

# KNMI VISIBILITY STANDARD FOR CALIBRATION OF SCATTEROMETERS

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## Abstract

Scatterometers (or forward scatter meters) are used to measure visibility. Calibration of scatterometers is not trivial. When scatterometers are used for aeronautical purposes, their calibration needs to be traceable and verifiable to a transmissometer standard, the accuracy of which has been verified over the intended operational range. The KNMI visibility standard consists of a well calibrated transmissometer and a scatterometer and is operated in De Bilt. The result is a calibration device which can be used to calibrate FD12P scatterometers, in accordance with the above regulations. The standard also allows regular checks of this calibration device, as well as a check of the linearity of the scatterometer.

## 1. Background

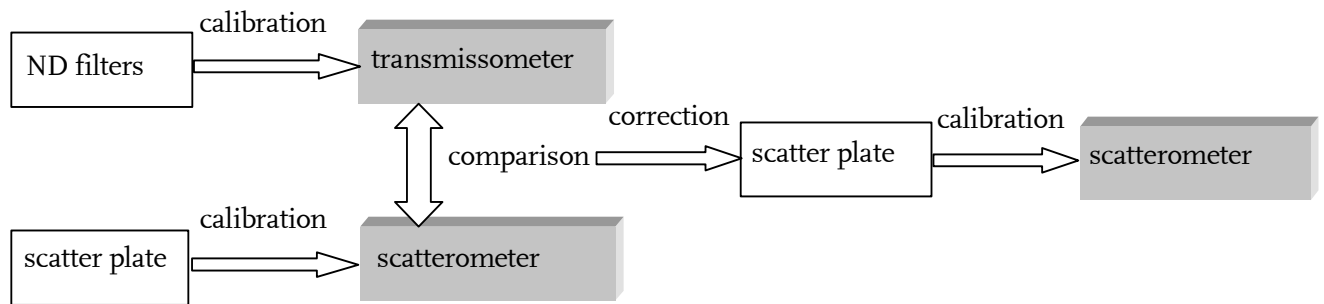
Scatterometers (or forward scatter meters) are used to measure visibility. Up until relative recently, transmissometers have been used for these measurements. But scatterometers have certain advantages compared to transmissometers: they are easy to install, they require relatively little maintenance (cleaning) and they are not as expensive. The main reason why scatterometers are only recently used widely, is that their calibration is not trivial.

Calibration of visibility instruments is of particular importance if they are used for aeronautical purposes such as for Runway Visual Range (RVR) measurements. For civil aviation, the International Civil Aviation Organization states: “*The calibration of a forward-scatter meter has to be traceable and verifiable to a transmissometer standard, the accuracy of which has been verified over the intended operational range.*”<sup>[1]</sup>

KNMI has, in order to comply with these ICAO regulations, set up its own standard for the calibration of scatterometers.

## 2. Calibration chain

The calibration chain of the scatterometers used by KNMI, the Vaisala FD12P Present Weather Sensor, is shown schematically in Fig. 1.



*Fig. 1 . The visibility standard shown schematically. See text for explanation.*

### **Transmissometer calibration**

The calibration chain for the FD 1 2P scatterometer starts with the calibration of a transmissometer. Transmissometers are calibrated (and adjusted) using Neutral Density Filters. These filters are in turn calibrated in the laboratory and are thus the primary source of calibration in the chain. The ND filters are placed in the baseline of the instrument and the transmission is measured by the instrument. Several filters are used with transmissions of approximately 0.25, 0.4, 0.6 and 0.8. Combination of these filters will provide additional data points. Comparing the measured transmission with the filter transmission will give the deviation from linearity of the instrument, which can be corrected for by the software.

### **Initial scatterometer calibration**

Initially, the FD 1 2P scatterometer of the standard is calibrated in the usual way. This means a calibration device called “scatter plate” is placed in the measuring volume of the instrument and the instrument is adjusted accordingly. More details can be found in instrument’s manual. [2]

### **Comparison between transmissometer and scatterometer**

An important part of the visibility standard is the comparison of the transmissometer and scatterometer in the standard. The two instruments are installed in the field close to each other, and the data are collected continuously (for details, see the measurements section of this paper). The Meteorological Optical Range (or MOR) values of the two instruments are compared, as this quantity depends solely on the state of the atmosphere and not on parameters like background luminance and lamp settings. The results of this comparison will indicate if the scatterometer agrees with the transmissometer within the required accuracy, or if the scatterometer needs to be adjusted. The amount of data used needs to be sufficient to make a good comparison. In practice for the setup in De Bilt, this can vary from 2 months to 6 months.

### **Adjustment of the scatter plate**

The previous step may indicate that the scatterometer of the standard deviates too much from the transmissometer and an adjustment is needed. For the FD 1 2P, this can be achieved by adjusting the scatter plate, a device used for calibration of the FD 1 2P. This is a glass plate which can be inserted into the measuring volume, resulting in a known amount of scatter. This amount is then input into the software of the instrument, and the instrument is adjusted. The value corresponding to this amount of scatter is adjusted such, that the FD 1 2P visibility corresponds to the transmissometer visibility.

### Calibrating other scatterometers

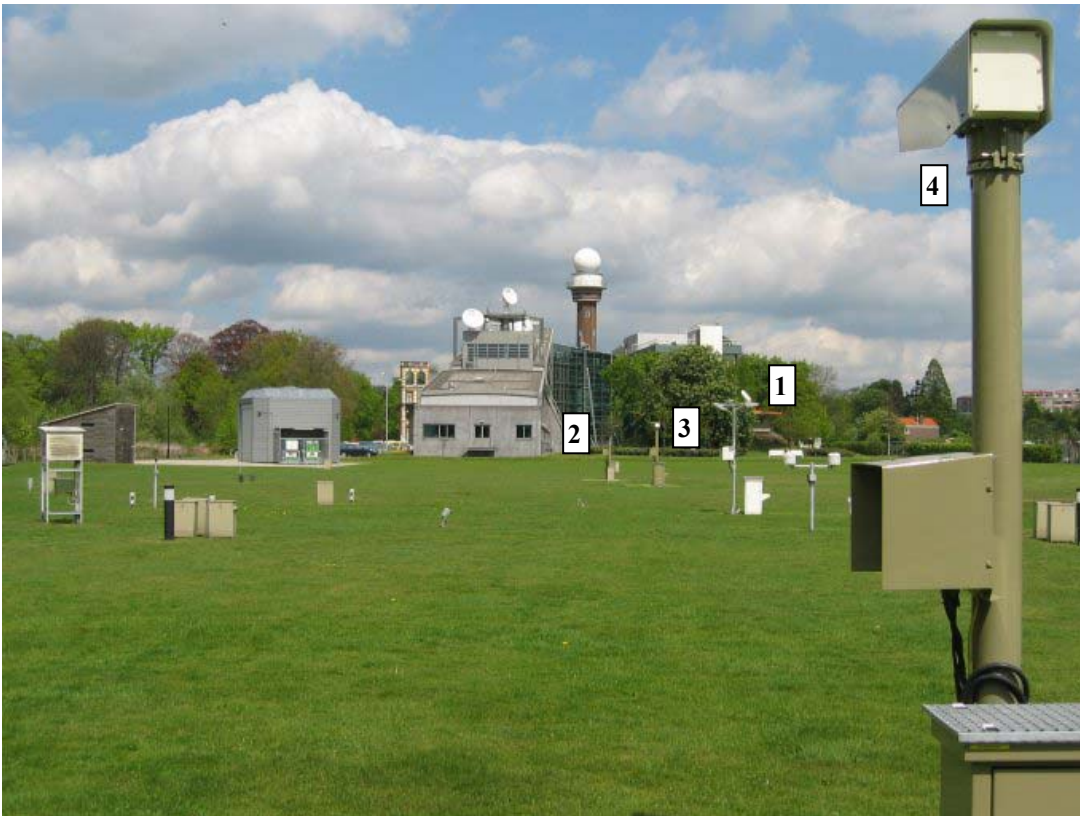
The previous step has resulted in a scatter plate which is now well calibrated and can be traced back to a transmissometer standard. So this scatter plate can now be used to calibrate/adjust other FD 1 2P's. This means that it is not necessary to place the instruments in the standard. They can be calibrated in the field or in the laboratory using only the scatter plate.

So the final result of the calibration chain is a well calibrated scatter plate which is used to calibrate FD 1 2P's.

## 3. Measurements

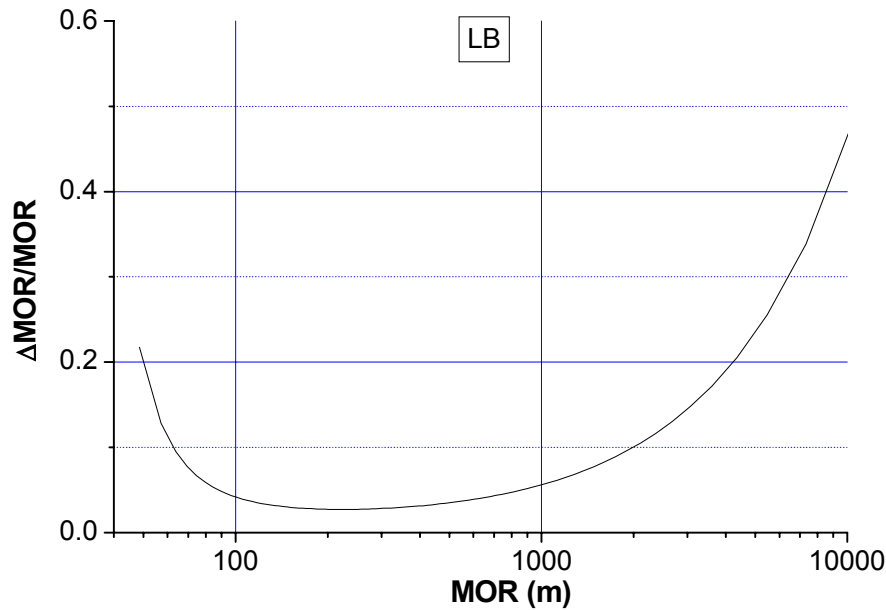
### 3.1 Instrument setup

The two instruments used in the visibility standard are the Vaisala transmissometer Mitras and the Vaisala scatterometer FD 1 2P Present Weather Sensor. Both instruments have a measuring height of 2.5 m, in accordance with airport regulations for visibility (RVR) measurements. The instruments are located in De Bilt and the FD 1 2P is placed at roughly the centre of the long baseline of the Mitras (see Fig. 2).



*Fig. 2 The Mitras transmissometer and FD 1 2P scatterometer of the visibility standard in De Bilt. 1: FD 1 2P, 2: Mitras transmitter, 3: Mitras receiver short baseline, 4: Mitras receiver long baseline.*

The Mitras transmissometer used is a double baseline system, with a long baseline of 74.4 m and a short baseline of 11.4 m. A xenon flash lamp emits light between 300 and 1100 nm with a 1 Hz frequency. This light is detected by receivers on both baselines with a filter of 300 - 700 nm, and the transmission (T) is determined. MOR (Meteorological Optical Range) is then calculated using  $MOR = -3 B / \ln(T)$ , with B the baseline. From this equation, it follows that the accuracy depends on the visibility itself, which is illustrated in Fig. 3. This means that the range of the instrument is 8 m – 3 km. The minimum averaging time is 1 minute.



*Fig. 3 The relative error in MOR (y-axis) as a function of MOR (x-axis) for the long baseline when an error of 0.01 is assumed in the determination of the transmission T. Note that a similar curve exists for the short baseline, thus significantly improving the accuracy for low visibilities.*

The Vaisala FD12P uses IR light at 875 nm, which is detected under an angle of about 30°. The amount of scatter measured in this way is empirically linked to the extinction coefficient. Extinction coefficients are averaged to a minimum averaging time of 1 minute. Software version V1.86 is used.

### 3.2 Data filtering

In order to compare the two instruments of the standard, the data need to be filtered properly. The main issue is that the visibility needs to be stable in order to compare the instruments properly. The following processing is performed:

- status: if an instrument gives a status message (error /warning), the measurement is not used.
- precipitation: if the precipitation intensity reported by the FD12P is > 0 mm/hr, the measurement is not used.
- availability: because 10-minute averaging is used (see below), a minimum of 8 1-minute measurements are needed to calculate the average. Otherwise, the interval is not used.
- stable fog: the instruments can only be compared properly if the fog (or visibility) situation is stable. This is ensured (according to ICAO recommendations, see [3]) by determining the average and standard deviation within a 10-minute interval. If the standard deviation is larger than 10 % of the average, then the interval is not used.
- 10-minute averaging: because the data used in aviation are 10-minute averages, these are used in the standard as well. The 1-minute transmissions are averaged for this.
- deviation: the deviation of the FD12P from the Mitras transmissometer is expressed by the ratio of the MOR:  $MOR_{FD12P}/MOR_{Mitras}$ . Data from the past 2 months is used where  $MOR_{Mitras} < 1500$  m (the limit for civil aviation) . If there are fewer 100 data points, or fewer than 50 below  $MOR_{Mitras} = 1000$  m , or fewer than 20 below  $MOR_{Mitras} = 500$  m, then the past 3 months are used. If this still is not enough, the past 4 months are used, etc...

## 4. Results

The results of the comparison of the two instruments are shown in Fig. 4 and Fig. 5 for 12 months of data, from September 2005 to August 2006. Explanations of the figures can be found in their captions.

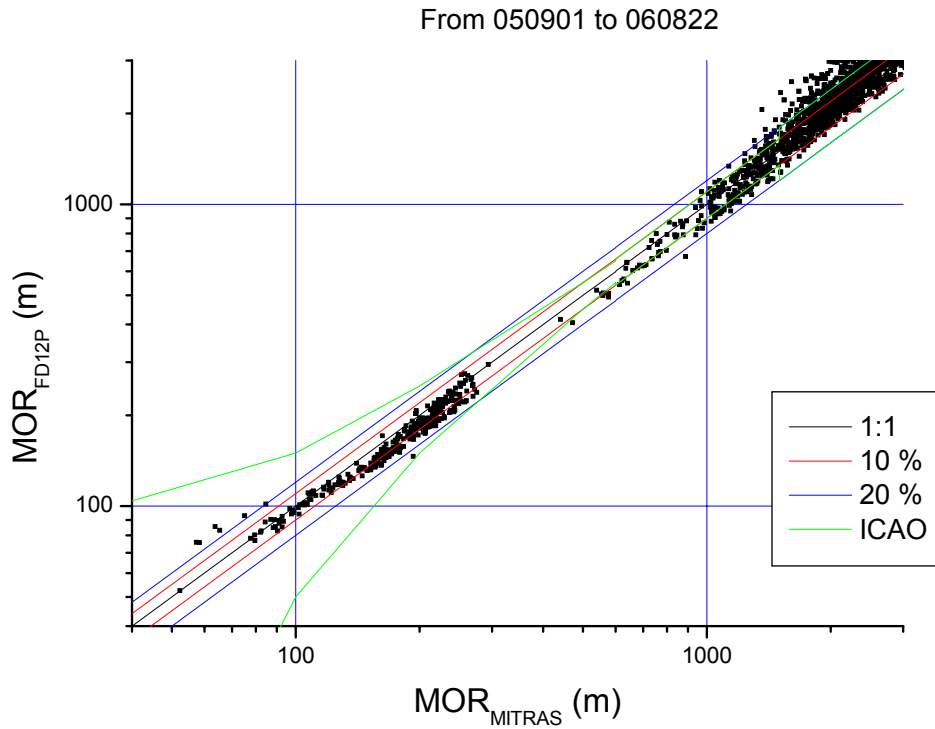


Fig. 4. 10 minute averages of the MOR from the FD12P (y-axis) as a function of the MOR from the Mitras (x-axis) for the 12 months of data indicated. Also shown are the ICAO limits (green line), the 20 % difference lines (blue), 10 % difference lines (red) and the 1:1 line (black). The applied data filtering is described in the text.

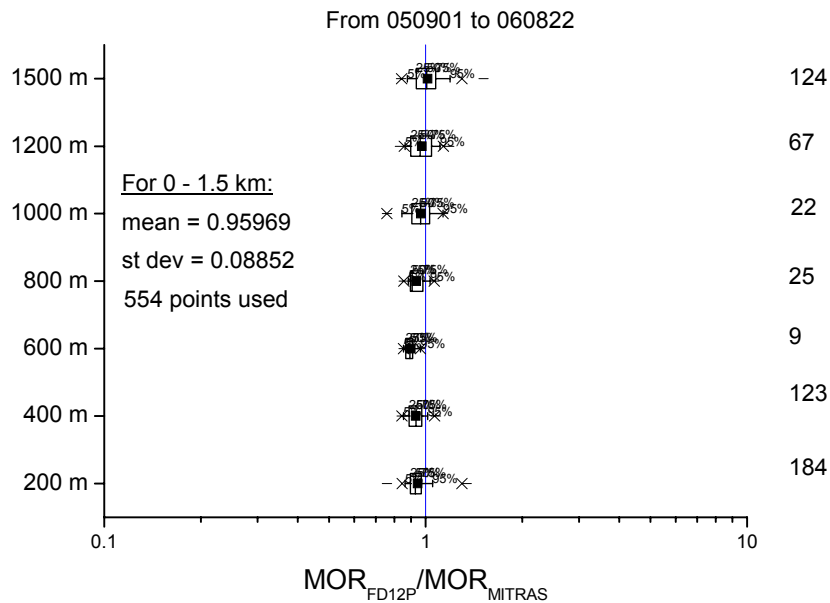


Fig. 5 The results from Fig. 4 as a box plot. On the x-axis the ratio  $MOR_{FD12P}/MOR_{Mitras}$ . On the y-axis, 200 m means  $MOR_{Mitras}$  between 0 and 200 m, 400 m means  $MOR_{Mitras}$  between 200 and 400 m, etc... On the right the number of data point are indicated. The percentages for the box plot are: box: 25 - 75 %, |: 5 - 95 %, x: 1 - 99 % and -: minimum and maximum.

For these data, the mean of the ratio  $MOR_{FD12P}/MOR_{MitraS}$  is 0.96, with a standard deviation of 0.09. The distribution of the visibilities is indicated of the right-hand side of Fig. 5, where the numbers are the number of data points for the interval indicated on the y-axis.

## 5. Error analysis

The uncertainty analysis of the visibility standard naturally follows the scheme shown in Fig. 1. An overview of the various error sources is shown below. Most of the errors are instrument specific and some details cannot be disclosed, so absolute values are not given. Instead, the means of determining the errors is given.

### Calibration ND filters

The ND filters are calibrated by placing them in a light beam, and measuring the transmittance. The standard deviation from multiple measurements will give a type-A uncertainty. In addition to this, the following possible error sources are identified:

possible error source	method
contamination ND filter	-visible inspection filter -cleaning filter -measuring at 16 different positions on filter -comparing results with previous calibration
degradation filter	-measuring at 16 different positions on filter -comparing results with previous calibration -regular checks of filter
non-uniformity filter	-measuring at 16 different positions on filter
positioning filter during calibration	-measure transmission with filter at angle
background light	-measure for each transmission measurement
spectral effects	-use green filter transmissometer -check effect glass plate in light beam (to simulate transmissometer windows)

### Calibration transmissometer

The transmissometer is calibrated by placing the ND filters in the long- and short base, and comparing the transmittance reading of the instrument with the filter. Here, multiple measurements will also give a standard deviation. Other possible error sources are:

possible error source	method
error in ND filter	-see above
estimation current visibility during calibration	-calculate effect
positioning ND filters	-measure transmission with filter at angle
contamination windows during calibration	-visible inspection -cleaning -check measurement contamination

### Calibration FD<sub>12P</sub> (i.e. comparison transmissometer-FD<sub>12P</sub>)

The comparison of the transmissometer and FD<sub>12P</sub> results in the calibration of the FD<sub>12P</sub>. Next to the standard deviation of the measurements, the following error sources are identified:

possible error source	method
error in transmissometer	-see above
contamination transmissometer	-monitor contamination -clean often -set contamination threshold
variation in visibility between fog cases	-ensure multiple cases -error incorporated in standard deviation
effect of non-homogenous fog	-use stable fog criteria in data filtering -remaining effect incorporated in standard deviation

### Calibration scatter plate

The scatter plate is calibrated by adjusting the value of the amount of scatter for a certain MOR value. This is done arithmetically.

possible error source	method
error in FD <sub>12P</sub>	-see above
error in internal calibration curve FD <sub>12P</sub>	-from manufacturer
degradation/contamination scatter plate	-visible inspection -cleaning -regular checks

### Calibration FD<sub>12P</sub>

The final calibration is of the FD<sub>12P</sub>'s used in the network.

possible error source	method
error in scatter plate	-see above
error due to visibility during calibration	-estimate using internal calibration curve FD <sub>12P</sub>
alignment scatter plate during calibration	-measure with plate at extreme angles
variation between different FD <sub>12P</sub> units	-measure with different FD <sub>12P</sub> units
other obstruction (rain, snow, etc)	-is not calibrated with this method
effects of small measuring volume FD <sub>12P</sub>	-is not calibrated with this method

## 6. Discussion

The first thing that is evident from Fig. 4 and Fig. 5 is that there is not a lot of data available for a good comparison. In total, there are only 554 10-minute averages available for about 1 year of continuous measurements. The main reason for this is that only stable visibility conditions can be used to compare the two instruments, and the requirements for these conditions are very strict (see Measurements

section). This is the reason why a good comparison may take a relatively long time. This naturally depends also on the climate at the location of the standard.

Another thing that shows clearly in the two figures, is that there is very little data between about 300 and 800 m. This is also a result of the fog conditions at the location of the standard. Fog with these visibilities is usually fog that is forming or dissipating, and thus it is not very stable. This can obviously not be helped, but as long as there are enough data points on either side of this interval, the data can be used for the standard.

The main result from the comparison of the instruments is that the mean of the ratio  $MOR_{FD12P}/MOR_{Mitas}$  is 0.96, with a standard deviation of 0.09. This means that within the margin of error, the instruments agree with one another. So the scatter plate does not need adjusting, and can be used to calibrate other FD12Ps. Checks like these can be used on a regular basis (e.g. once a month) to check the scatter plate and instruments for degradation effects.

Both Fig. 4 and Fig. 5 give information on the linearity of the scatterometer. Around roughly 200 m, the FD12P gives somewhat lower visibilities, but the differences are of about the same order as the standard deviation. Around 100 m and 1000 m both instruments agree very well.

## 7. Conclusions

The visibility standard of KNMI can be used to calibrate FD12P scatterometers. The standard ensures that the calibration can be traced back to a well-defined transmissometer standard, in accord with civil aviation regulations. A regular check of the calibration device used for the FD12P scatterometers is also part of the standard, as is a check of the linearity of the FD12P.

## 8. Acknowledgements

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## References

1. *Annex 3 to the Convention on International Civil Aviation; Meteorological Service for International Air Navigation*, 15<sup>th</sup> edition, July 2004, chapter 4.3: Runway visual range (page APP3-5).
2. *User's Guide Weather Sensor FD12P, M210296en-A*, May 2002, Vaisala.
3. *Manual of Runway Visual Range Observing and Reporting Practices*, Doc. 9328-AN/908, 2<sup>nd</sup> edition 2000, ICAO.