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.*"[1]
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.

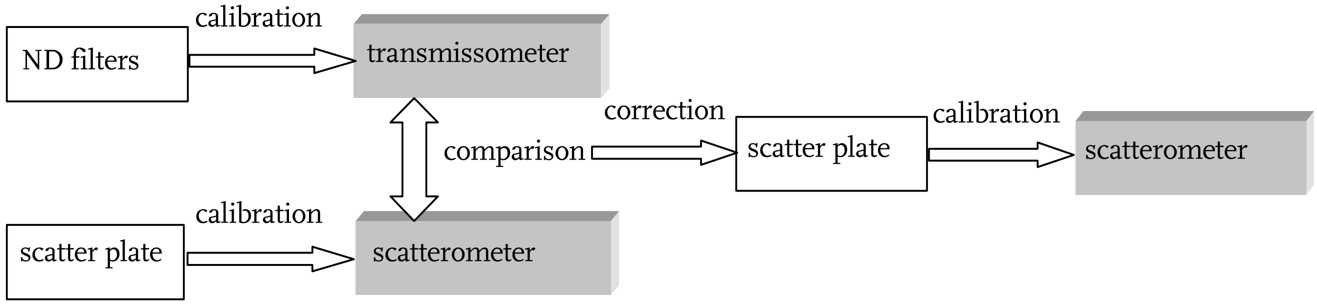

Fig. 1 . The visibility standard shown schematically. See text for explanation.

Transmissometer calibration

The calibration chain for the FD12P 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 FD12P 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 FD12P, this can be achieved by adjusting the scatter plate, a device used for calibration of the FD12P. 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 FD12P 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 FD12P'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 FD12P's.

3. MEASUREMENTS

3.1 Instrument setup

The two instruments used in the visibility standard are the Vaisala transmissometer Mitras and the Vaisala scatterometer FD12P 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 FD12P is placed at roughly the centre of the long baseline of the Mitras (see Fig. 2).

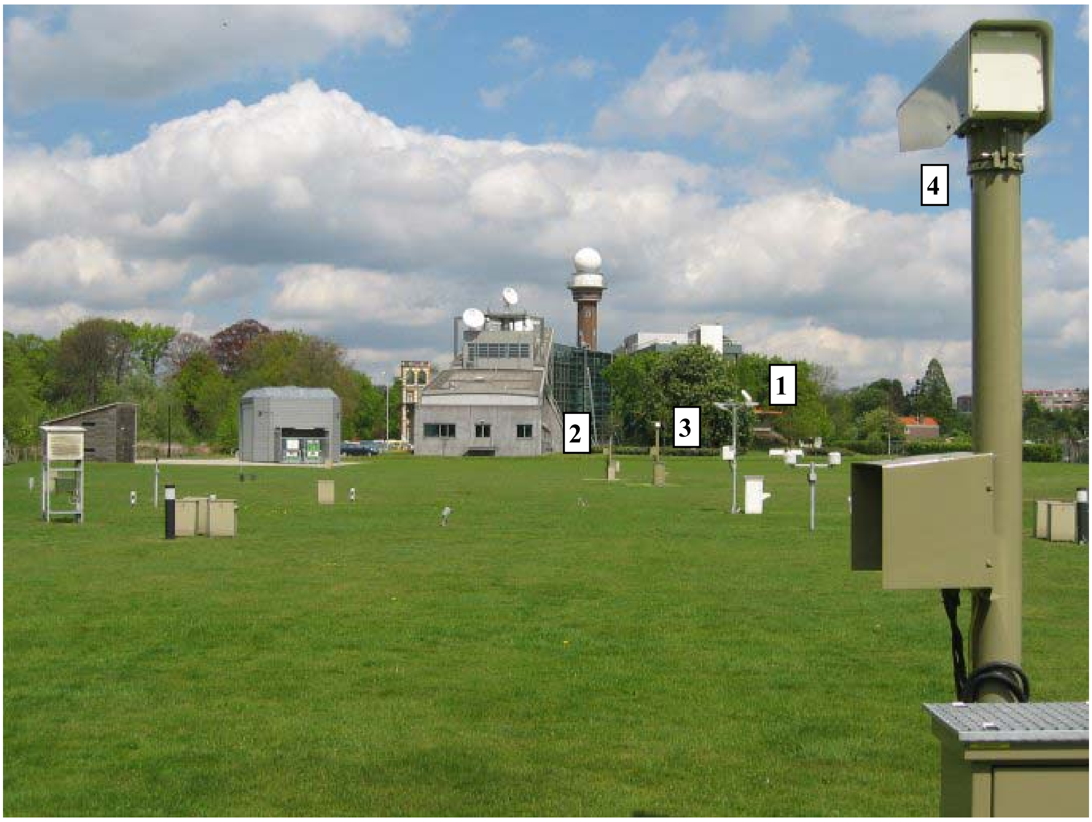

Fig. 2 The Mitras transmissometer and FD12P scatterometer of the visibility standard in De Bilt. 1: FD12P, 2: Mitras transmitter, 3: Mitras receiver short baseline, 4: Mitras receiver long baseline.

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.

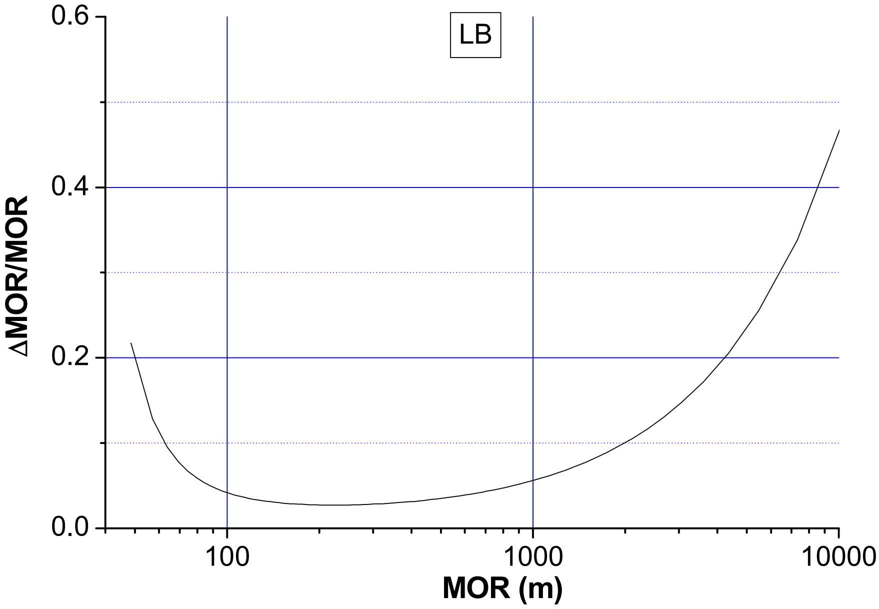

Fig. 3 The relative error in MOR (y-axis) as a function of MOR (x-axis) for the long baseline when an error of 0.01 is assumed in the determination of the transmission T. Note that a similar curve exists for the short baseline, thus significantly improving the accuracy for low visibilities.

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. The accuracy is given as 10 % for visibilities up to 10 km. 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 is 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 , of 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 six months of data, from September 2005 to February 2006 (including). Explanations of the figures can be found in their captions.

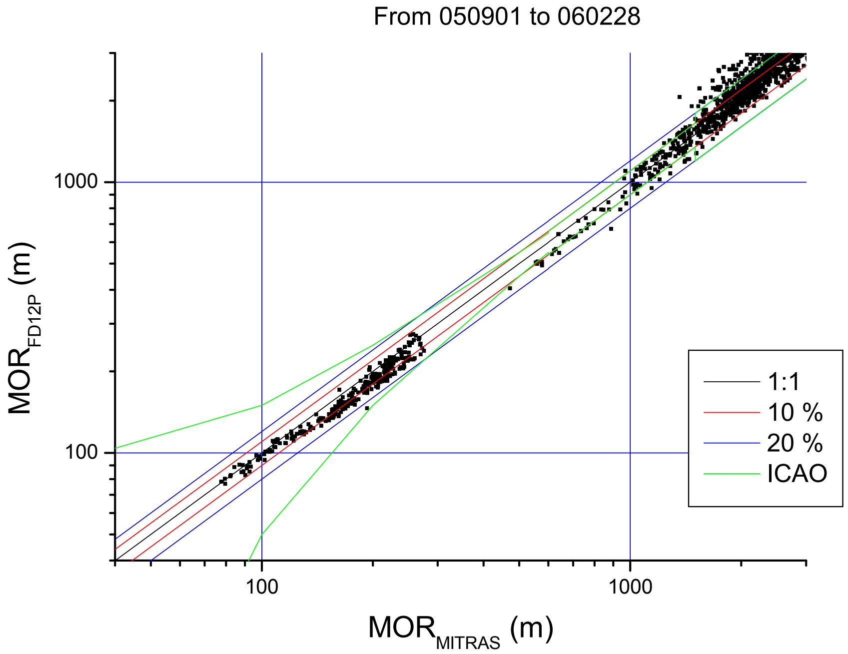

Fig. 4. 10 minute averages of the MOR from the FD12P (y-axis) as a function of the MOR from the Mitras (x-axis) for the 6 months of data indicated. Also shown are the ICAO limits (green line), the 20 % difference lines (blue), 10 % difference lines (red) and the 1:1 line (black). The applied data filtering is described in the text.

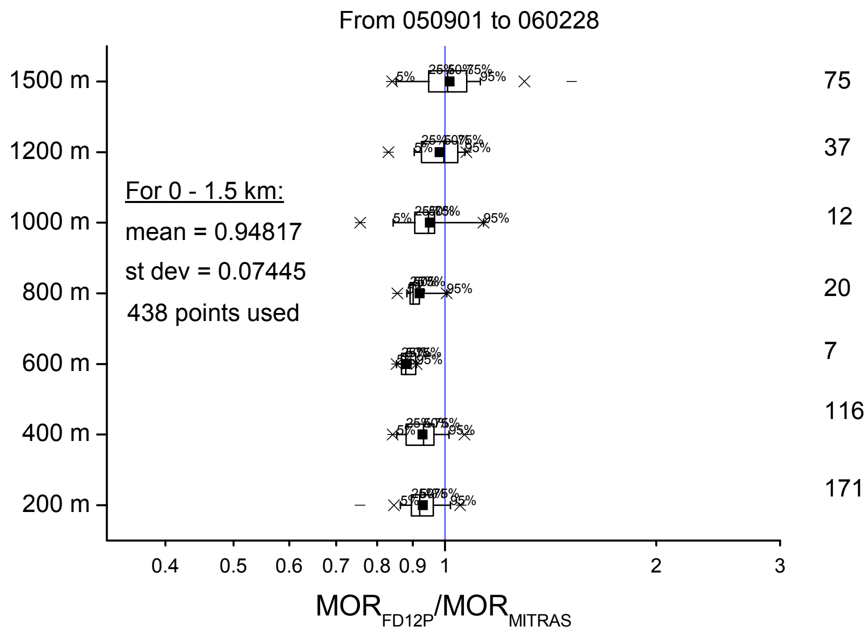

Fig. 5 The results from Fig. 4 as a box plot. On the x-axis the ratio MOR_{FD12P}/MOR_{Mitras}. On the y-axis, 200 m means MOR_{Mitras} between 0 and 200 m, 400 m means MOR_{Mitras} between 200 and 400 m, etc... On the right the number of data point are indicated. The percentages for the box plot are: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

For these data, the mean of the ratio MOR_{FD12P}/MOR_{Mitras} is 0.95, with a standard deviation of 0.07. 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. 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 438 10-minute averages available for 6 months 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 above, 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_{Mitras} is 0.95, with a standard deviation of 0.07. 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.
A thorough error analysis is being done at the moment, but unfortunately the results cannot yet be shown. However, within the visibility standard the scatterometer is only the secondary standard and the transmissometer the primary standard, and so the accuracy of the scatterometer will obviously

be less than that of the transmissometer. Furthermore, the comparison of the two instruments will introduce further uncertainty (illustrated by the spread of the measurements in Fig. 4).

6. 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.

7. ACKNOWLEGDEMENTS

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References

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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, 2nd edition 2000, ICAO.*