

FILTERING OF INSECT REDUCED MOR MEASUREMENTS BY A FORWARD SCATTER SENSOR *

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ABSTRACT

Significant reductions in the Meteorological Optical Range (MOR) reported by FD12P forward scatter sensors have been observed in The Netherlands due to the presence of insects in the measurement volume. Insects reduced MOR is a general problem encountered with all visibility sensors using the forward scattering technique. In order to overcome this problem the sensor firmware had to be adapted so that raw measurements samples that are affected by insects are filtered out before calculation of the MOR. This insect filtering of the MOR needs to be treated with care since faulty filtering of the MOR will lead to an overestimation of the MOR, which may cause safety issues. In collaboration with Vaisala, the manufacturer of the FD12P forward scatter sensor used by KNMI, a firmware with insect filtering of the MOR has been developed and evaluated in a field test setup. The field evaluation of the FD12P firmware with insect filtering of the MOR showed good results, but faulty insect filtering events, although generally with only a small effect on the reported MOR, do occur. Faulty insect filtering events occur near the onset of precipitation, hence a forward scatter sensor with present weather capabilities has the advantage that features in raw measurements samples of insects and precipitation can be better distinguished. KNMI introduced a validation filter that only accepts insect filtering events around sunrise and sunset and when no precipitation is reported. The field evaluation of the FD12P firmware with insect filtering of the MOR in combination with the validation filter shows good results. There are still some issues with the firmware, which are currently investigated by the manufacturer. KNMI decided to introduce the FD12P firmware with insect filtering of the MOR at regional civil airports. The corrected MOR will be used operationally and the uncorrected MOR will be made available for remote monitoring and evaluation purposes. Details of the field evaluation of the FD12P firmware with insect filtering of the MOR in combination with the validation filter and their performance will be shown.

1. INTRODUCTION

Traditionally, a transmissometer (TMM) is used to determine the Meteorological Optical Range (MOR) by measurement of the extinction of a light beam over a known atmospheric path. Forward scatter (FS) sensors can also be used for the determination of MOR by assuming a relationship between the amount of forward scattering and the extinction of the scattering medium. After extensive tests the World Meteorological Organization (WMO) and the International Civil Aviation Organization (ICAO) concluded that FS sensors are suitable for visibility measurements. ICAO recommends using either TMM or FS sensors for assessing the Runway Visual Range (RVR). Advantages of a FS sensor compared to a TMM are the lower procurement and installation costs,

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lower maintenance due to lower sensitivity of MOR measurements to contamination of lenses, and the possibility to measure accurately up to higher MOR values. As a result KNMI replaced its transmissometers at civil airports, which were at the end of their technical life time, by FS sensors.

2. THE PROBLEM

During the introduction of the automated aeronautical meteorological reports by KNMI in 2007 it was noted that occasionally significant reductions in the MOR reported by the FD12P FS sensor occurred. Figure 1 shows such a situation on September 18, 2008 at the test field in De Bilt. The figure shows several 10-minute averaged variables as a function of time (UT). MOR is reported for the “operational” FD12P FS sensor (green curve), the FD12P sensor under evaluation (black) and a MITRAS TMM (magenta) using the black logarithmic scale indicated on the left. Both FS sensors show reduced MOR values around 18 UT, whereas the TMM shows no features in MOR. Between 4 and 5 UT all three sensors show low MOR values during a fog event. Note that during the day both FS sensors report a MOR of about 30 km whereas the TMM only reaches values of about 5 km. The MOR of the TMM is only accurate below about 2 km, but at generally follows the features of the FS sensors at higher MOR values. Figure 1 also shows the background luminance of the FS sensor (light blue), which clearly indicates the daylight period. During night time the background luminance sensor reports a constant value of 4 cd/m^2 . Lastly, Figure 1 also gives the precipitation intensity of the “operational” FS (blue) which is 0 mm/h on this particular day.

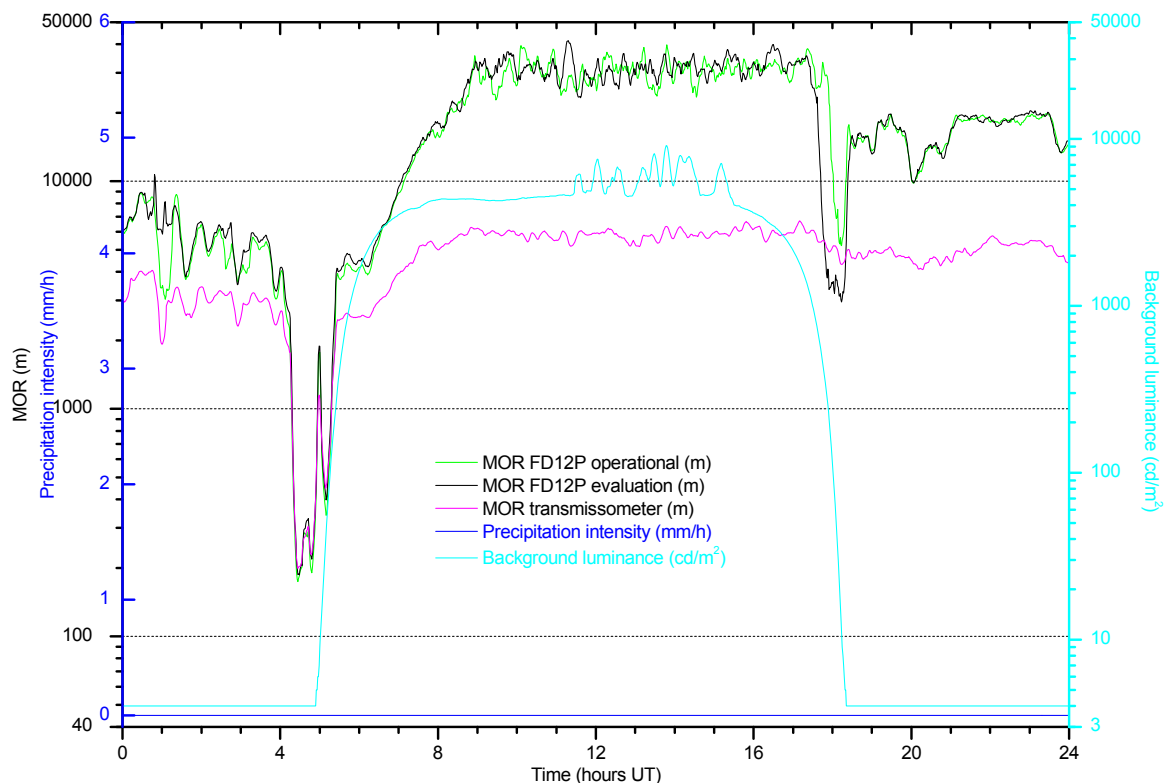


Figure 1: Example of the MOR reduction of the FD12P FS sensor observed around sunset in De Bilt on September 18, 2008 without a corresponding feature in the MOR reported by a TMM. See text for more details.

The cause of the visibility reductions was at first unclear. Replacements of FS sensors and experiences at other locations showed that the reduction was not an instrument- or site-specific problem. Since the MOR reductions occurred mainly during sunset reflection of sunlight into to receiver was considered. However, changing the orientation of the FS sensor did not overcome the problem. Inspection of archived data showed that similar MOR reductions also occurred for FS sensors installed at synoptic stations since 1998 and could also be observed in the MOR reported by the FS sensor of another manufacturer. The magnitude of the MOR reductions and their frequency of occurrence, however, seemed to have increased over the last years. Eventually the reduction of the MOR reported by the FS sensor was attributed to the presence of insects (mosquito's) in the measurement volume. This was confirmed by visual inspection (see Figure 2).

In order to convince both internal and external skeptics, a test was conducted with a FS sensor covered with a mosquito net (cf. Figure 3). The FS sensor covered with the net showed no reduction in the MOR around sunset whereas another nearby FS sensor reported significant MOR reductions. Inspection the next day showed small flies on the mosquito net (cf. inset of Figure 3).



Figure 2: A picture of the FD12P FS sensor in De Bilt around sunset on September 8, 2008 showing insects around the sensor during a MOR reduction event.

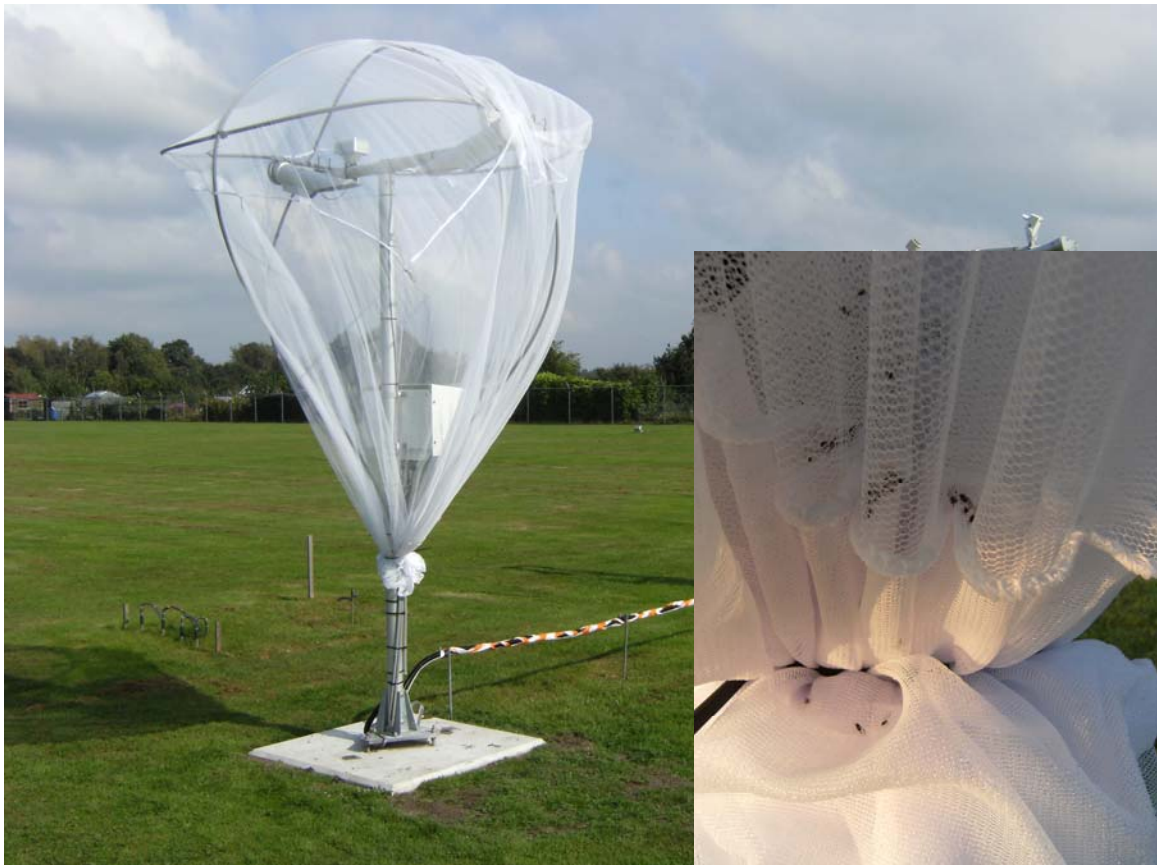


Figure 3: A FD12P FS sensor covered by a mosquito net. The inset shows the small flies on the mosquito net.

The MOR measurements of a FS sensor turn out to be very sensitive to insects in the measurement volume, whereas a TMM is less influenced by insects. A FS sensor can report MOR values below 1 km during insect events while the actual MOR is above 10 km. Such large MOR reductions put the MOR in different visibility classes used for aeronautical purposes. Fortunately, reporting a lower MOR poses no safety issue, but operations and the capacity of an airport can be affected.

3. EXPLORATION OF SOLUTIONS

The mosquito net shown in Figure 3 obviously cannot be considered as a solution of the insect problem encountered during MOR measurements with a FS sensor. In fact, the mosquito net reflects some radiation of the emitter of the FS sensor into the receiver so that the covered sensor reports a lower MOR. The literature reports various causes that attract mosquito's, such as heat, CO₂ and light. There are several commercial apparatus available for repelling or attracting and subsequently trapping or exterminating insects. However, these methods are generally not practical. KNMI performed tests with a FS sensor without lens and hood heating and equipped a FS sensor with an electronic ultrasonic insect repellent device. Both measures, however, did not discourage the insects from interfering with the MOR measurements.

The presence of insects in the measurement volume of a FS sensor will result in peaks in the optical signal resembling precipitation. Another way to eliminate the MOR reductions caused by insects is by filtering out the raw MOR measurements samples that are affected by the insects. A FS sensor has a typical internal measurement rate of several kHz, which enables the sensor to detect precipitation events. This raw data is not available to the user. Hence the filtering of the raw MOR data and the optimization of such a filter requires the cooperation of the manufacturer and cannot be performed offline. The design and evaluation of such a software filter is time consuming since it requires verification by a field setup. Note that the insect filtering of the MOR leads to higher MOR values, hence faulty filtering is a safety issue for aviation. Therefore the insect filtering of the MOR and particularly the possible faulty classification of precipitation events as insects need to be verified with care.

4. FD12P FS SENSOR

The Vaisala FD12P sensor consists of an optical transmitter and receiver and a capacitive wetness sensor which are all mounted on cross arm on top of a mast. It is also equipped with a temperature sensor and optionally a background luminance sensor can be placed on top. The optical transmitter emits infrared pulses with a wavelength of 875 nm at a frequency of 2.3 kHz. The receiver unit measures the intensity of the light which is scattered by the sample volume in an angle of 33°. The sample volume has a size of approximately 0.1 dm³ and is formed by the intersection of the transmitter and receiver beams. Figure 4 shows a picture of the FD12P sensor in De Bilt. The various instruments parts are indicated in the figure.

Generally, the receiver records a continuous signal due to scattering by aerosols in the sample volume. From this signal, the MOR is determined. During precipitation, peaks occur in the recorded signal. The amplitude of a peak is proportional to the size of the scattering particle. The capacitive wetness sensor gives a signal that is dependent on the thickness of the water film on the detector surface. Thus it is a measure of the liquid water content of the precipitation. The precipitation type discrimination of the FD12P uses the ratio of the optical signal and wetness signal in order to determine the basic precipitation type. Solid precipitation causes a lower signal on the capacitive detector than liquid precipitation, for particles of the same size. In addition, the internal FD12P precipitation type algorithm utilizes the temperature and the maximum size within the particle size distribution to determine the precipitation type in more detail. The instant precipitation type is determined in the internal software from the analysis of the measurements of the last 15 seconds to 5 minutes max.

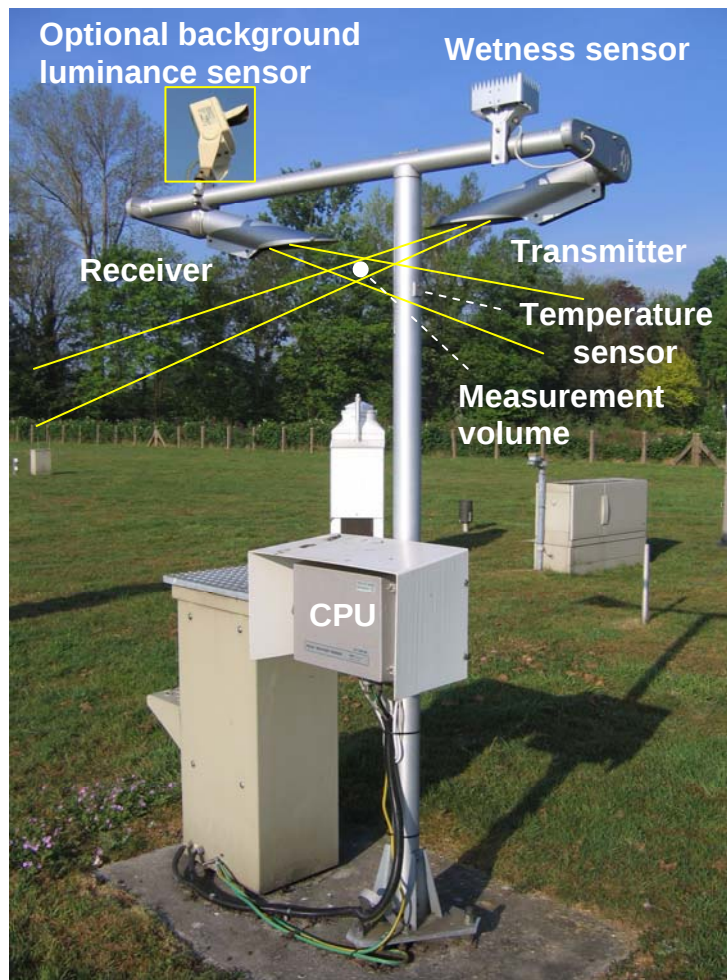


Figure 4: The Vaisala FD12P FS sensor with indication of the sensor parts.

5. THE SOLUTION

The presence of insects in the sample volume will result in an optical signal resembling precipitation, but without a corresponding signal from the wetness sensor. A temperature threshold is used in order to distinguish insects from solid precipitation that also give no wetness signal. At first the evaluation was performed with firmware that reported only the standard message with a corrected MOR. Hence it was difficult to determine whether MOR filtering was applied and how large the MOR correction was. Later versions had an extension of the output message that reported both the corrected and uncorrected 1-minute averaged MOR and in addition included an indicator showing whether insect filtering of the MOR had been applied. The FD12P firmware with insect filtering of the MOR sets the indicator if the optical signal detects precipitation, but the wetness sensor does not and the temperature is above the warm limit (8 °C). The MOR filter removes the peak samples from the raw internal MOR data before calculating the MOR. The filter is only applied for the 15 sec interval, where particles are detected. It is unknown whether size information is used in the identification of insect events.

The insect-induced MOR reductions of the FD12P were reported to Vaisala during a meeting in March 2008. During that meeting it was agreed that Vaisala would develop and implement insect filtering of the MOR in the firmware of the FD12P that would be evaluated by KNMI in a field setup. Several insect filtering firmware versions of the FD12P sensor have been evaluated and rejected, since all these versions proved to filter the MOR insufficiently during insect events. The FD12P firmware 1.91S dated 28 May 2010 that was installed at the KNMI test site on July 8, 2010 however, showed promising results and is evaluated below.

6. EVALUATION SETUP

The evaluation of the firmware has been performed with a field setup in De Bilt (cf. Figure 5). A Vaisala MITRAS TMM with a double baseline (12 and 75 m) is operated in De Bilt together with an operational FD12P, which serves as a reference FD12P in order to transfer the MOR calibration from the TMM to the FD12P for MOR values up to 1500 m. This setup has been extended with a second FD12P that was equipped with the firmware under evaluation. Both FD12P sensors are located about halfway between the emitter and long baseline receiver of the TMM. The reference FD12P with operational firmware version 1.87 is located 3 m East of the path of the TMM and the other FD12P with filtering firmware 1.91S is located 3 m West. The optical path of the TMM and the measurement volume of the FD12P are at a height of 2.5 m, which is identical to the setup at airports.



Figure 5: Field evaluation setup in De Bilt showing the emitter and short baseline receiver of the TMM in the background and the operational FD12P (right) and FD12P with the MOR filtering firmware (left) in the foreground.

7. EXAMPLES OF INSECT FILTERING OF MOR

The 1.91S firmware of the FD12P has been evaluated at KNMI from July 8 to December 31, 2010. Figure 6 and Figure 7 show 2 examples of the measurements of the FD12P with MOR filtering firmware. The examples illustrate the insect MOR filtering obtained from the 1.91S firmware of the FD12P. Both figures show the 1-minute averaged MOR of the FD12P without (black) and with insect filtering (red) and the MOR of the TMM (magenta) using the black logarithmic scale indicated on the left. The green curve is a constructed reference MOR. The constructed reference MOR equals by default the uncorrected MOR of the FD12P, but in case of insect filtering a rescaled MOR of the TMM is used as the reference MOR. The MOR of the TMM is scaled with the ratio between the 10-minute averaged MOR of the FD12P and TMM just before and after the insect filtering event and a linear interpolation in between. The rescaled MOR of the TMM is maximized at 50 km, i.e. the maximum MOR that can be reported by the FD12P. The rescaling of the MOR of the TMM is required because the MOR of the TMM is only accurate below about 2 km. Note that the brown curve of the uncorrected MOR of the FD12P is plotted on top of the red and green MOR curves of the corrected MOR of the FD12P and the reference MOR. Hence the red and green curves are only visible in case of significant MOR filtering events. Curves for the 1-minute averaged precipitation intensity (dark blue curve with scale on the left) and background luminance (light blue curve with logarithmic scale on the right) of the FD12P with MOR filtering firmware are also shown. The black bar near the bottom indicate whether the MOR filtering indicator of FD12P is available or not (NA) and whether the sensor applied insect filtering of the MOR (PWS) or not (NO). The gray bar indicates the sensor insect MOR filtering events that passed an off-line validation filter. These are considered the valid insect events.

The results of August 3, 2010 (Figure 6) show that there is no insect filtering of the MOR during a fog event (0 to 6 UT). At sunset a strong reduction in the MOR of the FD12P with values down to about 1 km occurs without a corresponding reduction of the MOR of the TMM. The filtered MOR puts the MOR above 10 km, i.e. above the relevant thresholds for aviation, although a reduction of the MOR can still be observed. During the day there are some faulty filtering events, but their effect on MOR is negligible. On October 24, 2010 (Figure 7) several insect filtering events occur around precipitation events. Faulty insect filtering often occurs just before the FD12P starts reporting precipitation. However, when the sensor starts reporting precipitation, the insect filtering of the MOR does not always stop immediately. It seems that the insect filtering of the MOR and the precipitation detection modules in the sensor firmware act independently from each other. Note that insect filtering events do not occur during extensive periods of precipitation.

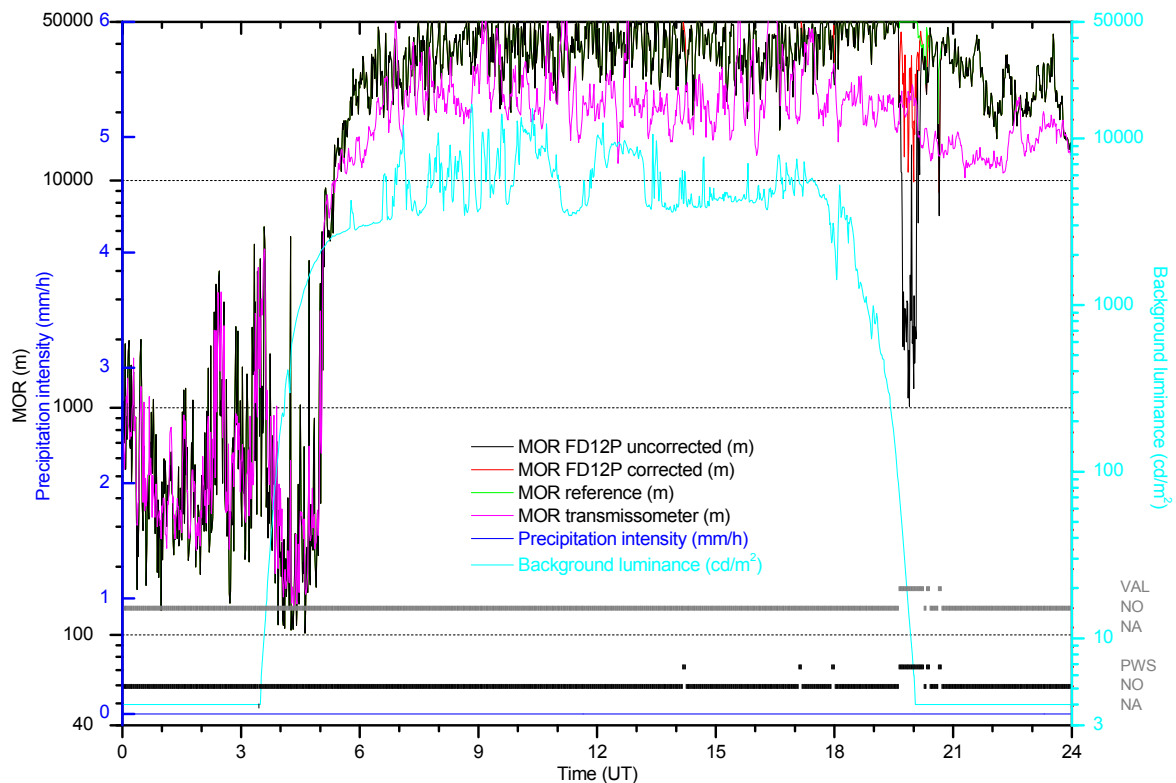


Figure 6: Example of the FD12P insect filtering of the MOR on August 3, 2010. See text for more details.

A validation filter was constructed that takes care of the shortcomings of the insect filtering of the MOR of the FD12P. This filter was based on a visual inspection of all data obtained during the evaluation period of the 1.91S firmware from July 8 to December 31, 2010. The validation filter is applied to the 1-minute MOR data reported by the FD12P and only accepts MOR corrections: (i) within ± 1 hour from sunrise and sunset; (ii) without precipitation in a ± 5 minutes interval; and (iii) without a 1-minute averaged MOR of the TMM below 1 km within a ± 5 minutes interval. The sunrise/sunset filter was introduced since inspection of the data showed that the main insect MOR reduction events (both in terms of duration and reduction) occurred around sunrise/sunset whereas isolated faulty corrections occur regularly at all times, albeit generally with a small impact on MOR. The precipitation filter is based on the fact that the FD12P uses data of the past 5 minutes in the internal precipitation detection and discrimination algorithm. In order to overcome the sensor delay an insect event close to or during precipitation is discarded. The last filter requires the MOR of a TMM that is not affected by insects and has been used to discard faulty filtering during fog events. Fortunately MOR filtering events during fog rarely occur, but the filter is introduced here in order to be able to trace and quantify these events.

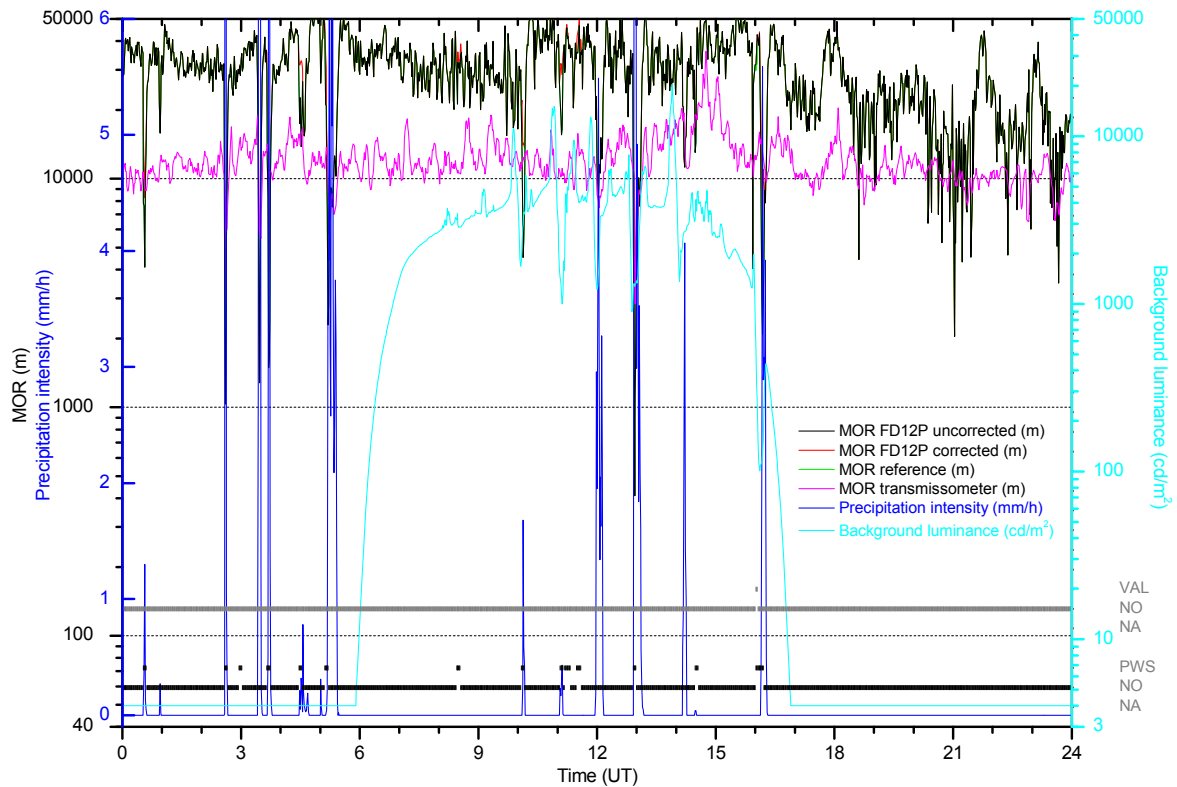


Figure 7: Example of the FD12P insect filtering of the MOR on October 24, 2010. See text for more details.

8. EVALUATION

The differences between the constructed reference MOR and the uncorrected and corrected 1-minute averaged MOR of the FD12P during MOR filtering events are shown in Table 1 using contingency matrices. The MOR data is binned into the visibility limits that are used for issuing local special reports at civil airports in The Netherlands, the so-called SPECIAL. In all cases the constructed reference MOR is indicated on the left. The gray diagonal denotes the cases where the (un)corrected MOR is in the same visibility bin as the reference MOR. The green area denotes the cases where the (un)corrected MOR is lower than the reference MOR, whereas the red areas denotes the cases where the (un)corrected MOR is larger than the reference MOR. Situations where the MOR filtering moves an entry from the green or gray into the red area are potentially dangerous because in these cases the MOR correction results in too optimistic MOR values. The top panels of Table 1 show the reference MOR versus the uncorrected (left panel) and the corrected MOR (right panel) for all events where the FD12P indicated insect filtering of MOR (PWS). The lower panels show the reference MOR versus the uncorrected and the corrected MOR for only those MOR filtering events that passed the validation filter (VAL).

The lower left panel shows many entries with uncorrected MOR < 3 km and reference MOR ≥ 8 km and that events with a reference MOR < 1500 m never occur whereas events with uncorrected MOR < 1500 m do occur. The lower right panel shows that the corrected MOR is always larger than 1500 m and that corrected and reference MOR show better agreement overall. The percentage of validated entries with MOR below the reference MOR decreases from 47 % for the uncorrected MOR to 8 % for the corrected MOR. However, situations do occur when the corrected MOR shows worse agreement with the reference MOR than the uncorrected MOR. For example the reference MOR < 5 km versus corrected MOR ≥ 8 km has 7 entries whereas the corresponding field for the uncorrected MOR has only 3 entries. Hence for at least 4 cases the MOR deteriorates due to the correction applied by MOR filtering if the reference MOR is assumed to be correct. On 83 occasions (0.7 %) the uncorrected MOR exceeds the reference MOR, all of which (2.1 %) occur during valid MOR filtering events. These events are caused by the asynchrony between calculation and messaging tasks of the FD12P firmware. The corrected MOR exceeds the reference MOR on

1690 occasions (13.8 %), but only 207 (5.3 %) occur during valid MOR filtering events. Hence the correction increases the number of valid MOR filtering events where the corrected MOR exceeds the reference MOR by 124 (3.1 %) when the SPECIAL visibility limits are considered. Note, however, that 147 out of the 207 valid MOR filtering events where the corrected MOR exceeds the reference MOR have a reference MOR above 5 km and are not relevant for aviation. Also note that only in 9 out of the 207 valid MOR filtering events the corrected MOR exceeds the reference MOR by more than 1 SPECIAL visibility bin. When the above comparison is performed using the full visibility reporting bins for aviation the correction increases the number of valid MOR filtering events where the corrected MOR exceeds the reference MOR by 6 %.

Table 1: Contingency tables of 1-minute averaged reference MOR versus uncorrected (left) and corrected (right) MOR using the SPECIAL visibility bins for all FD12P MOR filtering events (PWS, top) and the valid MOR filtering events (VAL, bottom).

MOR	Uncorrected →						PWS	MOR	Corrected →					
Ref↓	<800	<1500	<3000	<5000	<8000	≥8000		Ref↓	<800	<1500	<3000	<5000	<8000	≥8000
<800	17	0	0	0	0	0		<800	8	0	4	0	2	3
<1500	0	27	0	0	0	0		<1500	0	3	3	9	3	9
<3000	0	7	228	6	2	0		<3000	0	0	99	68	35	41
<5000	3	13	46	731	24	3		<5000	0	0	14	436	166	204
<8000	5	22	37	41	1737	48		<8000	0	0	0	10	737	1143
≥8000	164	425	477	281	315	7562		≥8000	0	0	6	68	217	8933
FALSE= 15.0% MISS= 0.68%								FALSE= 2.58% MISS= 13.8%						
MOR	Uncorrected →						VAL	MOR	Corrected →					
Ref↓	<800	<1500	<3000	<5000	<8000	≥8000		Ref↓	<800	<1500	<3000	<5000	<8000	≥8000
<800	0	0	0	0	0	0		<800	0	0	0	0	0	0
<1500	0	0	0	0	0	0		<1500	0	0	0	0	0	0
<3000	0	7	21	6	2	0		<3000	0	0	23	11	2	0
<5000	3	13	46	67	24	3		<5000	0	0	14	95	40	7
<8000	5	22	37	41	108	48		<8000	0	0	0	10	104	147
≥8000	164	425	477	281	315	1793		≥8000	0	0	6	68	217	3164
FALSE= 47.0% MISS= 2.12%								FALSE= 8.06% MISS= 5.30%						

9. SUMMARY AND DISCUSSION OF RESULTS

During the period of the evaluation of the FD12P 1.91S firmware with insect MOR filtering in De Bilt from July 8 to December 31, 2010, reductions of the MOR due to insects occurred quite regularly. Between July and the middle of November “validated” insects induced MOR reductions occurred on 86 % of the days during sunset and on 44 % during sunrise. The duration of the MOR filtering events reached values up to about 40 minutes during sunrise and about 1 hour during sunset.

The evaluation indicates that the insect filtering of the MOR by the FD12P with firmware 1.91S performs rather well. Whereas the uncorrected MOR shows reductions in the MOR due to insects below 1 km, the corrected MOR is nearly always above 3 km. Hence the correction puts the MOR correctly above the critical threshold for aeronautical purposes. Although the reduction in MOR due to insects is largely reduced by insect filtering a reduction is often still clearly noticeable in the corrected MOR data. Occasionally the onset of an event of reduced MOR due insects is not recognized as such by the FD12P.

The FD12P also performs insect filtering of the MOR outside the main insect periods, i.e. around sunrise and sunset. Generally these isolated events have no significant impact on the MOR. MOR corrections due to insect filtering have only been occasionally been observed during fog events, but in these cases the MOR correction is small. Corrections of the MOR due to insect filtering also occur during precipitation. These precipitation related corrections mainly occur just before the onset of precipitation. Once the FD12P identified and reported precipitation the MOR

corrections due to insect filtering still persists up to about 5 minutes. Solid precipitation events do not lead to insect filtering as the internal software limits filtering to temperatures above 8°C. Inspection of the MOR filtering results supports the usage of a validation filter, which considers only events within ± 1 hour from sunrise and sunset and without precipitation or MOR of the TMM below 1 km within ± 5 minutes as true insect related reductions of the MOR. The obvious insects events with significant MOR reductions lasting up to 1 hour are accepted by this filter, whereas isolated filtering events during the day or related to precipitation are discarded.

The uncorrected and corrected MOR of the FD12P have been compared with a constructed reference MOR. The validated insect filtering of MOR events are nearly always closer to the constructed reference MOR than the uncorrected MOR. The corrected MOR is too optimistic for 6 % of the valid filtering events and 3 % exceeds a SPECIAL visibility limit. Faulty corrections towards too optimistic MOR values pose a safety issue for aviation. However these faulty MOR corrections occur mostly at reference MOR values exceeding 5 km and are related to the use of a faulty FD12P during a large part of the evaluation period that sometimes reported too low MOR during clear days. The evaluation of the firmware with insect filtering of the MOR is not affected by this faulty FD12P, but “faulty” MOR corrections during such periods often place the MOR at roughly the correct value. In fact the magnitude and possibly also the number of faulty MOR corrections seem to be too pessimistic due to the use of this faulty FD12P. When the results of the insect filtering of MOR are compared with a reference MOR constructed by using the MOR of the operational FD12P in combination with the MOR of the TMM, the number of cases with a corrected MOR exceeding the reference MOR reduces significantly. The corrected MOR is now too optimistic in 2 % of the valid filtering events and less than 1 % exceeds a SPECIAL visibility limit. In addition, the number of invalid insect filtering events where the corrected MOR exceeded the reference MOR is reduced drastically. The invalid insect filtering events produce too high MOR values, which is not surprising since the uncorrected MOR value is assumed to be the reference MOR. Application of the validation step to insect filtering events of the MOR is crucial to eliminate these faulty corrections, although it should be noted that at least some of these faulty corrections actually seem to produce a better MOR value.

Note that the evaluation was performed on the 1-minute averaged MOR reported by the FD12P whereas for synoptic applications a 10-minute averaged MOR is used and for aviation 1- and 10-minute averaged VIS/RVR values are used. Averaging generally mitigates the impact of the reduced MOR values caused by insects, especially for isolated events. However, larger changes might be induced by a so-called marked discontinuity, in which case the averaging interval is temporarily reduced to 2 minutes in case of sudden changes in the MOR.

10. OPERETIONAL IMPLEMENTATION

The operational implementation of the FD12P firmware 1.91S in the MetNet observation network of KNMI is currently in progress.

- The KNMI sensor interface was changed in order to handle the additional information provided by the FD12P. The sensor interface makes the corrected and uncorrected MOR available to MetNet. Also the sensor interface polls the FD12P again if an invalid sensor message occurs. This reduced the number of invalid samples from about 5 % to about 1 ‰. Such small numbers of invalid sensor data will not lead to gaps in the derived 1- or 10-minute averaged visibility products.
- A real-time validation filter was implemented in MetNet. As a result the validation criteria were adapted. The period ± 1 hour around sunrise and sunset based on the background luminance was replaced by the solar elevation range -14 to 8° . Figure 8 shows the solar elevation 1 hour before and after sunrise and sunset as determined from the background luminance measurements in 2011. The peak at 28 June 2011 (day number 178) occurred because the background luminance dropped to 4 cd/m^2 about 1 hour before sunset during a precipitation event.

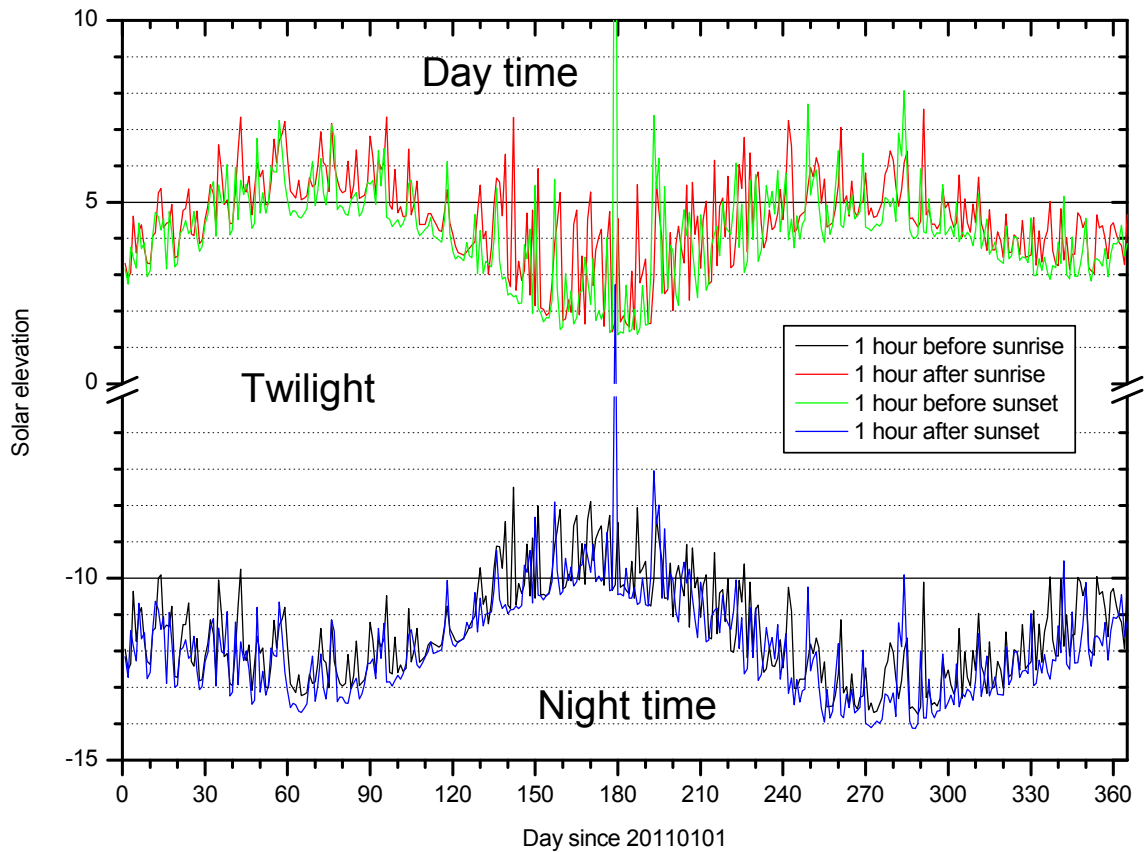


Figure 8: The solar elevation 1 hour before and after sunrise and sunset as determined from the background luminance measurements in 2011.

- The real-time validation filter disables insect filtering of the MOR when precipitation occurred in the past 5 minutes only.
- The real-time validation filter does not include the elimination of insect filtering events when a collocated TMM reports fog.
- Furthermore, filtering of MOR is assumed when the corrected MOR differs from the uncorrected MOR. This criterion introduces some faulty filtering events when the corrected and the uncorrected MOR reported by the FD12P are inconsistent due to the asynchrony between messaging and the measurement/calculation tasks. However, it should be noted that in these situations the corrected MOR equals the uncorrected MOR reported previously. Hence these situations only introduce a slight delay of the reported MOR.

An example of the real-time insect filter results in MetNet is shown in Figure 9 and Figure 10. In Figure 9, the lower curves show several flags with a 12-second update interval that is used at airports. The situations where the sensor indicated filtering of the MOR, that is when the corrected MOR differs from the uncorrected MOR, is denoted by the red curve (COR). The higher levels indicate filtering. The validation filter for precipitation (blue curve labelled precipitation) puts no constraints on this day without precipitation. The 10 negative flags correspond with missing samples. The validation filter for the sun elevation (light blue curve labelled elevation) indicates the periods around sunrise and sunset. The centres of which correspond with the background luminance (BL). The insect filtering events that pass the real-time validation filter are indicated by the green curve (valid) while the corresponding difference in MOR is given by the magenta curve (delta MOR). The main insect event around sunset leads continuously to changes in the MOR of about 5 to 20 km. During the beginning of the day many isolated filtering events occur that are mainly caused by the asynchrony between messaging and the measurement/calculation tasks. A total of 150 of such events occur during the day and many pass the validation filter around sunrise. However, their impact on MOR is only small.

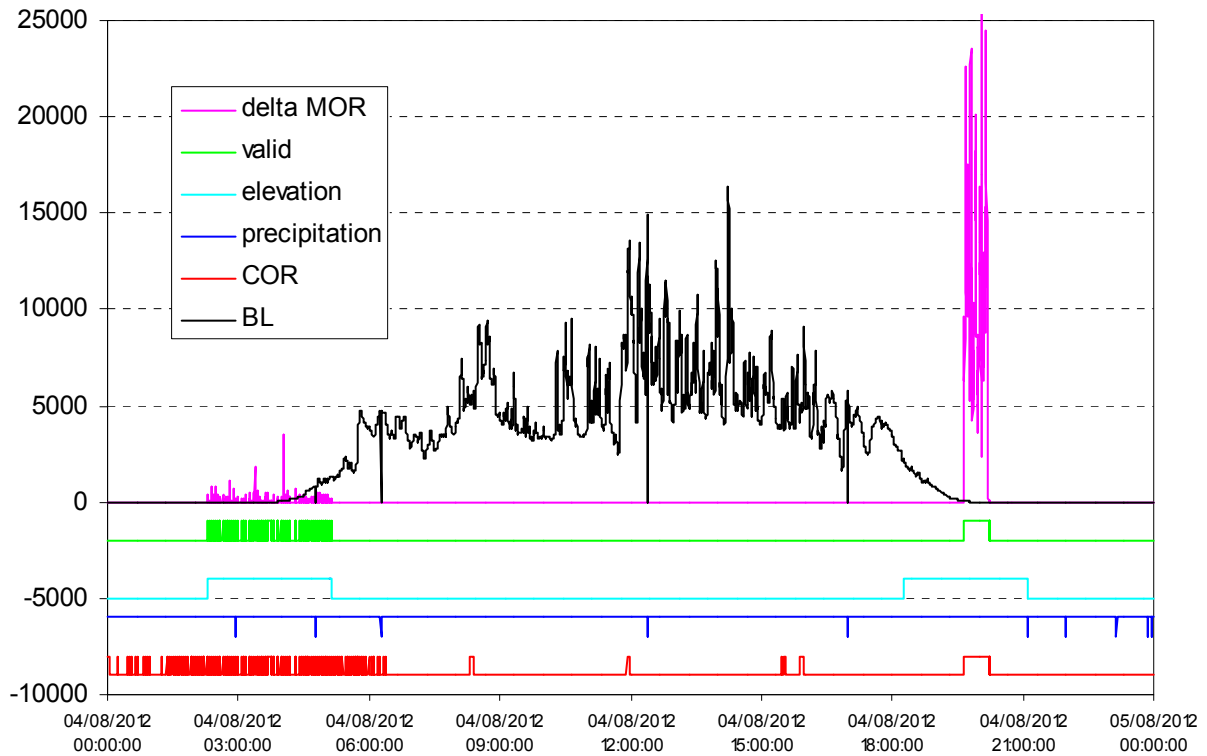


Figure 9: Example of the FD12P insect filtering of the MOR on August 4, 2012. See text for more details.

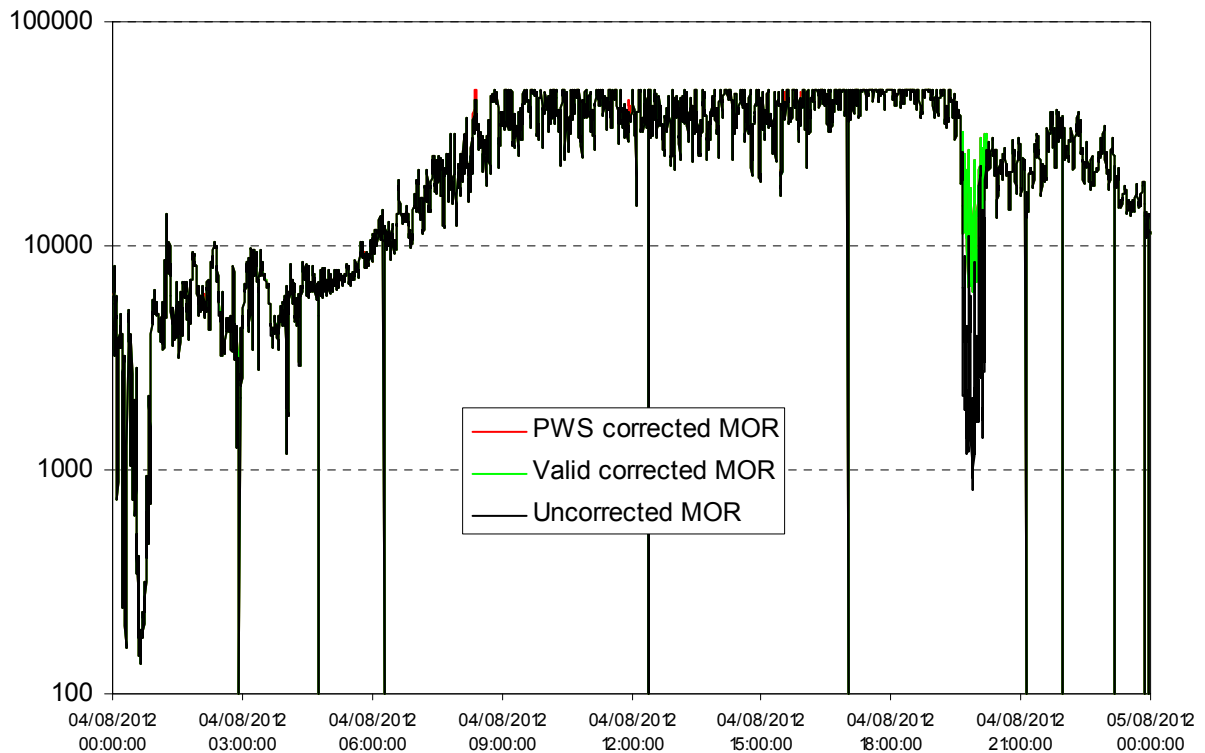


Figure 10: The uncorrected and corrected MOR on August 4, 2012.

When the uncorrected and corrected MOR are plotted (Figure 10) the impact of the correction of the MOR during the main insect event during sunset is clearly visible. The filtering events near sunrise are not visible since the change in MOR is small and the corrected value equals the

previous uncorrected MOR value. The 10 events when the MOR drops below 100 m indicate events when instantaneous data is missing. On this particular day 355 out of the 7200 messages had an invalid format, but only 6 remained invalid after the retry mechanism built into the sensor interface. The other 4 gaps in the data are situations when the sensor interface did not receive a sensor response at all or with too much delay.

Table 2: Contingency tables of 1-minute averaged reference MOR versus uncorrected (left) and corrected (right) MOR using the SPECIAL visibility bins for all FD12P MOR filtering events in 2011.

MOR	Uncorrected →						OPER	MOR	Corrected →					
Ref↓	<800	<1500	<3000	<5000	<8000	≥8000		Ref↓	<800	<1500	<3000	<5000	<8000	≥8000
<800	29	0	0	0	0	4		<800	29	0	0	0	0	4
<1500	2	14	5	4	0	5		<1500	2	14	5	4	0	5
<3000	4	15	172	53	0	7		<3000	3	12	171	57	1	7
<5000	5	25	100	786	142	15		<5000	1	11	77	809	158	17
<8000	14	42	113	268	1413	264		<8000	1	3	51	240	1525	294
≥8000	190	400	619	548	803	18522		≥8000	1	5	75	257	716	20028

FALSE= 12.81% MISS= 2.03%

FALSE= 5.92% MISS= 2.25%

Table 2 shows a contingency matrix of the reference MOR versus the uncorrected (left) and corrected (right) MOR obtained in De Bilt for 2011. Note that the MOR of the operational FD12P with firmware 1.87 and the TMM were used for the construction of the reference MOR that was used for the evaluation of the (un)corrected MOR of the FD12P with firmware 1.91S. Table 2 contains all 1-minute data of 2011 where filtering occurred (corrected MOR ≠ uncorrected MOR) and the corrected MOR reported by the FD12P sensor has been validated with the real-time filter. Again the effect of filtering is that the number of entries with MOR less than the constructed reference MOR, and particularly the extreme situations in the lower left corner, reduce significantly (from 13 to 6 %). That 6 % of the events that remain below the reference MOR are partly caused by the fact the insect filtering of the MOR often leaves MOR values that still show a deterioration due to insects and hence are too low compared to the reference MOR. On the other hand the number of entries with MOR exceeding the constructed reference MOR changes only slightly (from 2.0 to 2.3 %). It should be noted that, since the uncorrected and corrected MOR were obtained with another FD12P sensor than the reference MOR, some scatter in the contingency matrix is to be expected. When all data of 2011 during which no filtering occurred is compared, that is when the uncorrected MOR reported by the FD12P with firmware 1.91S is compared to the MOR reported by the operational FD12P, 0.9 % of the data has MOR less than the reference MOR and 4.3 % has higher values using the SPECIAL visibility bins.

11. CONCLUSIONS

Overall the insect filtering of the MOR by the FD12P with firmware 1.91S performs well and can be considered for operational use. However, there are some issues with the firmware that can be improved upon:

- The FD12P firmware sometimes produced invalid uncorrected MOR values (invalid or negative) that affect the reported MOR value for 1 minute.
- The FD12P firmware regularly gives replies to a data request with an invalid format.
- The corrected and uncorrected MOR reported by the FD12P are sometimes inconsistent due to the asynchrony between messaging and the measurement/calculation tasks.
- The FD12P MOR insect filtering algorithm should be coupled with the internal precipitation detection algorithm so that faulty insect filtering events related to precipitation are minimized.

The above items will be partially dealt with in the KNMI sensor interface and the real-time validation filter. Based on the evaluation results KNMI has decided to introduce the FD12P firmware with insect filtering of the MOR at civil airports in combination with the validation filter. Both the corrected and uncorrected MOR will be made available in the meteorological network. The corrected MOR will be used operationally and the uncorrected MOR will be used for remote

monitoring and evaluation purposes. It should be noted that even in the so-called AUTO METAR system the visibility (and all other meteorological parameters) which is included automatically in aeronautical reports are monitored remotely by a meteorologist.

In June 2012 Vaisala released FD12P firmware 1.92S in which the issues of firmware 1.91S reported in section 10 are solved, except the second item related to the message with invalid format since that could not be reproduced. This firmware will also be evaluated by KNMI.

12. REFERENCES

Vaisala: Weather Sensor FD12P User's Guide, M210296en-A, Helsinki, Finland, May 2002.

Wauben, Wiel: Evaluation of the Vaisala FD12P 1.91S firmware with insect filtering, KNMI Technical Report No. 316, De Bilt, The Netherlands, February 16, 2011.