Abstract

To replace the existing transmissometer for visibility/runway visual range measurements at Hong Kong International Airport, a field study of the latest models of transmissometer/forward scatter sensors was carried out over 2 years and 5 months. Different kinds of weather conditions were considered: haze, fog/mist and rain. Comparisons with SYNOP visibility reports were also made. The new model transmissometer performed better than the existing transmissometer. A low cost forward scatter sensor also performed well, but the performance in haze was less satisfactory compared with internationally adopted accuracy requirements. The forward scatter sensors under testing may not be well adapted for measurements in the types of aerosols over southern China based on international requirements. This study highlights the importance of establishing the performance of visibility sensors in local climatological conditions.

1. Introduction

Visibility is an important meteorological factor in weather reports. Historically, visibility was assessed using human observations of landmarks around weather stations. Automatic observation of visibility is now more common using visibility sensors. There are two main types of visibility sensors: transmissometers that measure the extinction of a light beam over an extended distance (in the order of several tens of metres) in the air, and forward scatter sensors that measure the amount of light scattered in a small volume of air.

However, there are various limitations associated with both types of sensor. Transmissometers work in a similar way to humans using visible light in a larger sampling volume. However, they have non-linear behaviour when visibility is above 2000-3000 m and are subject to various limitations, such as lens contamination and off-alignment with the poles bending due to differential solar heating. Forward scatter sensors are linear in behaviour, subject less to lens contamination and have no alignment issues. However, they have only a small sampling volume and most use infrared instead of visible light. Moreover, different suspended particulates/water droplets in the air have different scattering properties, and the use of a fixed wavelength of light and a fixed scattering angle may make forward scatter sensors less suitable in certain weather conditions.
The Flamingo transmissometer sensor for runway visual range (RVR) observations at the Hong Kong International Airport (HKIA) has been in use for more than 10 years. A field study of the latest visibility sensors was therefore carried out to find a suitable replacement. The performance of the sensors was studied for the climatological conditions seen in Hong Kong, including haze (in which infrared light forward scatter sensors do not behave as well as visible light sensors, according to ICAO (2005)), and fog/mist in which the amount of suspended particulates in the air can also be quite substantial. Both transmissometers and forward scatter sensors were considered. To ensure continuity in the measurement, their performance was studied with reference to the Flamingo transmissometer as a benchmark. The Flamingo transmissometer has its own limitations in measurement accuracy in certain meteorological conditions. The data from these sensors were also examined using human visibility observations as a reference.

2. Visibility sensors tested

The setup of the visibility sensors at the meteorological garden of HKIA is shown in Figure 1. Brief descriptions of the various sensors are given below.

2.1 Transmissometers:

Flamingo – It has been in use at HKIA since the airport opened in 1998. It is a double-base transmissometer with baseline length of 15 m for the short-base receiver and 75 m for the long-base receiver. The measurement range is between 10 m and 10 km, but linear behaviour is expected only between visibilities of 10 m and 3 km. A white light-emitting diode (LED) is used with a flash frequency of 2.5–3.5 Hz. Lens cleaning and manual alignment have to be conducted carefully and regularly. Bending of the poles occurs in the summertime, leading to a loss of alignment of the optical path. Further information of the sensor can be found in the Skopograph II Flamingo user manual (Impulsphysik, 1997).

LT31 – This is the latest model of transmissometer from the manufacturer. A single-base transmissometer is used with a baseline of 30 m. The measurement range is between 10 m and 10 km. The measurement of higher visibility is made possible by equipping the transmissometer with a mini forward scatter sensor unit. For the transmissometer part, a white LED is used with a modulation frequency of 1 kHz. There is automatic optical monitoring of lens contamination and alignment. If necessary, automatic compensation of the visibility data is made by detecting the degree of lens contamination, and auto-alignment is made with internal mechanical devices. Auto-calibration of visibility data is achieved using the forward scatter sensor readings in higher visibility conditions. The sensor is claimed to fulfill the latest accuracy requirements of the International Civil Aviation Organization (ICAO) but with no specific accuracy values. The product’s website (http://www.vaisala.com/en/products/visibilitiesensors/Pages/LT31.aspx) gives details. The ICAO accuracy requirements (ICAO, 2013) for RVR are: ±10 m up to 400 m; ±25 m between 400 m and 800 m; and ±10% above 800 m.
2.2 Forward scatter sensors:

FD12P – This sensor has been in use at HKIA for 9 years as a reference in the assessment of visibility. Apart from visibility, it also measures precipitation and temperature. The measurement range of the sensor is between 10 m and 50 km with an accuracy of ±10% from 10 m to 10 km, and an accuracy of ±20% above this. A near-infrared LED is used with a peak wavelength of 875 nm with a scattering angle of 33°. The modulation frequency is 2.3 kHz. The product’s website (http://www.vaisala.com/en/tabcontentadmin/Pages/FD12P.aspx) gives details.

FS11P – This is the latest model of forward scatter sensor-based present weather sensor from the manufacturer. The measurement range goes from 5 m up to 75 km. The measurement accuracy is claimed to be 10% for 5 m up to 10 km, and 20% above, with scatter measurement accuracy of 3%. A near-infrared LED is used with a peak wavelength of 875 nm and modulation frequency of 2.2 kHz. A scattering angle of 42 degrees is used, which is the major difference from its former version FD12P. There is automatic detection function of lens contamination, and if necessary, compensation for contamination would be applied to the visibility readings. The product’s website (http://www.vaisala.com/en/products/presentweathersensors/Pages/FS11P.aspx) gives details.

PWD20 – As indicated by the manufacturer, it is a low-cost version of the forward scatter sensor. It has a measurement range of 10 m to 20 km, with an accuracy of 10% from 10 m to 10 km, and an accuracy of 15% between 10 and 20 km. Similar to the FD12P and the FS11P, a near-infrared LED is used with a peak wavelength of 875 nm. The scattering angle is 45°. Lens contamination was monitored, but there was no compensation of the visibility value. Further details can be found on the product’s website (http://www.vaisala.com/en/roads/products/atmosphericsensors/Pages/PWDvisibility.aspx).

DF320 – A forward scatter sensor with a scattering angle of 35°. The main differences from the previously described sensors include: (i) the use of visible light (350–900 nm) and (ii) a much larger sampling volume of 5 dm³ (the previously mentioned sensors have a sampling volume around 0.1 cm³). The light is amplitude modulated at 20 Hz. The measurement range is between 5 m and 70 km. The accuracy is 10% for visibility up to 5000 m, 15% from 5000 m to 20 km and 20% above 20 km. Further details can be found on the product’s website (http://www.degreane-horizon.com/IMAGES/GB/meteo/chapitres/visibilite/T305111C-DF320-GB.pdf).

To ensure the normal functioning of the above sensors, regular maintenance was carried out. For example, lens cleaning was performed every day. Alignment was conducted every 6 months. Data from the various sensors were monitored routinely and corrective maintenance was carried out immediately if abnormal data were found. Data points related to lens contamination or improper alignment, as judged by the maintenance staff, were removed.
3. Comparison with readings from the Flamingo transmissometer

The visibility readings from the various sensors were compared with those of the Flamingo transmissometer to ensure continuity of the visibility measurements. They were classified according to the weather reports at the end of each hour made by the human weather observers at HKIA (i.e. haze, mist/fog and precipitation). Only the sensor readings in the 10 minutes before the end of the hour were considered to ensure consistency with the time of the SYNOP report. The study period was November 2010 to April 2013.

Comparisons were made in the form of a box plot: the y-axis was the visibility reading from the Flamingo transmissometer as a reference, and the x-axis was the ratio of the reading from the sensor to that of the Flamingo transmissometer. In each box plot, the two times of the ICAO accuracy requirement of visibility (as stipulated by ICAO, 2013) was drawn as two blue curves. The box plots included the plotting of the median, 1st, 5th, 25th, 75th, 95th and 99th percentiles, as well as the minimum and maximum ratios. Only those visibility values that fulfilled the homogenous criteria as stipulated in ICAO (2005) were included in the comparison.

Data analysis was conducted only during ‘homogeneous’ events. Past experience shows that it is possible to use the time variability of the meteorological optical range (MOR) to detect non-homogeneous periods. During such periods the MOR measured by a given instrument is usually changing quickly. Therefore the stability of the MOR over a short period of time is an indicator of its spatial (at the scale of the test field) homogeneity. For each data point, a homogeneity indicator was constructed by calculating the mean and standard deviation of MOR values over the period starting five minutes earlier and lasting until five minutes later. The ratio of the standard deviation with the mean value was the indicator. If this ratio was greater than 0.1, the conditions were considered ‘non-homogeneous’ for the given minute.

In the SYNOP reporting of weather type, mist was reported when the horizontal visibility was between 1000 m and 5000 m and fog was reported when the visibility was below 1000 m. Haze was reported for visibility below 5000 m. Haze was distinguished from mist based on relative humidity and consideration of the nature of the air mass.

The results for the various weather types are shown in Figures 2–4. We focused on the visibility readings of 2000 m or below because the Flamingo transmissometer was only able to provide reliable readings in this region. For haze (Figure 2), all forward scatter sensors tended to over-read the visibility compared with the Flamingo transmissometer. In particular, the spread of the visibility values was large, with the boxes extending over a large range. Forward scatter sensors were not suitable for measuring the visibility of the kinds of haze/aerosols over southern China. For LT31, it was able to provide values that were comparable with the Flamingo transmissometer within the ICAO accuracy requirement.

For mist/fog (Figure 3), LT31, PWD20 and FS11P were able to give visibility values that were comparable with the Flamingo transmissometer for visibility below 2000 m. The values were generally
within the ICAO accuracy requirements. By contrast, the other two forward scatter sensors tended to over-read visibility. It appears that, at least for certain models of forward scatter sensor, the scattering angles were suitable for measuring visibility for the kinds of mist/fog over southern China.

For precipitation (Figure 4), the performance of LT31, PWD20 and FS11P was better with the measured visibility being generally within the ICAO accuracy requirement compared with the Flamingo transmissometer for visibility below 2000 m. Again, the other two kinds of forward scatter sensors tended to over-read visibility.

The performance of the various sensors is shown in Table 1. LT31 had the best performance in terms of comparability with the measurements of the existing Flamingo transmissometer. For forward scatter sensors, it is interesting to note that the relatively low-cost PWD20 performed the best.

It should be noted that the comparison period was relatively long (2 years and 5 months) and the amount of data considered in box plots for each sensor and each weather type (haze, mist/fog and precipitation) was in the range of 2,000–12,000 minutes. The findings can be considered representative of the performance of the sensors under the climatological conditions typical of southern China.

### 3.1 Case studies

To give the readers an idea of the performance of the sensors in specific weather types, case studies of haze, fog/mist and precipitation are presented.

Figure 5 shows a case of haze. From the surface isobaric chart, it can be seen that the southwestern part of China is under the influence of a continental anticyclone with light winds over southern China. This weather pattern is favourable for the accumulation/advection of aerosols over Hong Kong. The time series of the measured visibilities (1-minute means) from the various sensors are given in Figure 5(b). For visibility below 2000 m, the values of LT31 were comparable with those from the Flamingo transmissometer. By contrast, the visibilities from the forward scatter sensors were generally higher. This is consistent with the observations in the overall results given in Figure 2.

Figure 6 shows a case of fog/mist. Southern China is under the influence of maritime easterly winds with a long sea track under the influence of the northeast monsoon. This is a rather typical pattern of the occurrence of foggy weather over the south China coast in the springtime. Fog/mist was reported at the airport at the early hours of the day. In general, for this fog/mist episode, the performance of the various sensors was comparable, with LT31 readings being slightly closer to the Flamingo transmissometer measurements. After the fog/mist event, Flamingo tended to under-read visibility, probably because of accumulation of water droplets/dirt on the lens. Lens cleaning was conducted every day, mostly in the morning. Moreover, the Flamingo sensors are equipped with heated airflow at the lenses as well as long protective tubes to minimise the accumulation of water droplets on the lenses.
Figure 7 shows a day with precipitation, namely, southern China under the influence of active southerly flow ahead of a trough of low pressure. Rain and thunderstorms were reported at the airport on that day. During periods of precipitation, visibilities were lower and then recover quickly to high values after the precipitation (Figure 7b). In general, the various sensors give comparable readings in the rain. There was also a signature of lens contamination by rain droplets on the Flamingo transmissometer in terms of the lower visibility values in the latter part of the day.

4. Comparison with human observations

The visibility readings from the various sensors were also compared with the human visibility observations (SYNOP) at the airport. The two observations were very different: sampling volume was much larger in the SYNOP; moreover, minimum visibility in all directions of observation was taken into account. Therefore the results are quoted here for reference only (particularly for visibility higher than 2000 m when the Flamingo transmissometer does not provide reliable readings). However, since homogeneous periods are chosen in the comparison, the visibility at those times should be reasonably uniform in the spatial scale. In the study period, comparison was again made for each of the weather types – haze, mist/fog and precipitation.

The results are shown in Table 2. The proportion of visibility ratio falling within the ICAO accuracy requirements was considered. For the transmissometer, the results of LT31 were more comparable with human observations than the Flamingo transmissometer, especially for haze, and as such it can be used as a replacement sensor for the airport. For forward scatter sensors, in general, the PWD20 provides readings that are most comparable with the Flamingo transmissometer among all the sensors. The performance in haze was not particularly satisfactory in comparison with the ICAO accuracy requirements, which may be because the forward scatter sensors are not well adapted for measuring in the kinds of aerosols over southern China. It should be noted that, during the measurement campaign, the weather observer was not allowed to look at the measurements from all the sensors under test. As a result, the comparison with SYNOP visibility serves as a rather stringent test of the performance of all sensors.

5. Conclusions

A field study of the latest visibility sensors in the market was carried at the meteorological garden of HKIA. The Flamingo transmissometer was used as a reference for the assurance of continuity of visibility observations. The latest model LT31 transmissometer had closest agreement with the Flamingo transmissometer measurements. The low cost PWD20 had a good performance in the limited period of the study for mist/fog and precipitation weather types. However, including PWD20, the performance of the forward scatter sensors did not compare well with the Flamingo transmissometer and SYNOP reported visibility in haze. This may suggest that the forward scatter sensors under consideration are not well adapted for measurements in the kind of aerosols over southern China. This also highlights the importance of testing the performance of the visibility sensors for the kinds of weather at a particular place or region,
especially for haze. By contrast, the LT31 measures visibility from first principles and it can serve as a replacement of the existing Flamingo transmissometer in all kinds of weather. The performance in haze was good, especially in comparison with the SYNOP reports.

Apart from the LT31, other transmissometers have recently become available (Mohan et al. 2015). These will also be tested at HKIA and further results will be reported in the future.

6. References


Table 1  Fraction of data points within the ICAO accuracy requirements for the differences between the visibility measurements of the various sensors and those of the Flamingo transmissometer in the study period. 10-minute mean values of the sensors are used. PPT, precipitation.

<table>
<thead>
<tr>
<th></th>
<th>FD12P</th>
<th>LT31</th>
<th>PWD20</th>
<th>FS11P</th>
<th>DF320</th>
</tr>
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<tbody>
<tr>
<td>Haze</td>
<td>0.000</td>
<td>0.825</td>
<td>0.299</td>
<td>0.000</td>
<td>0.033</td>
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<td>0.599</td>
<td>0.484</td>
<td>0.017</td>
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<tr>
<td>PPT</td>
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<td>0.723</td>
<td>0.663</td>
<td>0.595</td>
<td>0.076</td>
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</table>

Table 2  Fraction of data points within the ICAO accuracy requirements for the differences between the SYNOP visibility readings of the various sensors and those of the Flamingo transmissometer in the study period. 10-minute mean values of the sensors are used. FLG, Flamingo transmissometer; PPT, precipitation.

<table>
<thead>
<tr>
<th></th>
<th>LT31</th>
<th>FLG</th>
<th>FD12P</th>
<th>PWD20</th>
<th>FS11P</th>
<th>DF320</th>
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<tr>
<td>Haze</td>
<td>0.283</td>
<td>0.098</td>
<td>0.000</td>
<td>0.116</td>
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<tr>
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<td>0.347</td>
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<td>PPT</td>
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<td>0.200</td>
<td>0.409</td>
<td>0.365</td>
<td>0.121</td>
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Figure 1  Setup of the visibility sensors under testing at Hong Kong International Airport.
Figure 2  Box plots of the performance of the various visibility sensors in haze. Blue lines are the ICAO accuracy requirements in ICAO (2013) and red lines are twice these requirements. Comparisons are considered satisfactory if the box (25 to 75 percentiles) is within the red lines. 10-minute means are considered here. The number of cases for each visibility range is given on the right-hand side of each plot.
Figure 3  Box plots of the performance of the various visibility sensors in fog/mist.
Figure 4  
Box plots of the performance of the various visibility sensors in precipitation.
Figure 5  Surface isobaric chart (a) and time series of visibility sensor readings (1-minute means) (b) for a haze event in the measurement period.
Figure 6  Surface isobaric chart (a) and time series of visibility sensor readings (1-minute means) (b) for a fog/mist event in the measurement period.
Figure 7   Surface isobaric chart (a) and time series of visibility sensor readings (1-minute means) (b) for a rain event in the measurement period.