). The number between brackets indicate the values when only the sensors at aerodrome itself are considered. The slopes of the dependency on distance become steeper when only the sensors at aerodrome itself are considered. Figure 8 shows that the variables do not exactly vary linearly with distance, but level off at the larger distances. Figure 8 also shows that results for the FD12P sensors along the “Polderbaan” deviate from that of the other sensors at the aerodrome, but their dependency with distance is roughly the same.

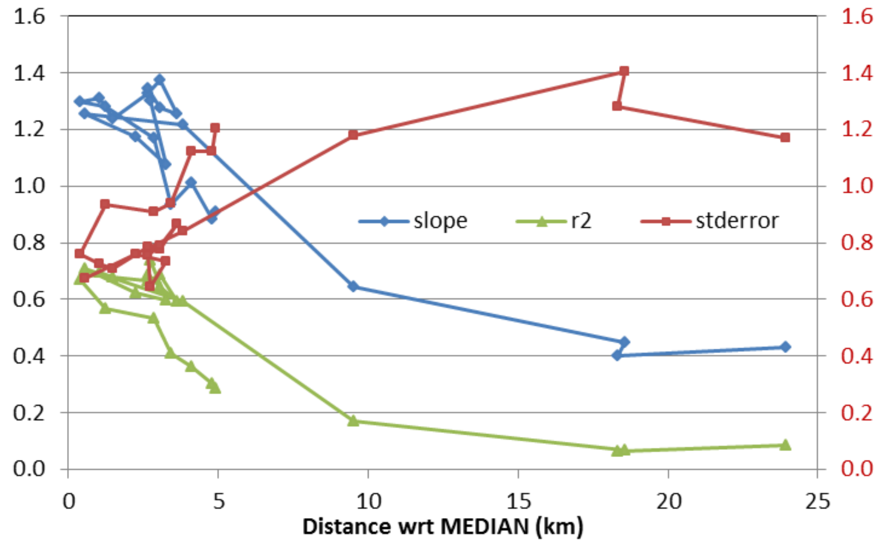


Figure 8: The slope of the linear regression, the standard error of the linear fit and the correlation coefficient of the 10-minute averaged precipitation intensity of each FD12P sensor at Schiphol versus the MEDIAN as a function of the distance.

The performance for specific precipitation events is considered next. The events are precipitation detection (yes/no) without (intensity exceeding zero) and with the WMO threshold (intensity equal to or exceeding 0.03 mm/h); light precipitation (intensity equal to or exceeding 0.03 mm/h and below 2.5 mm/h); moderate precipitation (intensity between 2.5 and 10 mm/h) and heavy precipitation (intensity equal to or exceeding 10 mm/h). The performance for these situations is again expressed in the probability of detection (POD), the false alarm rate (FAR) and the BIAS. Figure 9 shows the POD, FAR and BIAS for precipitation detection using the WMO threshold of 0.03 mm/h for each FD12P versus the MEDIAN as a function of the distance. The BIAS of the 10-minute averaged precipitation intensity of each FD12P sensor at Schiphol against the MEDIAN shows no dependency on distance at the 95% confidence level for all intensity classes. This is true when all FD12P sensors are considered or when only the sensors at the aerodrome itself are considered. The average precipitation intensity is identical due to the rescaling of the results. The BIAS is nearly always below unity and decreases with increasing intensities in the class, but this is the result of comparing the sensors to the MEDIAN. The variation in the intercept is relatively small for all intensity classes indicating that the FD12P sensors have no significant mutual deviations as a function of intensity. Note, however, that there not that many events in the heavy intensity class, whereas violent precipitation (intensity exceeding 50 mm/h) did not occur only once for any sensor. The POD and FAR have a dependency on distance for all intensity classes. The confidence level is 99.9% when all FD12P sensors are considered. The POD for precipitation detection (with WMO threshold) decreases by −1.4±0.1 % per km. The same value is obtained for light precipitation which contains the bulk of the data. The slope becomes steeper for moderate and heavy precipitation. The FAR for precipitation detection (with WMO threshold) increases by 1.3±0.1 % per km. The same value is again obtained for light precipitation, but the slope hardly changes for moderate and heavy precipitation. The FAR for moderate and heavy precipitation is rather poor. When only the sensors at the aerodrome itself are considered the confidence level is less, but POD and FAR still show a dependency on distance. The slopes of POD and FAR become steeper for all intensity classes when only the sensors at the aerodrome itself are considered.

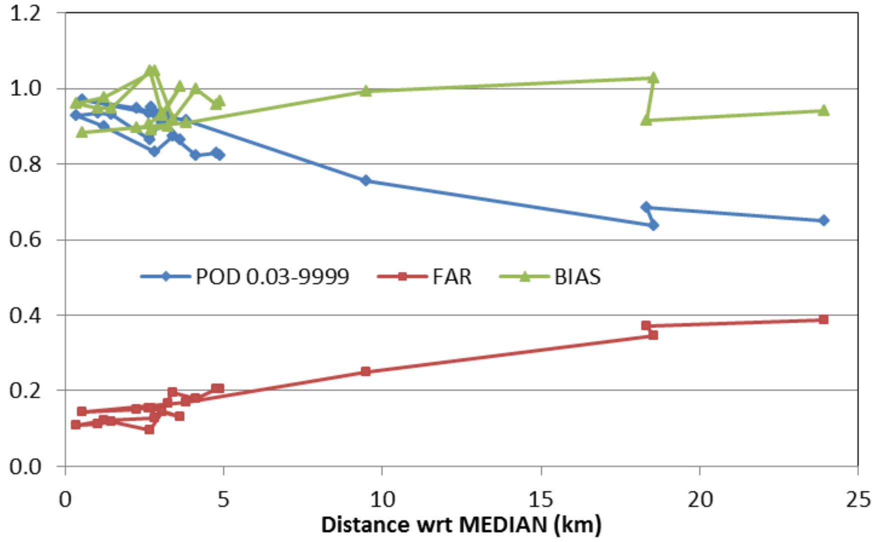
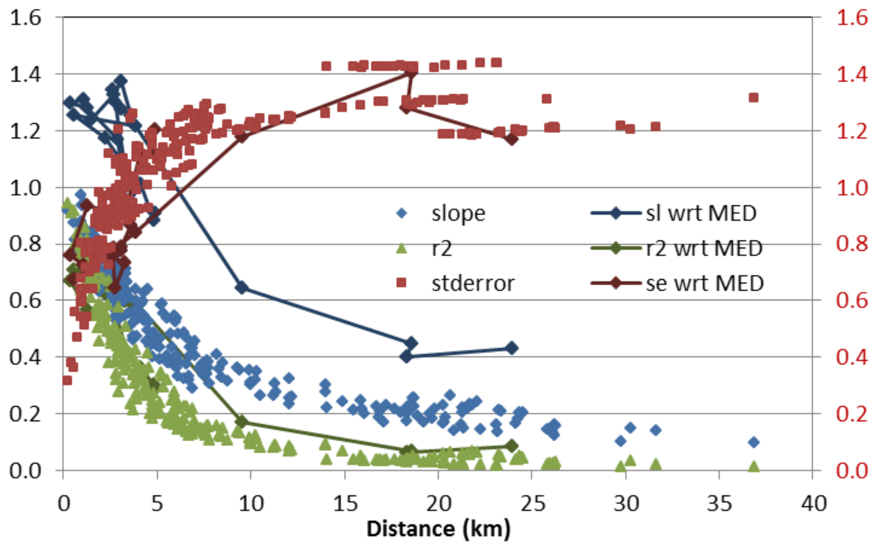


Figure 9: The POD, FAR and BIAS for precipitation detection for the 10-minute averaged precipitation intensity of each FD12P sensor at Schiphol versus the MEDIAN as a function of the distance.



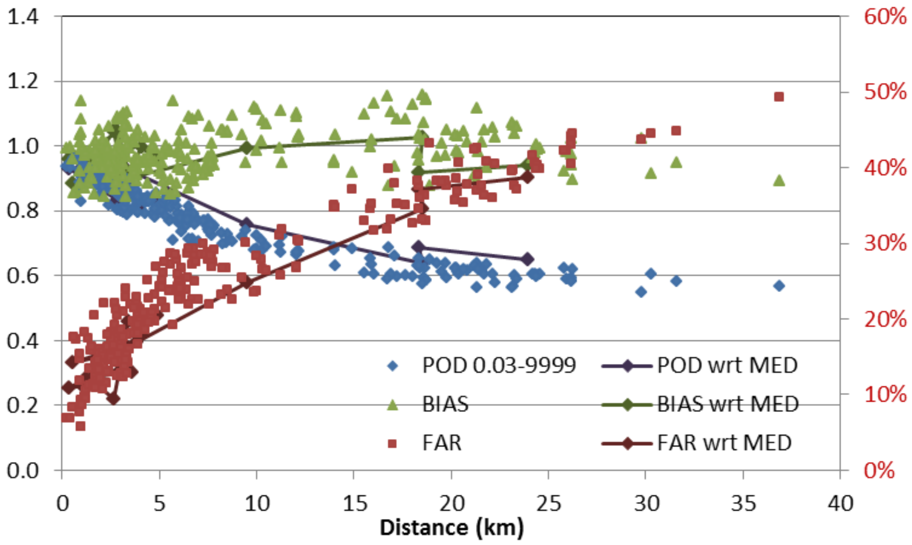


Figure 10: As Figure 8 and Figure 9, but also including the results obtained for each FD12P pair (BIAS uses the scale on the left).

The dependency on distance of the slope and standard error of the linear fit, the correlation coefficient and of the POD, FAR and BIAS for precipitation detection is analysed by considering these quantities for each FD12P pair. Figure 10 shows the results for the quantities obtained by each FD12P pair (symbols) and the results when compared to the MEDIAN are given by the corresponding lines. The results obtained by using all FD12P pairs shows the same behaviour as when the precipitation intensity of each FD12P is compared to the MEDIAN. The only significant difference is for the slope of the linear fit where the usage of the MEDIAN as reference introduces an offset. The offset in the slope also occurs, albeit a bit less, when the precipitation intensity of the sensors are compared to the average of all sensors.

4. SENSOR VISIBILITY VERSUS METAR VISIBILITY

The visibility sensors are used to determine the Runway Visual Range (RVR) and the aeronautical visibility (VIS) which are included in the local routine and local special reports. The visibility values reported in the local reports are representative for the conditions near touchdown and along the runways in use. The visibility (VIS) that is representative for the aerodrome is reported by the observer in the METAR. The visibility that is reported in the METAR is the so-called prevailing visibility, i.e. the greatest visibility value that is reached within at least half the horizon circle or within at least half of the surface of the aerodrome. When the visibility sensors are assumed to be homogeneously distributed over the relevant horizon circle or area of an aerodrome the prevailing visibility is the median of the visibilities reported by all sensors. The fact that so many visibility sensors are located at Schiphol allows studying the differences between the prevailing visibility reported by the observer and obtained by sensors. Also the impact of the number of visibility sensors used for deriving prevailing visibility can be investigated.

The visibility reported in the METAR of Schiphol is extracted from an archive. The half hourly METAR is generated using sensor data at HH+20 and HH+50. The observer can then enter the visibility and other information before submitting the report. The time stamp of the METAR is HH+25 and HH+55. The FD12P measures the MOR and the background luminance. These two variables are used in combination with a fixed lamp intensity of 1000 cd to calculate the aeronautical visibility (VIS). VIS is generally a 10-minute averaged value, but the interval is reduced in case of a sudden characteristic change, a so-called marked discontinuity. The processed visibility data at HH+20 and HH+50 (so visibility averaged over HH+10 to HH+20 and HH+40 to HH+50) are compared with the METAR visibility. METARs and sensor data of 2010 to 2014 are considered for that purpose. Note that visibility is reported using a bin width of 100 m up to 5000 m and 1000 m for higher visibility values. Visibility is rounded down to the nearest visibility bin. Visibility values of 10 km and more are denoted as 9999.

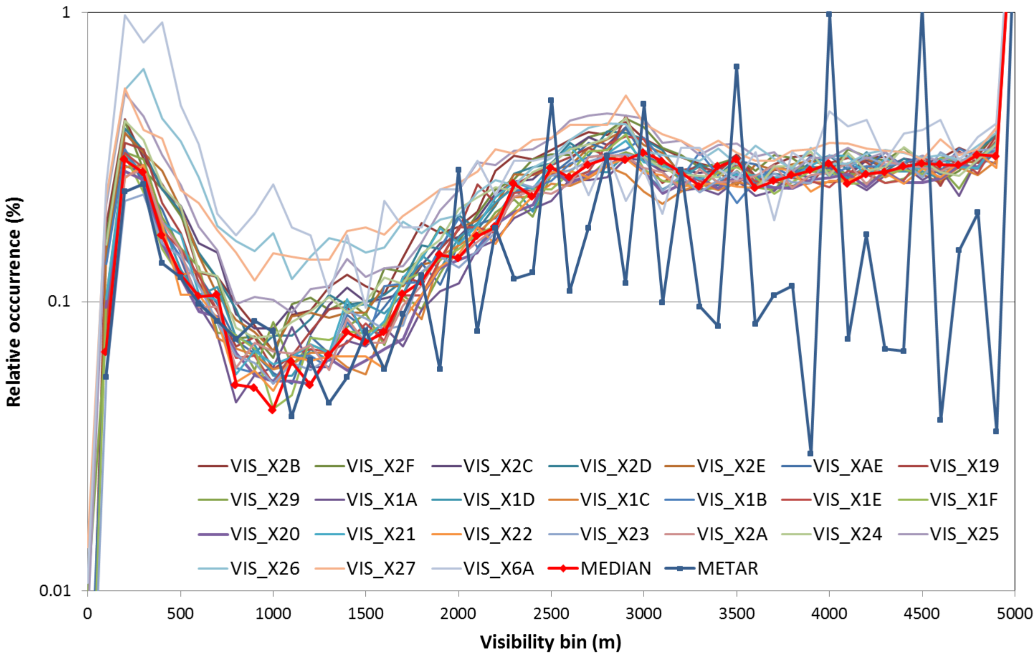


Figure 11: Frequency distribution of the 10-minute averaged visibility (VIS) for each visibility sensors at Schiphol, their MEDIAN and the METAR using visibility reporting bins up to 5000 m.

First the frequency distributions of the visibility (VIS) reported by all FD12P visibility sensors at Schiphol at HH+20 and HH+50 are considered. Figure 11 shows the relative number of entries as a function of the visibility bin. The bin width is 100 m up to 5000 m and 1000 m for higher visibility values. Visibility values of 10 km and higher are reported as 9999. The bin is identified by the visibility of the lower boundary, so 500 m contains visibility values equal or larger than 500 m and lower than 600 m. The visibility bins coincide with the reporting steps of visibility in the METAR. In addition to the distributions of the individual sensors, the frequency distribution of their median (excluding the sensors at the fog stations) and the visibility reported in the METAR are also shown in Figure 11. The results for the median visibility will be discussed in the next section. The visibilities below 5 km occur evenly with a fraction of about 0.3 % for each bin. The frequency distributions show reduced occurrences between 400 and 2000 m with a minimum at about 1000 m. Note that some sensors do not report any visibilities in the lowest bin (0 to 100 m). The sudden increase at 5000 m (not shown) is a result of the change in the bin width. The visibilities above 5 km occur with a fraction of about 3 % for each bin and visibilities of 10 km or more occur about 73 % of the time.

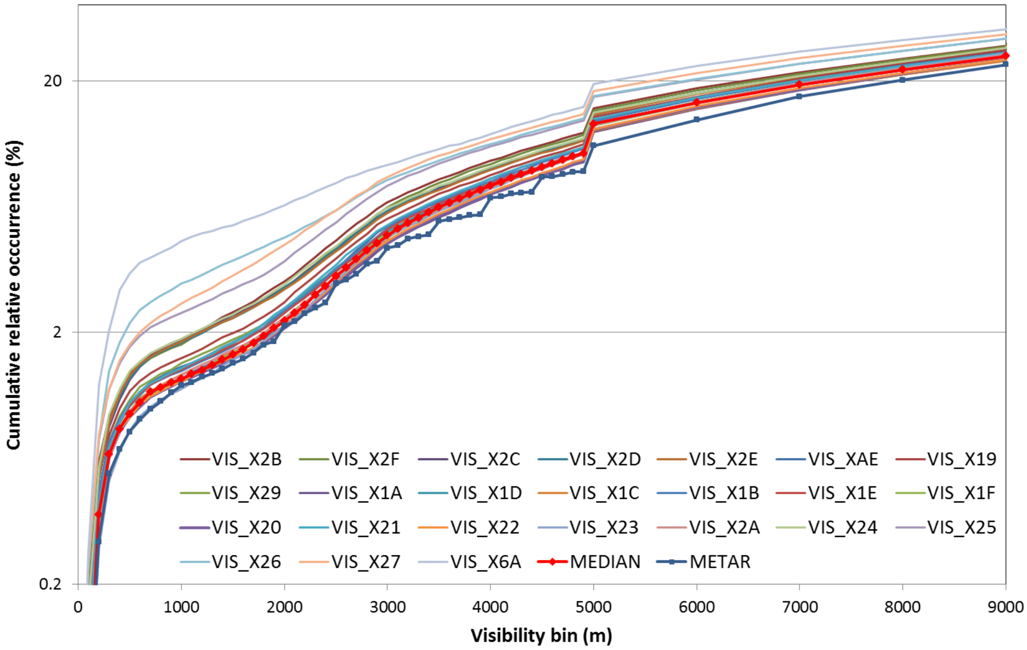


Figure 12: The cumulative relative occurrence of the 10-minute averaged visibility (VIS) of the visibility sensors at Schiphol, their MEDIAN and the METAR using visibility reporting bins.

Figure 11 shows that the occurrence in the low visibility bins varies largely between the individual sensors. Particularly the visibility sensors at the fog stations report visibilities below about 1500 m more often. The relative occurrence of the visibility reported in the METAR is generally at the lower end of the frequency distribution of the sensors. Between 2 and 5 km the observed visibility is predominantly reported in multiples of 500 m. Figure 12 shows the cumulative relative occurrence of the 10-minute averaged visibility (VIS) of the FD12P sensors at Schiphol at HH+20 and HH+50 and the visibility in the METAR. The cumulative curves are more smooth and more clearly show the enhanced number of low visibilities for the fog stations. The cumulative occurrences also shows that the results of the METAR, albeit with reduced values, closely follows that of the individual sensors. For visibilities above about 3 km the differences in the cumulative occurrences between individual curves changes little. In the last bin (9999, not shown) the cumulative relative occurrence for all curves go to 100 %. This shows that the visibilities in the METAR are nearly 77 % of the time 10 km or more, and about 75 % of the time for the median visibility.

Figure 13 gives the slope of the linear regression, the standard error of the linear fit and the correlation coefficient of the 10-minute averaged visibility (VIS) of each FD12P sensor at Schiphol versus the visibility reported in the METAR. All three variables are reported as a function of the distance between the sensor and the observer. The entry at zero distance is the median visibility (excluding fog stations). Note that the sensor visibility is limited to 9999 and converted into to METAR reporting steps prior to calculating the slope, standard error and correlation coefficient. The slope and correlation coefficient are reported with the scale on the left, the standard error uses the scale on the right. The standard error of the linear fit and the correlation coefficient show a clear dependency on the distance. The visibility of sensors closer to the observer generally have higher correlation coefficient and lower standard errors of the linear fit with the visibility reported in the METAR. Hence the visibility of the FD12P sensors at the fog stations show the poorest agreement with the METAR visibility. The visibility sensors along the 18R-36L runway (Polderbaan), within the red ellipse in Figure 13, also show reduced agreement with the METAR.

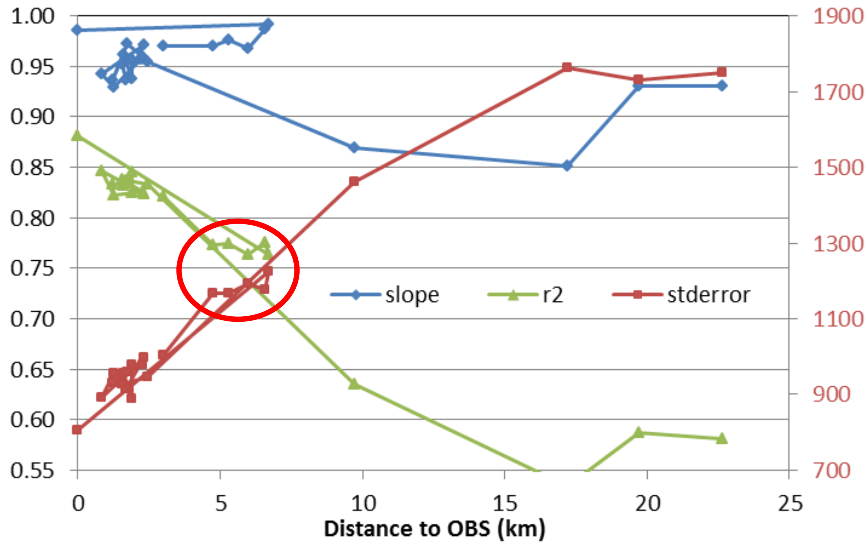


Figure 13: The slope of the linear regression, the standard error of the linear fit and the correlation coefficient of the 10-minute averaged visibility (MOR) of each FD12P sensor at Schiphol versus the METAR are reported as a function of the distance.

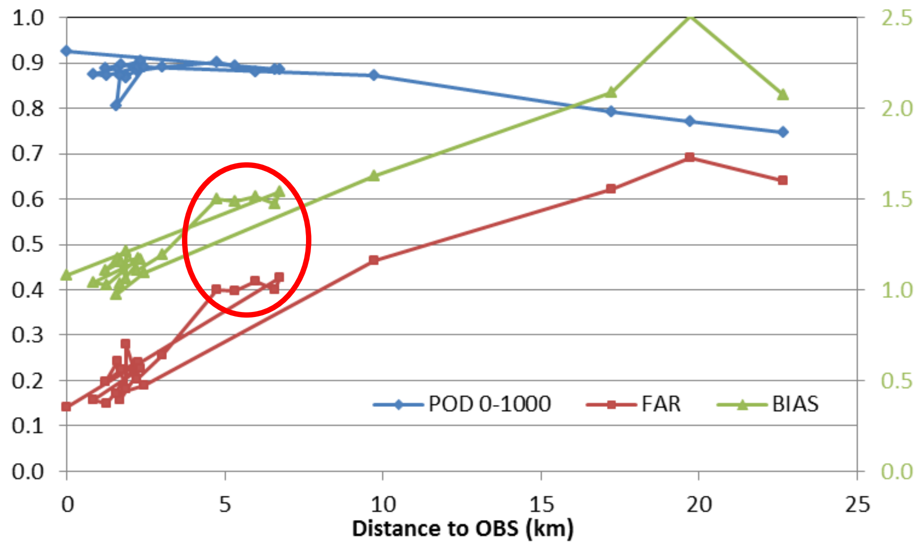


Figure 14: The POD, FAR and BIAS for visibility below 1000 m for the 10-minute averaged visibility (VIS) of each FD12P sensor at Schiphol versus the visibility reported in the METAR are reported as a function of the distance from the observer.

The agreement between the visibility reported by the FD12P sensor and in the METAR can also be expressed in scores that express the fact whether a specific condition is correctly reported. Here the presence of fog (visibility below 1000 m) is considered. Figure 14 shows the POD, FAR and BIAS for visibility below 1000 m for each FD12P versus the visibility reported in the METAR as a function of the distance of the sensor from the observer. The POD generally decreases for sensors farther removed from the observer whereas the FAR generally increases. The latter is also true for the BIAS. The visibility sensors at the fog stations report about twice as many cases of fog than the METAR and the visibility sensors along the 18R-36L runway (Polderbaan), within the red ellipse in Figure 14, has about 50 % more fog cases. Note that the dependence on distance of the scores for fog, and particularly the FAR and BIAS are affected by local conditions. The fog stations and the Polderbaan are locations that are more susceptible to fog. However, more fog does not necessarily lead to a higher POD, but the FAR will generally increase.

5. SENSOR PREVAILING VISIBILITY VERSUS METAR VISIBILITY

The sensor prevailing visibility, i.e. the median of the 10-minute averaged visibility (VIS) of all visibility sensor at Schiphol excluding the sensors at the fog stations, is considered next. The prevailing visibility is the median of 19 sensor visibility values and is denoted by median in Figure 11 and Figure 12. The frequency distribution of the median visibility shows the same behaviour as the individual sensors. The relative occurrence of the median visibility is generally at the lower end of the frequency distribution of the sensors, although higher than that of the METAR. The slope of the linear regression, the standard error of the linear fit and the correlation coefficient of the median visibility versus the visibility reported in the METAR are included in Figure 13 at zero distance from the observer. The median visibility shows a better agreement with the METAR visibility than any of the sensors individually. Note that the standard error and correlation coefficient of the median visibility is almost the value of these variables for individual sensors extrapolated to zero distance. The POD and FAR scores and the BIAS for visibility below 1000 m for the median visibility and the visibility reported in the METAR is also included in Figure 14 at zero distance from the observer. The median visibility has a BIAS of 1.08 and deviates more from the METAR than several individual sensors. However, the median visibility has a larger POD and a smaller FAR for fog than any of the sensors individually. Hence the median visibility gives a better agreement with the fog cases reported in the METAR than any of the sensors. The same applies for nearly all the visibility classes such as the SPECI visibility thresholds of 800, 1500, 3000, 5000 and 8000 m and the reporting threshold of 10 km.

The cases where the sensor median visibility reports fog (visibility below 1 km) whereas the prevailing visibility reported in the METAR does not report fog as considered in more detail. The conditional minimum visibility information that is reported in the METAR and the fog information in the weather group of the METAR are used for that purpose. Table 1 gives the number of cases that shallow fog (MIFG), fog patches (BCFG), partial fog coverage (PRFG) and fog (FG) are reported or the minimum visibility is below 1 km. Table 1 shows that in most cases with shallow fog or fog patches the prevailing visibility reported in the METAR and the median visibility of the sensors exceeds 1 km. The same is true for the cases when the minimum visibility is below 1 km. When the sensor median visibility is below 1 km there are 153 cases with METAR visibility ≥ 1 km; 90 cases with METAR visibility ≥ 2 km and 45 cases with METAR visibility ≥ 5 km. The number of cases that a specific type of fog is reported in these situations is also given in Table 1. In all cases where the median visibility is below 1 km and the prevailing visibility in the METAR is above ≥ 2 km the METAR reports MIFG, BCFG, PRFG or FG. In 148 of the 153 cases with METAR visibility ≥ 1 km and median visibility < 1 km the METAR reports MIFG, BCFG, PRFG or FG. The minimum visibility reported in the METAR also explains some of the cases with METAR visibility ≥ 1 km and median visibility < 1 km, but not so good as the fog reports in the weather part of the METAR.

Table 1: The number of cases where a specific type of fog or minimum visibility below 1 km is reported in the METAR of Schiphol in the period 2010 to 2014.

METAR visibility	any	≥ 1 km	≥ 1 km	≥ 2 km	≥ 5 km
Median visibility	**any**	**≥ 1 km**	**< 1 km**	**< 1 km**	**< 1 km**
MIFG	1452	1447	5	5	4
BCFG	1151	923	102	65	38
PRFG	187	91	35	16	3
FG	872	64	6	4	0
any FG			148	90	45
# cases			153	90	45
MIN VIS < 1 km	398	289	45	24	8

The median visibility of the sensors agrees better with the prevailing visibility reported in the METAR than any of the individual sensors. There are still differences that can only partly be explained in terms of differences in the time window or reporting practices. Next several methods to obtained the prevailing visibility from multiple visibility sensors are investigated. Specifically the number of sensors used for the determination of the prevailing visibility and their weight is varied. The cases considered are:

- MEDIAN 19 visibility sensors at Schiphol itself, excluding fog stations
- MED24 all 24 visibility sensors inclusive fog stations
- MED14 14 visibility sensors, excluding fog stations and Polderbaan (18R-36L)
- MED6 6 visibility sensors around Schiphol itself (18Rtw, 18Ct, 27t, 36Rt, 06t, 36Lt)
- MED18R 5 visibility sensors along Polderbaan (18R-36L)
- MED18C 4 visibility sensors along Zwanenburgbaan (18C-36C)
- MED18L 3 visibility sensors along Aalsmeerbaan (18L-36R)
- MED06 3 visibility sensors along Kaagbaan (06-24)
- MED27 3 visibility sensors along Buitenveldertbaan (27-09)
- MEDW 19 visibility sensors weighted with reciprocal of the distance to observer
- MEDW2 … weighted with reciprocal of the square root of the distance to observer
- MEDW3 … weighted with reciprocal of the distance to the power 3/2 to observer

The results for the various methods are given in Table 2. Again the slope and standard error of the linear fit and the correlation coefficient of the median visibility versus the visibility reported in the METAR and the POD, FAR and BIAS for several visibility classes are considered. The results are compared against the MEDIAN results. The overall results deteriorate when the visibility sensors at the fog stations are taken into account and they improve slightly when the visibility sensors along the Polderbaan (runway 18R-36L) are disregarded. This could be expected since the visibility of the individual sensors at the fog stations show the largest deviation from visibility in the METAR, and to a lesser degree this is true for the visibility sensors along the Polderbaan. When the 14 visibility sensors at Schiphol are considered the POD for low visibility decreases slightly, but the FAR is also reduced. When only the 6 visibility sensors around Schiphol are considered the overall results deteriorate the most. The POD for low visibility increases (probably because the two sensors near the Polderbaan are more exposed to fog), but at the expense of the FAR. The deterioration of the results is less when only the 3 visibility sensors along Kaagbaan (runway 06-24) are considered. Now the POD for low visibility is reduced, and the change in FAR is small. Using the visibility sensors along the other runways give similar results to that of the Kaagbaan, the results for the visibility sensors along the Polderbaan are much poorer. When the 19 visibility sensors at Schiphol are weighted with the reciprocal of their distance to the observer the best results are obtained. Here the POD for low visibility decreases slightly, but the FAR reduces a bit more. Using the reciprocal of the distance of the visibility sensor to the observer gives better results than using the reciprocal of the square root of the distance or the reciprocal the distance to the power 3/2.

Table 2: The slope and standard error of the linear fit, the correlation coefficient and the POD (%), FAR (%) and BIAS for various visibility classes using various methods to determine sensor prevailing visibility.

	MEDIAN	MED24	MED14	MED6	MED06	MED18R	MEDW
slope	0.986	0.991	0.979	1.009	0.962	0.988	0.974
standard error	804.	829.	793.	943.	868.	1121.	777.
r2	0.881	0.875	0.882	0.849	0.858	0.792	0.885
< 1000 POD	92.5	92.5	91.5	94.8	89.6	89.7	90.7
FAR	14.2	15.2	13.1	25.7	15.5	37.9	11.8
BIAS	1.078	1.091	1.052	1.275	1.061	1.446	1.028
< 800 POD	93.4	92.7	92.5	95.0	90.0	88.8	91.7
FAR	18.9	19.8	15.9	29.5	18.6	41.7	15.0
BIAS	1.151	1.156	1.100	1.347	1.106	1.523	1.079
800-1500 POD	70.8	72.4	70.1	78.4	61.8	62.3	68.2

	MEDIAN	MED24	MED14	MED6	MED06	MED18R	MEDW
FAR	42.0	46.8	38.9	54.8	49.4	71.4	38.3
BIAS	0.896	1.005	0.895	1.115	0.916	1.367	0.872
1500-3000 POD	83.2	82.9	83.6	82.4	78.5	72.7	82.7
FAR	32.1	34.3	29.8	42.0	35.3	49.4	28.9
BIAS	1.225	1.262	1.192	1.420	1.213	1.439	1.163
3000-5000 POD	74.7	74.1	74.9	70.0	69.7	62.8	74.7
FAR	36.7	37.5	36.0	44.2	38.4	49.6	34.8
BIAS	1.180	1.186	1.171	1.256	1.131	1.244	1.146
5000-8000 POD	68.2	67.1	69.0	62.8	66.5	57.5	69.7
FAR	34.7	35.8	34.3	41.7	37.2	45.4	33.2
BIAS	1.045	1.046	1.051	1.077	1.059	1.053	1.043
≥ 8000 POD	96.5	96.3	96.6	95.1	96.3	94.5	96.9
FAR	1.2	1.2	1.3	0.9	1.6	1.4	1.4
BIAS	0.977	0.975	0.978	0.960	0.979	0.959	0.982
≥ 10000 POD	95.6	95.4	95.7	93.9	95.3	93.4	96.0
FAR	2.0	2.0	2.1	1.6	2.4	2.2	2.2
BIAS	0.976	0.973	0.977	0.954	0.976	0.955	0.981

In all cases the results are better than when only a single visibility sensor is considered. Hence it is recommended to use the median visibility of all available visibility sensors at an aerodrome as the prevailing visibility that is reported in the AUTO METAR. Currently KNMI uses the visibility of a designated sensor for this purpose at regional airports. Note that many more methods to determine prevailing visibility from multiple visibility sensors could be constructed. For example each sensor can be given a weight that corresponds to the area for which it is considered representative based on local climatological conditions. Also conditional methods can be considered that dependent for example on the visibility itself (consider a larger area when the visibility is of the nearby sensors is good) or the runways in use. The latter would only consider the visibility sensors of the operationally relevant areas of the aerodrome. This is not applicable for the prevailing visibility reported in the (AUTO) METAR, which should be representative for the entire aerodrome, but is more suitable for the visibility representative for the situation along a runway as reported in the local routine and special reports.

6. CONCLUSIONS

The distance dependency of the 10-minute averaged visibility (MOR) and 10-minute averaged precipitation intensity is most pronounced in the standard deviation of the differences with the MEDIAN, thus the width of the distribution, the standard error of the linear fit and the correlation coefficient. The standard deviation of the differences and the standard error are similar and increase with distance and the correlation coefficient decreases with distance. The dependency with distance for the 10-minute averaged visibility can be described by a linear regression line with a 99.5 to 99.9% confidence level. The 10-minute average precipitation intensity shows levelling off of the distance dependency suggesting a correlation length of about 15 km. This is probably related to the size of cumuliform precipitation events. The distance dependency can be better analysed by using the results obtained by comparing all FD12P pairs as a function of their distance. Here the width of the scatter in the graphs using each FD12P pair can serve as an estimate of the uncertainty. Using each FD12P pair shows that the results for the 10-minute averaged visibility do also not vary linearly with distance, but change more rapidly at small distances. The distance dependency is also evident in the POD and FAR for the occurrence of specific events. POD generally decreases and FAR increases with distance. Here one has to be careful that the results are not affected by local climatological conditions. This is for example the case for fog since some locations are more susceptible to fog. Again, the scatter of the results of the FD12P pairs indicates the validity of the distance dependency and/or the sensor(s) that cause the scatter.

The measurements of the visibility sensors at Schiphol have been compared to the prevailing visibility reported by the observer in the METAR. The results of individual sensors show that the standard error increases with distance while the correlation coefficient decreases. The median visibility of the sensors gives better results than the sensors individually. The usage of the median visibility leads to a reduced number of low visibility values as compared to individual sensors, but the METAR reports even less low visibility values. The median visibility of the sensors also gives better results (in term of POD and FAR) for visibility in specific classes. The agreement is further improved by giving each sensor a weight that is the reciprocal of its distance to the observer. The median visibility derived from multiple sensors gives better results than the visibility of a single sensor, even when only 3 sensors are considered. Hence it is recommended to use the median visibility of all available visibility sensors at an aerodrome as the prevailing visibility that is reported in the AUTO METAR. Currently KNMI uses the visibility of a designated sensor for this purpose and generally uses another sensor as backup. Note that this redundancy can also be part of the calculation of the median. In this study a median is given when the visibility of at least one sensor is available.

Although the use of multiple sensors gives better results for the prevailing visibility than using a single sensor, even the median of all available visibility sensors at Schiphol and the application of a weight leaves significant deviations between observed and derived prevailing visibility. A difference in the time window of five minutes can only partially explain the deviation between sensor and METAR visibility. The agreement is also affected by the fact that the observer “favours” multiples of 500 m when the visibility is between 2 and 5 km, probably since there is a lack of visibility markers. The sensor visibility data, which are available to the observer (but not their median), seem not to be generally used to determine (or at least to enhance the resolution) the observed visibility in this range, as it seems to be the case for lower visibilities. Also note that the observer is located in a tower (at 37 m), and has not a full 360° view of the aerodrome. Fog indicated by the sensors but not reported as prevailing visibility by the observer is generally reported as shallow or partial fog or fog patches. During these situations the median sensor visibility is not considered representative for the aerodrome. Detailed analysis of specific situations and reporting practices are required to investigate whether further optimization of the method to determine prevailing visibility from multiple sensors is possible.

REFERENCES

ICAO: Meteorological Service for International Air Navigation, Annex 3, 17th edition, International Civil Aviation Organization, Montréal, Canada, July 2010.