Koninklijk Nederlands
Meteorologisch Instituut
Ministerie van Infrastructuur en Milieu

Evaluation of the Vaisala FD12P 1.91S firmware with insect filtering

Wiel Wauben

De Bilt, 2011 | Technical report; TR-316

Evaluation of the Vaisala FD12P 1.91S firmware with insect filtering

Wiel Wauben

R&D Information and Observation Technology

KNMI

February 16, 2011

Table of contents

1. Introduction

A so-called transmissometer (TMM) measures the extinction of a light beam over an atmospheric path between an emitter and a receiver. The atmospheric extinction is by definition directly related to the Meteorological Optical Range (MOR). Since a TMM measures extinction, its signal varies exponentially with MOR. As a result a TMM can only measure low MOR values very accurately, although a second receiver, placed at a larger distance from the emitter, is often used to increase the MOR range of a TMM. The MOR reported by a double baseline TMM is only used by KNMI up to values of 3 km and the reporting of runway visible range for aviation is restricted to values below 2 km. A so-called forward scatter sensor (FS) measures the amount of light scattered by a small measurement volume at an angle of about 33 °. Its signal varies linearly with MOR so that it can be used to measure higher MOR values. However a relation between the amount of forward scattering and the extinction of the scattering medium needs to be taken into account. KNMI uses the Vaisala FD12P forward scatter sensor for measurements of the MOR up to 50 km. At first the sensor was only used at synoptic weather stations, but after approval by ICAO the sensor is now also used for (runway) visibility measurements at airports. The advantages of a FS compared to a TMM are the lower procurement and installation costs (a double baseline TMM consists of 3 separate sensor units that need to be carefully aligned), lower maintenance due to lesser sensitivity of MOR measurements to contamination of lenses, the possibility to measure up to higher MOR values, and some FS sensors, like the FD12P, have extensions so that it can measure the so-called present weather, i.e. precipitation type and intensity. In fact, the FD12P and similar instruments are often called present weather sensors (PWS). The advantages of a TMM are that it measures MOR (extinction) directly and that it can be calibrated through neutral density filters with a known extinction. The calibration of a FS requires a field setup so that the MOR of a reference FS can be related to that of a calibrated TMM. The reference FS is then used to calibrate a scatter plate by which the calibration is transferred to other FS sensors (cf. *Bloemink et al., 2010*). Note that there is no field reference for high MOR values although sensor inter-comparisons and comparisons with human observations over the full MOR range have been performed (cf. e.g. *Wauben, 2003*). A TMM or FS can be equipped with a background luminance sensor, which is required to convert the observed MOR into the aeronautical (runway) visibility that is defined as the maximum distance at which a standard (or actual runway) lights can be distinguished form the background. The background luminance sensor measures the brightness of the sky to the North at an elevation of about 30 °.

During the introduction of the automated aeronautical meteorological reports it was noted that occasionally significant reductions in the visibility reported by the FD12P occurred. Figure 1a 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). The MOR is reported for the “operational” FD12P (PWS), the FD12P with insect filtering (FD12Pc, where “c” denotes that the corrected MOR is considered) and the TMM using the black logarithmic scale indicated on the left. The “operational” FD12P and the FP12P with insect filtering show reduced MOR due to insects around 18 UT, whereas the TMM shows no features in MOR. Between 4 and 5 UT all three sensor shows low MOR values during a fog event. Also note that during the day both FD12P report a MOR of about 30 km whereas the TMM only reaches values of 5 km. Figure 1a also shows the background luminance of the PWS (light blue curve with logarithmic scale on the right), which clearly indicates the daylight period. During nighttime the background luminance sensor reports a constant value of 4 cd/m^2. Lastly, Figure 1a also gives the precipitation intensity of the “operational” FD12P (dark blue curve with scale on the left) which is 0 mm/h on this particular day. Eventually the reduction of the MOR reported by the FD12P was attributed to the presence of insects (mosquito’s) in the measurement volume, which was confirmed by visual inspection (cf. Figure 1b). Note that the MOR filtering of the FD12P at that time hardly changes the MOR. The large differences in the MOR reductions of Figure 1a between PWS and FD12Pc are an indication of the differences of the local conditions, although the FS sensors are only 6 m apart. Furthermore note, that the reduction of the MOR due to insects is a general problem encountered with FS sensors, which is related to the measurement technique. In fact insect induced MOR reductions have also been observed in the MOR measurements of other FS sensors. The top panel of Figure 2 shows measurements obtained at De Bilt on August 13, 1998. In addition to the 10-minute averaged MOR and precipitation intensity of a FD12P also the 1-minute averaged MOR of a HSS 402B FS sensor are shown. At that time the HSS was the operational FS sensor of KNMI and the FD12P was under test and did not have a background luminance sensor and neither was TMM installed in De Bilt. Both FS sensors show a reduction of the MOR between 19 and 20 UT. Note that the HSS reports MOR values exceeding 50 km during the day

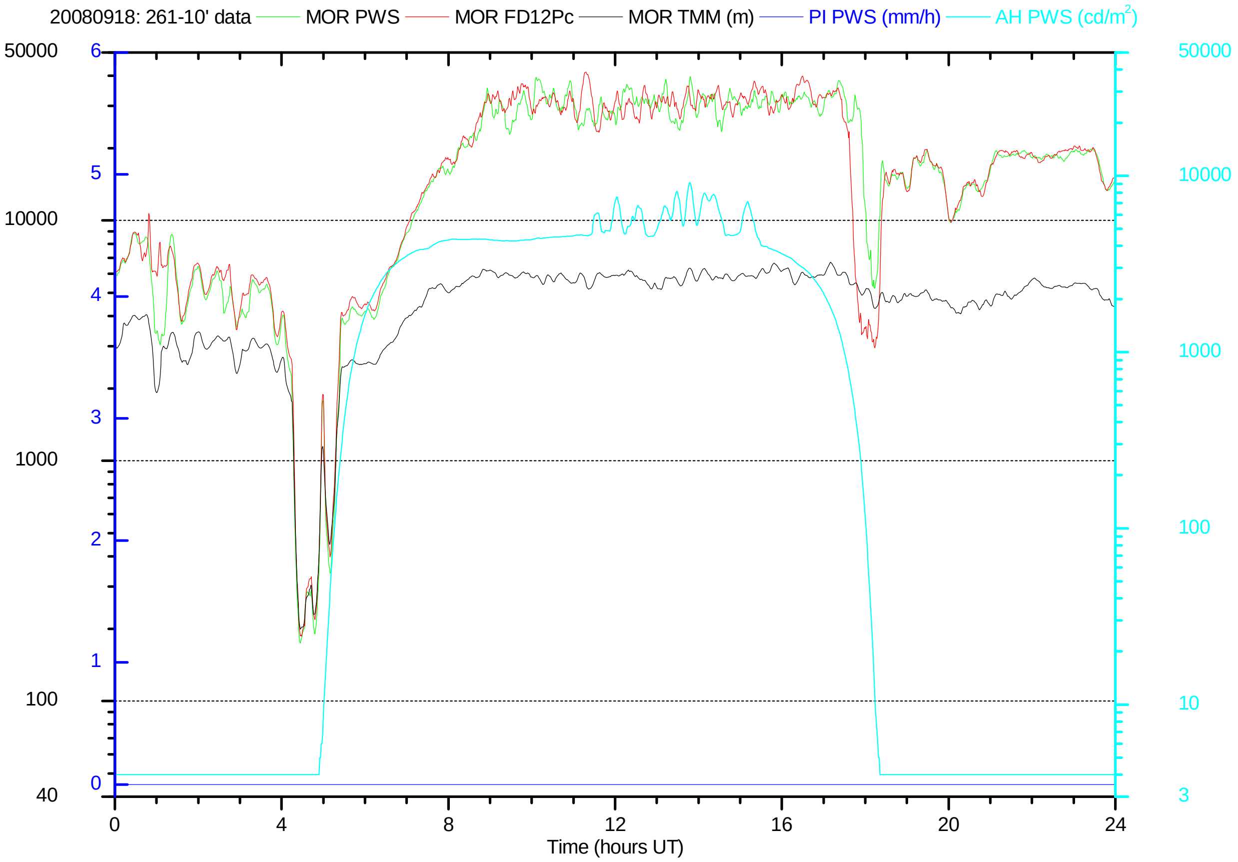


Figure 1: Example of the MOR reduction of the FD12P by insects observed in De Bilt on September 18, 2008 (a) and a picture showing insects around the FD12P on September 8, 2008 during a similar MOR reduction event (b).

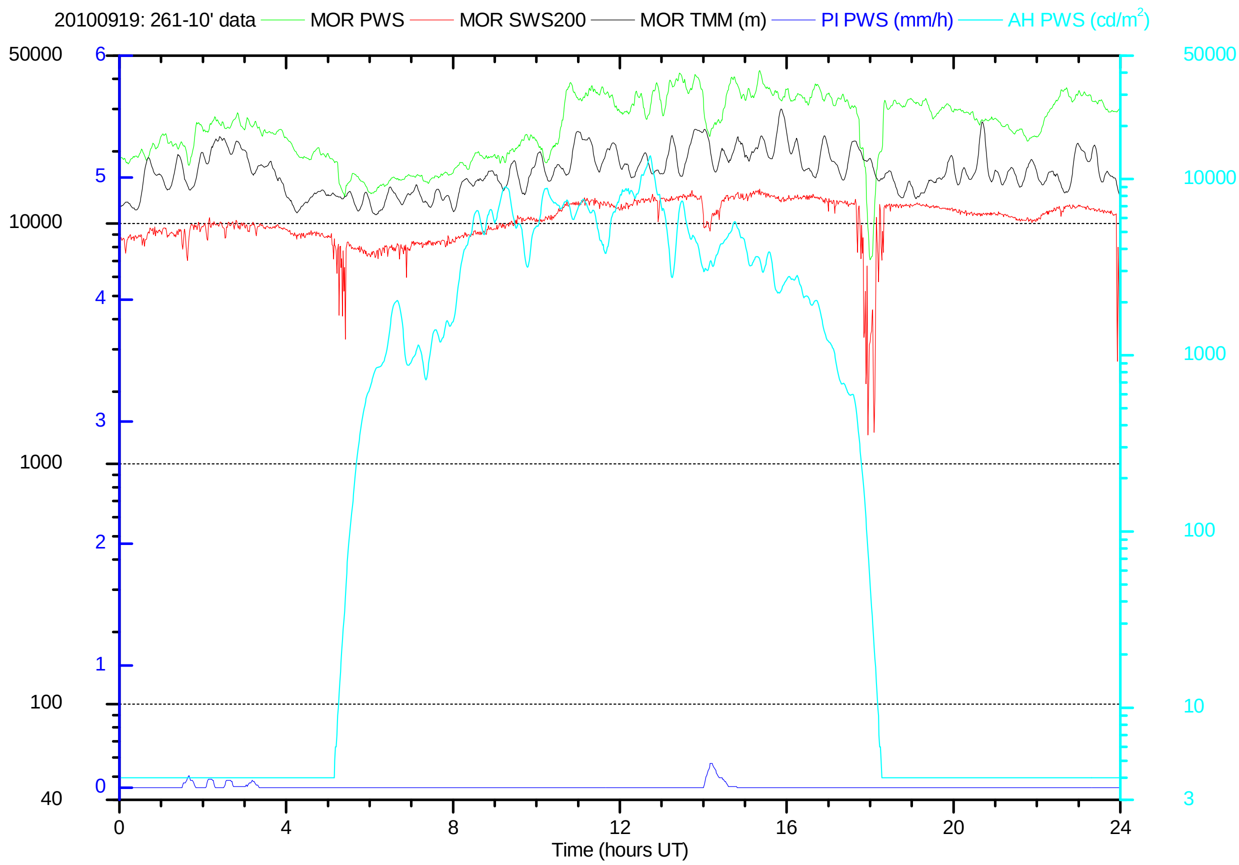


Figure 2: Examples of the insect induced MOR reduction of a HSS (top) and SWS200 (bottom) FS sensor observed in De Bilt on August 13, 1998 and September 19, 2010, respectively.

since it had a range up to 150 km. The lower panel of Figure 2 shows the measurements in De Bilt on September 19, 2010. In addition to the 10-minute averaged data of the PWS and TMM the 1-minute averaged MOR of a SWS200 FS sensor is shown. The SWS200 is a new sensor that is similar to the SWS100 that KNMI will be using for profile measurements of the MOR in the meteorological tower at Cabauw. The manufacturer of the SWS200 claimed that the additional backscatter signal of this sensor is used internally to discriminate the signal due to insects from the atmospheric signal and that the corresponding measurements are not used in the internal MOR calculation. However, a comparison in De Bilt showed that the MOR of the SWS200 sensor also showed significant reductions of the MOR due to insects. Figure 2 shows insects reduced MOR events both near sunrise and sunset. Note that the event near sunrise is more clearly visible in the 1-minute than in the 10-minute averaged MOR since the large variability of the MOR reductions during the event, which diminishes the effect in the 10-minute averaged values. Also note that the SWS200, which has a MOR range of 20 km, underestimates the higher MOR values. The TMM in this case reports MOR value above 10 km, whereas its values MOR did not exceed 5 km in Figure 1a. However, such a behavior can be expected when the MOR is above 3 km since small changes in the calibration of the TMM or contamination of the lenses, acceptable at MOR values of the TMM below 3 km, can have a large impact at higher visibilities.

A FS is very sensitive to insects in the measurement volume, whereas a MOR measured by a TMM seems to be less affected. FS MOR values below 1 km have been observed during insect events while the actual MOR was above 10 km. Such large MOR reductions put the MOR in different visibility classes used for aeronautical purposes, which can affect operational limits. Luckily, reporting a lower MOR poses no safety issue, but operations and the capacity of an airport can be affected. Since the visibility reported by a FS during insect events is evidently incorrect, this problem needs to be solved. The insect induced MOR reductions can be tackled either by eliminating the insects or preventing them from entering the measurement volume of the FS or by filtering out the raw MOR measurements samples that are affected by insects. The first option is generally not practical, although some measures are addressed below. The filtering of MOR has the preference, but the design and evaluation of such a software filter is time consuming. A FS 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, so that the filtering of the raw MOR data and the optimization of such a filter cannot be performed offline. The insect induced MOR reductions of the FD12P were reported to Vaisala during a meeting in March 2008. 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. In September 2008 a first version of the insect filtering firmware has been evaluated and rejected. KNMI provided data to Vaisala so that they were able to improve the filtering. Firmware updates followed in November 2008, February 2009 and June 2009, but all these versions proved to filter the MOR insufficiently during insect events.

In this report the FD12P firmware 1.91S dated 28 May 2010 that was installed at the KNMI test site on July 8, 2010 is evaluated. In section 2 the field setup used for the evaluation of the FD12P firmware is described as well as the results of some measures taken to confirm and overcome the presence of insects. Section 3 shows examples of FD12P data messages used for the evaluation and illustrates some aspects of the filtering in details. Section 4 gives some typical examples of the MOR reductions and the MOR filtering observed during the evaluation period. In addition the constructed reference MOR and the validation filter that has been applied to the MOR filtering events of FD12P are introduced. Section 5 contains information on the occurrence of MOR filtering events, i.e. how often, when and under what conditions. In section 6 the MOR reduction due to insects and the performance of the correction is quantified by comparison with a constructed reference. Finally, section 7 gives a summary, conclusions and recommendations. Appendices A and B show the results of quantitative analysis of section 6 in the highest MOR reporting resolution. Appendix C relates sunrise and sunset, which are in this report considered the times when the background luminance deviates or reaches the nighttime value, to calculated values. It should also be noted that in this report insects should be read as flying insects (mosquito's, flies etc.), and that the term FD12P is used for the FD12P with 1.91S firmware unless stated otherwise. During a large part of the evaluation period a faulty FD12P was used that sometimes reported too low MOR values in good visibility conditions. The evaluation of the MOR filtering firmware is not affected by this faulty FD12P, but the magnitude and possibly also the number of faulty MOR corrections seems to be too pessimistic due to the use of this faulty FD12P. In the addendum the results of the MOR filtering are compared with an "independent" reference MOR constructed from the operational FD12P.

2. Field setup and tests

The evaluation of the firmware has been performed with a field setup in De Bilt. 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. The VIS/RVR reference 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, one 3 m East (reference FD12P with operational firmware version 1.87) and the other 3 m West (FD12P with filtering firmware 1.91S) of the path of the TMM (Figure 3). The optical path of the TMM and the measurement volume of the FD12P are at a height of 2.5 m, which is the same as for visibility sensors used for aviation. Note that the test field in De Bilt has a ditch, allotments and boscage nearby.

Figure 3: 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.

In order to make sure that the reductions in MOR are caused by insects one of the FD12P sensors was covered by a mosquito net (cf. Figure 4). The mosquito net reflects some radiation so that the FD12P reports a lower MOR (Figure 6 top panel). However, the FD12P with the net showed no reduction in the MOR around sunset whereas the other FD12P shows a clear MOR reduction due to insects. Inspection the next day showed small flies on the mosquito net (cf. inset of Figure 4). So possibly not only mosquito's (cf. Figure 1b), but also small flies cause the MOR reductions of the FS sensors. Other tests that were tried to discourage the insects from entering the measurement volume of the FS sensor involved attaching an electronic ultrasonic insect repellent close to the measurement volume (Figure 5), and switching of the lens and hood heating of the FD12P. Both measures did not discourage the insects from interfering with the MOR measurements. Without the heating the measurements of the FD12P can be affected by condensation on the lenses, which occurred during a fog event in the morning (cf. Figure 6 bottom panel) and resulted in deviations of the MOR up to about 9 UT. During the rest of the day the MOR of the FD12P shows good agreement with MOR of the operational FD12P, but between 17 and 18 UT the unheated FD12P shows reductions of the MOR due to insects. The operational FD12P does not show the MOR reductions. Such striking differences between the insect induced MOR reductions of closely collocated FD12P sensors have been observed quite often. The FD12P sensor with the MOR filtering firmware generally is more affected by insects, probably because it is closer to the ditch and boscage. Note that the above tests have been performed on the FD12P with an old version of the MOR filtering firmware that only made very small corrections to the MOR.

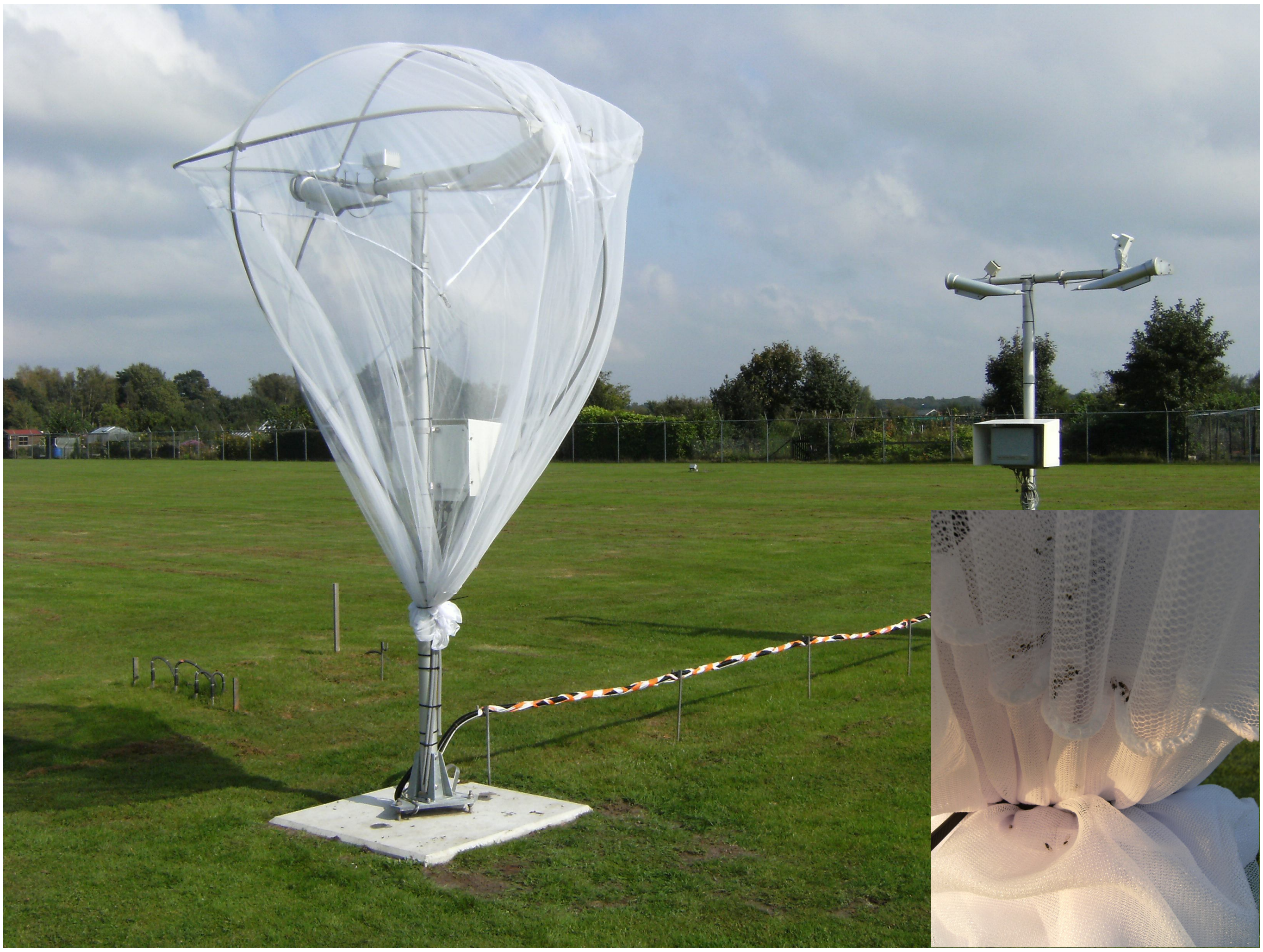


Figure 4: A FD12P covered by a mosquito net. The inset shows the small flies on the mosquito net.

Figure 5: The FD12P equipped with an ultrasonic insect repellent device mounted inside a tube fixed to the mast of the FD12P indicated by the yellow rectangle (left panel) and shown inside the tube looking upwards from the ground (right panel).

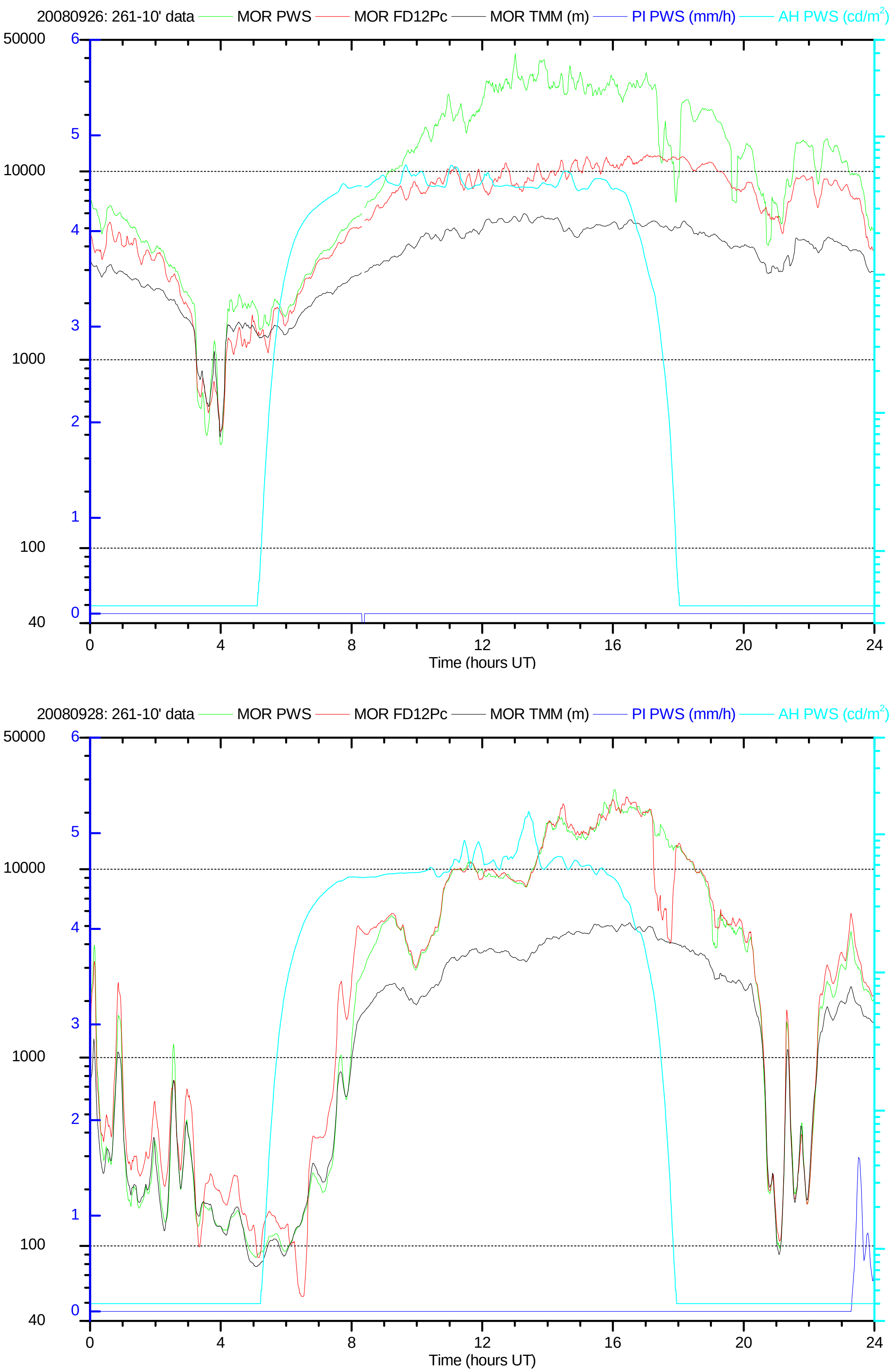


Figure 6: The measurements at De Bilt on September 26, 2008 with the FD12P covered with a mosquito net (top) and on September 28, 2008 with the FD12P operating without hood and lens heating (bottom).

3. FD12P filtering and sensor data

The FD12P sensor (cf. *Vaisala, 2002*) consists of an optical transmitter and receiver and a capacitive wetness sensor which are mounted on cross arm on top of a mast. It is also equipped with a temperature sensor and optionally a background luminance sensor is placed on top. The optical transmitter emits 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 dm^3 and is formed by the intersection of the transmitter and receiver beams. Figure 7 shows a picture of the FD12P sensor in De Bilt with the boscage in the background. The various instruments parts are indicated in the figure.

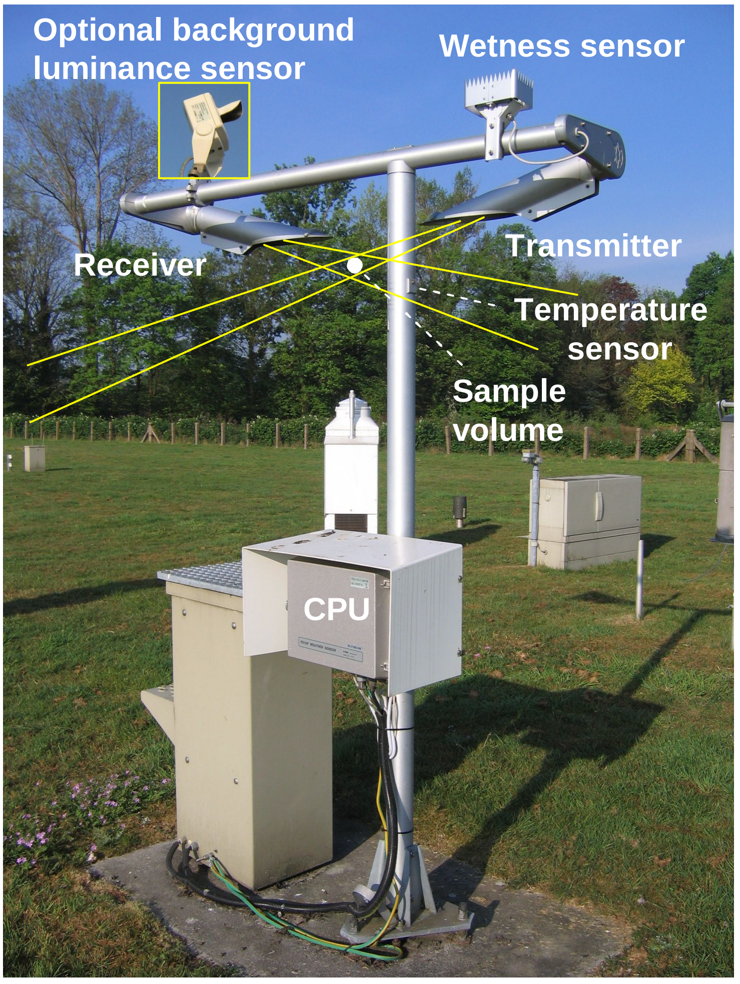


Figure 7: The Vaisala FD12P sensor with indication of the sensor parts.

Generally, the receiver records a continuous signal due to scattering by aerosol in the sample volume, from which 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, which gives a signal that is dependent on the thickness of the water film on the detector surface, gives a measure of the liquid water content of the precipitation. The precipitation type discrimination of the FD12P uses the ratio of the optical 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 at maximum.

The presence of insects in the sample volume will result in an optical signal resembling precipitation 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 messages 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 8 that reported the filtered MOR in the message 7 format, but included in addition an indicator showing whether filtering had been applied and the uncorrected 1-minute averaged MOR. The FD12P firmware with MOR filtering sets the filtering flag of the FD12P 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. It should be noted that the MOR insects filter indicator in the message may not be in synchronization with the reported MOR because of the asynchrony between messaging and the measurement/calculation tasks.

Data message 8 is used for the evaluation of the MOR filtering firmware and is meant for research purposes. Message 8 is based on standard data message 7, which is used operationally by KNMI, but additional information is placed to the end of the data message. The basic part of message 8 is updated every 15 seconds. Every 5 minutes, additional information on the particle size is generated. The content of message 8 is given below.

Basic message (message 7 and 8) line 1:
```
FD  1_00  6325  7423  L- 51 51 10   0.15  36.53    0  15.4     4
                                                            ----- background luminance
                                                      ----- temperature
                                                 ---- snow sum
                                            ------ water sum
                                     ------ 1’ precipitation intensity
                                  -- 1h wawa present weather code
                               -- 15’ wawa present weather code
                            -- instant wawa present weather code
                        --- instant precipitation type, NWS codes
                  ----- 10’ MOR corrected, with MOR filtering
            ----- 1’ MOR corrected, with MOR filtering
          - hardware error
         - visibility alarm
        - start of text (ASCII 2)
      -- unit identifier
-- sensor identifier
```
Basic message (message 7 and 8) line 2:
```
-DZ
---- instant METAR weather codes
```
Basic message (message 7 and 8) line 3:
```
REDZ
---- recent METAR weather
```
Basic message (message 8) line 4:
```
  2.72  2.318   5  39 1  5664
                          ----- 1’ MOR uncorrected
                        - indicator for MOR filtering
                    --- maximum droplet size (internal units)
                --- droplet amount
         ------ wetness signal average
------ optical signal average
```
Extended message (message 8 every 5 minutes, 0 to 127 lines for each internal size bin with entries):
```
004    23
     ---- number of particles
--- droplet size (internal units)
```
Extended message (message 8 every 5 minutes) last line (5-132):
```
   0
---- number of droplets larger than 127 (internal units)
```
Message 7 and 8 are both terminated by an ASCII 3 character (end of text).

The FD12P sensor is connected to the KNMI sensor interface (cf. *Bijma, 2007*) which polls the sensor every 12 seconds, processes the received message and passes the sensor information on to the measurement network in a fixed format. For the purpose of the evaluations a test sensor interface was programmed that polled the sensor for message 8 instead of message 7, but only processed that part of the message that is identical to message 7. By splitting the line between sensor and sensor interface the responses could be acquired and stored. Each message received was preceded by the data-acquisition time. Note that the sensor is polled every 12 sec whereas its internal update cycle of 15 sec, hence 2 out of the 5 messages received per minute are identical.

During the period of evaluation of firmware a total of 1,172,901 valid messages were received, whereas 66,391 invalid messages (5%) were received. Most of these invalid messages (65,801 or 99%) had a different format, as illustrated by the red lines below:

```
20100912 002756
FD  1_00 11826 10230  C   0 22 22   0.00  36.52    0  15.5     4


  0.00  0.000   0   1 1 10001

_
20100912 002808
FD  1_00  11500 125.32_
20100912 002820
FD  1_00 11530 10228  C   0 22 22   0.00  36.52    0  15.5     4


  0.00  0.000   0   1 1 10005

_
```

This incorrect reply to a message 8 request occurs quite often, but generally the previous and next requests are correct. The evaluation is not affected by these faulty replies since the evaluation is based on 1-minute data and uses the last valid message in each 1-minute interval. There are 581 invalid messages that are not caused by the above mentioned incorrect replies. The background luminance sensor produced faulty data on 257 occasions. The background luminance always became available again after a short period. Other background luminance sensors - including the one on the TMM - did not show this problem. The other invalid messages are related to missing (slashed) MOR, weather and/or other parameters. Also note that 13 events occurred where the instantaneous 1-minute averaged MOR with filtering as reported in line 1 of message 8 was zero, whereas all other parameters were valid. In the evaluation of the MOR filtering these events are considered valid, although the specified range of the MOR of the FD12P is 10-50000 m.

Line 4 of message 8 with the indicator for filtering and the uncorrected MOR showed invalid values on 143 occasions when the first line was correct. In these situations the uncorrected 1-minute averaged MOR contained an invalid value, i.e. either ****** or negative. All these events occurred when filtering was active, or was active within the previous minute. The example below shows a situation during filtering when an event occurs where the uncorrected MOR is ******, followed by 2 events (in fact 1) where the uncorrected MOR is larger than the corrected MOR and 2 events with negative uncorrected MOR. One minute after the ****** event the uncorrected 1-minute averaged MOR seems to return to the correct value.

```
20100920 175800
FD  1_00 22275 16358  C   0  0  0   0.00  98.16    0  16.0    13


  0.00  0.002   0   1 1  2169

_
20100920 175812
FD  1_00 25898 16689  C   0  0  0   0.00  98.16    0  16.0    13


  0.00  0.001  23  20 1******

_
20100920 175824
FD  1_00 24974 17195  C   0  0  0   0.00  98.16    0  16.0    13


  0.00  0.003   0   1 1 26079

_
20100920 175836
FD  1_00 24974 17195  C   0  0  0   0.00  98.16    0  16.0    13


  0.00  0.001   0   1 1 26079

_
20100920 175848
```

```
FD  1_00 30417 19779  C   0  0  0   0.00  98.16    0  16.0    12


  0.00  0.003   8   6 1 -7865

_
20100920 175900
FD  1_00 27846 20308  C   0  0  0   0.00  98.16    0  16.0    11


  0.00  0.000   0   3 1 -8674

_
20100920 175912
FD  1_00 23358 20460  C   0  0  0   0.00  98.16    0  16.0    11


  0.00  0.000   7  22 1  3186

_
```

The next data example show a situation negative uncorrected 1-minute averaged MOR values shortly after MOR filtering stops, but with a ****** value. The first entry shows the last report with MOR filtering, but with an uncorrected MOR exceeding the corrected MOR. Then filtering stops and the uncorrected MOR value jumps to 50 km, followed by 3 events (in fact 2) with negative uncorrected MOR values, a message with incorrect format, and finally the uncorrected MOR has a realistic value and equals the corrected 1-minute averaged MOR – which could be expected 1-minute after cessation of MOR filtering.

```
20100814 113254
FD  1_00 17235 14748  C   0  0  0   0.00   0.00    0  24.4  6350


  0.00  0.000   0   2 1 20086

_
20100814 113306
FD  1_00 23646 15230  C   0  0  0   0.00   0.00    0  24.4  6392


  0.00  0.000   0   3 0 50000

_
20100814 113318
FD  1_00 24471 15122  C   0  0  0   0.00   0.00    0  24.4  6351


  0.00  0.000   0   2 0-79764

_
20100814 113330
FD  1_00 24471 15122  C   0  0  0   0.00   0.00    0  24.4  6351


  0.00  0.000   0   2 0-79764

_
20100814 113342
FD  1_00 24317 15365  C   0  0  0   0.00   0.00    0  24.5  6316


  0.00  0.000   0   2 0-64456

_
20100814 113354
FD  1_00  17300 125.32_
20100814 113406
FD  1_00 14533 15164  C   0  0  0   0.00   0.00    0  24.5  6954


  0.00  0.000   0   4 0 14533

_
```

Situations when the uncorrected MOR exceeds the corrected MOR can also occur when MOR filtering is not active and the MOR values are realistic as is shown in the next example. Note that in evaluation of the MOR filtering situations where the uncorrected 1-minute averaged MOR exceeds the corrected MOR are taken into account. There are 14,572 of these events and only 333 occur during MOR filtering events. The reason for the occurrences of these inconsistencies is probably the asynchrony between calculations and messaging tasks. The inconsistent uncorrected MOR of 1793 m is reported as the next corrected MOR in the example below.

```
20100726 235717
FD  1_00   716  1315  C  10 10 10   0.00  38.71    0  11.2     4
BR

  0.00  0.000   0   2 0   716

_
20100726 235729
FD  1_00    720 125.46_
20100726 235741
FD  1_00   718  1317  C  10 10 10   0.00  38.71    0  11.2     4
BR

  0.00  0.000   0   1 0  1793

_
20100726 235753
FD  1_00  1793  1320  C  10 10 10   0.00  38.71    0  11.2     4
BR

  0.00  0.000   0   1 0  1793

_
```

The final data example shows a situation where MOR filtering occurs shortly before the FD12P starts reporting precipitation. At first the FD12P reports some droplets, but MOR filtering is not applied. MOR filtering starts at the moment when the wetness detector signal increases, which in fact is an indicator of precipitation. However, the FD12P start reporting precipitation after 3 messages. The FD12P now reports precipitation while MOR filtering is applied. MOR filtering stops 5 minutes after the FD12P started reporting precipitation.

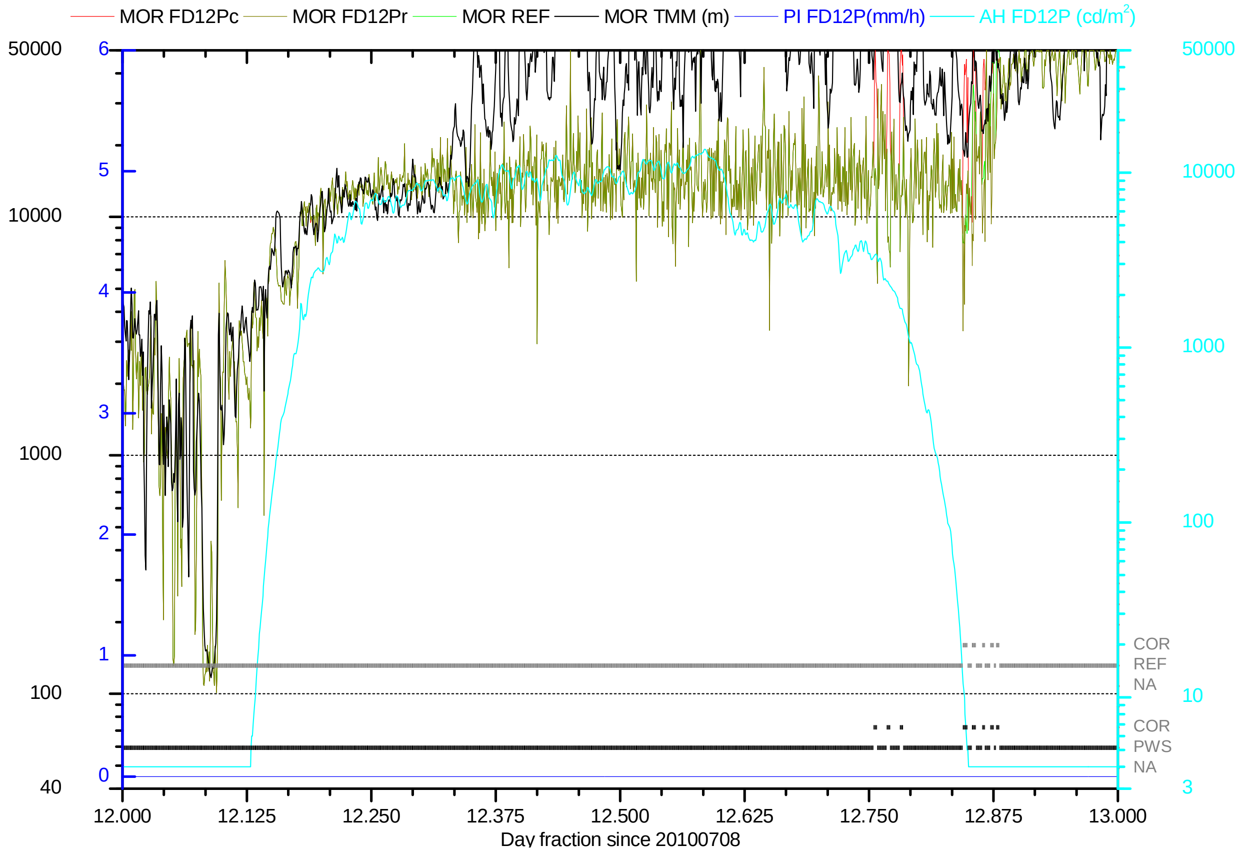
```
20100912 010208
FD  1_00  7172  7763  C  10 10 10   0.00  36.52    0  15.4     4


  0.00  0.069   1  13 0  7172
001     1
012     1
   0

_
20100912 010220
FD  1_00  7172  7763  C  10 10 10   0.00  36.52    0  15.4     4


  0.00  0.048   1  13 0  7172

_
20100912 010232
FD  1_00  7564  7743  C  10 10 10   0.00  36.52    0  15.4     4


  0.00  0.233   0   1 1  7553

_
20100912 010244
FD  1_00  7043  7695  C  10 10 10   0.00  36.52    0  15.4     4


  0.00  0.142   2   7 1  6940

_
20100912 010256
FD  1_00  6875  7635  C  10 10 10   0.00  36.52    0  15.4     4


  0.00  0.228   1   6 1  6700

_
20100912 010308
FD  1_00  7182  7694  R- 61 61 10   0.00  36.52    0  15.4     4
-RA

  0.19  0.219   1  11 1  6899

_
.
.
.
20100912 010708
FD  1_00  6325  7423  L- 51 51 10   0.15  36.53    0  15.4     4
```

```
-DZ

  2.72  2.318   5  39 1  5664
001    23
002    20
003    11
004     5
005     5
006     7
007     3
008     1
010     1
038     1
   0

_
20100912 010720
FD  1_00  6325  7423  L- 51 51 10   0.15  36.53    0  15.4     4
-DZ

  2.72  1.845   5  39 1  5664
_
20100912 010732
FD  1_00  6080  7376  L- 51 51 10   0.17  36.53    0  15.4     4
-DZ

  1.62  1.417  11  26 1  4915
_
20100912 010744
FD  1_00  6057  7330  L- 51 51 10   0.47  36.54    0  15.4     4
-DZ

  0.44  1.045  14   8 1  4784
_
20100912 010756
FD  1_00  6265  7280  L- 51 51 51   0.50  36.54    0  15.4     4
-DZ

  0.59  1.780  12   9 1  4830
_
20100912 010808
FD  1_00  6336  7210  L- 51 51 51   0.55  36.54    0  15.4     4
-DZ

  0.25  1.675   8   7 0  5089
_
```

4. Examples MOR filtering

The 1.91S firmware of the FD12P has been evaluated at KNMI from July 8 to December 31, 2010. On July 14, 2010 the orientation of the FD12P was changed slightly so that the receiver did not point towards to the A-building of KNMI, but between the seismology and radiosonde buildings (355°). All these buildings are far removed from the FD12P, so the change did not have any effect. In fact, the change was made to facilitate the mounting of the SWS200 to the mast of the FD12P according to installation instructions without interference to the FD12P optical path. On September 23 the FD12P with the firmware under evaluation was replaced by a spare FD12P that had also been equipped with the MOR filtering firmware. The reason for this change was that the FD12P reported sometimes too low MOR values with a larger variability when visibility was good (cf. e.g. Figure 8a).

In Figure 8 and Figure 9 some examples of the measurements of the FD12P with MOR filtering firmware are given. The examples illustrate the insect MOR filtering obtained from the 1.91S firmware of the FD12P as well as the performance of validation filter and the magnitude of the MOR reductions during insect events. The uncorrected and the corrected MOR values are shown as well as a constructed reference MOR. The figures show the 1-minute averaged MOR of the FD12P without (brown) and with MOR insect filtering (red) and the MOR of the TTM (black) using the black logarithmic scale indicated on the left. Note that in contrast to the previous figures the 1-minute instead of the 10-minute averaged MOR is shown in order to shown the insect events and the effect to filtering more clearly and in the rawest data available. The green curve is a constructed reference MOR that will be used in section 6. The **reference MOR** equals by default the uncorrected MOR of the FD12P. In case of insect filtering the reference MOR is the MOR of the TMM but



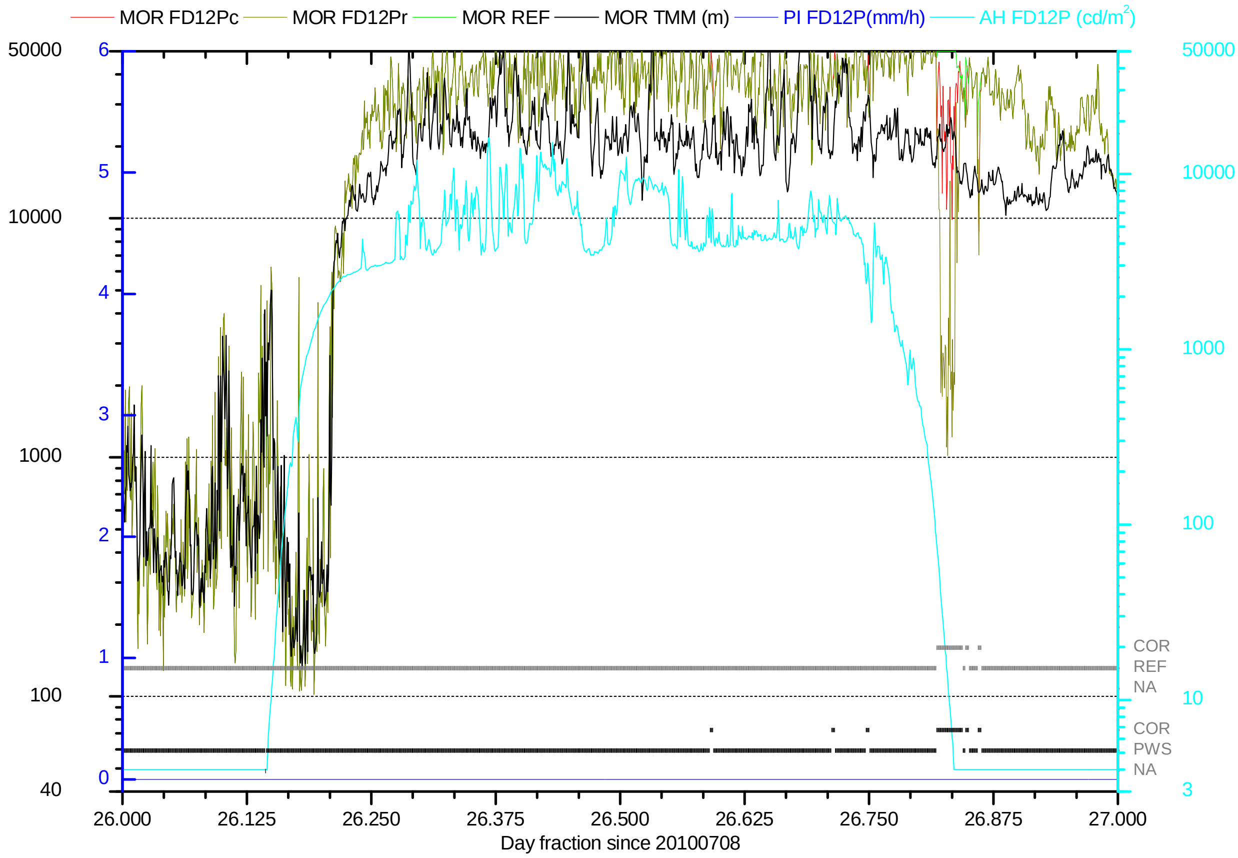
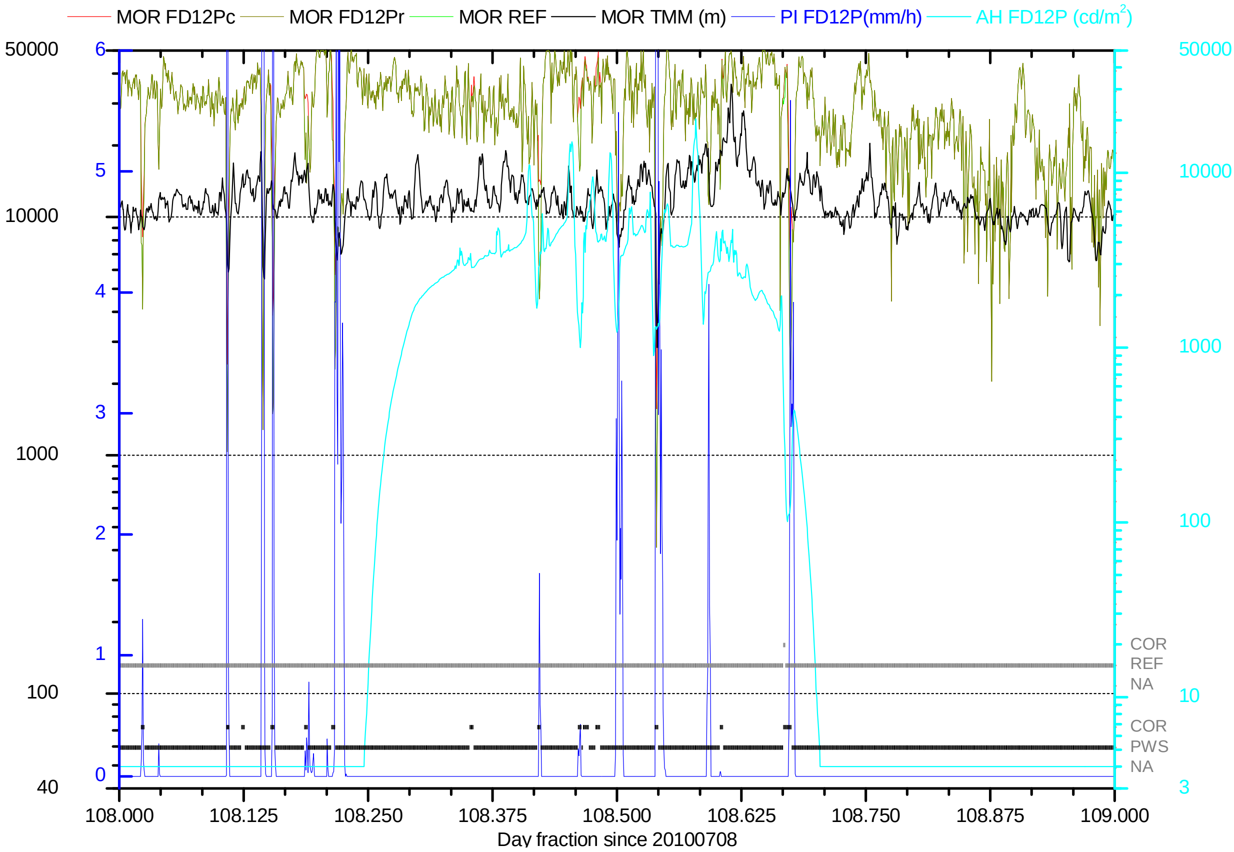


Figure 8a-b: Some examples of the FD12P filtering of the MOR on July 20 (a, top panel) and August 3, 2010 (b, bottom panel).



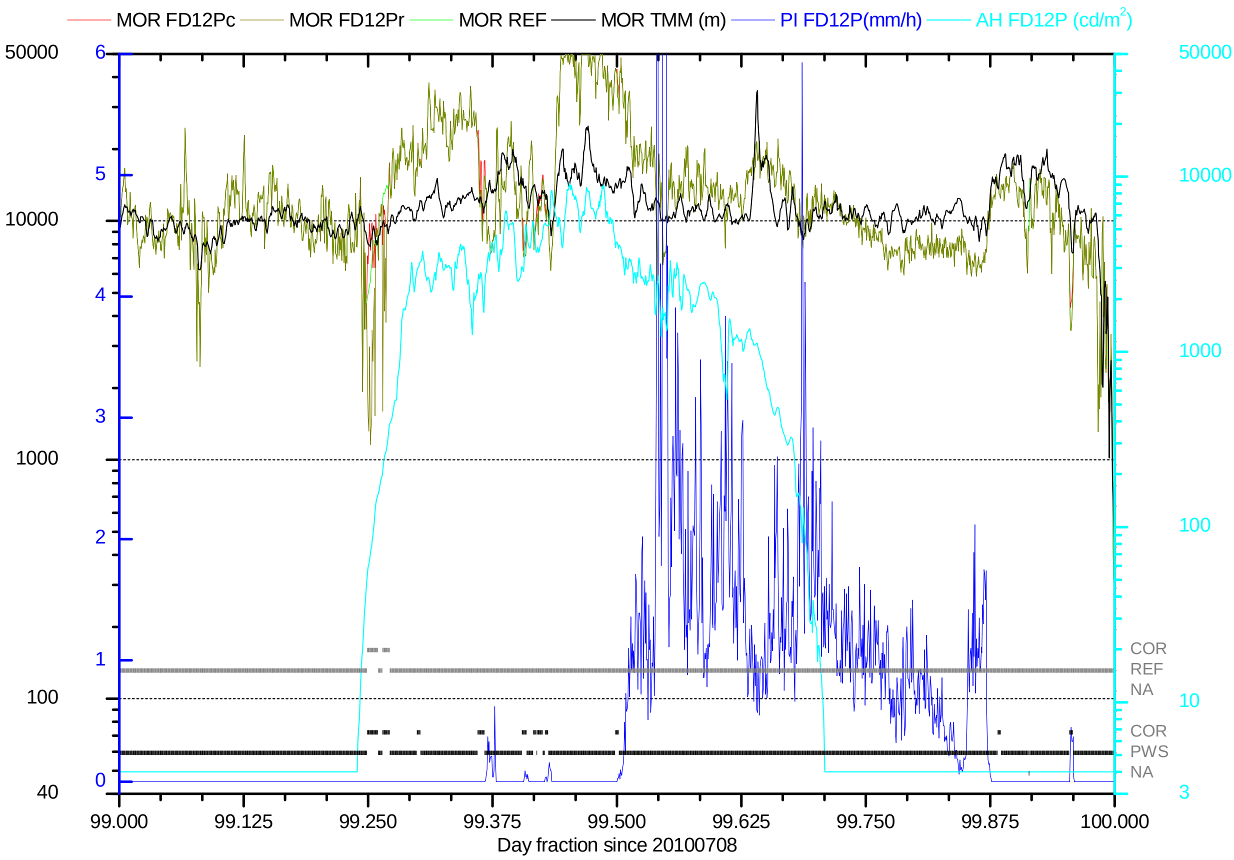
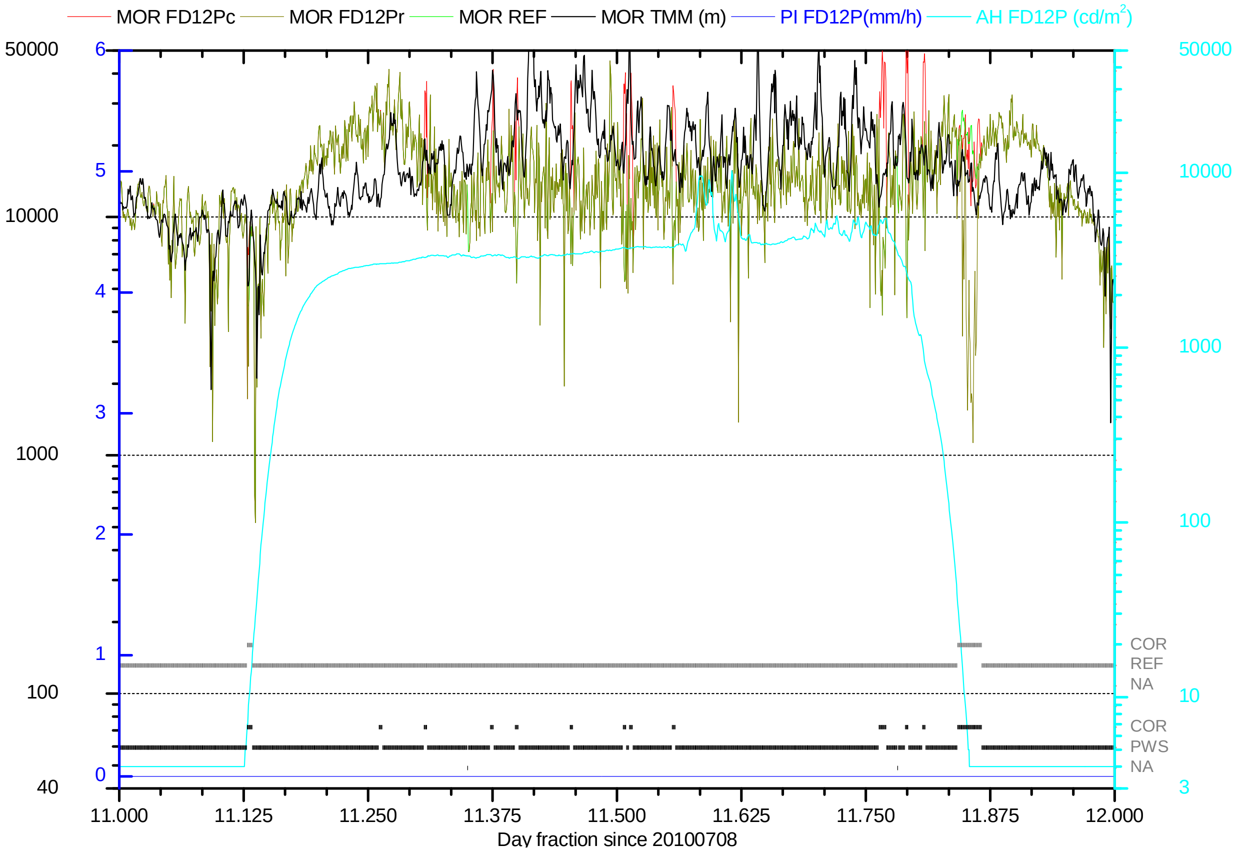


Figure 8c-d: Some examples of the FD12P filtering of the MOR on October 24 (c, top panel) and October 15, 2010 (d, bottom panel).

scaled with the ratio between the 10-minute averaged MOR of the FD12P and TMM. For that purpose the last and first 10-minute averaged MOR of the FD12P and TMM just before and after the insect filtering event is used and a linear interpolation between these two ratios is applied during the insect event. Note that the scaled MOR of the TMM is also used as the reference in case the MOR of the FD12P is not available. The rescaling of the MOR of the TMM is required because the MOR of the TMM is only accurate below about 3 km. The rescaled MOR of the TMM is maximized at 50 km, i.e. the range of the MOR of the FD12P. 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 ticks near the bottom indicate whether the MOR filtering indicator of FD12P is available or not (NA) and, if available, whether MOR filtering was applied (COR) or not (PWS). The gray ticks (indicated by REF) are the sensor MOR filtering events but validated by a filter. The **validation filter** only accepts MOR corrections within ±1 hour from sunrise and sunset (according to background luminance); without precipitation in a ±5 minutes interval around the events; and without a 1-minute averaged MOR of the TMM below1 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 elsewhere isolated faulty corrections occur regularly. 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 this sensor delay an insect event close to or during precipitation is discarded. The MOR filter has been used to discard faulty filtering during fog events. The latter filter requires the MOR of a TMM that is not affected by insects. Fortunately MOR filtering events during fog hardly occur, but the filter is introduced here in order to able to trace and quantify these events. The validation filter has been constructed and optimized by visual inspection of the data. A final inspection of all data showed that the validation filter removed the faulty corrections effectively without affecting the true insect events. The main insect events have been classified correctly, but naturally some individual events might be falsely classified. In this report the FD12P MOR filtering events that passed validation filter are considered correct. It is only these validated insect filtering events that have been replaced by the rescaled MOR of the TMM in the construction of the reference MOR. Regarding the reference MOR it should also be noted that it is a constructed reference and not a true reference MOR. The x-axis in the plots gives the day fraction since July 8, 2010 that is similar to the time in UT with ticks at every hour. Day fraction is used, because the daily graphs are all part of a single large graph spanning the entire evaluation period that could be quickly inspected during the construction of the validation filter and reference MOR.

Figure 8a shows a situation with fog in the morning of July 20, 2010 during which the FD12P correctly does not filter the MOR. Between 8 and 22 UT the FD12P reports too low MOR values while the variability in the MOR is large. The TMM and the operational FD12P (not shown) report higher MOR values. The reason for the too low MOR values is not related to the firmware, but seems to be related to a specific batch of faulty FD12P sensors. Around sunset some MOR filtering events occur that sometimes correct the MOR to 50 km, the maximum range of the FD12P. The operational FD12P also regularly reports values of 50 km between 8 and 22 UT. The results of August 3, 2010 (Figure 8b) again show that there is no insect filtering of the MOR during a fog event. On this clear day the FD12P with filtering firmware (the same sensor as July 20, 2010) gives the high MOR values correctly. At sunset a strong reduction in the MOR of the FD12P with values down to about 1 km occur 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 can still be observed. During the day there are 3 faulty filtering events, but the effect on MOR is negligible. On October 24, 2010 (cf. Figure 8c) several filtering events occur around precipitation events. The validation filter that requires no precipitation within ±5 minutes removes nearly all these filtering events except an event shortly before sunset. The results of October 15, 2010 (Figure 8d) indicate that filtering does not occur during an extensive period of precipitation but only near the onset and cessation of the precipitation event. October 15 also shows an insect event with reduced MOR values during sunrise, where the filtering again performs well. Only the onset of the insect event during sunrise is not correctly interpreted as such by the MOR filtering firmware. Hence the MOR reduction just before 6 UT is falsely treated as a correct MOR reduction and the reference MOR also shows this reduction.



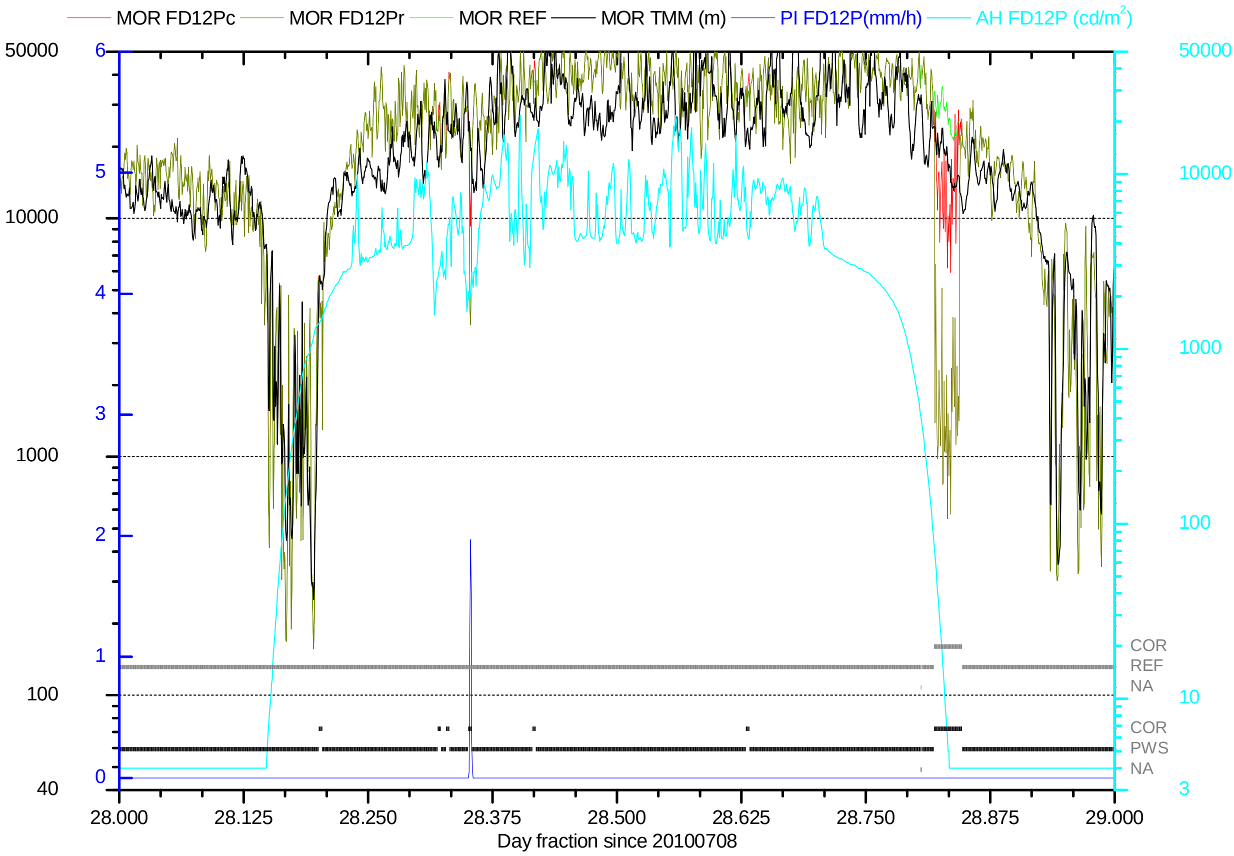
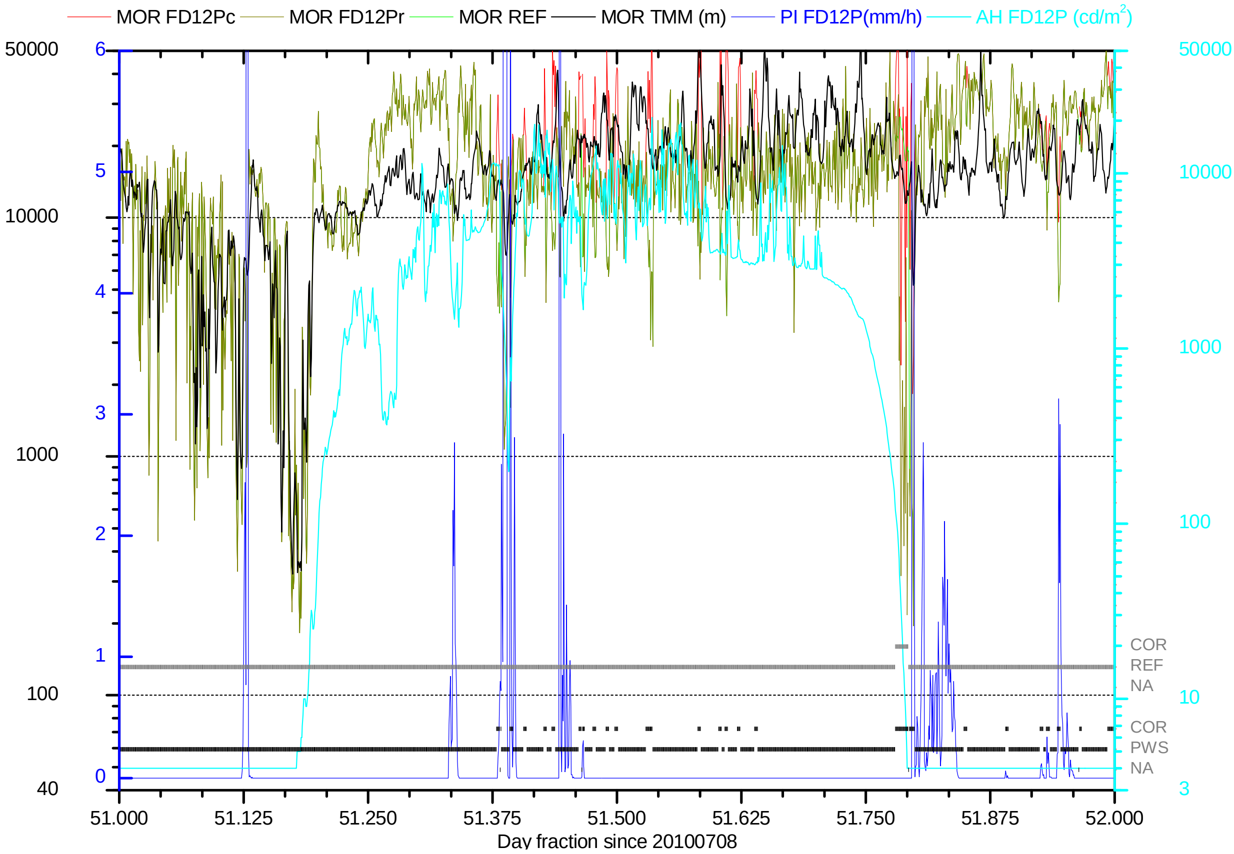


Figure 9a-b: Some more examples of the FD12P filtering of the MOR on July 19 (a, top panel) and August 5, 2010 (b, bottom panel).



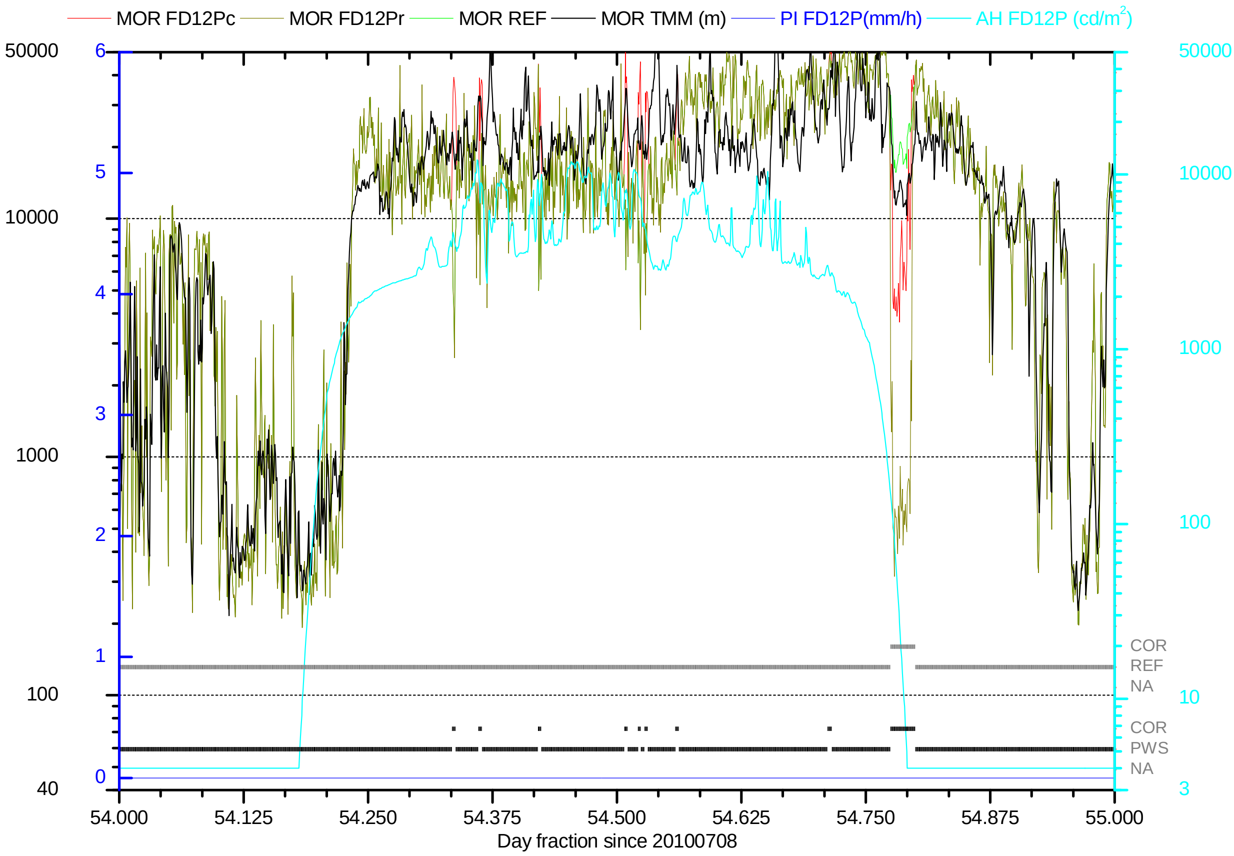
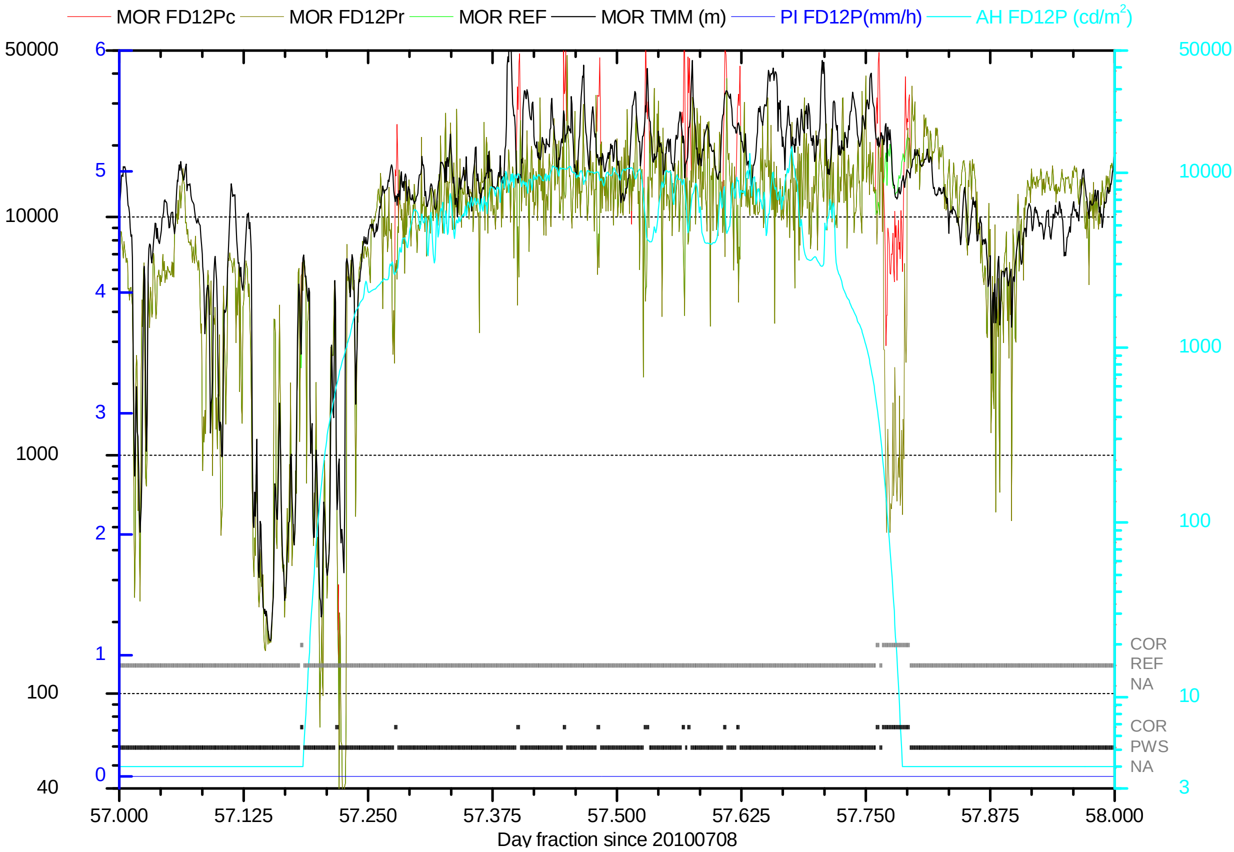


Figure 9c-d: Some more examples of the FD12P filtering of the MOR on August 28 (c, top panel) and August 31, 2010 (d, bottom panel).



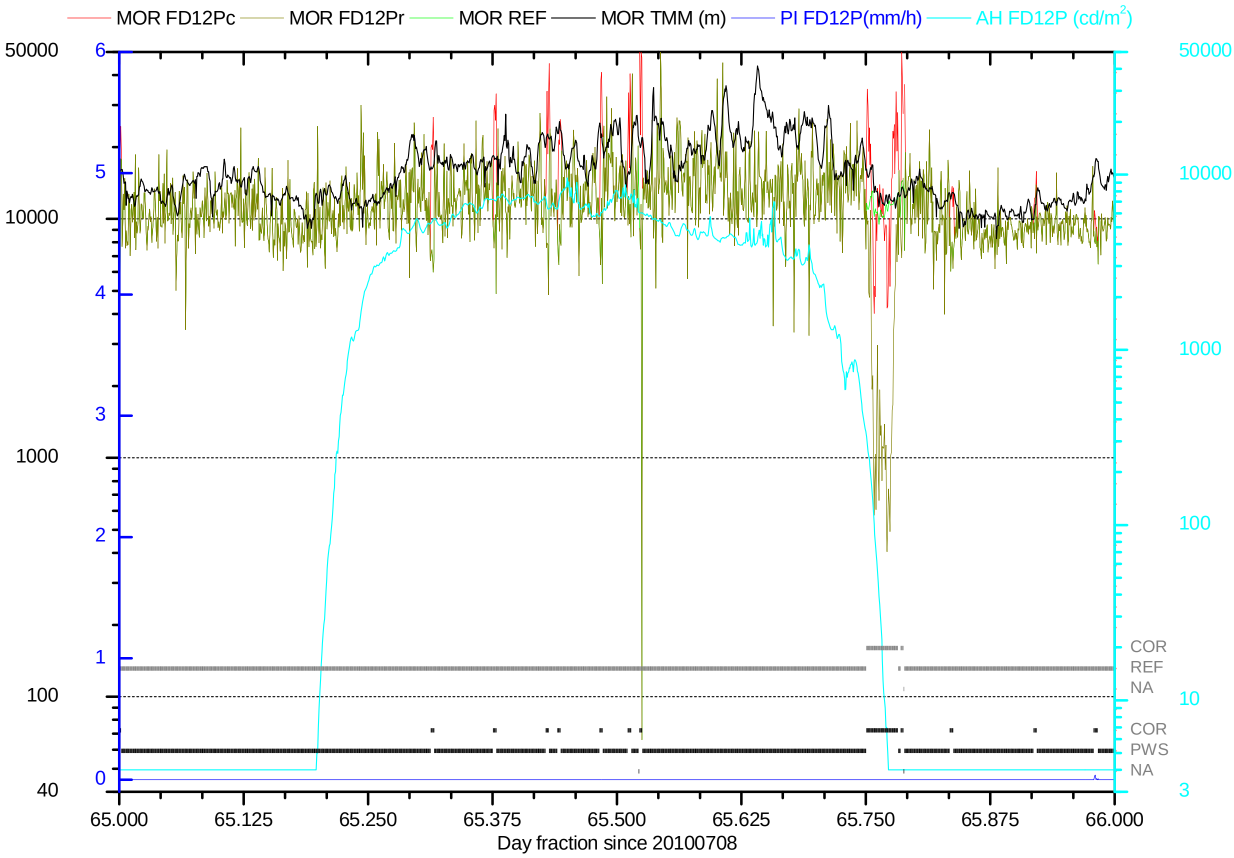
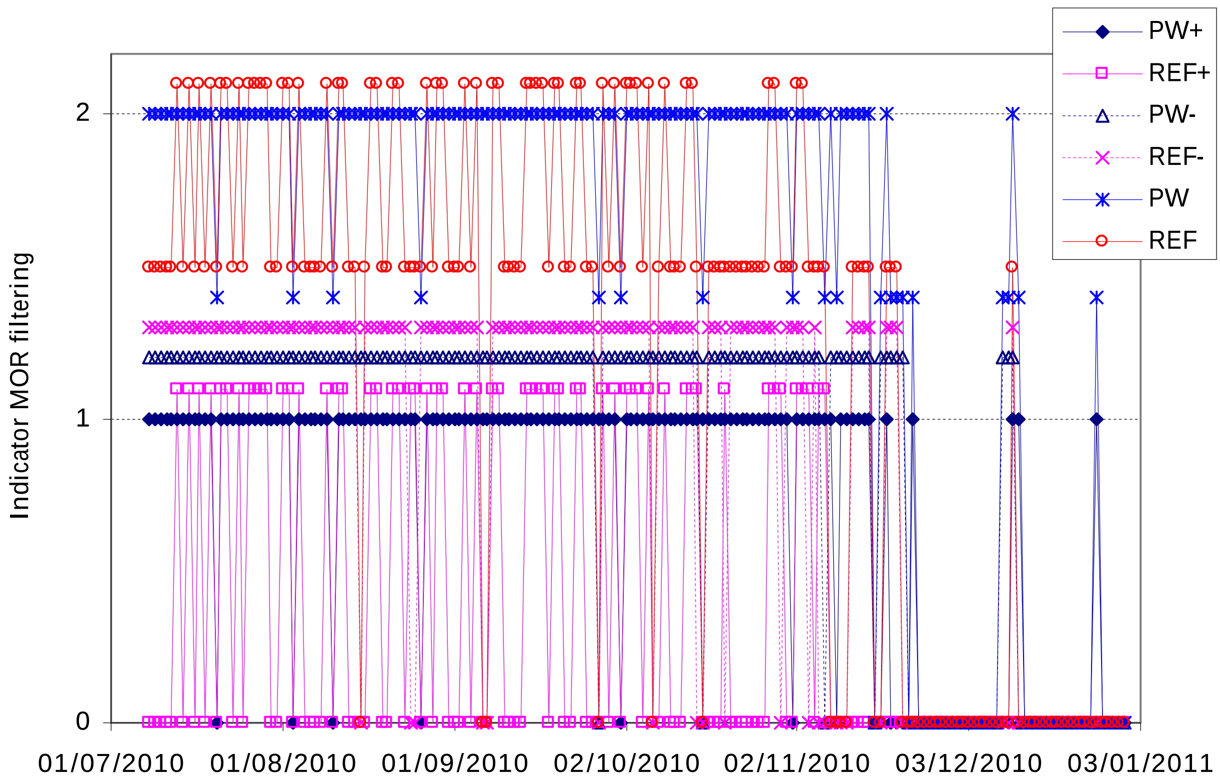


Figure 9e-f: Some more examples of the FD12P filtering of the MOR on September 3 (e, top panel) and September 11, 2010 (f, bottom panel).

The results of August 5 (Figure 9b) and September 3, 2010 (Figure 9e) illustrate some of the few cases where the FD12P applied MOR filtering during a fog event. On September 3, 2010 the validation filter of the MOR insect filtering events does not discard this event as a valid filtering event, whereas on August 5, 2010 the event is discarded by the TMM MOR <1 km within ±5 minutes filter. The MOR correction on both events is, however, small. August 28, 2010 (Figure 9c) shows a situation with insect reduced MOR near sunset shortly before a precipitation event. The validation filter that requires no precipitation within a time window of ±5 minutes rejects the correction shortly before the precipitation event, but since the uncorrected MOR of the FD12P is low during the precipitation the derived reference MOR would be too low if the uncorrected MOR during precipitation was used for rescaling the MOR of the TMM. August 31, 2010 (Figure 9d) shows a rare situation where the MOR of the TMM also seems affected by insects. This situation hardly occurs. Naturally the derived reference MOR also shows reduced MOR values during this event. August 31 and September 3, 2010 show insect events during sunset that still show clearly reduced MOR values after insect MOR filtering. July 19, August 28 and 31, September 3 and 11, 2010 show situations with corrected MOR values larger than the reference value that are related to situations where the FD12P reports too low MOR with large variability. On all these days the operational FD12P that is part of the VIS/RVR standard reported MOR values between 30 en 50 km. Most of the too high corrected MOR values are rejected by the validation filter, but some occur during real insect events near sunset. On July 19, 2010 (Figure 9a) the lowest valid corrected MOR of 1724 m occurs near 3 UT. Only a small correction is applied to the MOR, the uncorrected MOR is 1723 m, whereas 2 minutes later a MOR value of 2360 m is corrected to 6949 m. Also note that on September 11, 2010 (Figure 9f) an isolated dip, which lasted 3 minutes, in the MOR of 66 m is corrected to 47 km near 12:30 UT. In the invalid filtering events this shows up as a very large correction, whereas the graph suggests that the correction might be valid. A nearby Doppler radar and an optical disdrometer both reported (faulty) precipitation events during the isolated MOR reduction event.

5. Occurrences of the MOR reductions due to insects

In this section the occurrences of the MOR reductions due the insects are analyzed. Both the occurrences of the MOR filtering events as indicated by the firmware of the FD12P itself and the validated filtering events are considered for this purpose. The validated MOR filtering events, i.e. the events indicated by the FD12P, but only within ±1 hour from sunrise and sunset (according to background luminance), and no precipitation or MOR of the TMM below 1 km within a ±5 minutes, are considered here as the true insect related events. The top panel of Figure 10 shows with indicators for each day of the evaluation period if MOR filtering occurred according to the FD12P during sunrise or sunset (PW+ and PW-, respectively), and similarly for the validated filtering events (REF+ and REF-). Also shown are the indicators for sunrise and sunset combined (PW and REF) where 2 denotes the filtering occurred during sunset and sunrise while 1 denotes that filtering occurred only during sunset or sunrise. Filtering occurred quite often between July and mid of November during sunset and sunrise. The bulk of the MOR filtering events occur between July and mid of October, the number of events is slightly reduced between mid of October and mid of November, and there are almost no events afterwards. The validation eliminates many events, particularly for sunrise. In the period from July 8 to November 15, 2010 there are respectively 124 and 128 days at which MOR filtering occurs during sunrise and sunset, i.e. 95 and 98 % of the time. The validation filter reduces the percentage of days with MOR filtering during sunrise and sunset to 44 and 86 %, respectively. The lower panel of Figure 10 shows the accumulated duration of the MOR filtering events at sunrise and sunset. The duration of the MOR filtering events is significantly reduced by the validation filter. The longest MOR filtering events occur during sunset with durations after validation of about 1 hour with a maximum duration of 75 minutes at July 31, 2010. The durations are on average smaller from October 1 onwards. The duration of the validated insect MOR filtering events at sunrise is typically 20 minutes with a maximum of nearly 40 minutes. The distribution of the duration of the filtering events during sunrise and sunset is given in Figure 11. Again, the significant reduction in the duration after application of the validation filter is evident, particularly at sunrise. The overall duration of MOR filtering at sunrise decreases from about 4400 to 690 minutes (16 %) after passing the event through the validation filter. At sunset the overall duration decreases from 7800 to 3570 minutes (46 %).



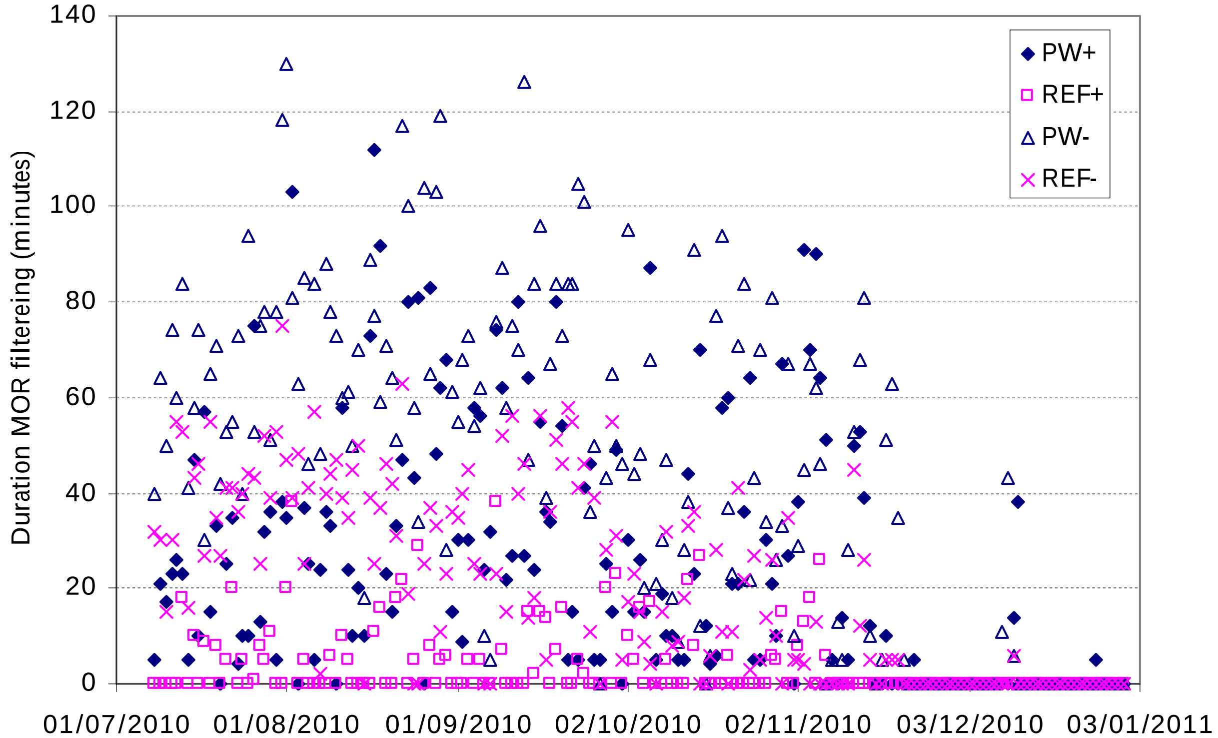


Figure 10: Overview of the daily occurrence of MOR filtering events during sunrise (+) and sunset (-) (top) and the accumulated duration of the filtering events (bottom). The MOR filtering events as indicated by the FD12P firmware (PW) and the validated filtering events (REF) are shown.

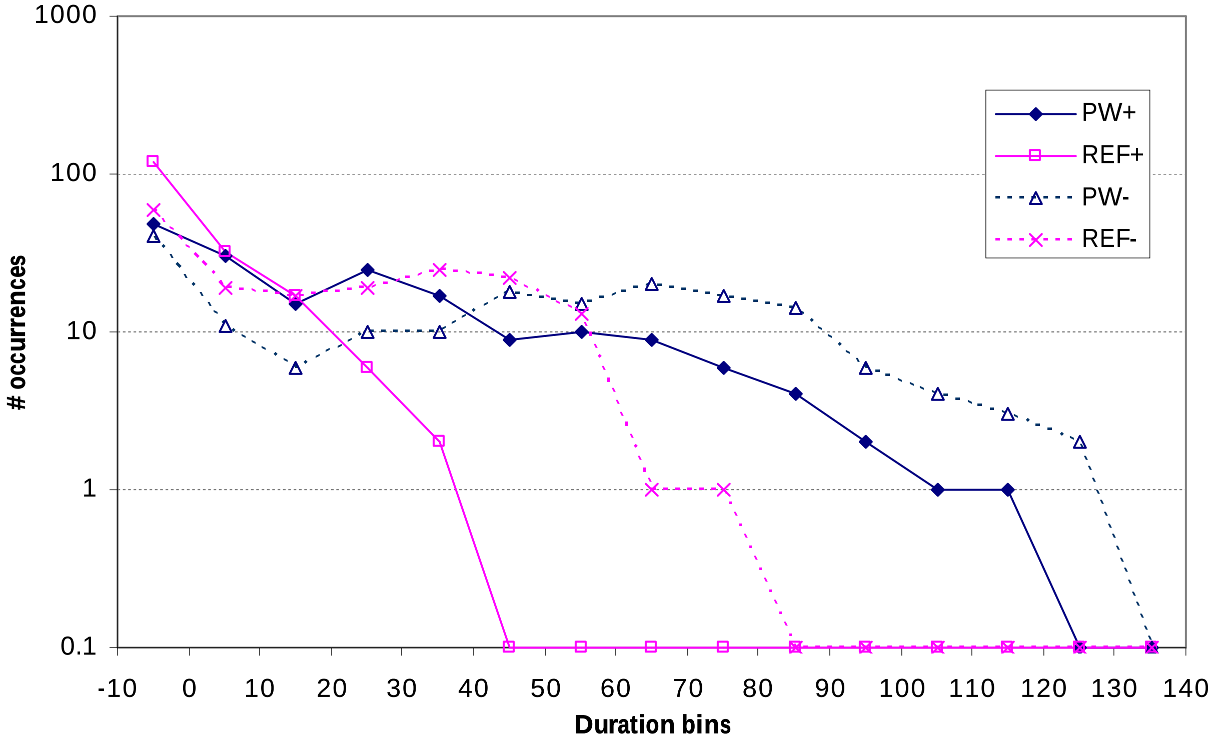


Figure 11: The number of days with MOR filtering events during sunset and sunrise with an accumulated duration in bins with steps of 10 minutes. The first bin shows the number of days without filtering.

Figure 12 shows the number of occurrence of the 1-minute MOR filtering events as a function of various meteorological parameters. As before, the figure shows the distributions of the MOR filtering events as indicated by the FD12P firmware (PW) and the validated filtering events (REF). In addition the distributions for all 1-minute data (ALL) are shown as a reference. The top left panel shows the distribution of the filtering events as a function of the corresponding 1-minute averaged relative humidity (RH). The bins size is 10 %, but above 90 % bin boundaries of 95, 96, 97, 98, 99 and 100 % are used in an attempt to zoom in on fog events. The first bin show some events when RH is not available. MOR filtering occurs over a wide range of relative humidity values. The reduced numbers above 95 % are mainly caused by the change in bin size. The accuracy of RH is considered to be ±3 %, which makes it hard to determine the real events with saturation. There are only 4 filtering events of the FD12P with RH=100 %, and all of them are discarded by the validation filter. However, of the 277 events with RH=99 % 116 are considered valid. Hence RH cannot be used for validating the MOR filtering events, except possibly at low RH values. In the 50 to 60 % RH bin only 5 % of the sensor MOR filtering events are valid and none at lower RH values, whereas for higher RH values 19 to 49 % are valid. The top right panel of Figure 12 shows the distribution of the filtering events as a function of the corresponding 1-minute averaged ambient temperature (TA) using a bin size of 2 °C for TA below 10 °C and a bin size of 5 °C for higher temperatures. MOR filtering hardly occurs below 4 °C, which could be expected since the FD12P MOR filtering algorithm uses a threshold of 8 °C using the temperature measured by the FD12P. The 6 and 101 filtering events in the 2 to 4 °C and 4 to 6 °C TA bins, respectively, are situations when the temperature of the FD12P sensor gives higher values than the ambient temperature measured at 1.5m in a radiation shield. All these 6 events and 97 out of 101 are discarded by the validation filter. Also at the high temperature range most of the MOR filtering events are discarded by the validation step, respectively, 115 out of 120, all 46, and 1 for the TA ranges 25-30, 30-35 and 35-40 °C. For TA between 8 and 25 °C more than 23 % of the sensor MOR filtering events are valid, 10 % for TA between 6 and 8 °C and 4 % at lower temperatures. The dependency of the number of occurrence of the 1-minute MOR filtering events on wind speed in bins of 1 m/s is given in the lower left panel. It is expected that insect only occur during calm conditions. However, this is not clear from the figure where MOR filtering up to 5 m/s occur. The wind speed used for the binning is the 10-minute averaged value measured at a height of 10 m. Due to the sheltered surroundings of the field setup used for the evaluation the wind speed at location and height of the FD12P will be much lower. However, the fraction of valid MOR filtering events drops rapidly with increasing wind speed, with values below 7 % at 4 m/s. The lower right panel gives the distribution of the MOR filtering events as a function of the 1-minute averaged uncorrected MOR value of the FD12P. The MOR bin width is 1 km. Filtering occurs quite uniformly in all MOR bins. The largest MOR bin also contains the filtering events for MOR values above 11 km and therefore has enhanced number of events. The fraction of valid MOR filtering events has a minimum value of 19 % for the MOR bin 7 to 8 km. Clearly there is no evident relation between the uncorrected MOR and the occurrence of MOR filtering events.

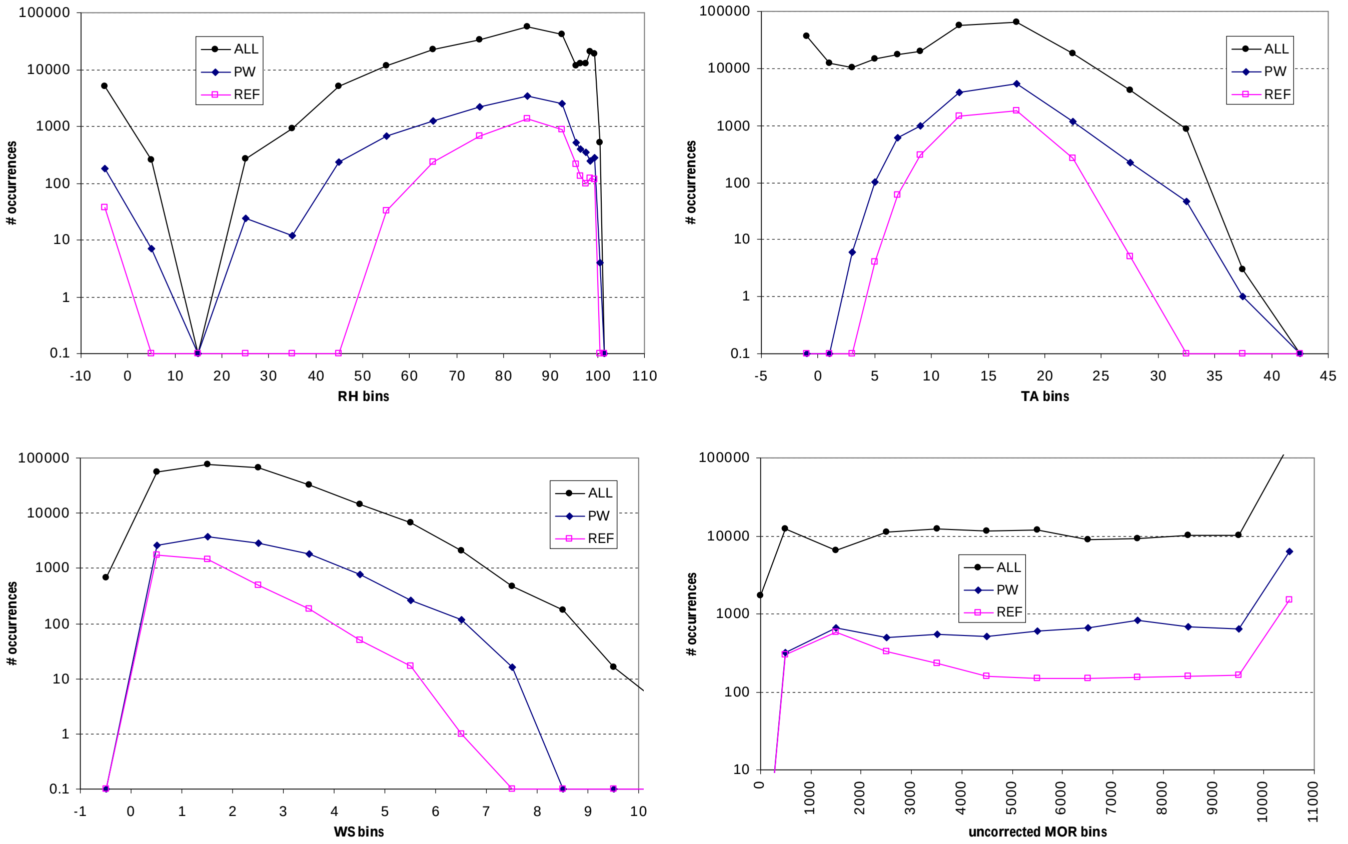


Figure 12: The number of occurrence of 1-minute MOR filtering events as a function of relative humidity (top left), ambient temperature (top right), wind speed (bottom left), and uncorrected MOR (bottom right panel).

Figure 13 shows the number of occurrence of the 1-minute MOR filtering events as a function time difference with sunrise and sunset. The time difference is given in 2-minute bins. The first bin shows the number of invalid entries, i.e. the entries that correspond with the other half of the day, since for sunrise only the MOR filtering cases between 0 and 12 UT are considered and for sunset 12 and 24 UT is used. The first but one and the last bin contain also all entries where the time difference exceeds -120 and +120 minutes, respectively. The distribution at sunrise shows the largest values between -6 and +21 minutes. The MOR filtering events show no clear dependency outside this central “peak”. The distribution at sunset shows the largest values between -22 and +24 minutes. The central “peak” for sunset is more pronounced than for sunrise. The fraction of valid cases also shows almost no dependence with time around sunrise and sunset. This could be expected since the validation mainly consist of the sunrise / sunset filter. Out of the total of 12,221 1-minute sensor MOR filtering events, 1849 occur within ±5 minutes of precipitation, whereas only 3908 events are valid. The distributions around sunset and sunrise do not give a strong support for the validation filter, but the visual inspection shown above - which includes the duration of events and most importantly also the measure of MOR reduction – strongly support the validity of this filter. Also the range of the filter (±1 hour around sunrise and sunset) are determined by distinct MOR reduction events induced by insects.

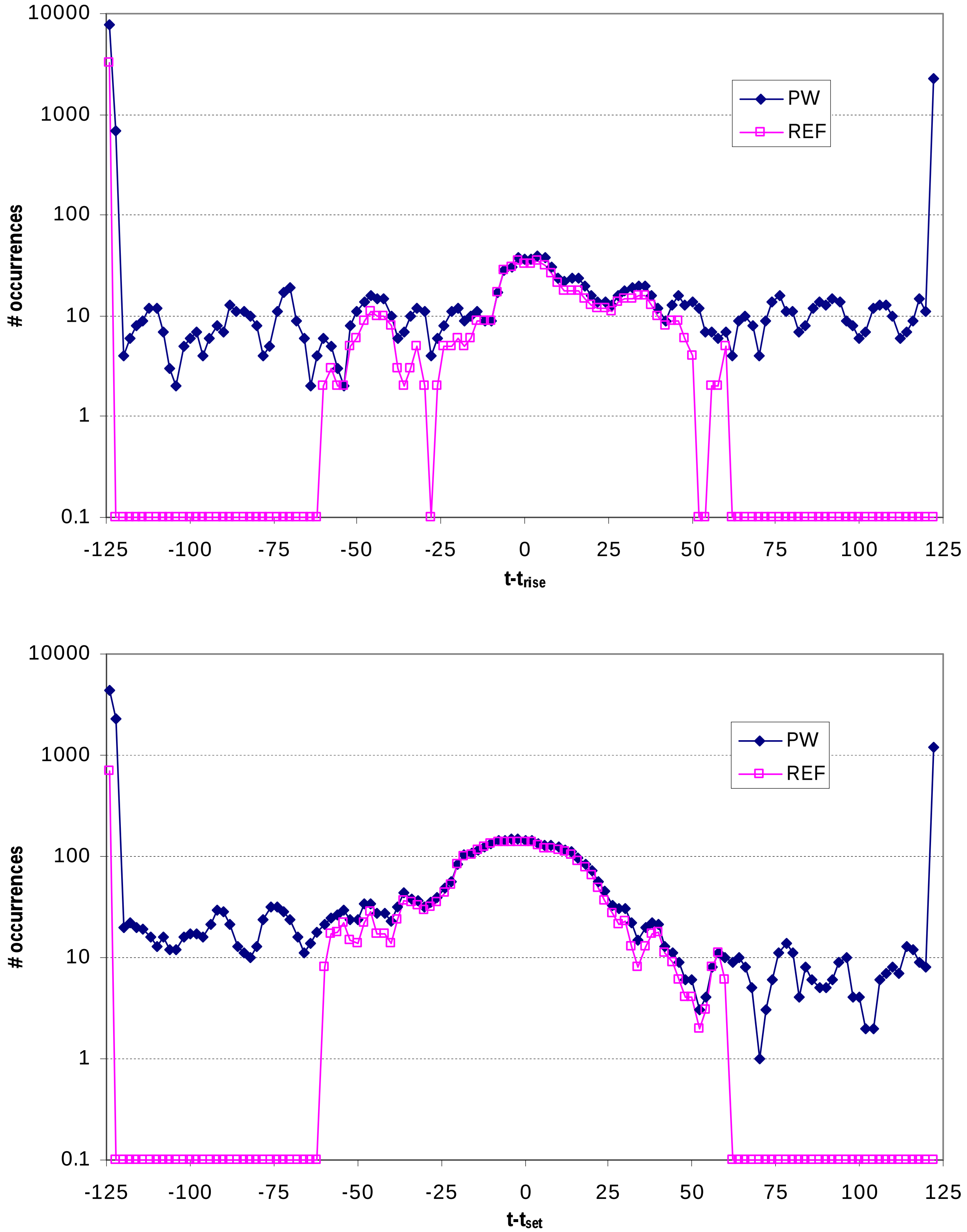


Figure 13: The number of occurrence of 1-minute MOR filtering events as a function of the time difference with sunrise (top) and sunset (bottom panel).

6. Quantification of corrected MOR reductions due to insects

Figure 14 shows the uncorrected and corrected 1-minute averaged MOR of the MOR filtering events as a function of the day fraction since the start of the evaluation period. A separation is made between the validated (REF) and the rejected MOR filtering events (NON_REF). The valid MOR filtering events show many cases with low uncorrected MOR while the corrected MOR is generally larger than 3 km. The lowest 1-minute valid corrected MOR is 1724 m occurs on day 11, i.e. July 19, 2010, during a spike at the start of a filtering event when the actual correction is small (cf. Figure 9a). The invalid MOR filtering events also show events when low uncorrected MOR are corrected to MOR values above 3 km, but situations with corrected MOR values below 3 km occur regularly. Histograms of the uncorrected and corrected 1-minute averaged MOR for the validated and the rejected MOR filtering events are given in the lower panel of Figure 14 with a bin width of 1000 m.

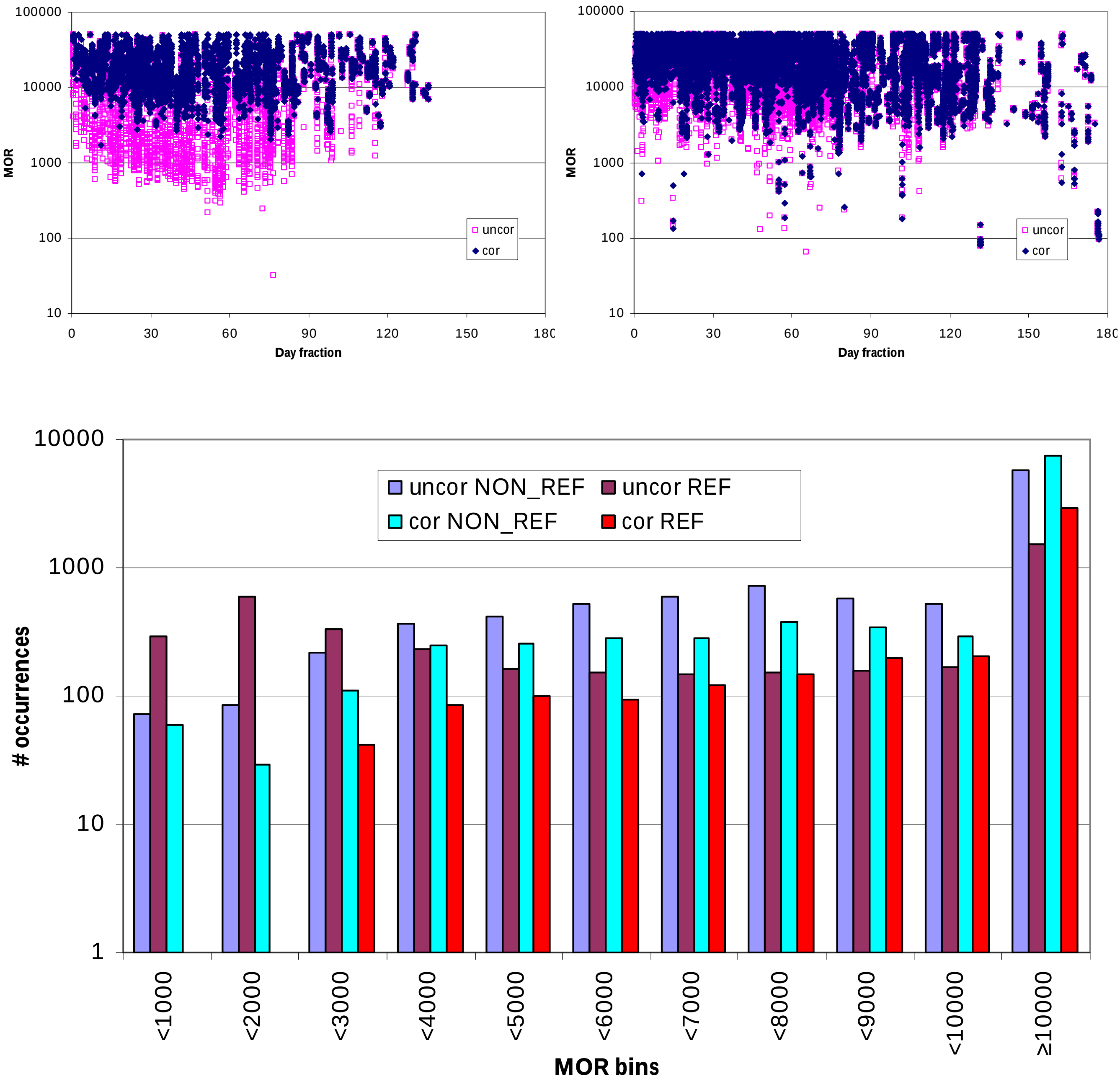


Figure 14: Uncorrected and corrected 1-minute averaged MOR as a function of the day fraction since the start of the evaluation period. The top left and right panels show the validated (REF) and rejected (NON_REF) MOR filtering events, respectively. The bottom panel shows a histogram of the data as a function of the MOR.

The differences between the uncorrected and corrected 1-minute averaged MOR of the FD12P during MOR filtering events is shown in Figure 15 using contingency matrices. For that purpose the MOR data is binned into the visibility limits that are used to trigger SPECIAL reports for aviation, i.e. 800 m, 1500 m, 3 km, 5 km and 8 km. The contingency matrix shows the uncorrected MOR value of the FD12P on the left and the corrected MOR value on the top. E.g. the number 50 in the top right corner of the upper left panel of Figure 15 indicates that on 50 occasions an uncorrected MOR of less than 800 m was corrected to a value equal or above 8 km. The gray diagonal indicates the cases where the corrected MOR is in the same SPECIAL visibility bin as the uncorrected MOR. Since a correction increases the MOR value, entries are expected above and/or to the right of the diagonal. Similar contingency tables, but generated by using the full resolution of the visibility reporting scale for aviation, are given in Appendix A. The upper left panel of Figure 15 shows the 12,221 events where the FD12P indicated MOR filtering (PW). For most cases the corrected and uncorrected MOR are above 8 km. For lower uncorrected MOR values a large fraction of the cases is corrected to MOR larger than 8 km. The 3908 cases with valid MOR filtering (REF) are shown in the top right panel. Although the REF cases are about a third of the PW cases, most cases with significant corrections for low MOR values (uncorrected MOR < 3 km and corrected MOR > 5 km) are valid cases. The fact that the invalid MOR filtering events generally have a smaller MOR correction is also evident in the lower left panel, which shows the complement of the REF cases. These 9845 cases are denoted NON_REF. Note that REF+NON_REF≠PW since the NON_REF also includes 1532 cases where the corrected and uncorrected MOR are not equal. The entry for uncorrected MOR <3 km and corrected MOR < 800 m corresponds e.g. with the inconsistent MOR in message 8 on July 26, 2010 shown in the message 8 data examples above which are probably related to the asynchrony between calculations and messaging tasks. Although NON_REF shows much less off diagonal entries than REF, significant correction still occur. However, most of these off diagonal NON_REF cases occur during precipitation events. When only the NON-REF without precipitation are taken into account, as shown in the lower right panel, the number of off diagonal is reduced even further. The 6084 NON-REF cases without precipitation are denoted NON_REF_NON_PI. The extreme entry for uncorrected MOR < 800 m and corrected MOR ≥ 8 km corresponds e.g. with an isolated dip in the MOR down to 66 m around noon on September 11, 2010 during a clear day with MOR above 10 km (Figure 9f).

PW

U\C	<800	<1500	<3000	<5000	<8000	≥8000
<800	8	0	11	52	68	50
<1500	0	3	14	31	102	344
<3000	0	0	101	91	81	515
<5000	0	0	0	417	158	484
<8000	0	0	0	0	751	1327
≥8000	0	0	0	0	0	7613

REF

U\C	<800	<1500	<3000	<5000	<8000	≥8000
<800	0	0	7	52	66	47
<1500	0	0	11	22	99	335
<3000	0	0	25	34	48	474
<5000	0	0	0	76	32	287
<8000	0	0	0	0	118	331
≥8000	0	0	0	0	0	1844

NON_REF

U\C	<800	<1500	<3000	<5000	<8000	≥8000
<800	56	0	4	0	2	3
<1500	1	10	4	9	3	10
<3000	1	2	123	67	35	43
<5000	0	0	0	431	143	210
<8000	0	0	0	1	760	1097
≥8000	0	0	0	0	4	6826

NON_REF_NON_PI

U\C	<800	<1500	<3000	<5000	<8000	≥8000
<800	44	0	0	0	0	1
<1500	1	7	1	0	0	5
<3000	1	2	50	4	0	20
<5000	0	0	0	200	19	99
<8000	0	0	0	0	420	625
≥8000	0	0	0	0	4	4581

Figure 15: Contingency tables of uncorrected versus corrected 1-minute averaged MOR using the SPECIAL visibility bins for situations (see text).

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 Figure 16 using contingency matrices. The MOR data is again binned into the SPECIAL visibility limits and the contingency tables using the full resolution of the visibility reporting bins are again given in appendix A. In all cases the reference MOR is indicated on the left. The gray diagonal again denotes the cases where the (un)corrected MOR is in the same SPECIAL 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. In Figure 16 only the cases PW and REF need to be considered since the NON_REF and NON_REF_NON_PI cases are not affected as in these situations the reference MOR equals the uncorrected MOR. Hence differences between the reference and the corrected MOR are identical to differences between the uncorrected and the corrected MOR given in Figure 15 and appendix A for the NON_REF and NON_REF_NON_PI cases. The top panels of Figure 16 show the reference MOR versus the uncorrected and the corrected MOR for all events where the FD12P indicated MOR filtering (PW). Since the NON_REF cases have no or a known contribution for the uncorrected and the corrected MOR, respectively, the PW results are basically a complement of the valid MOR filtering events (REF) given in the lower panels and the NON_REF and are therefore not discussed. The panels are included to show the effect of the validation filter of MOR filtering events. The lower left panel shows many entries with uncorrected MOR < 3 km and reference MOR ≥ 8 km and that reference MOR < 1500 m never occurs 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 are show overall better agreement. However, situations 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 the uncorrected MOR exceeds the reference MOR, all of which occur during valid MOR filtering events. These events are again caused be the asynchrony between calculations and messaging tasks. The corrected MOR exceeds the reference MOR on 1690 occasions, but only 207 occur during valid MOR filtering events. Note, however, that for 147 of these valid MOR filtering events where the corrected MOR exceeds the reference MOR have a reference MOR above 5 km.

PW

R\U	<800	<1500	<3000	<5000	<8000	≥8000
<800	17	0	0	0	0	0
<1500	0	27	0	0	0	0
<3000	0	7	228	6	2	0
<5000	3	13	46	731	24	3
<8000	5	22	37	41	1737	48
≥8000	164	425	477	281	315	7562

PW

R\C	<800	<1500	<3000	<5000	<8000	≥8000
<800	8	0	4	0	2	3
<1500	0	3	3	9	3	9
<3000	0	0	99	68	35	41
<5000	0	0	14	436	166	204
<8000	0	0	0	10	737	1143
≥8000	0	0	6	68	217	8933

REF

R\U	<800	<1500	<3000	<5000	<8000	≥8000
<800	0	0	0	0	0	0
<1500	0	0	0	0	0	0
<3000	0	7	21	6	2	0
<5000	3	13	46	67	24	3
<8000	5	22	37	41	108	48
≥8000	164	425	477	281	315	1793

REF

R\C	<800	<1500	<3000	<5000	<8000	≥8000
<800	0	0	0	0	0	0
<1500	0	0	0	0	0	0
<3000	0	0	23	11	2	0
<5000	0	0	14	95	40	7
<8000	0	0	0	10	104	147
≥8000	0	0	6	68	217	3164

Figure 16: Contingency tables of reference MOR versus uncorrected (left) and corrected (right) 1-minute averaged MOR using the SPECIAL visibility bins for all FD12P MOR filtering events (PW, top) and the valid MOR filtering events (REF, bottom).

The contingency matrices of Figure 16 only give the overall number of changes and do not resolve the cases where the corrected MOR is closer to the reference MOR than the uncorrected MOR or vice versa. For that purpose the differences of uncorrected-reference 1-minute averaged MOR in SPECIAL visibility bins are shown versus the corresponding differences of uncorrected-reference MOR in Figure 17. Figure 17 uses the same color coding as Figure 16. The grey diagonal denotes the cases where the corrected and the uncorrected MOR have the same deviation from the reference MOR. The green area denotes the cases where the corrected MOR is closer to the reference MOR but does not exceed the reference MOR, whereas the red areas denotes the potentially dangerous cases where corrected MOR exceeds reference MOR. A similar contingency table, but generated showing the differences using the full resolution of the visibility reporting bins for aviation, is given in the Appendix B. The numbers obtained from the contingency table with the full resolution of the visibility reporting bins are given in square brackets [ ]. The top panel of Figure 17 shows the valid MOR filtering events (REF). The REF results show 2063 [1801] events (53 [46] %) on the diagonal, i.e. uncorrected and corrected MOR in the SPECIAL visibility bins have the same deviation from the reference MOR. There are 1720 [1827] events (44 [47] %) where the MOR correction leads to an improvement of the MOR of which 1451 [1302] events (37 [33] %) put the corrected MOR into the same visibility bin as the reference MOR. In addition, there are 125 [279] events (3 [7] %) where the corrected MOR has a larger value than the reference MOR and the uncorrected MOR. These are potentially dangerous situations where the MOR is falsely corrected to a better visibility. However, it should be noted that the reference MOR constructed here is not a true reference. E.g. the extreme events at (MOR_{uncor}-MOR_{ref}, MOR_{cor}-MOR_{ref}) (-3,+2), (-1,+2) and (+1,+2) all occur on September 22, 2010 during the insect event after sunset. The MOR is corrected to too high values, but the MOR reported by the FD12P between 12 and 19UT is probably too low. The TMM and the FD12P that is part of the visibility reference indicate higher MOR values during that period. The NON_REF events have reference MOR equal to uncorrected MOR. Therefore, the PW case only shows differences form the REF case for that particular row, and the NON_REF, NON_REF_PI, and NON_REF_NON_PI cases only have events in that row. Hence for these other cases only this single row is reported in Figure 17. Since only changes in the corrected MOR are involved in these situations, the results of Figure 17 can be derived from the corresponding panels of Figure 15. The NON_REF and related cases again show some events where the corrected MOR is lower than the reference MOR. Most corrections leave the MOR in the same visibility class, but many corrections put the MOR in higher classes. The extremes correspond to the situations in Figure 15 where isolated dips in the MOR are corrected to a MOR above 10 km.

REF		MOR_{cor}–MOR_{ref}										
		-5	-4	-3	-2	-1	0	+1	+2	+3	+4	+5
MOR_{uncor}–MOR_{ref}	-5	0	0	5	51	65	43	0	0	0	0	0
	-4	0	0	0	12	92	323	3	0	0	0	0
	-3	0	0	1	2	29	456	13	1	0	0	0
	-2	0	0	0	3	13	291	24	0	0	0	0
	-1	0	0	0	0	42	338	27	2	0	0	0
	0	0	0	0	0	0	1935	54	0	0	0	0
	+1	0	0	0	0	0	0	77	1	0	0	0
	+2	0	0	0	0	0	0	0	5	0	0	0
	+3	0	0	0	0	0	0	0	0	0	0	0
	+4	0	0	0	0	0	0	0	0	0	0	0
	+5	0	0	0	0	0	0	0	0	0	0	0
PW												
	0	0	0	0	0	0	8765	1236	243	44	11	3
NON_REF												
	0	0	0	0	1	8	8206	1311	258	46	12	3
NON_REF_PI												
	0	0	0	0	0	1	2900	658	159	26	7	2
NON_REF_NON_PI												
	0	0	0	0	1	7	5302	649	99	20	5	1

Figure 17: Contingency table of the differences in SPECIAL visibility bins between uncorrected-reference MOR versus corrected-reference MOR for all valid MOR filtering events (top) and other cases.

Finally, Figure 18 gives the differences in SPECIAL visibility bins between uncorrected-reference and corrected-reference MOR versus the reference MOR with the corresponding matrices using the full resolution of the visibility reporting bins in Appendix B. The colors denote the cases where the (un)corrected MOR is less or equal (green) or larger (red) than the references MOR, whereas entries in the gray areas are by definition impossible. As in Figure 16, the uncorrected MOR exceeds the reference MOR on 83 occasions (top left), all of which occur during valid MOR filtering events (bottom left). The invalid MOR correction events show up as additional entries in the uncorrected MOR equals reference MOR column. The corrected MOR exceeds the reference MOR on 1690 occasions (top right), but only 207 occur during valid MOR filtering events (bottom left) and 147 and 47 of these valid MOR filtering events where the corrected MOR exceeds the reference MOR occur when the reference MOR is above 5 km and between 3 and 5 km, respectively. When all situations with FD12P MOR filtering are considered (top right) the number of entries in the red area increases significantly. Figure 19 shows that there is also a relative increases in the number of red entries although the numbers are small, except for reference MOR values between 5 and 8 km.

PW

UNCOR-REF versus REF

R\UR	-5	-4	-3	-2	-1	0	+1	+2	+3	+4	+5
<800	0	0	0	0	0	17	0	0	0	0	0
<1500	0	0	0	0	0	27	0	0	0	0	0
<3000	0	0	0	0	7	228	6	2	0	0	0
<5000	0	0	3	13	46	731	24	3	0	0	0
<8000	0	5	22	37	41	1737	48	0	0	0	0
≥8000	164	425	477	281	315	7562	0	0	0	0	0

COR-REF versus REF

R\CR	-5	-4	-3	-2	-1	0	+1	+2	+3	+4	+5
<800	0	0	0	0	0	8	0	4	0	2	3
<1500	0	0	0	0	0	3	3	9	3	9	0
<3000	0	0	0	0	0	99	68	35	41	0	0
<5000	0	0	0	0	14	436	166	204	0	0	0
<8000	0	0	0	0	10	737	1143	0	0	0	0
≥8000	0	0	6	68	217	8933	0	0	0	0	0

REF

UNCOR-REF versus REF

R\UR	-5	-4	-3	-2	-1	0	+1	+2	+3	+4	+5
<800	0	0	0	0	0	0	0	0	0	0	0
<1500	0	0	0	0	0	0	0	0	0	0	0
<3000	0	0	0	0	7	21	6	2	0	0	0
<5000	0	0	3	13	46	67	24	3	0	0	0
<8000	0	5	22	37	41	108	48	0	0	0	0
≥8000	164	425	477	281	315	1793	0	0	0	0	0

COR-REF versus REF

R\CR	-5	-4	-3	-2	-1	0	+1	+2	+3	+4	+5
<800	0	0	0	0	0	0	0	0	0	0	0
<1500	0	0	0	0	0	0	0	0	0	0	0
<3000	0	0	0	0	0	23	11	2	0	0	0
<5000	0	0	0	0	14	95	40	7	0	0	0
<8000	0	0	0	0	10	104	147	0	0	0	0
≥8000	0	0	6	68	217	3164	0	0	0	0	0

Figure 18: Contingency table of the differences in SPECIAL visibility bins between uncorrected-reference (left) and corrected-reference MOR (right) versus reference MOR for all FD12P MOR filtering events (PW, top) and the valid MOR filtering events (REF, bottom).

PW

UNCOR-REF versus REF

R\UR	-5	-4	-3	-2	-1	0	+1	+2	+3	+4	+5
<800	0	0	0	0	0	0.14	0	0	0	0	0
<1500	0	0	0	0	0	0.22	0	0	0	0	0
<3000	0	0	0	0	0.06	1.87	0.05	0.02	0	0	0
<5000	0	0	0.02	0.11	0.38	5.98	0.20	0.02	0	0	0
<8000	0	0.04	0.18	0.30	0.34	14.2	0.39	0	0	0	0
≥8000	1.34	3.48	3.90	2.30	2.58	61.9	0	0	0	0	0

COR-REF versus REF

R\CR	-5	-4	-3	-2	-1	0	+1	+2	+3	+4	+5
<800	0	0	0	0	0	0.07	0	0.03	0	0.02	0.02
<1500	0	0	0	0	0	0.02	0.02	0.07	0.02	0.07	0
<3000	0	0	0	0	0	0.81	0.56	0.29	0.34	0	0
<5000	0	0	0	0	0.11	3.57	1.36	1.67	0	0	0
<8000	0	0	0	0	0.08	6.03	9.35	0	0	0	0
≥8000	0	0	0.05	0.56	1.78	73.1	0	0	0	0	0

REF

UNCOR-REF versus REF

R\UR	-5	-4	-3	-2	-1	0	+1	+2	+3	+4	+5
<800	0	0	0	0	0	0	0	0	0	0	0
<1500	0	0	0	0	0	0	0	0	0	0	0
<3000	0	0	0	0	0.18	0.54	0.15	0.05	0	0	0
<5000	0	0	0.08	0.33	1.18	1.71	0.61	0.08	0	0	0
<8000	0	0.13	0.56	0.95	1.05	2.76	1.23	0	0	0	0
≥8000	4.20	10.9	12.2	7.19	8.06	45.9	0	0	0	0	0

COR-REF versus REF

R\CR	-5	-4	-3	-2	-1	0	+1	+2	+3	+4	+5
<800	0	0	0	0	0	0	0	0	0	0	0
<1500	0	0	0	0	0	0	0	0	0	0	0
<3000	0	0	0	0	0	0.59	0.28	0.05	0	0	0
<5000	0	0	0	0	0.36	2.43	1.02	0.18	0	0	0
<8000	0	0	0	0	0.26	2.66	3.76	0	0	0	0
≥8000	0	0	0.15	1.74	5.55	81.0	0	0	0	0	0

Figure 19: As Figure 18, but showing the number of entries as a percentage.

7. Summary, conclusions and recommendations

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 86 % of the time during sunset and 44 % during sunrise. The duration of the MOR filtering events is up to about 40 minutes during sunrise and about 1 hour during sunset. During these insect events reductions of the MOR below 1 km have been observed while the true MOR exceeds 10 km. 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 relevant for aeronautical purposes. Although the reduction in MOR due to insects is largely reduced by 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 the MOR correction is only 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 (according to background luminance) and without precipitation or MOR of the TMM below 1 km within a ±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. Other meteorological parameters seem to contribute little to the validation of the MOR filtering events.

The uncorrected and corrected MOR of the FD12P have been compared with a reference MOR that equals the uncorrected MOR of the FD12P outside the validated MOR filtering periods and varies the MOR according to the behavior of the MOR of the TMM during MOR filtering periods. The ratio of the 10-minute averaged MOR of the uncorrected FD12P and the TMM before and after each MOR filtering event is interpolated linearly during the filtering event to scale the MOR of the TMM to that of the FD12P. The validated MOR filtering events are nearly always closer to the constructed reference MOR than the uncorrected MOR. The corrected MOR is too optimistic in 7 % 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 a faulty FD12P that produced a too low MOR during clear days. The invalid MOR 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 for MOR filtering events 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.

During a large part of the evaluation period a faulty FD12P was used that sometimes reported too low MOR values in good visibility conditions. During the periods with these deviations the MOR reported by the FD12P also shows a larger variability. The periods last typically for several hours, and generally occur during day-time, but they can also start/stop during the day and extend well into the night. These deviations are not caused by the MOR filtering firmware, but they are related to FD12P hardware. KNMI was not able to identify the sensor part that causes this behavior since all internal checks and the visibility calibration were valid. Eventually the FD12P was replaced with a spare that did not show this problem. The evaluation of the MOR filtering firmware 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. This is illustrated in the addendum, where the results of the MOR filtering are compared with a reference MOR constructed by using the MOR of the operational FD12P and the TMM. The number of cases with a corrected MOR larger than 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 MOR filtering events where the corrected MOR largely exceeded the reference MOR is reduced drastically.

Overall the insect filtering of the MOR by the FD12P with firmware 1.91S and should be considered for operational use. However, there are some issues that need to be solved or decided.

- The FD12P firmware sometimes produced invalid uncorrected MOR values (invalid or negative) that affect the reported MOR value for 1 minute.
- The FD12P firmware produces regular incorrect MES 8 reports so that it cannot be considered for operational use. This could be taken care of in the KNMI sensor interface (another data request if the first is invalid), but a fix of the problem in the FD12P firmware is preferred.
- The corrected and uncorrected MOR is sometimes inconsistent due to the asynchrony between messaging and the measurement/calculation tasks. This asynchrony should be overcome, if possible, or at least minimized since the inconsistency of the corrected and uncorrected MOR hampers a possible real-time validation of the MOR filtering results.
- The FD12P MOR filtering algorithm should be coupled with the internal precipitation detection algorithm so that MOR filtering events related to precipitation do not occur. At least the MOR filtering during precipitation could easily be filtered out.

The insect filtering of the MOR by the FD12P showed good results during the evaluation in De Bilt, but faulty MOR corrections sometimes occur. Note that the evaluation was performed on the 1-minute averaged MOR whereas for synoptic applications a 10-minute averaged MOR is used and for aviation 2- and 10-minute averaged VIS/RVR values are used. The 10-minute averaging generally reduces the magnitude of the reduced MOR values and the associated reductions, 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. Due to the urgency of the problem and the additional need of verification operational use of the FD12P with MOR filtering firmware can be considered (if possible with improvements related to the above items). Usage of the corrected MOR should be considered if suitable safeguards for monitoring and evaluation are implemented. In that case the corrected and uncorrected MOR should be made available in the meteorological network and stored for further evaluation.

- The FD12P firmware with MOR filtering should be made operational once the most essential problems of firmware 1.91S are solved. Operational use might be restricted to crucial locations at selected airports.
- The new DZ4 sensor interface should request MES8 of the FD12P and make the corrected and uncorrected MOR as well as the filtering indicator available to the measurement network.
- The corrected and uncorrected MOR as well as the filtering indicator (that is translated into the quality of the MOR) should be made available in METNET and stored for evaluation.
- The corrected MOR should be validated by the sunrise/sunset and precipitation filter as described above. The precipitation type indicator of the sensor itself can be used for the latter purpose, with the possibility to validate MOR values up to 5 minutes ago. The period around sunrise/sunset can be calculated from the actual time (cf. appendix C) and the geographical location.
- The MOR and derived (runway) visibility values should be derived from corrected MOR after application of the validation filter, but it should be clearly indicated to the supervisor that MOR filtering is active. This can e.g. be achieved by a suitable change in the quality of the MOR (and derived variables) or by a separate indicator.
- The uncorrected and corrected MOR and/or derived variables should be available for monitoring and evaluation purposes. Note that the evaluation of the MOR filtering firmware is based on a field test of half a year in De Bilt. Although a similar behavior can be expected at other locations, the frequency and magnitude of the insect events can differ with location and show large year-to-year variations.
- In case the MOR correction is evidently wrong the meteorological supervisor is able to overrule the visibility using the uncorrected MOR.

8. References

Bijma, J.R.: DZ4-SIAM Vaisala FD12P PW-sensor, ID-30-059, KNMI, De Bilt, The Netherlands, December 4, 2007

Bloemink, H., M. de Haij, W. Wauben: Recent Research on Meteorological Observations and Instrumentation at KNMI, 15th Symposium on Meteorological Observations and Instrumentation, American Meteorological Society, Atlanta, USA, 2010

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

Wauben, W.M.F.: Comparison of Visibility Measurements with Routine Visual Observations in the Netherlands, 3rd International Conference on Experiences with Automatic Weather Stations, Torremolinos, Spain, February 2003.

WMO: Guide to Meteorological Instruments and Methods of Observation, 7th edition, WMO No. 8, Geneva, Switzerland, 2008.

Appendix A

Differences between the uncorrected, corrected and reference 1-minute averaged MOR of the FD12P during MOR filtering events in contingency matrices using the full visibility reporting bins for aviation. The grid lines indicate the SPECIAL visibility reporting bins.

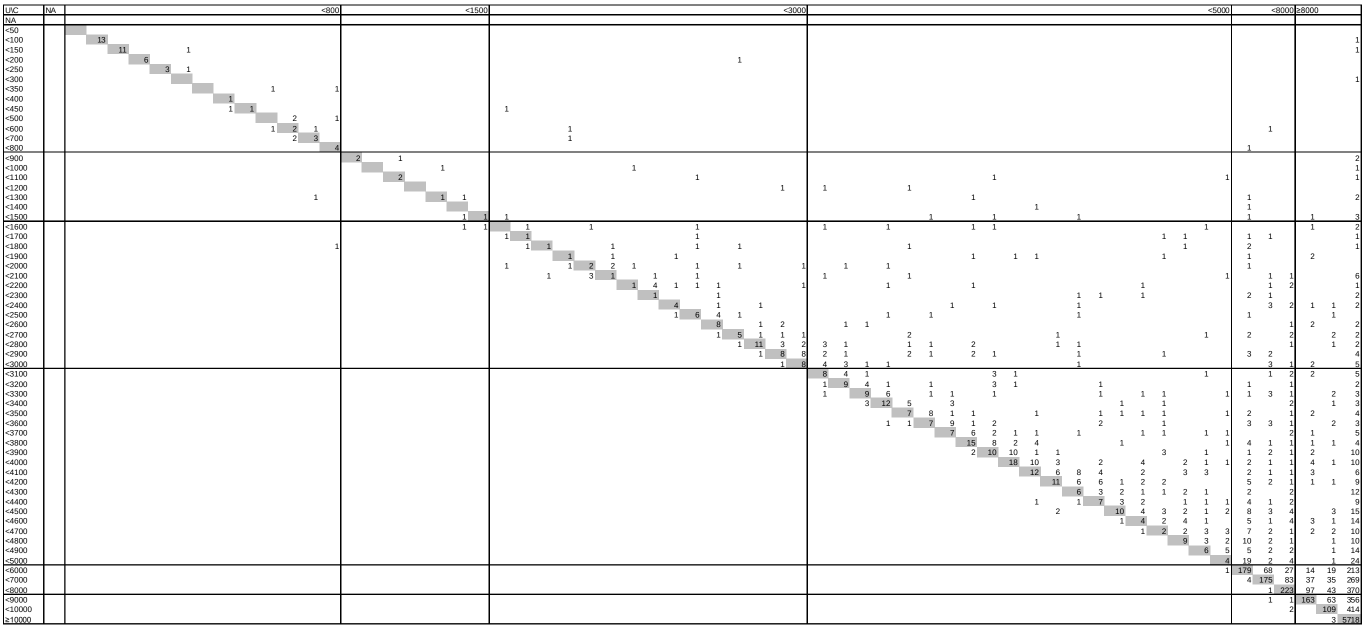
Uncorrected versus corrected 1-minute MOR for all MOR filtering cases, PW.

U\C	NA													<800							<1500															<3000																				<5000			<8000	≥8000		
NA																																																															
<50																																																															1
<100																																																															1
<150							1																																																							1
<200					1																												1																														
<250																																																															2
<300																													1																																	1
<350																															1																											1					
<400																																							1	1	1								1														
<450									1													1																		1							1		2									1					1
<500													1																						1							1	2	2	1		1	1		2						2	1			1	
<600											2														1					1									1	1			2	1	1		1	1	2	4	1	1	1	1	1	3	8	8	5	1	1	1
<700												1													1									1	1	1							1	1		1			2							1	9	8	7	4	4	6
<800													1																															1	1			1		1		2				6	5	7	4	5	16
<900														1																				1	1											1	1				2	1				8	9	12	11	8	16
<1000																										1	1										1										1					1					4	4	6	8	7	22
<1100																2														2										1					1									2		1	3	5	9	11	9	34
<1200																													1					1			1	1	1		1			1							1		1		1		4	6	10	5	11	34
<1300																													1			1	1				1							2			1							1			1	2	4	6	7	46
<1400																																															1										2	1	5	9	8	34
<1500																															1	2										2			1				1								2	2	3	7	5	46
<1600																										1					1						1			1				1	1										2			6	3	4	2	36
<1700																							1								1				1				1							1							1	1		1	3	2	2	6	4	42
<1800																								1			1				1	1	1																1					2		1	5	1	3	5	3	35
<1900																											1			1							2				1			1		1	2						1				2		2	4	5	24
<2000																											1	1		1	1		1					1		1													1				1	1	1	3	1	38
<2100																													1		1	1			1		1				1											1				1		2	1	2	1	31
<2200																													2	1	1		1	1		1	2			2				1	1							1					2	4	3	3		31
<2300																																1											1		1				1	1		1			1		2	1		1	1	29
<2400																														2		1		2									1		1							1						5	3	3	3	27
<2500																															2	4			1					1		1				1			1							1	1	1			4	24
<2600																																7		4	3			1	1				1													1		4		4		24
<2700																																	4	1	1	1	1		1		3												1		1		3		2	2	4	17
<2800																																		9	3	2	3	1			1		2	1				1	1								1		3	1	2	24
<2900																																			9	6	1	1			1	1		1	1		1		1				1		1		3	1		2	1	26
<3000																																				10	4	3											1		1						2	4	1	3	1	32
<3100																																					7	4	1						3	1									1			2	6	2	1	27
<3200																																						10	2			1			3	1				1							1		1		1	18
<3300																																							8	7		1	1		1					1		1				1		4			4	20
<3400																																								12	6		3			1			1		1						1		4		2	26
<3500																																									8	9	1	1			1			1	1	1	1	1		1	2		1	2	2	16
<3600																																										10	10	3	1					2			1				3	3	1	1	3	13
<3700																																											10	7	1		1		1			1	1		1	1		2	2	1		17
<3800																																												13	8	2	3				2					1	5	1	1	2	2	18
<3900																																													10	12	1	2					1		1		1	2	3	1		28
<4000																																														21	10	3				3		2		1	3	1	2	3	1	24
<4100																																															9	7	5	4	1	2		3	2		2	1	1	4	1	15
<4200																																																12	5	7	1	2	2				4	1	1	3	1	20
<4300																																																	8	3	1	1		2			3	1	3			26
<4400																																																		8	2	3		1	1	1	5	1	2		1	22
<4500																																																			7	5	3	1	1	2	7	4	4		2	21
<4600																																																				5	2	3	1		6	2	4	3	1	25
<4700																																																					2	2	4	3	6	2	1	1	3	20
<4800																																																						10	3	1	10	3	1	1		19
<4900																																																							6	4	5	3	2	1		22
<5000																																																								6	16	3	2		1	36
<6000																																																									158	68	26	19	23	303
<7000																																																										173	87	32	40	335
<8000																																																											239	98	38	439
<9000																																																												214	67	393
<10000																																																													164	476
≥10000																																																													2	6297

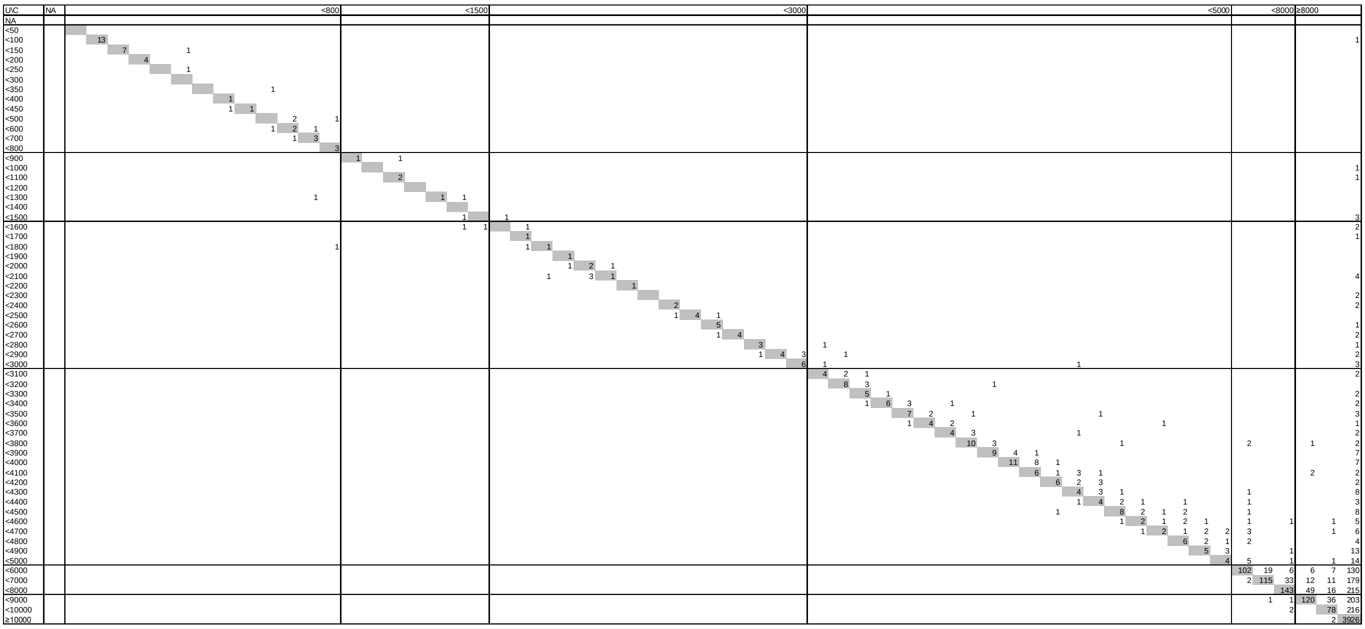
Uncorrected versus corrected 1-minute MOR for all valid MOR filtering cases, REF.

U\C	NA													<800							<1500															<3000																				<5000			<8000	≥8000		
NA																																																															
<50																																																															1
<100																																																															
<150																																																															
<200																																																															
<250																																																															2
<300																													1																																	
<350																															1																											1					
<400																																							1	1	1								1														
<450																																								1							1		2									1					1
<500																																			1							1	2	2	1		1	1		2						2	1			1	
<600																														1									1	1			2	1	1		1	1	2	4	1	1	1	1	1	3	8	7	5	1	1	1
<700																																		1	1	1							1	1		1			2							1	9	8	7	4	4	6
<800																																												1	1			1		1		2				5	5	7	4	5	16
<900																																		1	1											1	1				2	1				8	9	12	11	8	14
<1000																										1											1										1					1					4	4	6	8	7	21
<1100																														1										1														2			3	5	9	11	9	33
<1200																													1									1	1					1							1		1		1		4	6	10	5	11	34
<1300																													1			1	1				1							1			1							1				2	4	6	7	44
<1400																																																									1	1	5	9	8	34
<1500																															1	2										1															1	2	3	6	5	44
<1600																																																							1			6	3	3	2	34
<1700																																			1				1						1											1	2	1	2	6	4	41
<1800																								1								1																	1					1		1	3	1	3	5	3	34
<1900																																					2				1						1										1		2	2	5	24
<2000																														1																							1					1	1	3	1	38
<2100																																1			1																	1						1		2	1	25
<2200																																	1	1			2			1					1												2	3	1	3		30
<2300																																											1		1										1					1	1	28
<2400																																		1																		1						2	1	2	2	25
<2500																																1			1											1										1		1			3	24
<2600																																1		3	1								1													1		4		2		22
<2700																																	1				1		1		1												1				1			2	2	15
<2800																																		1	1								2														1		2	1	1	22
<2900																																			1	1											1								1					2	1	23
<3000																																				4															1						2	1		1	1	27
<3100																																					1		1																			1	4		1	22
<3200																																						2																							1	16
<3300																																								1		1																1			2	17
<3400																																								4	1		1			1			1								1		2		1	23
<3500																																									3	3	1											1							2	12
<3600																																										3	1	2														1		1	1	10
<3700																																											3	1														2				12
<3800																																												1							1						1			1	1	14
<3900																																														2		1										1	2			18
<4000																																														5	2										2		1	1		15
<4100																																															1	2	1		1						1			1	1	9
<4200																																																4		1										2		11
<4300																																																	2			1					1	1	1			16
<4400																																																		4		1					1				1	13
<4500																																																			1	1		1				1				6
<4600																																																				2					1	1				13
<4700																																																					1	1	1	1					1	10
<4800																																																						2			1	1		1		9
<4900																																																							1			1		1		8
<5000																																																								2	1	1				13
<6000																																																									24	9	4	8	6	99
<7000																																																										29	15	3	6	94
<8000																																																											37	11	3	101
<9000																																																												68	14	74
<10000																																																													71	95
≥10000																																																													1	1521

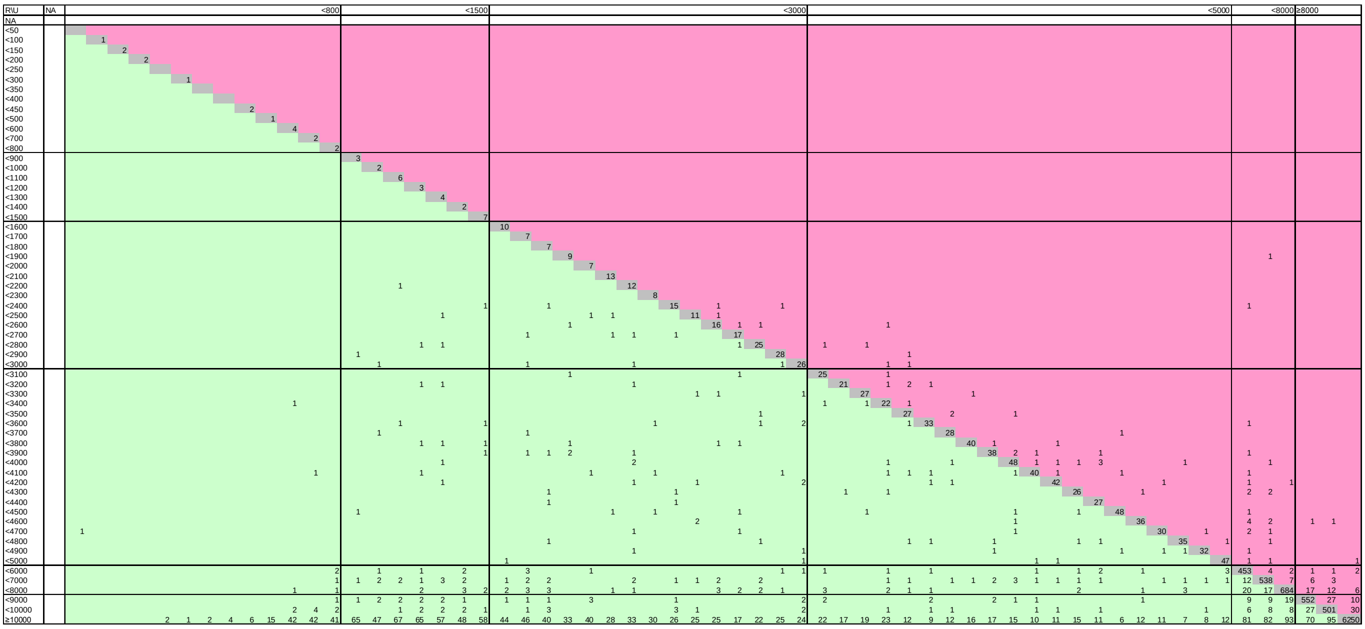
Uncorrected/reference versus corrected 1-minute MOR for all invalid MOR filtering cases, NON_REF.



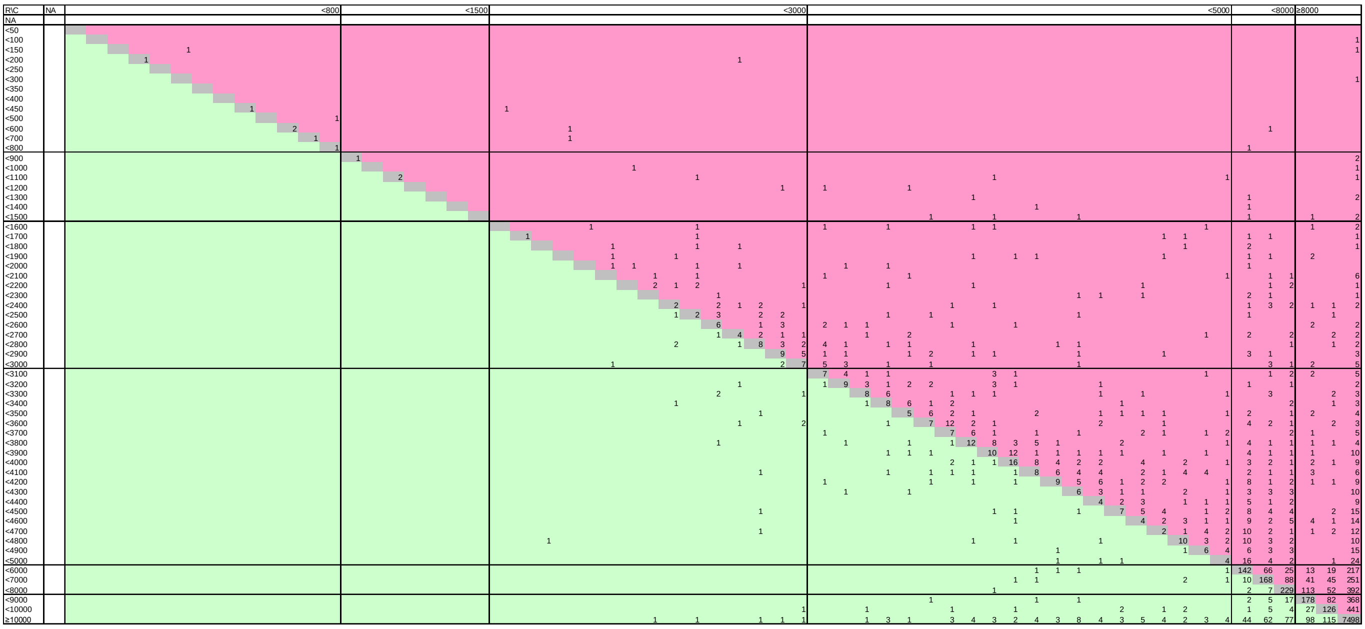
Uncorrected/reference versus corrected 1-minute MOR for all invalid MOR filtering cases without precipitation within ±5 minute interval, NON_REF_NON_PI.



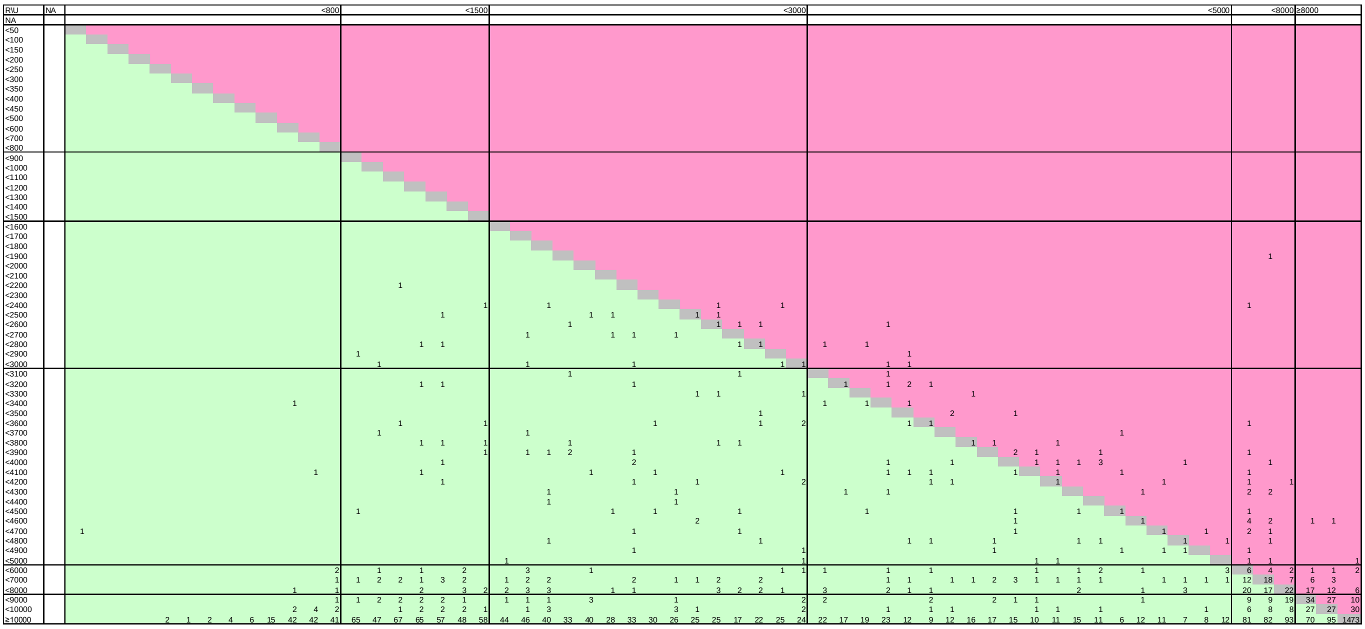
Reference versus uncorrected 1-minute MOR for all MOR filtering cases, PW.



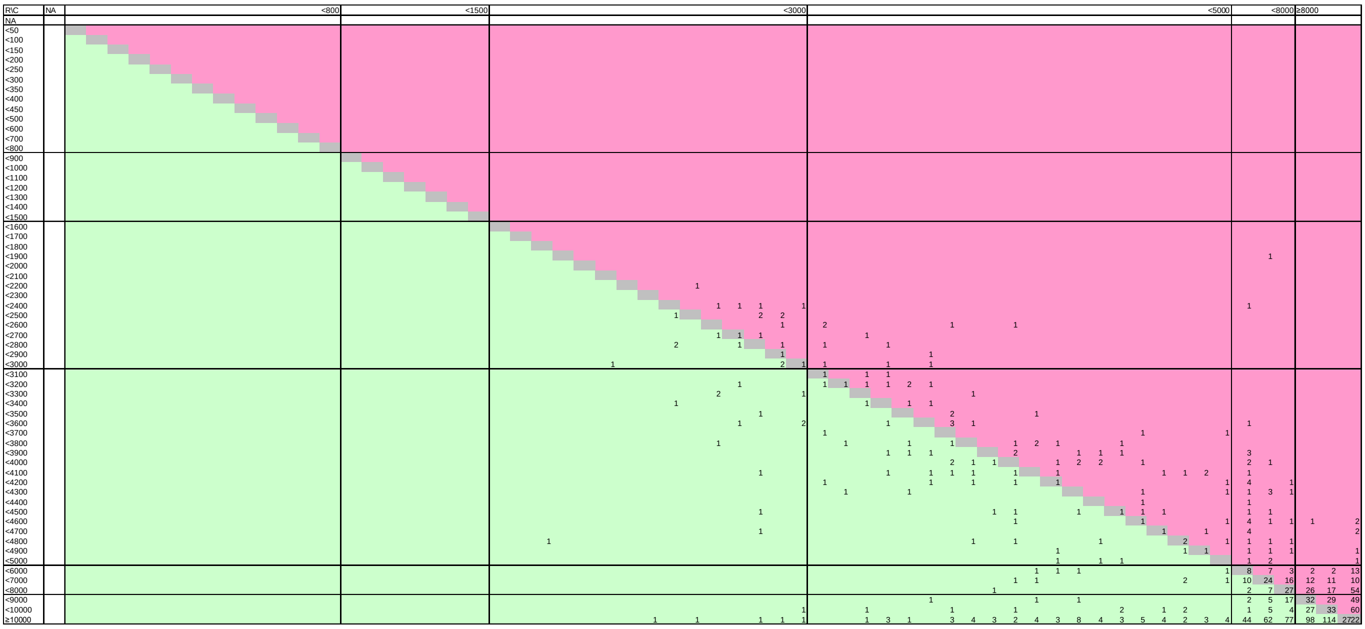
Reference versus corrected 1-minute MOR for all MOR filtering cases, PW.



Reference versus uncorrected 1-minute MOR for all valid MOR filtering cases, REF.

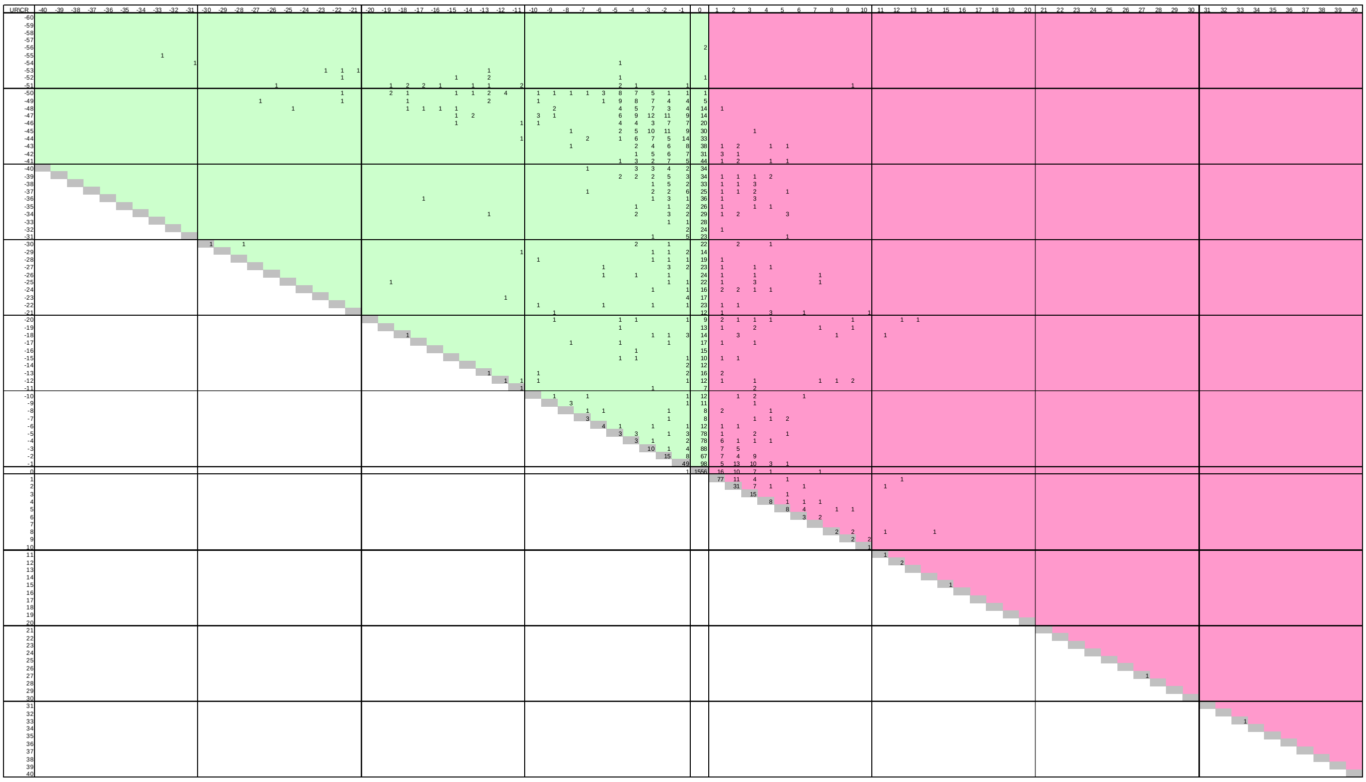


Reference versus corrected 1-minute MOR for all valid MOR filtering cases, REF.



Appendix B

Contingency matrix of the differences of uncorrected-reference versus corrected-reference 1-minute MOR for all valid MOR filtering cases, REF, using the full visibility reporting bins for aviation.



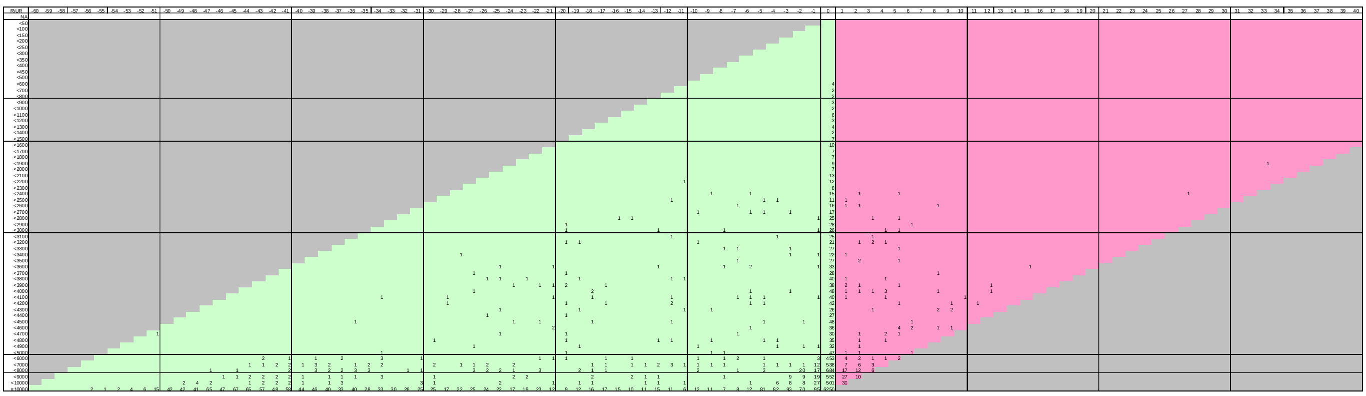
The row where uncorrected equals reference MOR showing the differences corrected-reference 1-minute MOR for all MOR filtering cases, PW, using the full visibility reporting bins for aviation.

UR\CR	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
0										2	7236	794	466	431	280	224	41	39	37	24	25	23	22	25	18	16	17	15	9	17	4

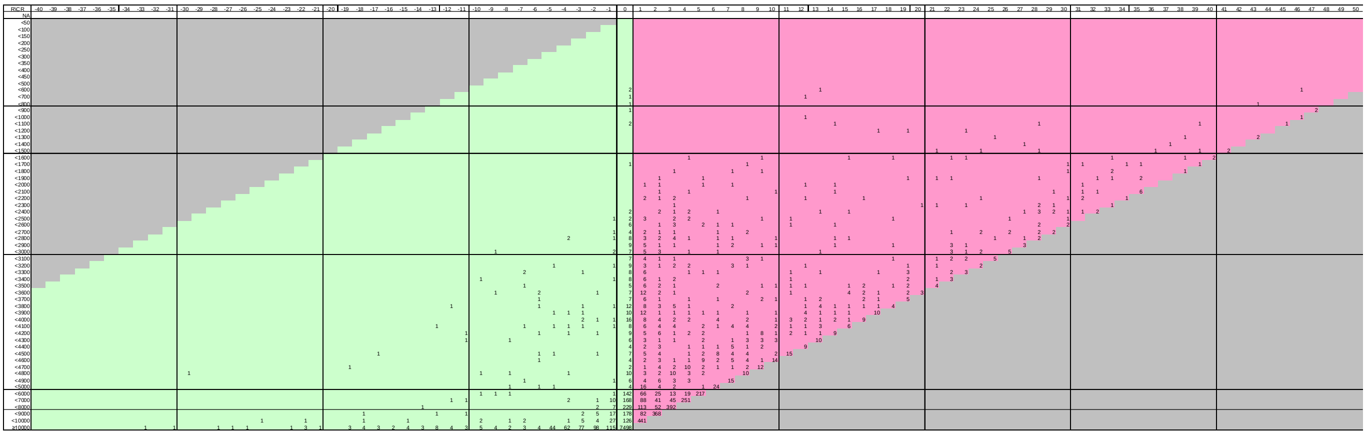
UR\CR	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
0	10	16	10	8	7	8	5	15	6	7	6	4	4	2	9	1	1	3	3	2	2		3		1	2	2								1			1	1	

Differences between the (un)corrected and reference 1-minute averaged MOR of the FD12P during MOR filtering events as a function of the reference MOR using the full visibility reporting bins for aviation. The vertical grid lines indicate the SPECIAL visibility reporting bins.

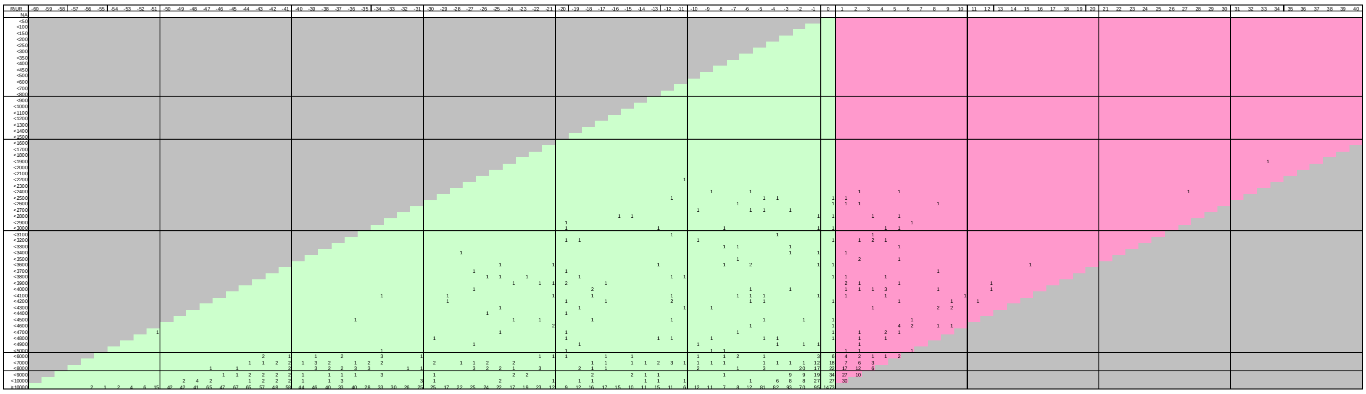
Reference versus difference between uncorrected and reference 1-minute MOR for all MOR filtering cases, PW.



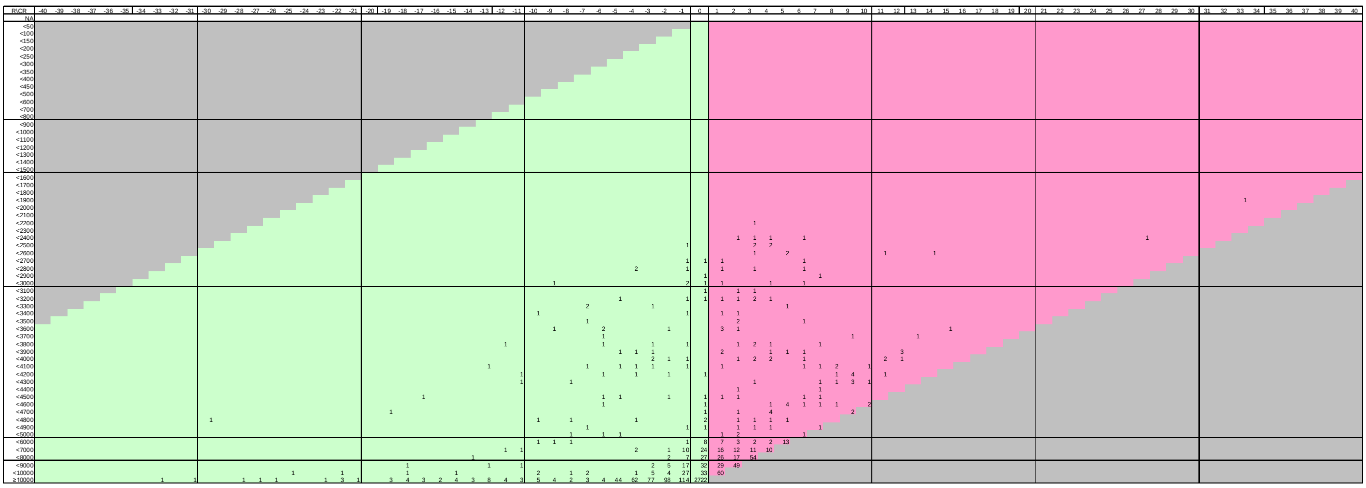
Reference versus difference between corrected and reference 1-minute MOR for all MOR filtering cases, PW.



Reference versus difference between uncorrected and reference 1-minute MOR for all valid MOR filtering cases, REF.



Reference versus difference between corrected and reference 1-minute MOR for all valid MOR filtering cases, REF.



Appendix C

In this report the sunrise and sunset was determined from the 1-minute background luminance data. Sunrise was defined as the 1-minute interval before the background luminance reaches or exceeds 7 cd/m^2 and sunset as the interval when it decreases below 7 cd/m^2 again. Sunrise and sunset can also be calculated from astronomical data given date and the geographical location (cf. *WMO, 2008* Annex 7.D). Figure 20 shows the difference in minutes between the time of sunrise and sunset obtained from the background luminance data and the astronomical calculation, without taking into account atmospheric refraction. The averaged deviation a sunrise is -28 minutes with a standard deviation of 7 minutes and at sunset the deviation is +30 minutes with a standard deviation of 8 minutes. An offset is to be expected since the background luminance will increase before the sun rises above the horizon. The averaged solar elevation at the time of sunrise according to the background luminance is -3.8 ° with a standard deviation of 0.8 °. Sunset corresponds with an averaged solar elevation -4.1 ° with a standard deviation of 0.9 °. Hence a solar elevation of -3.9 ° can be used as the moment when the background luminance indicates sunrise and sunset.

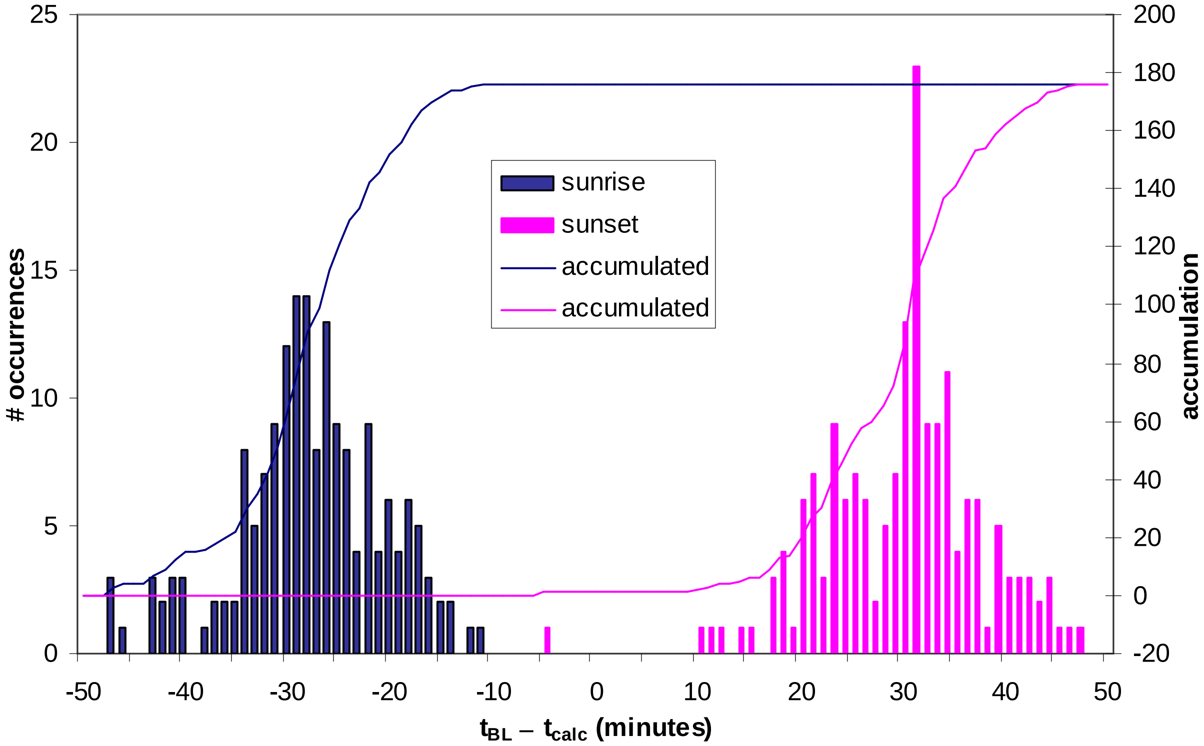


Figure 20: The histogram of the time difference in sunrise and sunset determined by background luminance data and astronomical calculations for the evaluation period.

Addendum

In this addendum the results of section 6 of uncorrected and corrected MOR versus the constructed reference MOR are shown, but here the MOR of the operational FD12P and the TMM are used in the construction of the reference MOR. The detailed inspection of the differences between the results is left to the reader. It can again be noted that the MOR correction generally puts the MOR closer to the references MOR than the uncorrected MOR. However, the number of events where the corrected MOR exceeds the reference MOR is much less compared to the results in section 6. In addition, the invalid MOR filtering events where the corrected MOR largely exceeded the reference MOR are now absent. Section 6 assumes that the uncorrected MOR is the reference MOR for these invalid filtering events so that the MOR correction can only deteriorate the MOR towards too optimistic MOR values, whereas in fact the MOR correction is often closer to the MOR of the operational FD12P. However, it should be noted that faulty MOR corrections do occur although the results here indicate that this happens only about 1-2 % of the time and often the too optimistic faulty MOR is in the MOR visibility bin adjacent to the reference MOR visibility bin.

PW

R\U	<800	<1500	<3000	<5000	<8000	≥8000
<800	7	0	1	0	0	0
<1500	2	3	0	0	0	0
<3000	2	6	71	3	3	1
<5000	2	20	94	357	39	2
<8000	2	13	77	169	662	59
≥8000	174	452	545	530	1374	7551

PW

R\C	<800	<1500	<3000	<5000	<8000	≥8000
<800	7	0	1	0	0	0
<1500	1	3	1	0	0	0
<3000	0	0	70	11	4	1
<5000	0	0	44	407	59	4
<8000	0	0	3	88	752	139
≥8000	0	0	7	85	345	10189

REF

R\U	<800	<1500	<3000	<5000	<8000	≥8000
<800	0	0	0	0	0	0
<1500	0	0	0	0	0	0
<3000	0	4	13	1	3	0
<5000	1	13	32	56	21	2
<8000	2	7	35	39	63	31
≥8000	169	443	501	299	362	1811

REF

R\C	<800	<1500	<3000	<5000	<8000	≥8000
<800	0	0	0	0	0	0
<1500	0	0	0	0	0	0
<3000	0	0	15	3	3	0
<5000	0	0	20	78	25	2
<8000	0	0	2	33	88	54
≥8000	0	0	6	70	247	3262

Figure 21: Contingency tables of reference MOR versus uncorrected (left) and corrected (right) 1-minute averaged MOR using the SPECIAL visibility bins for all FD12P MOR filtering events (PW, top) and the valid MOR filtering events (REF, bottom). As Figure 16, but using the MOR of the operational FD12P in the construction of the reference MOR.

REF		MOR_{cor}–MOR_{ref}										
		-5	-4	-3	-2	-1	0	+1	+2	+3	+4	+5
MOR_{uncor}–MOR_{ref}	-5	0	0	5	52	66	46	0	0	0	0	0
	-4	0	0	0	13	97	334	1	0	0	0	0
	-3	0	0	1	4	35	468	1	0	0	0	0
	-2	0	0	0	3	31	305	8	0	0	0	0
	-1	0	0	0	0	71	360	6	0	0	0	0
	0	0	0	0	0	0	1930	13	0	0	0	0
	+1	0	0	0	0	0	0	53	0	0	0	0
	+2	0	0	0	0	0	0	0	5	0	0	0
	+3	0	0	0	0	0	0	0	0	0	0	0
	+4	0	0	0	0	0	0	0	0	0	0	0
	+5	0	0	0	0	0	0	0	0	0	0	0

PW		MOR_{cor}–MOR_{ref}										
		-5	-4	-3	-2	-1	0	+1	+2	+3	+4	+5
MOR_{uncor}–MOR_{ref}	-5	0	0	5	52	68	49	0	0	0	0	0
	-4	0	0	0	13	97	343	1	0	0	0	0
	-3	0	0	2	4	47	506	1	0	0	0	0
	-2	0	0	0	19	69	528	13	0	0	0	0
	-1	0	0	0	0	197	1433	14	1	0	0	0
	0	0	0	0	0	0	8569	82	0	0	0	0
	+1	0	0	0	0	0	0	99	2	0	0	0
	+2	0	0	0	0	0	0	0	6	0	0	0
	+3	0	0	0	0	0	0	0	0	1	0	0
	+4	0	0	0	0	0	0	0	0	0	0	0
	+5	0	0	0	0	0	0	0	0	0	0	0

NON_REF _NON_PI		MOR_{cor}–MOR_{ref}										
		-5	-4	-3	-2	-1	0	+1	+2	+3	+4	+5
MOR_{uncor}–MOR_{ref}	-5	0	0	0	0	0	1	0	0	0	0	0
	-4	0	0	0	0	0	5	0	0	0	0	0
	-3	0	0	1	0	0	20	0	0	0	0	0
	-2	0	0	0	8	2	99	0	0	0	0	0
	-1	0	0	0	0	84	624	0	0	0	0	0
	0	0	0	0	0	4	5153	21	0	0	0	0
	+1	0	0	0	0	0	2	52	2	0	0	0
	+2	0	0	0	0	0	1	0	3	0	0	0
	+3	0	0	0	0	0	0	0	1	1	0	0
	+4	0	0	0	0	0	0	0	0	0	0	0
	+5	0	0	0	0	0	0	0	0	0	0	0

Figure 22: Contingency table of the differences in SPECIAL visibility bins between uncorrected-reference MOR versus corrected-reference MOR for all valid MOR filtering events (top) and other cases. As Figure 17, but using the MOR of the operational FD12P in the construction of the reference MOR.

PW

UNCOR-REF versus REF

R\UR	-5	-4	-3	-2	-1	0	+1	+2	+3	+4	+5
<800	0	0	0	0	0	7	0	1	0	0	0
<1500	0	0	0	0	2	3	0	0	0	0	0
<3000	0	0	0	2	6	71	3	3	1	0	0
<5000	0	0	2	20	94	357	39	2	0	0	0
<8000	0	2	13	77	169	662	59	0	0	0	0
≥8000	174	452	545	530	1374	7551	0	0	0	0	0

COR-REF versus REF

R\CR	-5	-4	-3	-2	-1	0	+1	+2	+3	+4	+5
<800	0	0	0	0	0	7	0	1	0	0	0
<1500	0	0	0	0	1	3	1	0	0	0	0
<3000	0	0	0	0	0	70	11	4	1	0	0
<5000	0	0	0	0	44	407	59	4	0	0	0
<8000	0	0	0	3	88	752	139	0	0	0	0
≥8000	0	0	7	85	345	10189	0	0	0	0	0

REF

UNCOR-REF versus REF

R\UR	-5	-4	-3	-2	-1	0	+1	+2	+3	+4	+5
<800	0	0	0	0	0	0	0	0	0	0	0
<1500	0	0	0	0	0	0	0	0	0	0	0
<3000	0	0	0	0	4	13	1	3	0	0	0
<5000	0	0	1	13	32	56	21	2	0	0	0
<8000	0	2	7	35	39	63	31	0	0	0	0
≥8000	169	443	501	299	362	1811	0	0	0	0	0

COR-REF versus REF

R\CR	-5	-4	-3	-2	-1	0	+1	+2	+3	+4	+5
<800	0	0	0	0	0	0	0	0	0	0	0
<1500	0	0	0	0	0	0	0	0	0	0	0
<3000	0	0	0	0	0	15	3	3	0	0	0
<5000	0	0	0	0	20	78	25	2	0	0	0
<8000	0	0	0	2	33	88	54	0	0	0	0
≥8000	0	0	6	70	247	3262	0	0	0	0	0

Figure 23: Contingency table of the differences in SPECIAL visibility bins between uncorrected-reference (left) and corrected-reference MOR (right) versus reference MOR for all FD12P MOR filtering events (PW, top) and the valid MOR filtering events (REF, bottom). As Figure 18, but using the MOR of the operational FD12P in the construction of the reference MOR.

PW

UNCOR-REF versus REF

R\UR	-5	-4	-3	-2	-1	0	+1	+2	+3	+4	+5
<800	0	0	0	0	0	0.06	0	0.01	0	0	0
<1500	0	0	0	0	0.02	0.02	0	0	0	0	0
<3000	0	0	0	0.02	0.05	0.58	0.02	0.02	0.01	0	0
<5000	0	0	0.02	0.16	0.77	2.92	0.32	0.02	0	0	0
<8000	0	0.02	0.11	0.63	1.38	5.42	0.48	0	0	0	0
≥8000	1.42	3.70	4.46	4.34	11.2	61.8	0	0	0	0	0

COR-REF versus REF

R\CR	-5	-4	-3	-2	-1	0	+1	+2	+3	+4	+5
<800	0	0	0	0	0	0.06	0	0.01	0	0	0
<1500	0	0	0	0	0.01	0.02	0.01	0	0	0	0
<3000	0	0	0	0	0	0.57	0.09	0.03	0.01	0	0
<5000	0	0	0	0	0.36	3.33	0.48	0.03	0	0	0
<8000	0	0	0	0.02	0.72	6.15	1.14	0	0	0	0
≥8000	0	0	0.06	0.70	2.82	83.4	0	0	0	0	0

REF

UNCOR-REF versus REF

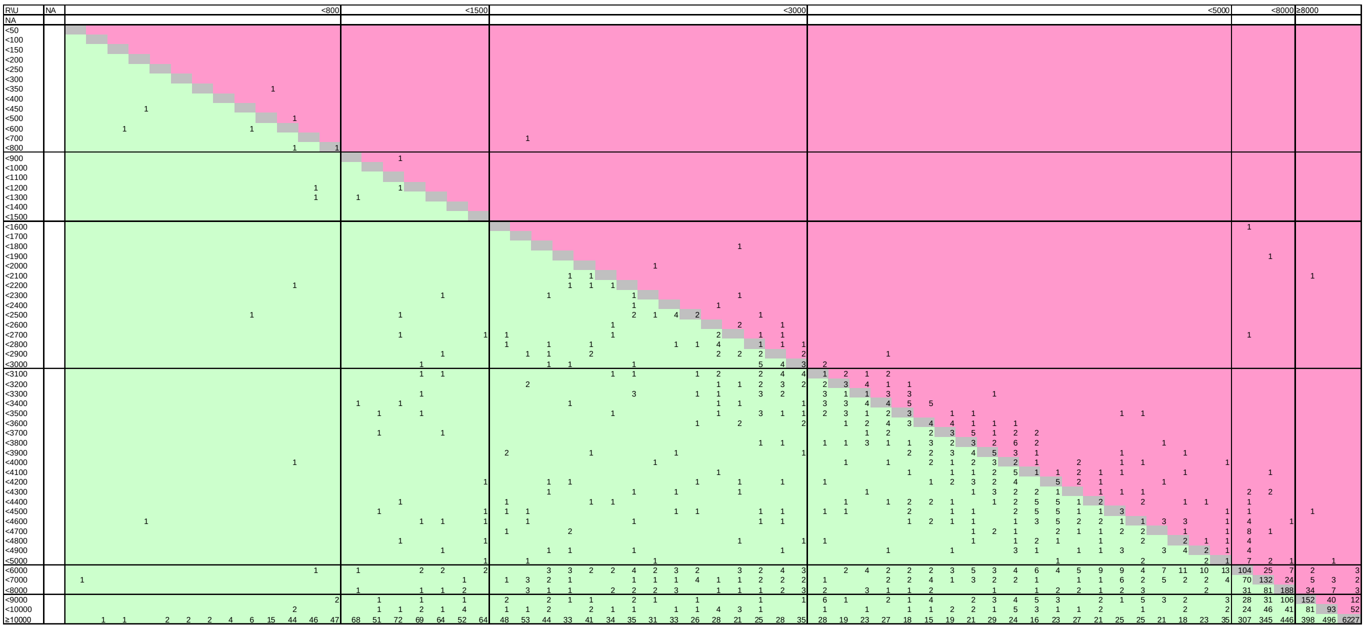
R\UR	-5	-4	-3	-2	-1	0	+1	+2	+3	+4	+5
<800	0	0	0	0	0	0	0	0	0	0	0
<1500	0	0	0	0	0	0	0	0	0	0	0
<3000	0	0	0	0	0.10	0.33	0.03	0.08	0	0	0
<5000	0	0	0.03	0.33	0.82	1.43	0.54	0.05	0	0	0
<8000	0	0.05	0.18	0.90	1.00	1.61	0.79	0	0	0	0
≥8000	4.32	11.3	12.8	7.65	9.26	46.3	0	0	0	0	0

COR-REF versus REF

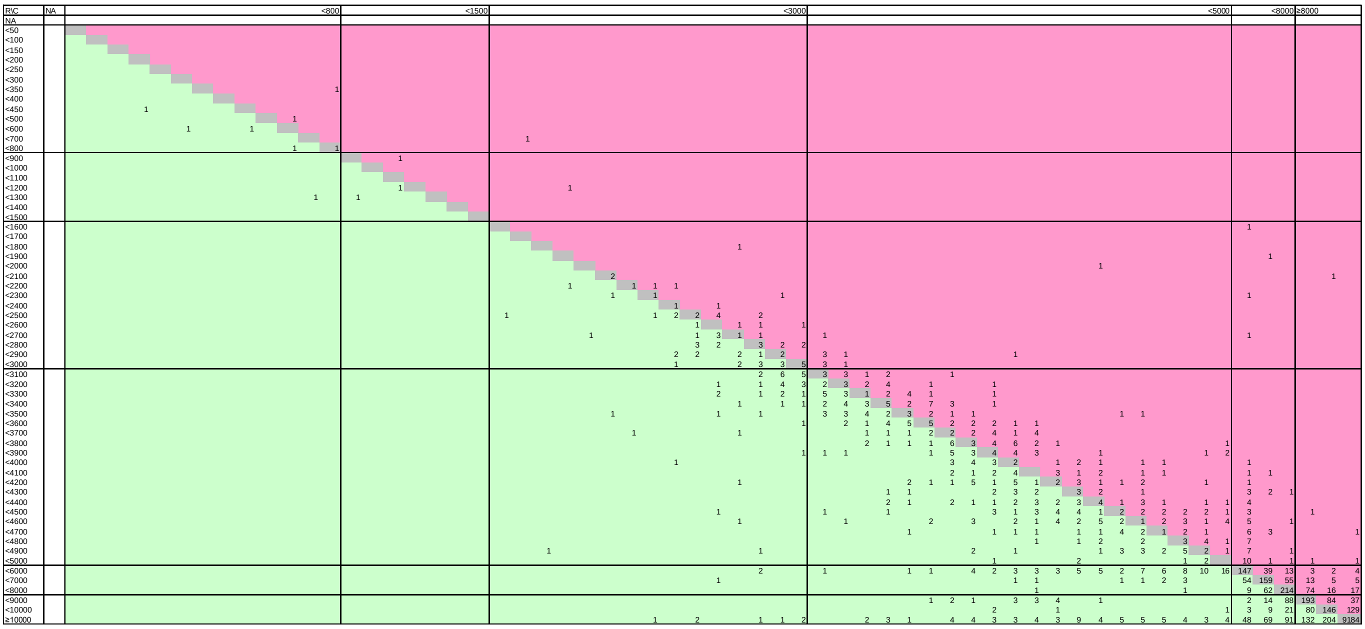
R\CR	-5	-4	-3	-2	-1	0	+1	+2	+3	+4	+5
<800	0	0	0	0	0	0	0	0	0	0	0
<1500	0	0	0	0	0	0	0	0	0	0	0
<3000	0	0	0	0	0	0.38	0.08	0.08	0	0	0
<5000	0	0	0	0	0.51	2.00	0.64	0.05	0	0	0
<8000	0	0	0	0.05	0.84	2.25	1.38	0	0	0	0
≥8000	0	0	0.15	1.79	6.32	83.5	0	0	0	0	0

Figure 24: As Figure 23, but showing the number of entries as a percentage. As Figure 19, but using the MOR of the operational FD12P in the construction of the reference MOR.

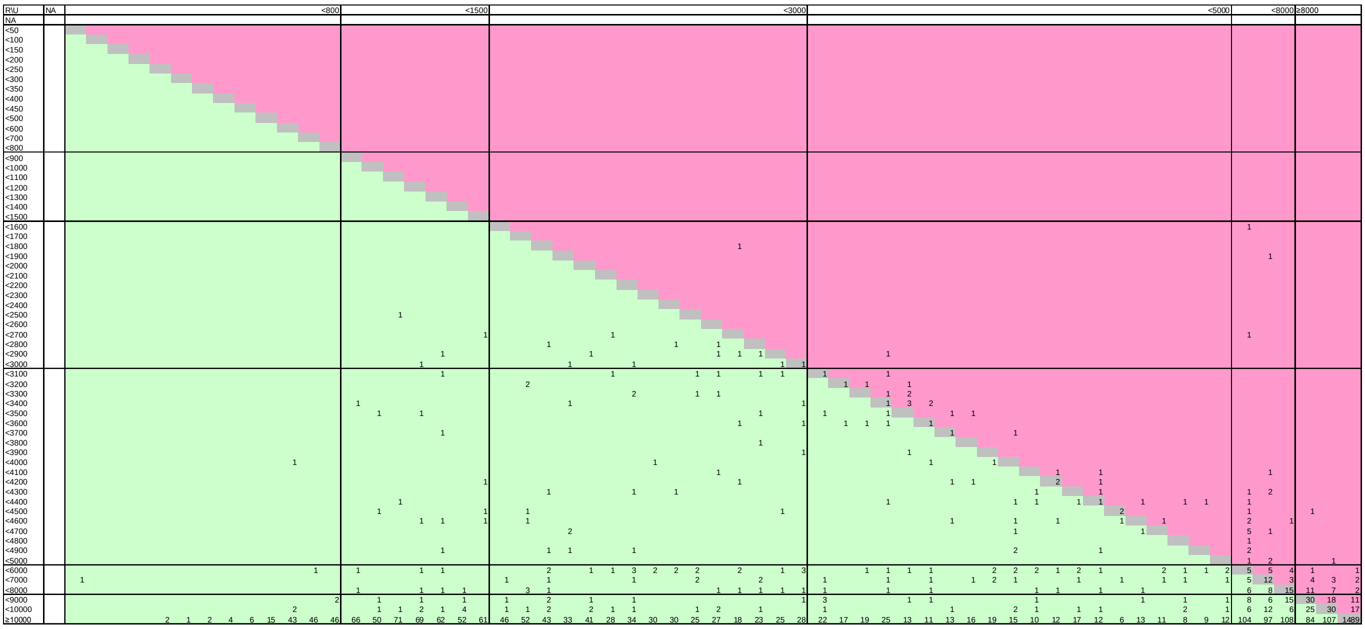
Reference versus uncorrected 1-minute MOR for all MOR filtering cases, PW.



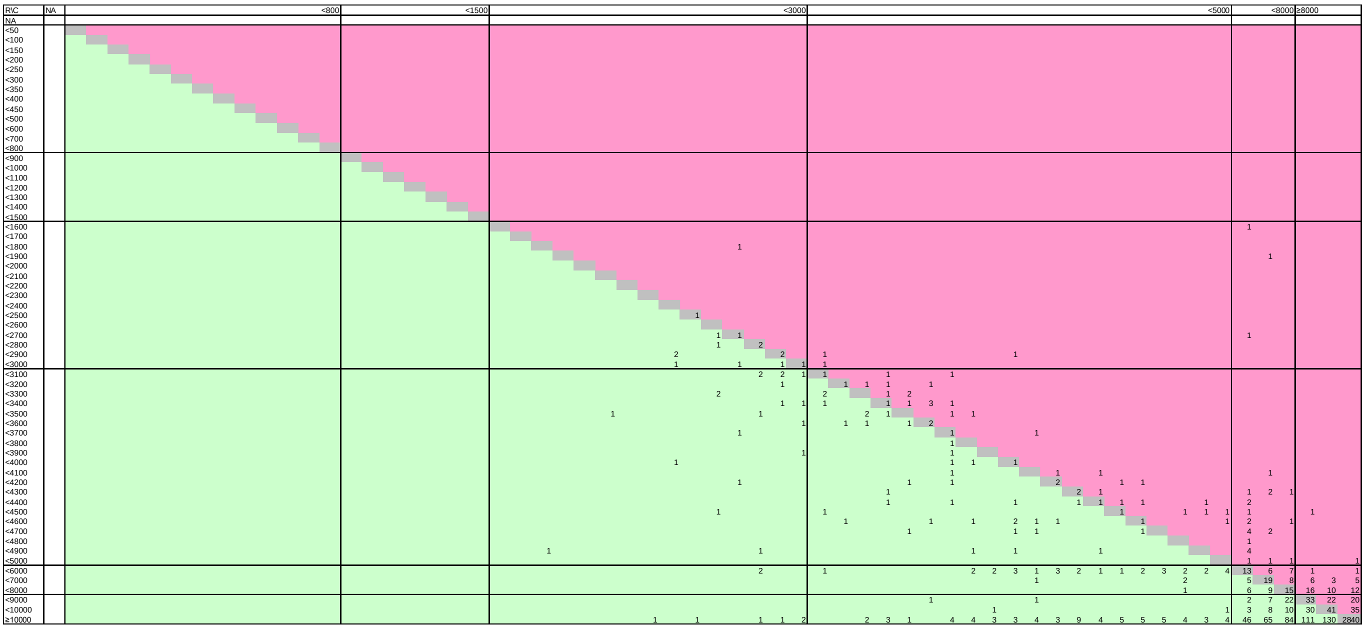
Reference versus corrected 1-minute MOR for all MOR filtering cases, PW.



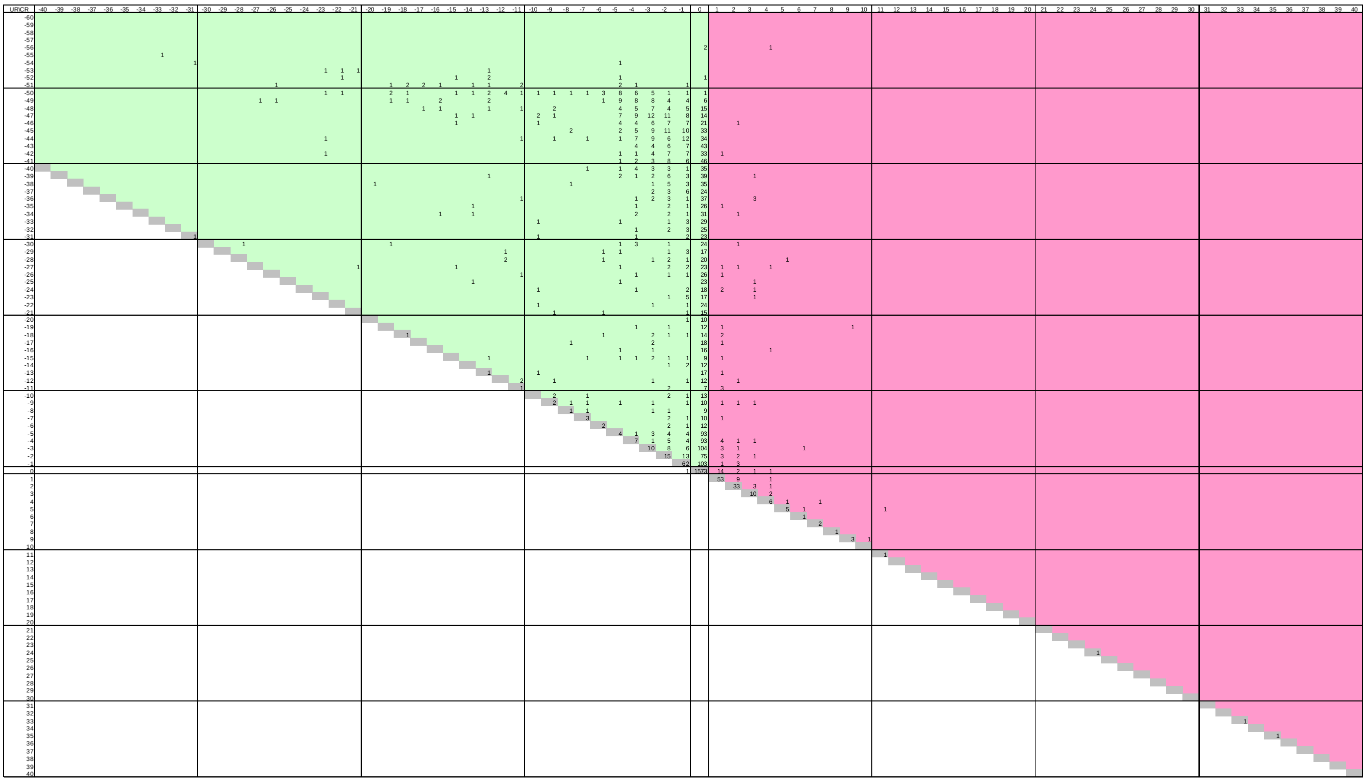
Reference versus uncorrected 1-minute MOR for all valid MOR filtering cases, REF.



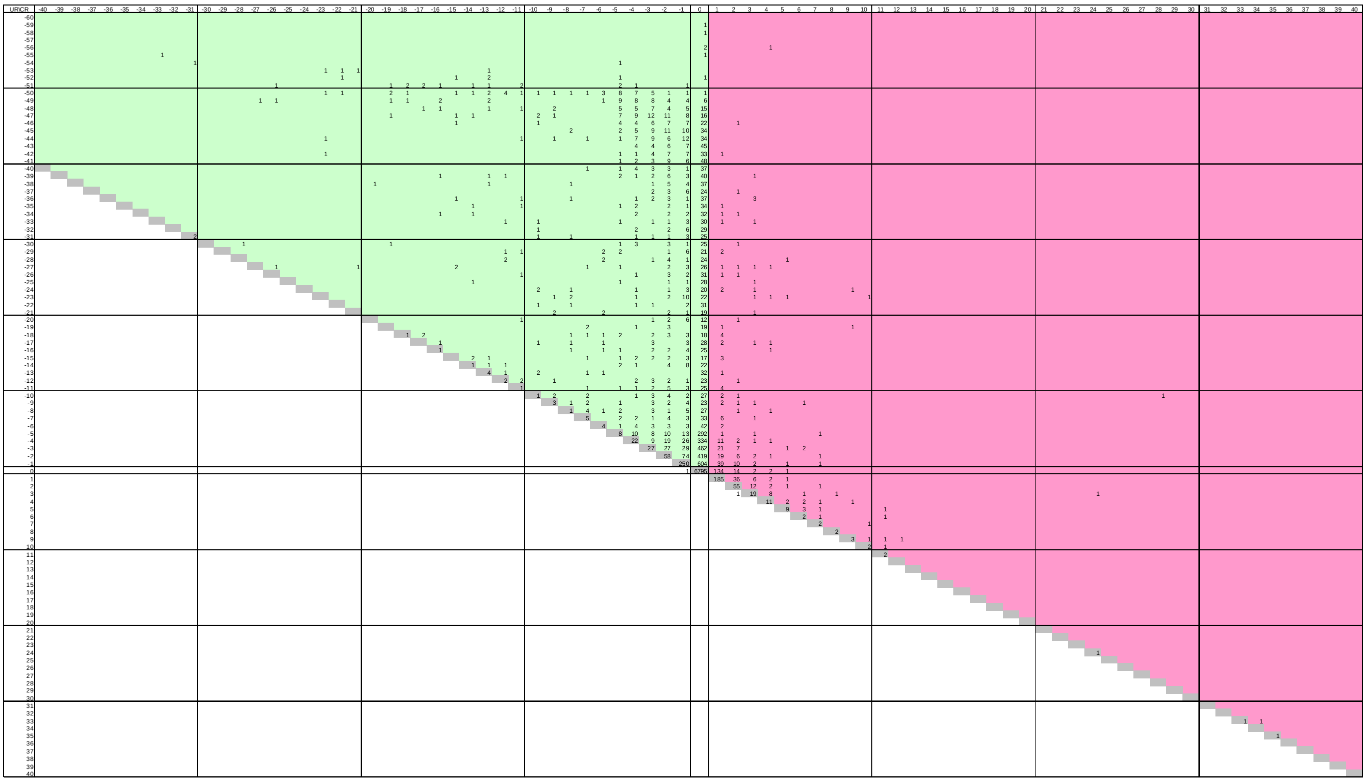
Reference versus corrected 1-minute MOR for all valid MOR filtering cases, REF.



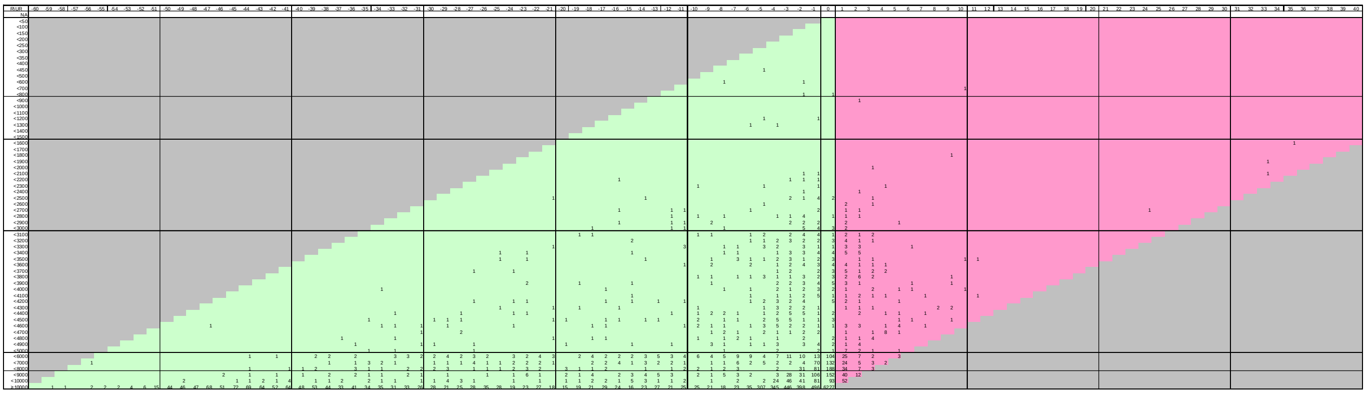
Contingency matrix of the differences of uncorrected-reference versus corrected-reference 1-minute MOR for all valid MOR filtering cases, REF, using the full visibility reporting bins for aviation.



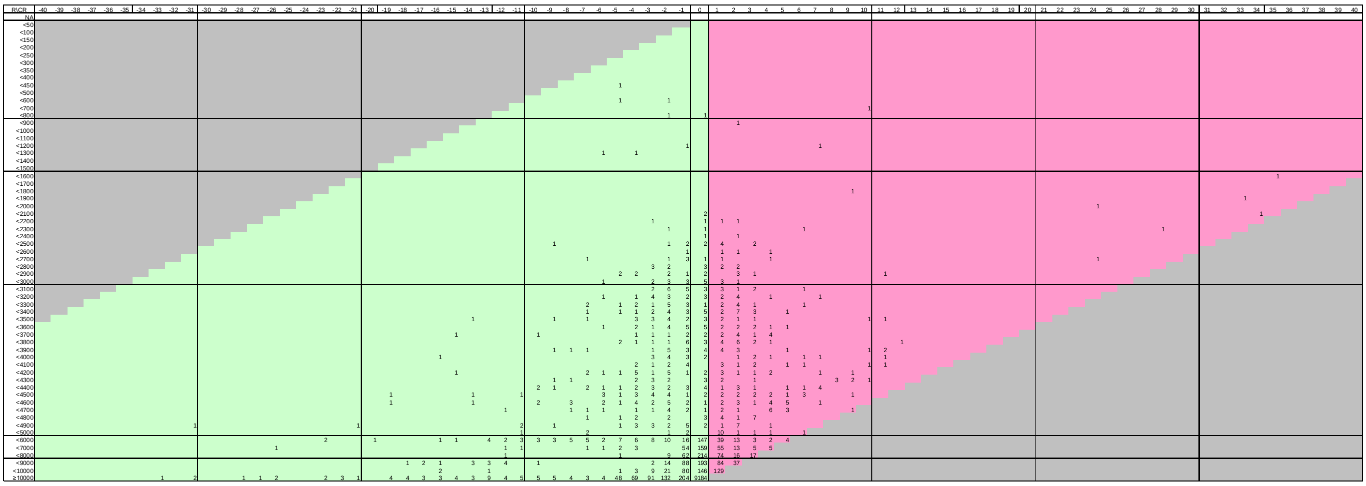
Contingency matrix of the differences of uncorrected-reference versus corrected-reference 1-minute MOR for all MOR filtering cases, PW, using the full visibility reporting bins for aviation.



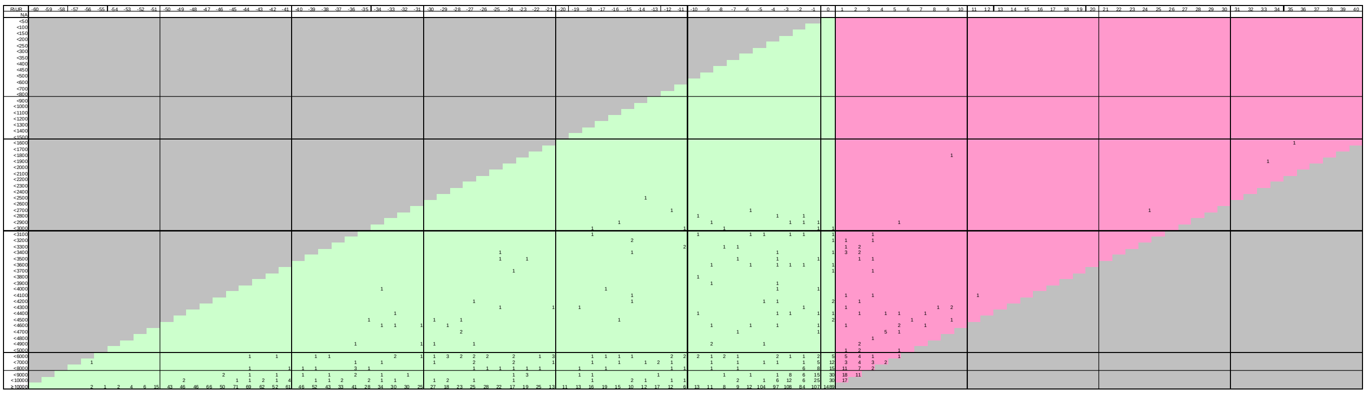
Reference versus difference between uncorrected and reference 1-minute MOR for all MOR filtering cases, PW.



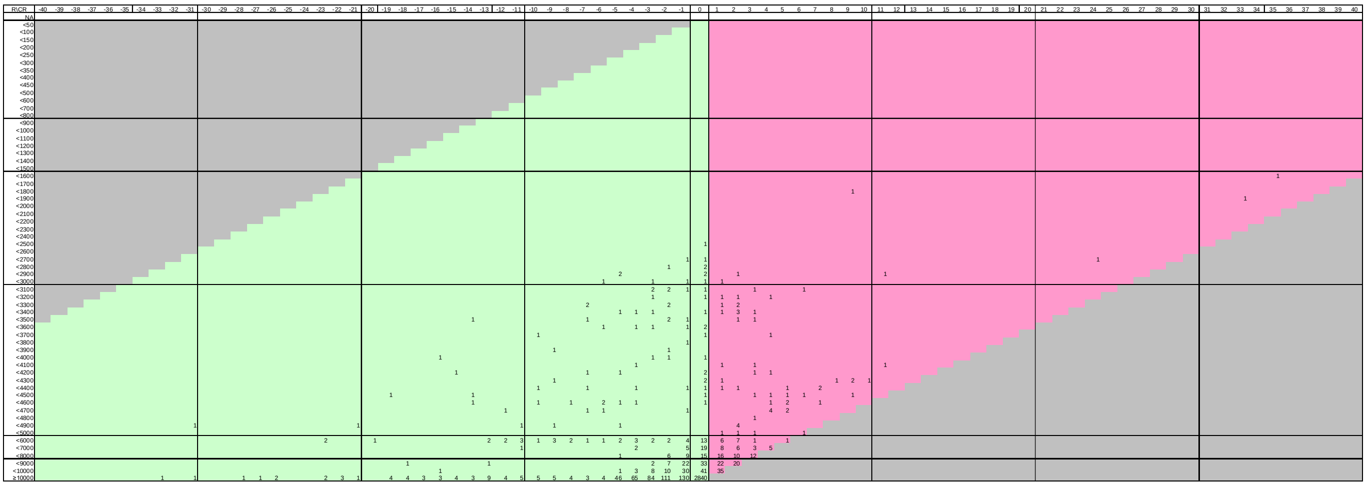
Reference versus difference between corrected and reference 1-minute MOR all MOR filtering cases, PW.



Reference versus difference between uncorrected and reference 1-minute MOR for all valid MOR filtering cases, REF.

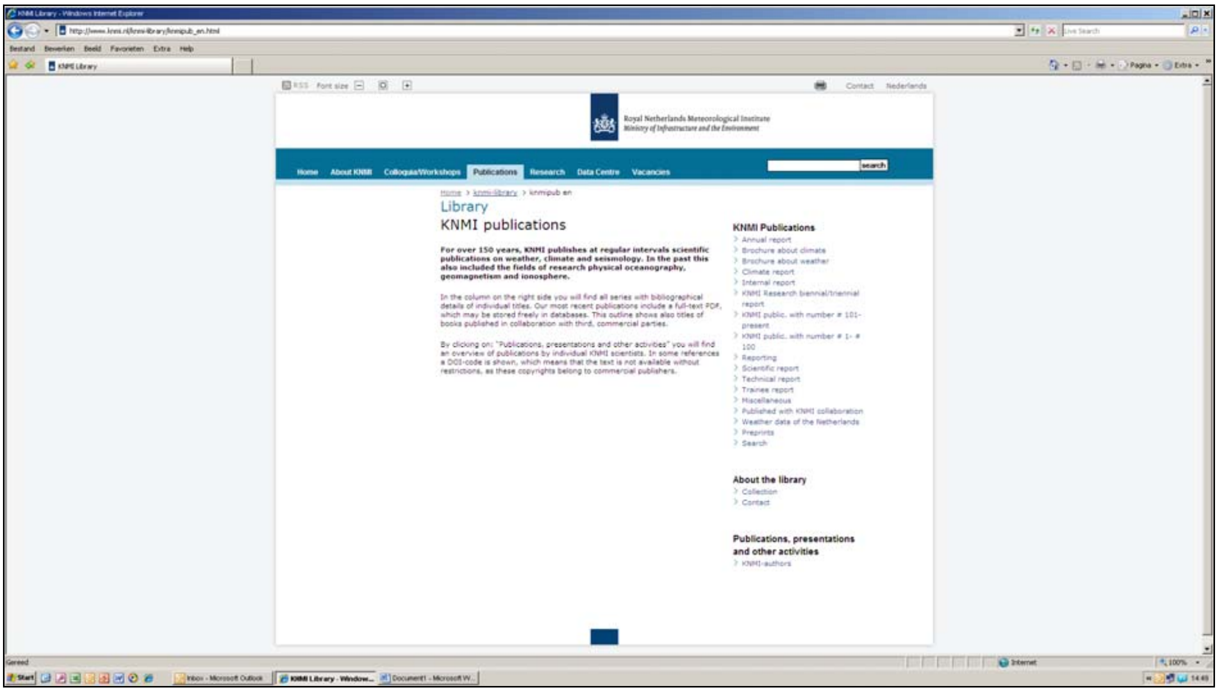


Reference versus difference between corrected and reference 1-minute MOR for all valid MOR filtering cases, REF.



A complete list of all KNMI-publications (1854 – present) can be found on our website

www.knmi.nl/knmi-library/knmipub_en.html



The most recent reports are available as a PDF on this site.