On the use of SODAR reflectivity data during low visibility conditions at Schiphol Airport

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1 Introduction

A SODAR (Sonic Detection and Ranging) is a ground-based remote sensing instrument for measuring wind and turbulence in the lower atmosphere. A monostatic, multi-frequency METEK PCS2000-64 SODAR (Figure 1) is operated and maintained by KNMI at Amsterdam Airport Schiphol (AAS) since March 2006. The SODAR is installed about halfway along the Polderbaan (18R-36L), approximately 200 m east of the centerline. This distance is large enough to overcome the influence of noise from passing airplanes on the measurement. The location of the instrument is indicated in the map in Appendix A, which presents an overview of all meteorological measurement equipment of KNMI at Schiphol.

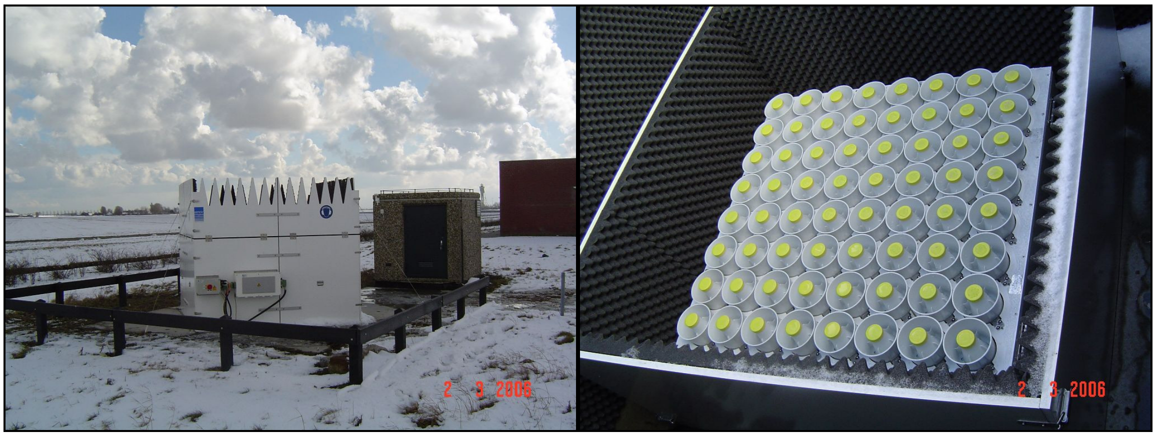

Figure 1. The METEK SODAR at Schiphol Airport. The SODAR PC is installed in the small building next to the instrument. In the right-hand panel a close-up of the array with 64 loudspeakers is shown.

Presently only the wind profile information from the SODAR is used as input for wind shear warnings in the lowest 2,000 ft of the atmosphere. However, SODAR echo registrations show many interesting structures of the atmospheric boundary layer. Recent literature (e.g. Keder, 1999; Emeis et al., 2004; Dabas, 2008; Mursch-Radlgruber, 2009) suggests that SODAR reflectivity data has promising capabilities for the determination of the inversion height above fog and low stratus clouds. The fog layer is vertically restricted by the inversion and knowing its depth could give better insight in the development or dissipation of the fog layer, together with other important parameters like incoming radiation, soil conditions and wind. Note that the cloud ceilometer only provides measurements of the cloud base height and is generally not useful to estimate the top of the cloud or fog layer. Other sources that provide useful information on the height of the inversion are e.g. radiosondes, tall tower and aircraft measurements (AMDAR), but these techniques have shortcomings when it comes to spatial collocation, timeliness and availability (De Haan, 2009).

In this report an exploration is performed of the added value of SODAR reflectivity measurements at Schiphol during events with fog and low clouds. It will give an overview of the characteristics for several case studies with low visibility that were encountered in the period November 2008-January 2009. A rough estimation of the inversion height as inferred from AMDAR profiles will be used for comparison. Furthermore, an estimate of the success rate for the 3-month period of analysis will be given.

2 The METEK PCS2000-64MF SODAR

The METEK PCS2000-64MF (METEK, 2002) is a monostatic, multi-frequency SODAR instrument. It emits short acoustic pulses into the atmosphere and receives atmospheric echoes from turbulent density fluctuations, caused by small-scale temperature or velocity variations. The SODAR at Schiphol (Figure 1) is operated on 4 configurable frequencies: 1386, 1612, 1862 and 2087 Hz. The instrument contains an array of 64 loudspeakers which can be used as 5 separate logical antennas for transmitting and receiving acoustic signals. The transmitted signals can be phase shifted to point the beam in different directions. Five directions are possible, but only three are in use for the instrument at Schiphol. One antenna is oriented vertically. The zenith angle of the other beams is dependent on the transmit frequency and varies between 10 and 30°.

Backscattered echoes are received and processed by the internal software which runs unattended on the SODAR PC system. The distance of the measuring volume is determined from the propagation time of the acoustic wave and the estimated acoustic velocity. Since the temperature inhomogeneities move with the wind, a Doppler frequency shift is observed that makes it possible to derive the wind speed relative to the beam axis. By measuring the Doppler shift for different beam directions, the full 3-dimensional wind profile can be determined. Thereby it is assumed that the flow is horizontally homogeneous over the area containing the different measuring volumes. To retrieve reliable mean wind data a clustering method is applied that uses the radial components taken from instantaneous spectra.

Table 1. Specifications of the METEK PCS2000-64MF SODAR.

	General specifications	Schiphol configuration
General		
Frequencies	1000-3000 Hz	1386, 1612, 1862, 2087 Hz
Number of speakers	64 (8x8)	
Total transmit power	max. 800 W	
No. of beam directions	max. 4 + vertical	3 (50, 140° azim. + vertical)
Number of height gates	1-40, adjustable	28
Lowest measuring height	15 m, adjustable	50 m
Range (70% availability)	500-800 m	
Height resolution	5-100 m, adjustable	25 m
Time resolution	10-1800 s, adjustable	900 s (15 min)
Measurements		
Horizontal wind speed	0-35 m/s	
Accuracy	0.1-0.3 m/s or 5%	
Vertical wind speed	>-10 - +10 m/s	
Wind direction	0-360°	
Accuracy	1-3° (>5m/s), 3-5° (0-5m/s)	

An overview of most relevant specifications of the SODAR used at Schiphol is listed in Table 1. The maximum measurement height depends on the used frequency, atmospheric stability and ambient noise. Time and height resolution can be refined down to 10 s and 5 m minimum, with a maximum number of 40 height gates. The SODAR at Schiphol is configured to provide output on the vertical range 50-700 m with a vertical resolution of 25 m and a time resolution of 15 minutes. This gives optimal conditions for a reliable, clustered wind profile in the desired height range.

The SODAR at Schiphol reports profiles of the wind vector, peak power, reflectivity, signal-to-noise ratio, a stability classification and error codes in a defined format (METEK, 2006). Presently only the wind profile information from the instrument is used at KNMI. This data is distributed to the ADCM airport system every 15 minutes and consulted by users to generate warnings for wind shear in the lowest 2,000 ft. The data is primarily used by the aviation meteorologist (LMet) and Meteorological Advisor Schiphol (MAS).

A measure for the intensity of the SODAR echoes is available in the form of reflectivity profiles for all beam directions and frequencies used, on an instantaneous (20-second) or averaged (15-minute) basis. These data are presently not transmitted to KNMI, but only available locally on the SODAR PC. Reflectivity profiles measured by the SODAR can give a good estimation of the inversion height as for a monostatic instrument the backscattered intensity is determined exclusively by turbulent temperature fluctuations. An elevated inversion will create significant temperature fluctuations because at least a bit of a wind and mechanically induced turbulence is always present. Hence in most cases the inversion can be recognized by a maximum in the measured reflectivity with strong signal reduction in the levels aloft. Earlier investigations (Dabas, 2008) showed good agreement with thermodynamically derived estimates of the inversion height from balloon soundings.

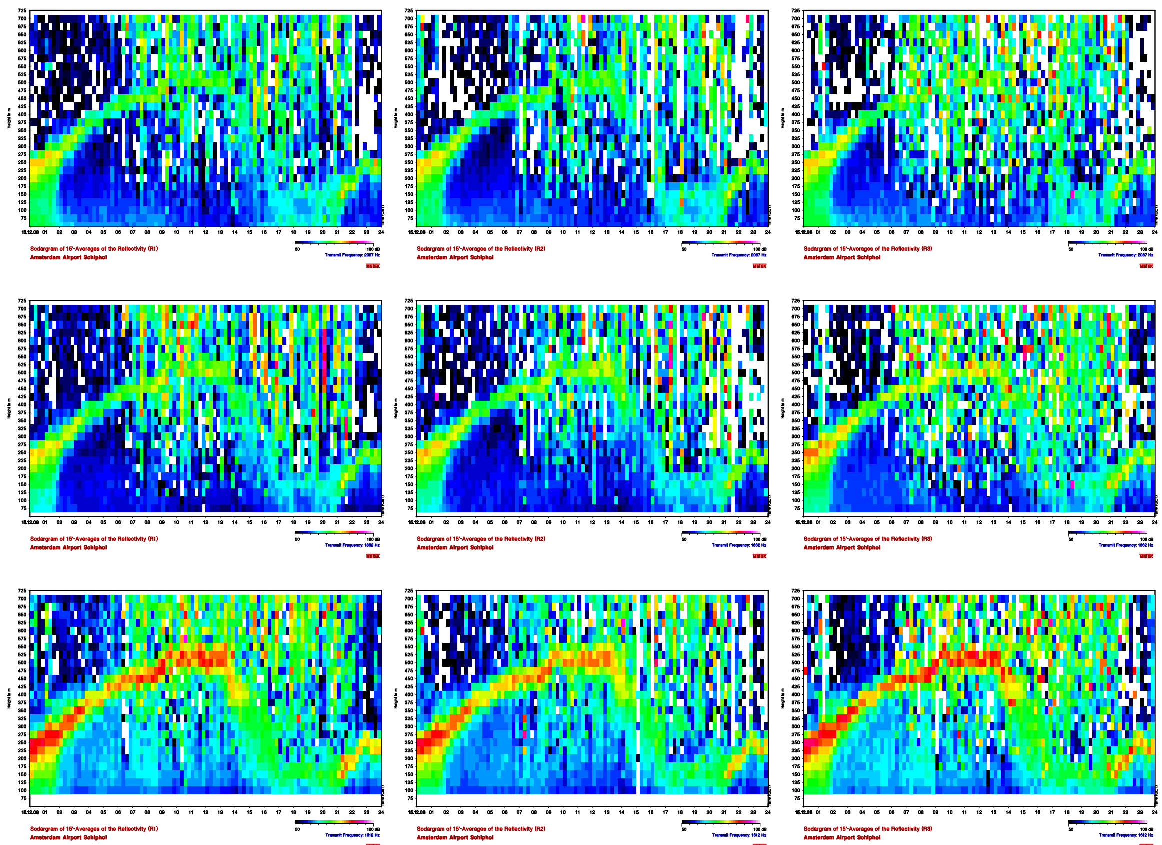

Figure 2. Sodargrams of 15' reflectivity data measured at Schiphol on 15 December 2008. Presented are data for three frequencies (2087, 1862 and 1612 Hz) along the vertical and three beam directions (50° and 140° azimuth and the vertical beam) along the horizontal.

An example of reflectivity data measured with the Schiphol SODAR on 15 December 2008 is presented in Figure 2. The 9 panels cover the different frequencies (2.1, 1.9 and 1.6 kHz along the vertical – 1.4 kHz is not included here) and beam directions (50 and 140° azimuth and vertical direction along the horizontal). The grid of the surface plot is defined by the time and height resolution of 15 minutes and 25 meters, respectively. Cells, for which the error code determined by the SODAR software is non-zero, are left blank. From analysis of some individual low visibility cases with strong inversions it could be concluded that the reflectivity signatures appear most evidently for the vertical beam direction and a transmit frequency of 1.6 kHz. Therefore, as from now on this mode will be used for the presentation of SODAR reflectivity information in this report.

3 Results

3.1 Introduction

To investigate the added value of SODAR data for an estimation of the depth of the fog layer, six low visibility events that occurred at Schiphol from November 2008 till January 2009, are analyzed in detail in this section. Each individual case study is accompanied by figures of:

- **Surface measurements**

KNMI operates around 50 meteorological sensors at Schiphol Airport (see Figure A.1), most of them for real-time monitoring of wind and visibility along the runways. Visibility is measured with the Vaisala FD12P scatterometer at 2.5 m above the surface and provides direct information about the onset and cessation of fog episodes. Fog reduces the visibility to values below 1,000 m, whereas in dense fog visibility even gets below 200 m. For each case the 1-minute MOR data (ZMm) for positions touchdown 18R, mid-north 18R and touchdown 18C will be shown together with 1.5 m air temperature (TAm) and relative humidity (RHm) at touchdown 18R and incoming global radiation (QGm) measured at the observation field near touchdown 27. Note that we will use the Meteorological Optical Range (MOR) measurements for the visibility presented in the next section, as it depends solely on atmospheric conditions, and not on additional information such as background luminance levels.

- **SODAR reflectivity data**

The reflectivity surface plots, or sodargrams, present the time series of the profiles measured for the vertical beam direction (zenith=0°) and a frequency of 1.6 kHz. Measurements that have not passed the error checks successfully, are left blank. In each graph, a rough estimate of the inversion boundaries from AMDAR profiles (see next bullit), and 1-minute cloud base measurements from the LD40 LIDAR ceilometers at touchdown 18R [●] and 18C [●] are also included. Furthermore, an estimate of the mixing layer height from SODAR using the method of Emeis and Türk (2004) was used as a first approximation for the height of the inversion (see also Wauben et al., 2008). The detection combines the search for a surface inversion and an elevated inversion and is based on the sharp decrease of the reflectivity at the top of the turbulent layer. Note that the MLH value presented in the figures [●] is the median of 12 individual MLH values determined over the 3 directions and 4 transmit frequencies.

- **AMDAR temperature profiles**

The EUMETNET AMDAR (Aircraft Meteorological Data Relay) program runs since 2000 and is a cooperation between National Meteorological Institutes and national airlines. Designated AMDAR aircraft provide measurements of temperature and wind during flight and send meteorological messages through ground stations. The availability of the measurements is configured depending on the flight phase, so that most data points will be available in the boundary layer, during ascents from and descents into airports.

AMDAR profiles recorded in the analysis period were extracted from the KNMI database for all records in a radius of 1 degree around Schiphol (N 52.32 E 04.80). The altitude of the measurements was calculated by using the reported pressure altitude in combination with the surface pressure measured at the Schiphol observation field. This facilitates the comparison of marked levels in the SODAR reflectivity and the AMDAR profiles. As a first approximation the first two levels between which the temperature rise is 1 K or more, are indicated in the SODAR reflectivity graphs as lower [▲] and upper [▼] boundary of the inversion. It should be noted that this determination is far from ideal, given the arbitrary criterion of 1 K and the limited vertical resolution of the measurements. For the 24 days in the analysis (cf. Table 2), a total of 295 AMDAR profiles were used, with on average 9 data

points below an altitude of 1,000 m. In practice this means that the resolution in the lower atmosphere is typically not better than 100 to 150 m.
Note that the lowest data point in the AMDAR graphs in this section – indicated by a star – is actually the 1.5 m temperature measured at the observation field. Although matching is not guaranteed, the combination of AMDAR profiles and the surface observations can give insight in the presence and strength of a surface inversion.

3.2 Case studies November 2008-January 2009

4 November 2008

Low visibilities due to dense fog were observed in large parts of The Netherlands on 4 November. As a result, the capacity of Schiphol Airport was reduced and delays, diversions and cancellations occurred. Figure 3 presents the surface observations for Schiphol on this day.

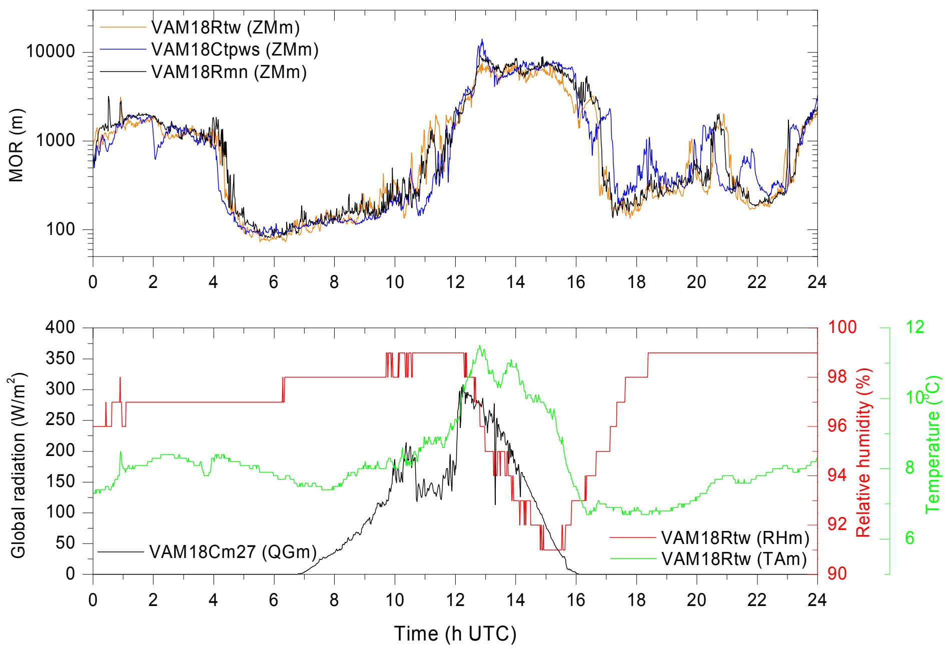

Figure 3. Upper panel: 1-minute surface observations of Meteorological Optical Range (MOR) measured at touchdown and mid-north 18R and touchdown 18C. Lower panel: 1.5 m temperature and relative humidity measured at touchdown 18R and incoming global radiation measured at the observation field on 4 November 2008.

The first period with fog abruptly sets in around 04 UTC and seems quite homogeneous over the area of the three visibility readings in the upper panel. The MOR decreases to values between 100 and 300 m. After sunrise, around 07 UTC, visibility gradually increases whereas from 12 UTC the fog dissipates and the MOR exceeds 1,000 m. The clearing of the sky is also seen in the global irradiance measurement from the observation field, which reaches its maximum value around 300 W/m² just after this fog event has ended. After sunset, around 16 UTC, the visibility measurements demonstrate the beginning of a new fog episode. This one lasts until approximately 23 UTC. Note that the MOR values at touchdown 18C are generally higher than for the two locations along the Polderbaan, indicating the spatially inhomogeneous character of the fog in this case.

The SODAR reflectivity plot of the vertical beam at 1.6 kHz is shown in Figure 4. A strong maximum can be clearly recognized for the periods mentioned above, where the visibilities are low, roughly from 04 to 12 and from 16 to 21 UTC. The maximum reflectivity values easily exceed 80 dBz with significant decrease aloft, upon which the SODAR MLH detection is constantly triggered and provides output with low scatter. The height where the cloud bases that actually lead to the fog are initially detected, correspond well with the automated SODAR MLH detections for both fog events on this day. The same holds for the dissipation phase of the fog around noon. In the figure it can be seen that the fog layer dissipates when the inversion comes down, and the ceilometer cloud base starts to rise as the fog releases from the surface. At the time that the (virtual) trend lines of the SODAR MLH and ceilometer cloud base cross each other, the clouds dissolve and the visibility increases significantly. Note that the time differences that were observed for the visibility improvements between touchdown 18C and touchdown 18R are visible in the cloud base measurements as well.

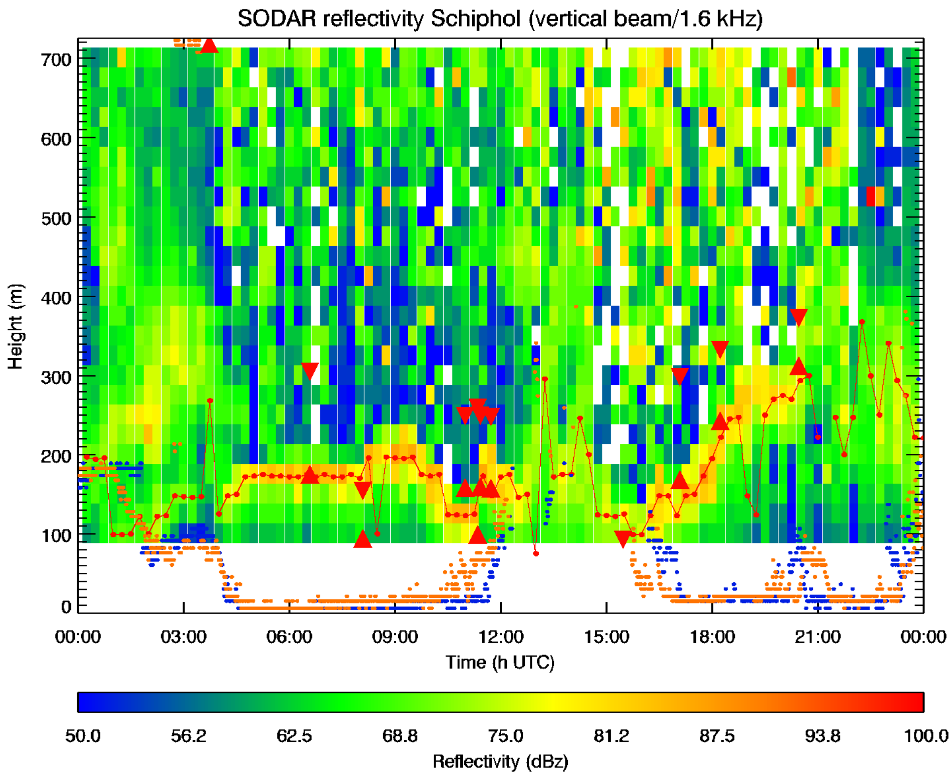

Figure 4. SODAR reflectivity values measured on 4 November 2008 for the vertical beam at 1612 Hz. The median MLH values from the automated method and the cloud bases reported by the ceilometers at runways 18R and 18C are presented by red [•], orange [•] and blue [•] dots, respectively. Inversion estimates from AMDAR data are denoted by red triangles [▲/▼].

Seven (out of 15) AMDAR temperature profiles measured on 4 November 2008 are presented in Figure 5, for altitudes up to 700 m above the surface. Both the presence and the height of the inversion as visually determined from AMDAR temperature corresponds well to the reflectivity maxima that were observed in the SODAR data. For the period with good visibilities in the afternoon a stable layer near the surface is clearly missing (cf. profile at 1452), whereas after 16 UTC the increase of the SODAR inversion estimate towards 300 m shows good agreement with the rise of the temperature inversion level inferred from the AMDAR profiles at 1705, 1814 and 2027.

The weaker reflectivity signal after 21 UTC coincides with a temperature inversion that also becomes less strong, given the measurements at 2136. However, it should be kept in mind that the vertical resolution of the AMDAR profiles is actually too coarse to perform a good quantitative comparison. Note that all AMDAR temperature profiles in the Schiphol area for the six days included in this section are presented in Appendix B.

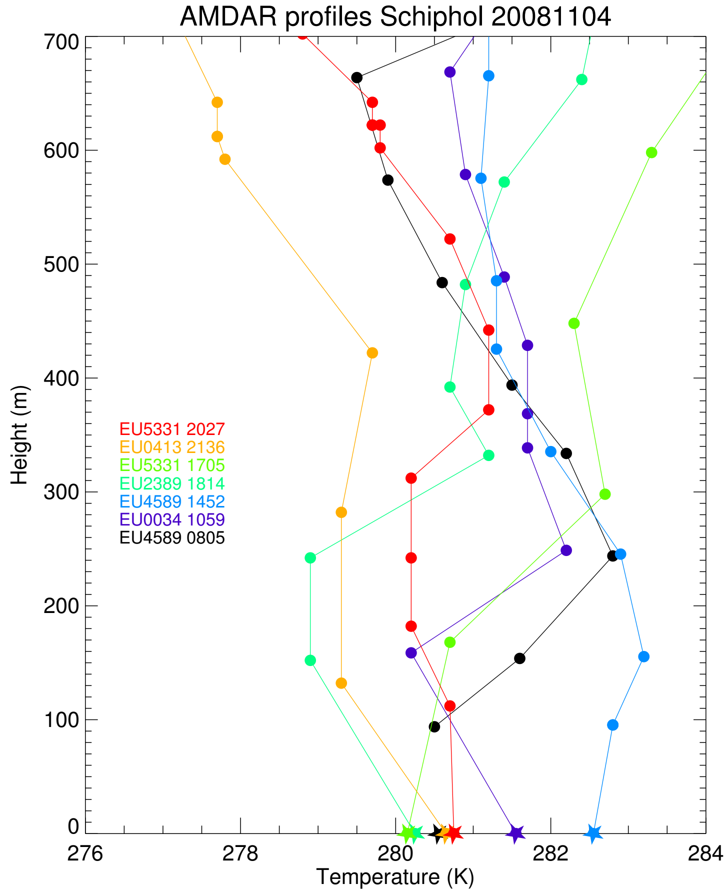

Figure 5. AMDAR temperature profiles for the Schiphol area in the lowest 700 m, measured on 4 November 2008. The lowest data point represents the 1.5 m temperature at the observation field. The time reported is the observation time of the lowest AMDAR data point in hours UTC.

27 November 2008

A completely different situation occurred on 27 November, illustrated in Figures 6 and 7. The observed MOR at Schiphol is typically between 600 en 700 m during the night, caused by the advection of stratus clouds. Cloud base detections (Figure 7) at a height below 50 m set in shortly after 02 UTC, where visibilities drop below 1,000 m. Driven by moderate south-southwesterly winds, the low clouds at touchdown 18R are in this case behind those at touchdown 18C.

Above the detected cloud bases, a maximum in the measured reflectivity is seen in first instance around 150-300 m, but this signal disappears and leaves the MLH algorithm undecided for a large part of the day. The sodargram shows a rather diffuse image without clear patterns that can be directly related to turbulence boundaries and the height of the inversion layer. This is similar for all frequencies and beam directions (not shown). In spite of the low contrast the maximum values in the assumed cloud layer are around 75-80 dBz.

The AMDAR temperature profiles presented in Figure B.2 (see Appendix B) partially explain this behavior and confirm the lack of a strong inversion. None of the profiles measured during the night/morning shows a sign of stable layering near the surface. Because the acoustic signals emitted by the SODAR need a temperature gradient together with some wind to scatter upon, the received echoes will be very weak in this case. Note that an estimate of the inversion height could be made for only 2 of the 14 AMDAR profiles that are available on this day, at 1156 and 2117 UTC. Apparently, both SODAR and AMDAR information do not give useful information on the boundaries of the low cloud layer for this case.

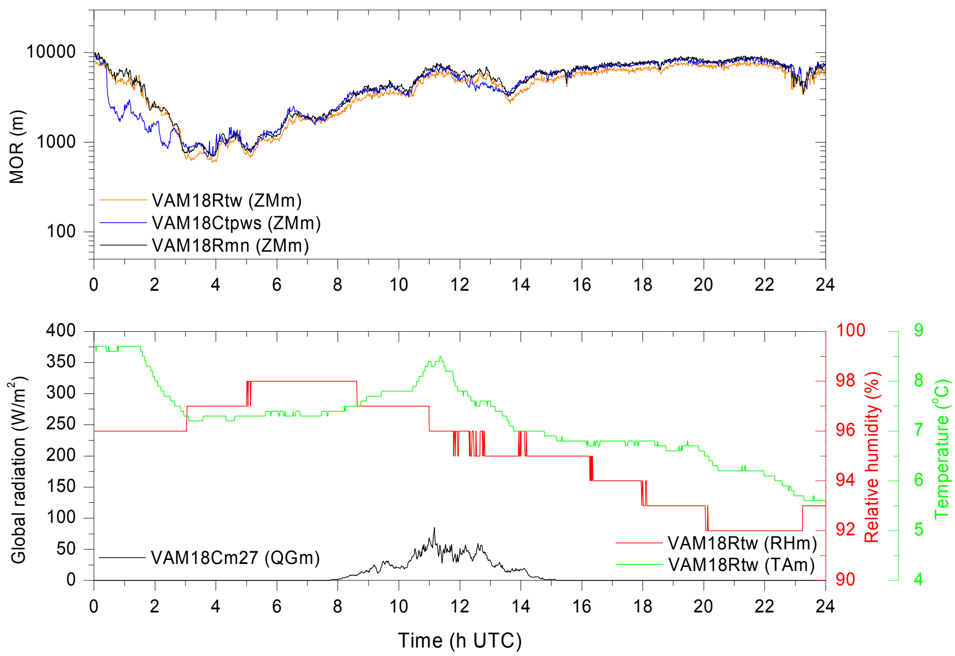

Figure 6. Same as Figure 3, but for 27 November 2008.

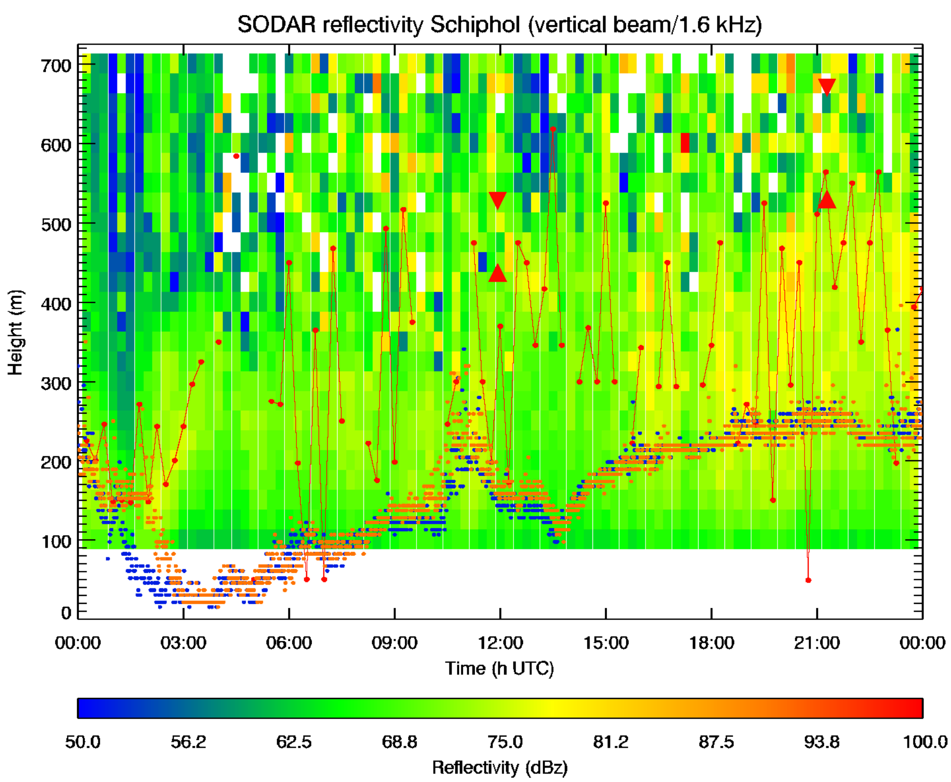

Figure 7. Same as Figure 4, but for 27 November 2008.

15 December 2008

Dense fog occurred at Schiphol Airport in the late evening of 15 December. This can be clearly observed in the visibility values presented in Figure 8, which are reduced to 100-300 m between 20 and 24 UTC. The fog episode coincides with advection from a northeasterly direction. Cloud base registrations at a height of 50 m (150 ft) start just after 19 UTC for the sensor at 18R and somewhat later at 18C. From then on, the clouds rapidly reach the ground and the fog lasts until noon of the next day. Note that the 1.5 m temperature stabilizes around 1°C in the period with fog, whereas it dropped below zero shortly before.

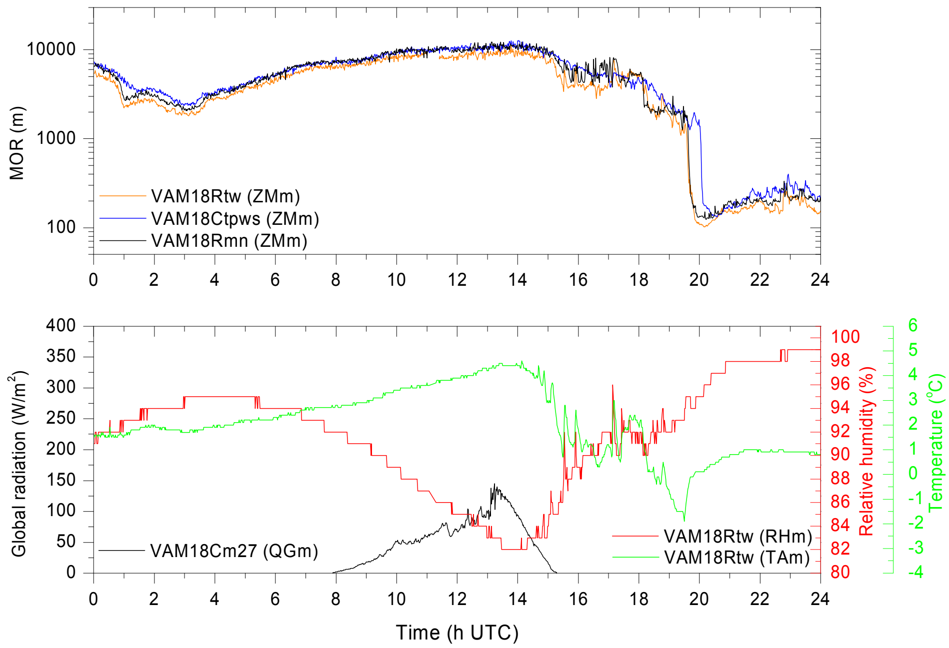

Figure 8. Same as Figure 3, but for 15 December 2008.

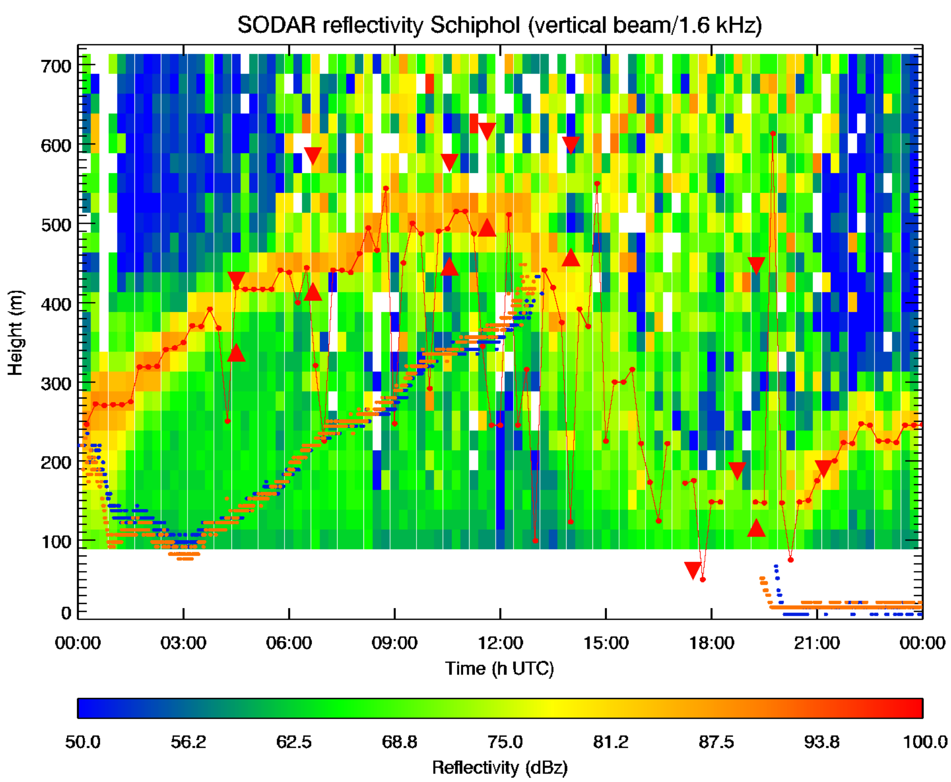

Figure 9. Same as Figure 4, but for 15 December 2008.

Figure 9 shows that the apparent boundaries of the low cloud layer that is present from midnight till 12 UTC can be well identified in the sodargram. The period does not contain events with MOR below 1 km, but is nevertheless interesting. The depth of the cloud layer, which is assumed to be dependent on the difference between the SODAR MLH and the measured cloud base, initially grows and then diminishes around noon. At that point, the SODAR MLH decreases to a height of 400-450 m and the ceilometer cloud bases are detected very close to this level as well. Note that the five inversion estimates from the AMDAR temperature information in this period (see Figure B.3) correspond very well with the ascending reflectivity maximum that is observed between 00 and 12 UTC; the band of high SODAR reflectivity falls within the range defined by the lower and upper estimate. Note furthermore that one of the profiles (HK0003) was already measured at 2244 UTC on 14 December and shows an inversion close to the level where clouds set in at midnight.

For the dense fog event that sets in after 19 UTC the maximum in SODAR reflectivity is again markedly visible above the low cloud bases. The MLH shows constant behavior in time and increases from an initial value of 75 m at 20 UTC to 250 m at 24 UTC. Given that the cloud base is almost fixed near the surface it is assumed that the depth of the fog layer has notably increased the evening. The next case study (16 December) will show that the inversion remains located around this level and does not rise much further. Note that the AMDAR profiles are not very useful in the evening; either the vertical resolution is too poor (1917) or the profile indicates an inversion below the first level above the surface (2111).

16 December 2008

The low visibility event observed in the evening of 15 December continues for a large part of the 16th, at temperatures around 0°C. Freezing fog (FZFG) was reported in the METAR reports for Schiphol between 0555 and 1425. The severity of the fog becomes clear from the visibility measurements that remain below 300 m until 12 UTC for all three locations (see Figure 10). Global irradiances hardly exceed 70 W/m² in the morning and so the fog did not disappear shortly after sunrise. As a result of this situation, the capacity of Schiphol was seriously reduced. By 12 UTC a secondary cloud layer (not shown) sets in over the persistent fog layer and the fog begins to disappear.

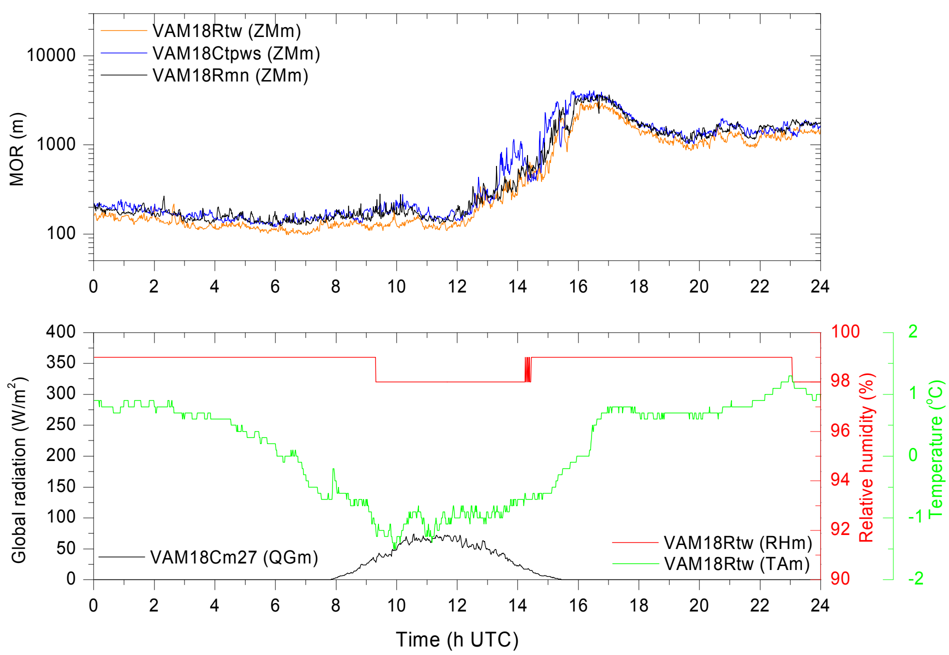

Figure 10. Same as Figure 3, but for 16 December 2008.

The SODAR reflectivity profiles are shown in Figure 11. A strong maximum with values above 80 dBz for the depicted mode (vertical beam, 1.6 kHz) is present above the low cloud bases. Especially until 06 UTC the signal contrast with the levels above the maximum is large. The automated MLH estimates demonstrate little scatter and persist at heights between 175 and 275 m until 15 UTC. By that time the cloud base height starts to rise from values below 100 m to less critical levels and the fog event ends. An interesting point is that the decrease of the inversion height between 14 and 15 UTC may be caused by radiative warming due to the secondary cloud layer aloft. Consequently, the low clouds disappear around the intersection of the SODAR MLH and the cloud base height time series.

During this fog episode the AMDAR temperature profiles (at 0458, 0645, 1344 and 1414) indicate inversion height estimates between 150 and 350 m, more or less in agreement with the location of the reflectivity maxima. After 15 UTC the estimates still appear around the maximum in SODAR reflectivity (found at 400-525 m), that is likely associated with the top of a new layer with low clouds, but less marked than the maximum above the fog layer earlier on the day. The strength of the temperature inversion observed in the AMDAR profiles presented in Figure B.4 is nevertheless significant and amounts to 8 or 9 K over a layer of approximately 200 m. The base of the low clouds in the evening does not reach the surface but remains above 75 m (250 ft). It should be remarked here that only 9 AMDAR profiles in the Schiphol area are available on this day, possibly caused by diversions and cancellations due to the persistent low visibility conditions. Given the continuous availability of the SODAR data, it is clear that the instrument may serve as a valuable source of additional information in these cases.

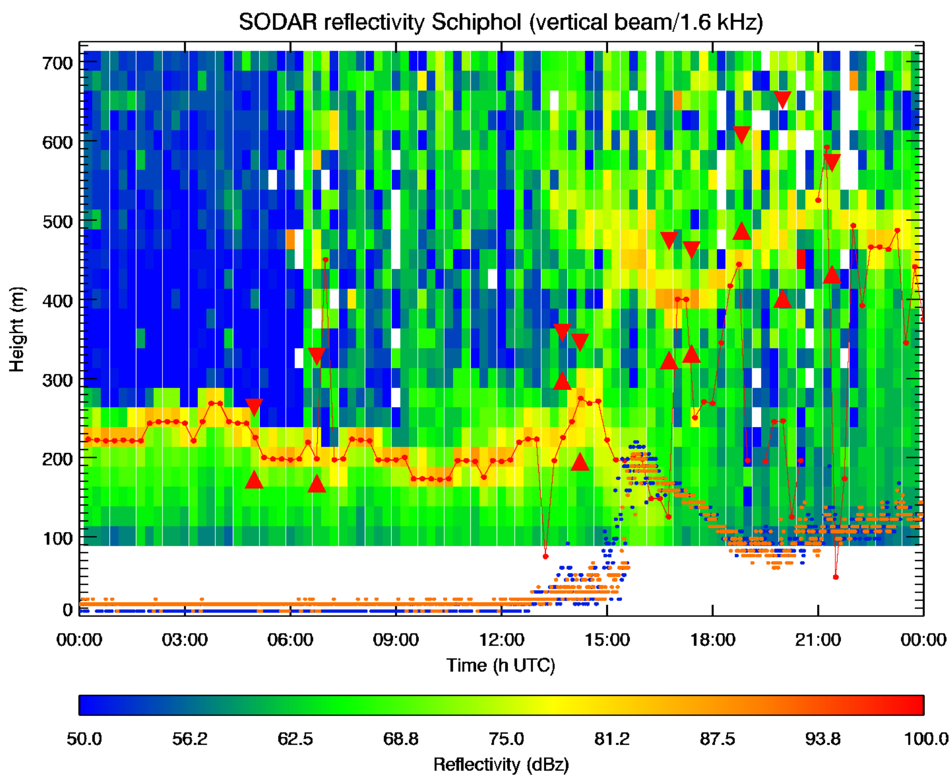

Figure 11. Same as Figure 4, but for 16 December 2008.

23 December 2008

Patches of radiation fog were observed at Schiphol in the morning of 23 December, when a high pressure area was over The Netherlands. A large variability in the visibility measurements is seen for the three sensor positions shown in Figure 12, both in time and between different locations. The MOR values for the period 00-08 UTC range between 100 and 800 m.

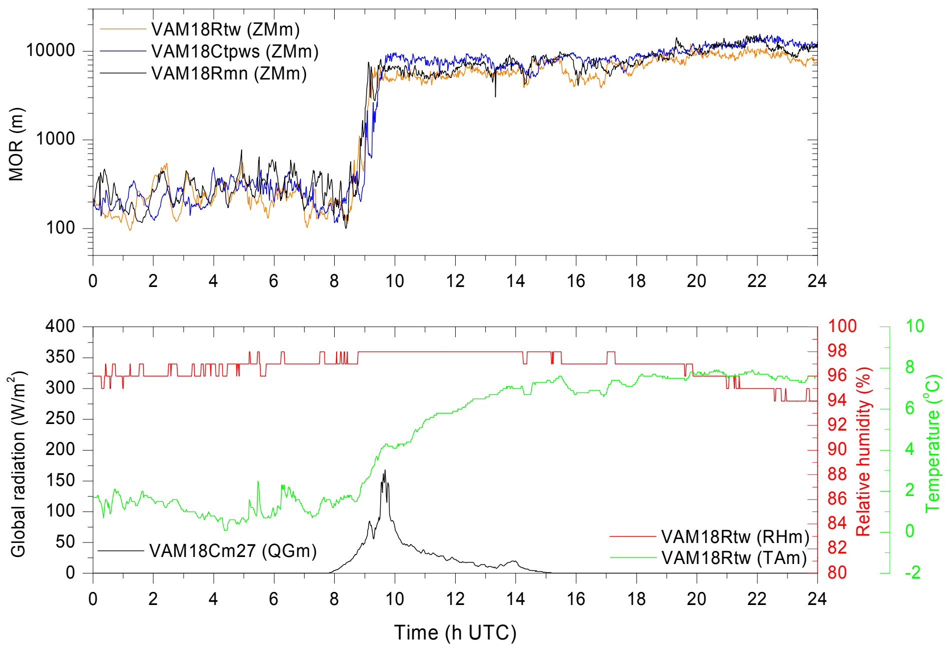

Figure 12. Same as Figure 3, but for 23 December 2008.

The presence of a shallow layer of fog in the early morning is supported by the LD40 ceilometer backscatter profiles at location 18C(Figure 13), which show a situation with very low cloud base hits combined with a backscatter profile with sufficient signal-to-noise up to higher levels. The other ceilometers at the airport show similar measurements. Shortly after sunrise, just before 08 UTC, the fog event is suddenly terminated, and a secondary cloud layer with a cloud base around 600 m is detected. In the METAR reports for Schiphol, fog (FG) is reported from 0025 until 0925, with patchy fog (BCFG) at 0455, 0525, 0555 and 0925.

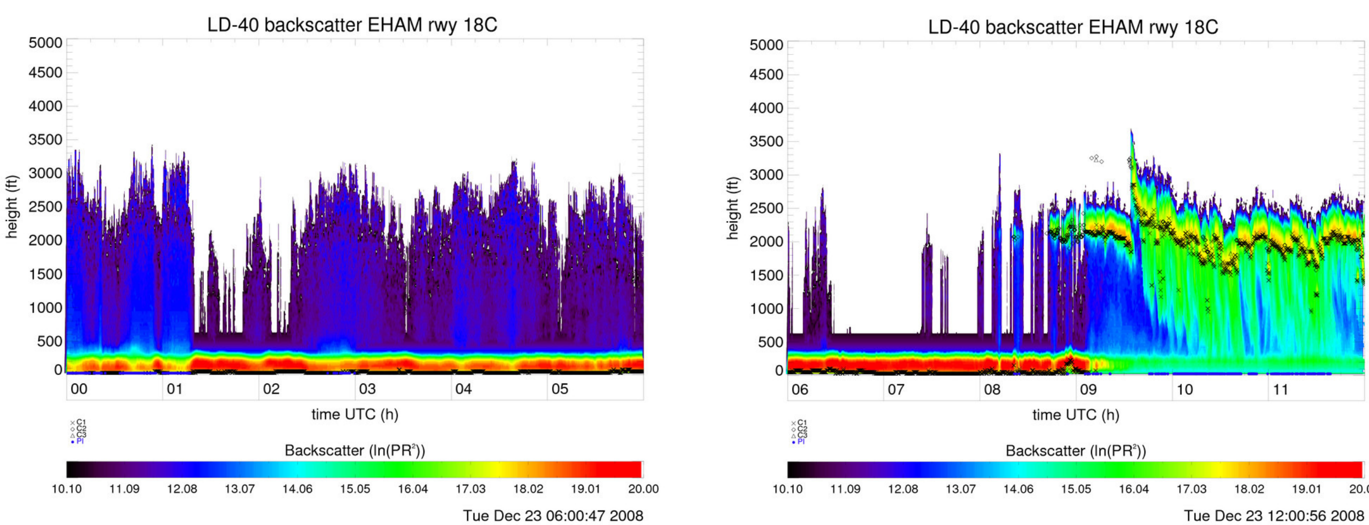

Figure 13. Backscatter profiles [in ln (PR^2)] measured by the LD40 ceilometer at Schiphol touchdown 18C from 00 to 06 (left panel) and 06 to 12 UTC (right panel) Cloud bases are presented by a cross (x).

The sodargram for this case (Figure 14) contains reflectivity profiles for the vertical beam direction at 2.1 kHz, because the inversion is likely present below the lowest measurement level in the 1.6 kHz mode. The 2.1 kHz mode already gives valid information from a height of 50 m above the surface. During the period with fog it shows moderate reflectivity values in the range 75-80 dBz for the lowest levels. The MLH estimates, which are primarily based on the 3 measurements at 2.1 kHz for this case, indicate the presence of an inversion between 50 and 125 m. Because of the low altitude of this apparent inversion, the estimates should however be treated with care. For an unknown reason the contrast in reflectivity with levels aloft is lost around 05 UTC, leading to erroneous SODAR MLH estimates. Relative humidity measurements in the Cabauw tall tower (40 km south of Schiphol) indicate saturation of the air up to 80 m for the period 00-08 UTC (not shown). Hence, the inversion height for Cabauw is expected to be located somewhere between 80 and 140 m.

Because of the limited height of the apparent inversion, the AMDAR information (Figure B.5) is not very useful for evaluation in this case. Only for the two temperature profiles at 0625 and 0936 UTC, a significant increase up to 6 K can be observed between the 1.5 m temperature and the first AMDAR level, which is located between 200 and 300 m. Obviously, a strong surface inversion is restricting the layer of fog, but unfortunately the information in the AMDAR profiles is too coarse to draw conclusions. The temperature difference between the surface observation and the first AMDAR level has already reduced significantly in the profile of 1025 UTC, as a result of vertical mixing activity after sunrise. No inversion estimate could be made for the other AMDAR profiles on this day.

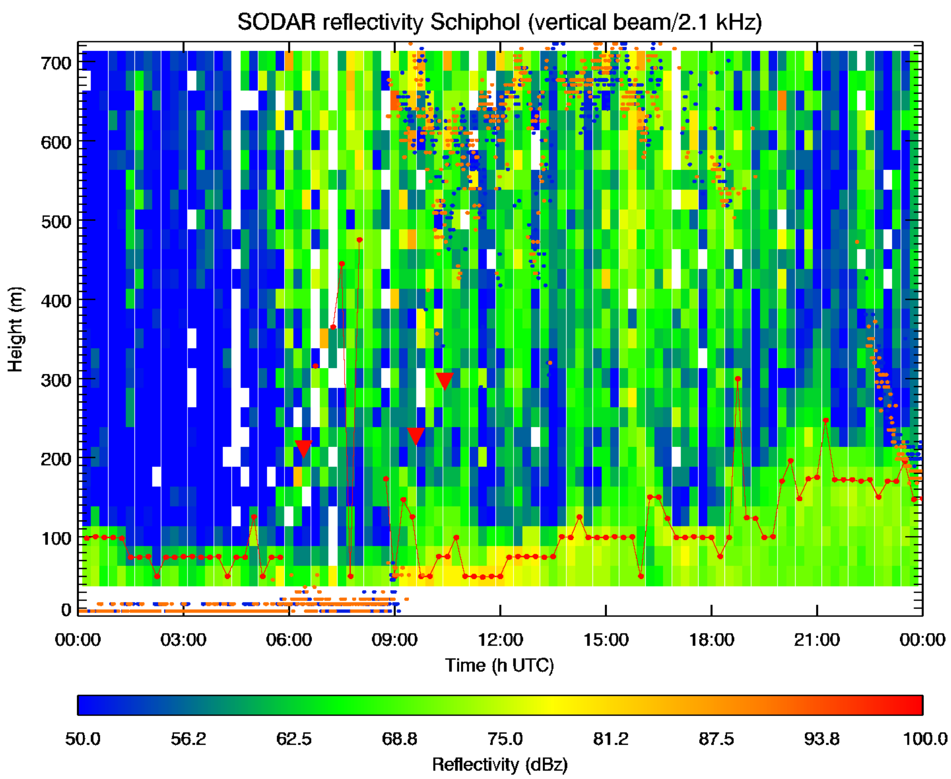

Figure 14. Same as Figure 3, but for 23 December 2008. Note that, in contrast with earlier figures, reflectivity data for the vertical beam at 2.1 kHz is presented here.

8 January 2009

An exceptional situation with snowing fog at Schiphol occurred on 8 January, for which Figure 15 shows the daily time series of visibility, temperature, relative humidity and global irradiance. During the night period some patches of fog (0130-0500) were already observed at Schiphol, indicated by the strong temporal variability of the MOR values between 250 m and 10 km. Shortly after 08 UTC a more persistent fog event sets in, lasting until the end of the day with only some short periods with improved visibility in the afternoon.

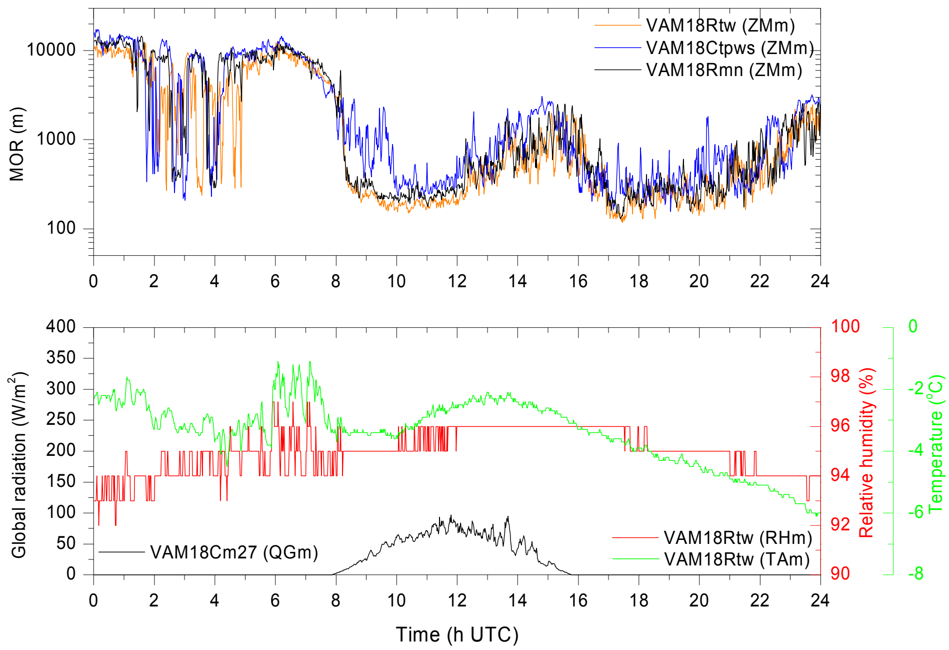

Figure 15. Same as Figure 3, but for 8 January 2009.

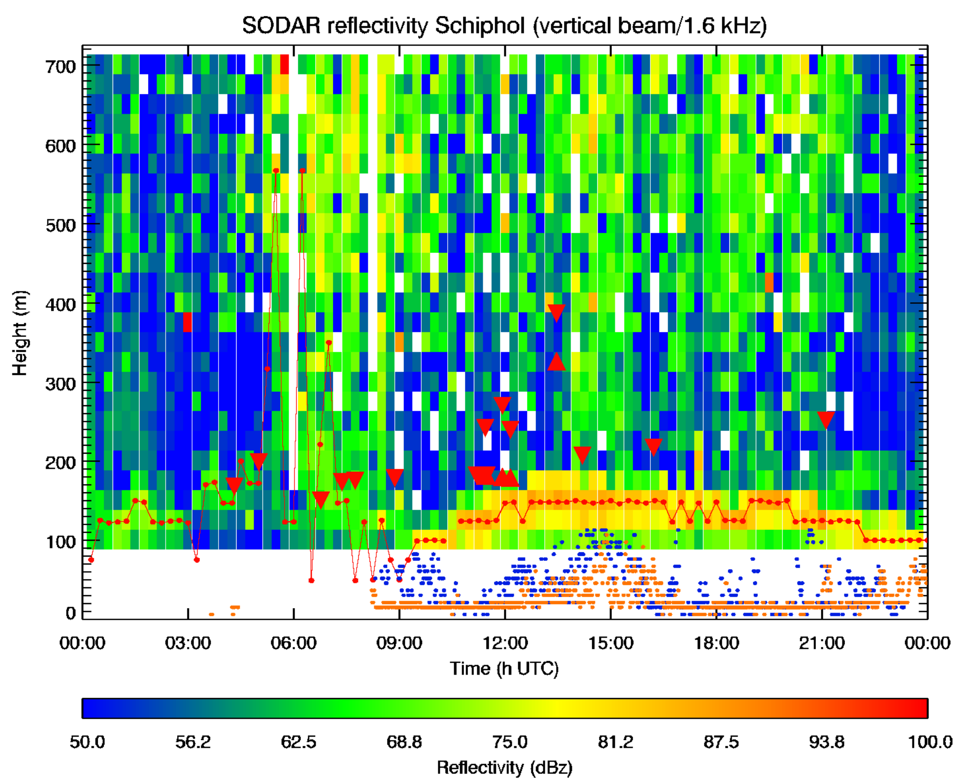

Figure 16. Same as Figure 4, but for 8 January 2009.

From the reflectivity plot in Figure 16 it becomes clear that the SODAR MLH, associated with the upper boundary of the fog layer, shows similar features as found for previous cases, and remains present even when the visibility increases to values above 1,000 m in the afternoon. Presented together, the cloud base and SODAR MLH information likely give useful insight in the possible development of the fog layer. The event in Figure 16 eventually ends shortly after midnight on 9 January, after a period where the MOR gradually increases and the expected cloud boundaries get closer to each other. Temperature and humidity measurements in Cabauw show that the inversion for the period 10-20 UTC is located between 140 and 200 m, as the last level with saturated air (100% RH) is the 140 m level (not shown). This corresponds well to the SODAR MLH estimates that are found for Schiphol, although the measurements are done 40 km apart.

A very strong temperature increase between the surface observation and the first AMDAR data point can be seen in the AMDAR profiles (Figure B.6) during the morning (04-08 UTC). Furthermore, a marked inversion located between roughly 150 and 250 m is present in the measurements taken around noon (11-12 UTC). This is somewhat higher than the SODAR MLH estimates. However, because the first AMDAR level is generally just only at 170 m, it could well be that the inversion starts some tens of meters lower and is in better agreement with the location of the maximum in the SODAR echoes. This can not be concluded from this observational information.

3.3 Overview of cases

After the detailed analysis of several low visibility events in the previous section, an overview of all low visibility and low cloud episodes that were recognized near the SODAR at Schiphol Airport in the period November 2008-January 2009 is listed in Table 2. The events were selected based on 1-minute data from the FD12P scatterometer (MOR) and the LD40 ceilometer (cloud base) near position touchdown 18R, when at least one of the following criteria was satisfied for more than half an hour:

- Meteorological Optical Range (ZMm) < 1,000 m
- Cloud base (C1s) < 300 ft

The table presents the starting and cessation time of the events, together with the minimum values for visibility (MOR) and cloud base reached within that time frame. Cases where only short improvement of the visibility or cloud conditions occurred, are presented together. The last column gives a (color) classification of the signature recognized in the SODAR reflectivity for the vertical beam direction and a frequency of 1.6 kHz. This classification is derived from the maximum reflectivity value for this mode within ±2 levels of the median MLH from the SODAR. The classification is divided as follows: <70 dBZ (weak), between 70 and 80 dBZ (light), between 80 and 85 dBZ (strong), >85 dBZ (very strong). The color coding in the legend corresponds more or less to the colors used in the sodargrams.

The abovementioned low visibility/low cloud criteria were met in 4.7%, 6.9% and 6.5% of the time for November, December and January, respectively. The large number of cases (22, i.e. around ¼ of the total number of days) indicates that fog and low clouds are an important weather limitation at Schiphol Airport, especially during the winter season. Appendix C contains all daily time series of the automated SODAR MLH [●], ceilometer cloud base at touchdown 18R [●] and the rough estimate of the inversion height from AMDAR [▲ and ▼], for all days with low visibility or low cloud periods. In the lower panel of each figure the maximum reflectivity around the SODAR MLH is presented.

In 9 out of the 22 selected cases, a reflectivity maximum with values > 85 dBz ('very strong') was found above the cloud bases detections of the ceilometer, and in 13 cases the maximum was either strong or very strong. In only 4 cases the measured SODAR reflectivity around the MLH estimate was weak and did not exceed 70 dBz. For those situations, the automated derivation of MLH (using the Emeis method) shows very scattered results in time because the reflectivity maximum associated with the inversion is either not present or not pronounced enough. In those cases a visual presentation of cloud bases in combination with reflectivity is not likely to provide additional information. In none of the cases with dense fog (MOR < 200 m) was the strength of the SODAR maximum classified as weak.

Table 2. Overview of cases with low visibility or low cloud base according to filter criteria on 1-minute sensor data from touchdown 18R: Meteorological Optical Range <1,000 m or cloud base < 300 ft. The last column presents the maximum SODAR reflectivity that was present around the median MLH value for the vertical beam at 1.6 kHz.

Case #	Start		End		MOR min. [m]	CBASE min. [ft]	SODAR
NOVEMBER							
1	20081103	03	20081103	08	272	70	
2	20081103	23	20081104	12	73	20	
3	20081104	15	20081104	24	135	20	
4	20081106	02	20081106	06	296	50	
5	20081107	03	20081107	06	131	20	
6	20081113	00	20081113	01	368	2050	
7	20081114	05	20081114	08	1470	170	
8	20081126	19	20081126	20	1610	220	
9	20081127	02	20081127	08	598	50	
DECEMBER							
10	20081208	22	20081209	06	240	20	
11	20081215	02	20081215	03	1810	250	
12	20081215	19	20081216	15	98	20	
13	20081216	18	20081216	21	865	200	
14	20081217	00	20081217	10	239	50	
15	20081222	22	20081223	09	96	20	
16	20081231	04	20081231	16	204	20	
JANUARY							
17	20090101	04	20090101	10	421	1070	
18	20090108	02	20090109	00	118	20	
19	20090113	11	20090114	05	149	20	
20	20090117	00	20090117	06	1250	170	
21	20090128	05	20090128	11	512	100	
22	20090128	22	20090129	06	200	50	

Legend

R > 85 dBz	very strong
80 < R < 85 dBz	strong
70 < R < 80 dBz	light
R < 70 dBz	weak

4 Conclusions and recommendations

4.1 Summary and conclusions

KNMI operates since March 2006 a METEK SODAR along the Polderbaan of Schiphol Airport. Presently only the wind profile information from the instrument is used, mainly for wind shear warnings in the lowest 2,000 ft of the atmosphere. This report presents the results of an investigation of the added value of reflectivity data from this SODAR during low visibility conditions. The analysis is based on the 3-month period November 2008-January 2009.

For most low visibility events at the airport a distinct maximum in the SODAR reflectivity is observed, above the cloud base detected by ceilometers nearby. This maximum is associated with a surface or low level temperature inversion that restricts the cloud layer at the top. Six days, showing various types of low visibility weather conditions at the airport, were studied in more detail, using surface observations and AMDAR temperature profiles. It can be concluded that time series of the reflectivity profiles measured by the SODAR are a powerful tool for monitoring the thickness of a fog layer, especially when combined with cloud base detections from a collocated ceilometer.

More specifically, it can be concluded that:

- The reflectivity signal of the vertical beam shows the strongest maxima around the inversion height for the 1.6 kHz frequency mode. The automated mixing layer height (MLH) method based on the algorithm of Emeis and Türk (2004) can be used as a first estimate of the height of this level.
- The combined registrations of the SODAR MLH and the ceilometer cloud base often give consistent and meaningful information on the depth of the fog layer, also during the development and cessation phase of the layer.
- The presence and height of the inversion layer in the SODAR reflectivity corresponds well to rough estimates of the temperature inversion as inferred from AMDAR temperature profiles. The vertical resolution of the latter profiles is however coarse and therefore limits a quantitative comparison.
- Difficulties arise when the temperature inversion is weak and in case of shallow fog layers, restricted by a surface inversion below 100 m. Because the measurement range of the SODAR starts only at 50 m for 2.1 kHz, it is not easy to recognize the inversion height in these conditions.
- During the period November 2008-January 2009, 22 low visibility cases occurred, 13 of which (59%) showed a marked inversion in the sodargram that was also detected by the automated MLH method.

For operational purposes, the vertical resolution of the SODAR measurements at Schiphol is 25 m, and the data is averaged over 15 minutes in time. The vertical range runs from 50 to 700 m, which is sufficient to cover most inversion layers above fog and low stratus clouds. Reducing the vertical resolution will require an adjustment in the configuration and is not recommended by METEK.

Note that the advantages of SODAR as a source of information for inversion monitoring are mainly the continuous availability and the time resolution of 15 minutes. For AMDAR measurements this depends of course on the availability and number of ascents and descents of designated aircraft. AMDAR data is only sparsely available between 00 and 06 UTC, whereas this is a relevant period to monitor the characteristics of fog and low clouds.

4.2 Recommendations

This investigation indicates that the SODAR delivers valuable information for monitoring the boundaries of fog and low clouds. The following recommendations are made:

- **Assessment of the added value of SODAR information in COBEL**
  KNMI has started a project to implement a 1D column model (COBEL) for short-term forecasts of fog development and cessation at Cabauw and Schiphol. One of the parameters important for initialization and validation is the depth of the fog layer. It should be investigated whether the fog thickness obtained from ceilometers and the SODAR at Schiphol improves the forecast.
- **Further assessment of quality of SODAR information and the added value for nowcasting**
  Because not all observational information was available in detail for this study, it is suggested to perform an evaluation of the SODAR reflectivity information by the meteorologist. A special subject of study should be the translation of the SODAR data to products or rules of thumb (e.g. in combination with incoming radiation) that can be used to improve the reliability and timeliness of forecasts related to fog onset and dissipation.
  Several additional evaluation tools for the low cloud top can be considered, like balloon soundings and Pilot Reports (on request), AMDAR profiles with a higher vertical resolution and evaluations of the cloud top by the observer or MAS.
- **Data connection**
  Presently a modem connection is available for maintenance purposes only. Daily data files used for this off-line study were incidentally taken to De Bilt on memory stick. In the recommendations resulting from the evaluation of ceilometer backscatter profiles at Schiphol, it should also be considered to establish data connections with the SODAR that permit real-time evaluations and to archive the data for off-line studies.

4.3 Acknowledgements

The contributions of Jan Hemink, Siebren de Haan, Wiel Wauben (all KNMI), Alain Dabas (Météo France) and Hans-Jürgen Kirtzel (METEK) are greatly acknowledged. Hannelore Bloemink and Jitze van der Meulen are acknowledged for reviewing the manuscript.

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Appendix A   Map with KNMI sensor positions at Schiphol Airport

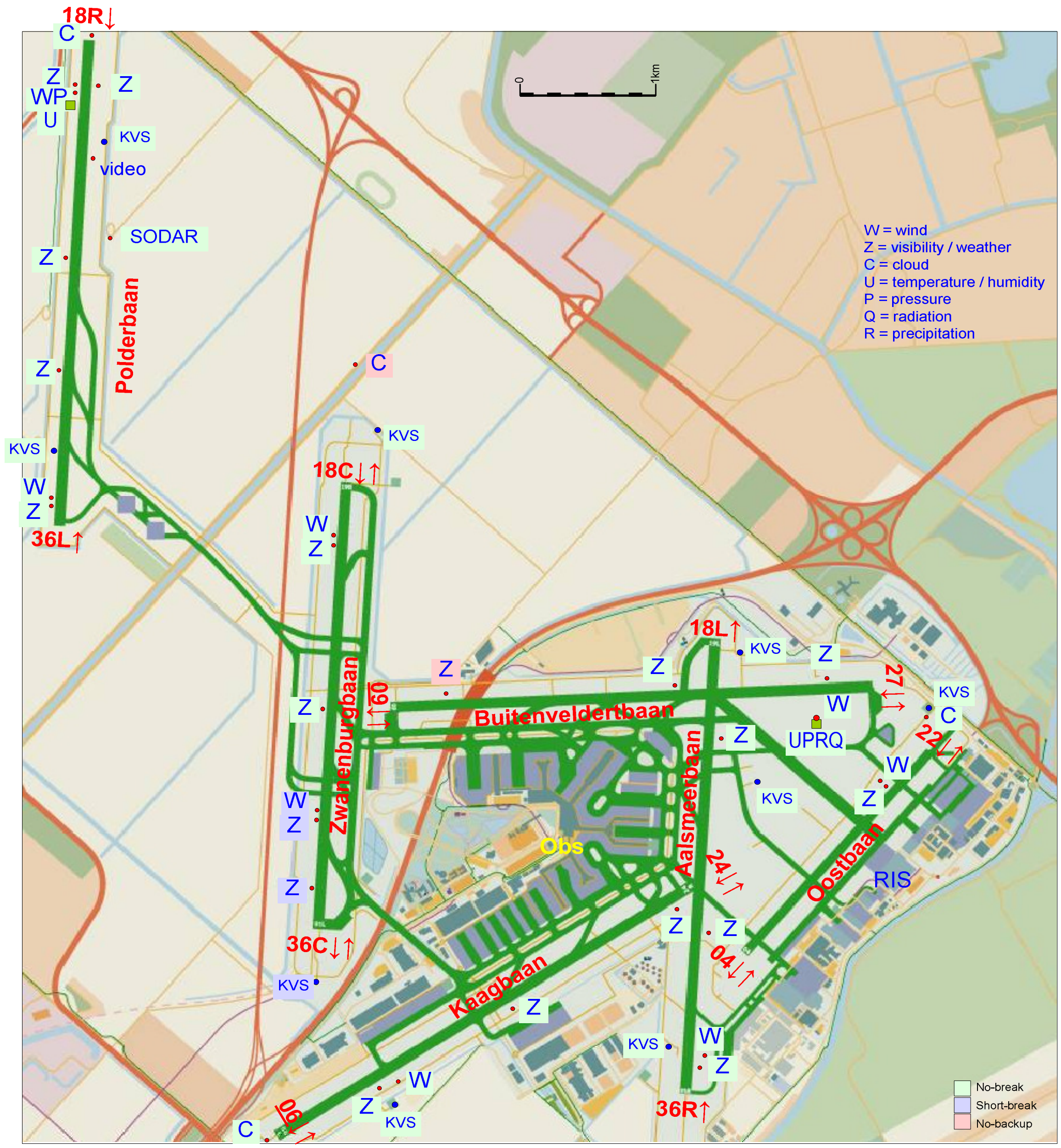

Figure A.1. Overview of meteorological sensor locations at Schiphol Airport (courtesy: W. Wauben). The legend in the upper right corner describes the parameter abbreviations. Note that the SODAR is located about halfway and 200 m east of the Polderbaan (18R-36L). Ceilometers (indicated by "C") are situated close to the touchdown zones of runways 18R, 18C, 06 and 27.

Appendix B AMDAR profiles for selected cases

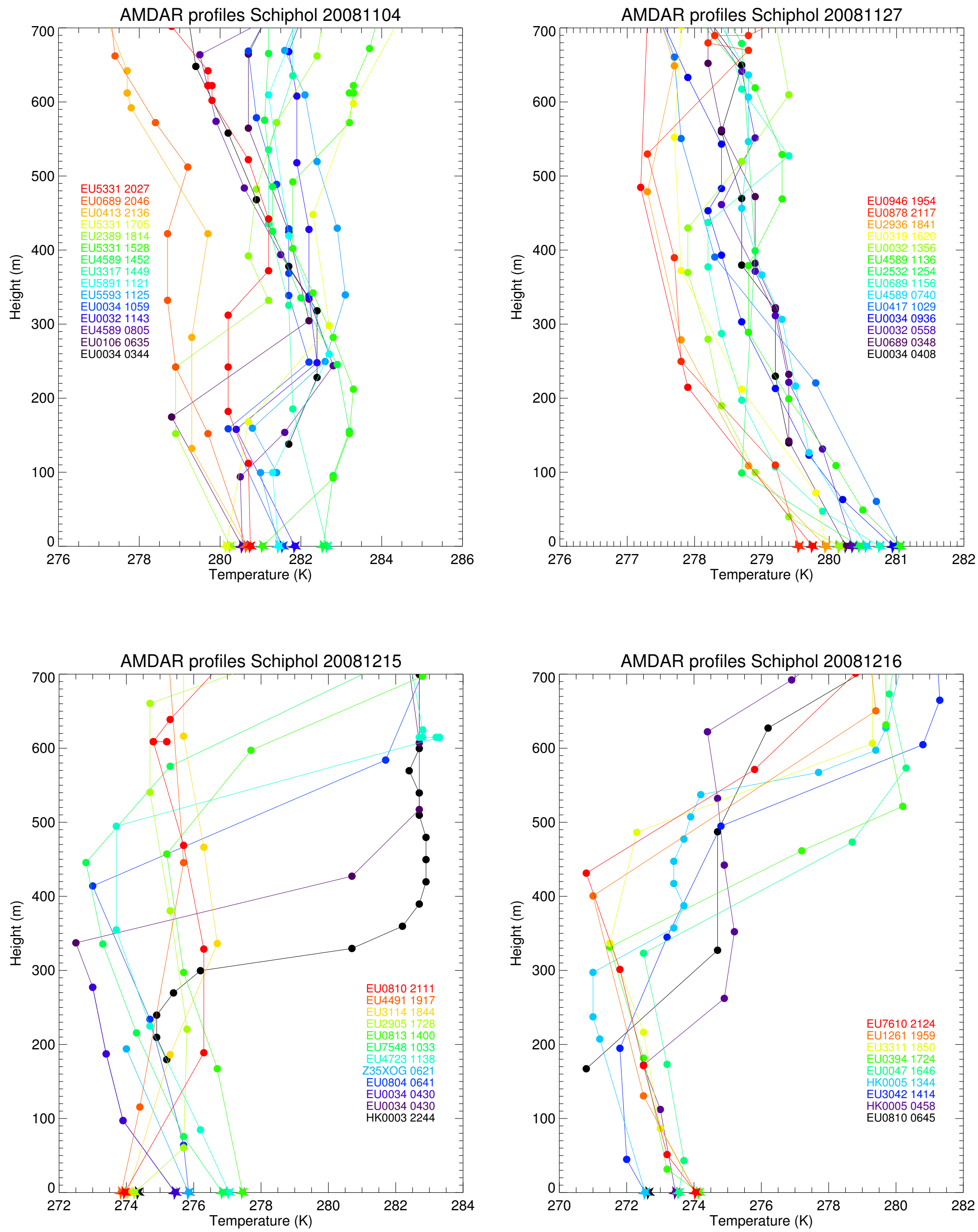

Figure B.1-B.4. AMDAR temperature profiles for the Schiphol area in the lowest 700 m, reported on 4 and 27 November, and 15 and 16 December 2008 (in order of appearance). The lowest data point represents the 1.5 m temperature at the observation field. The time reported in the legend is the observation time of the lowest AMDAR data point in hours UTC.

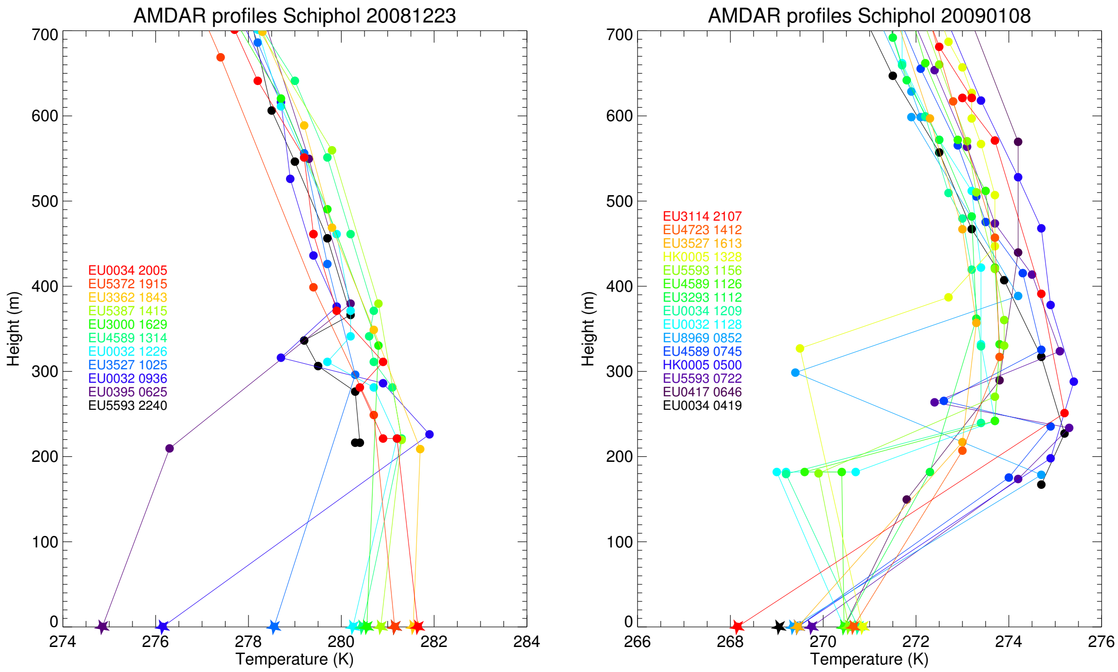

Figure B.5-B.6. Same as Figures B.1-B.4, but for 23 December 2008 and 8 January 2009.

Appendix C Ceilometer, SODAR and AMDAR data for selected cases: November

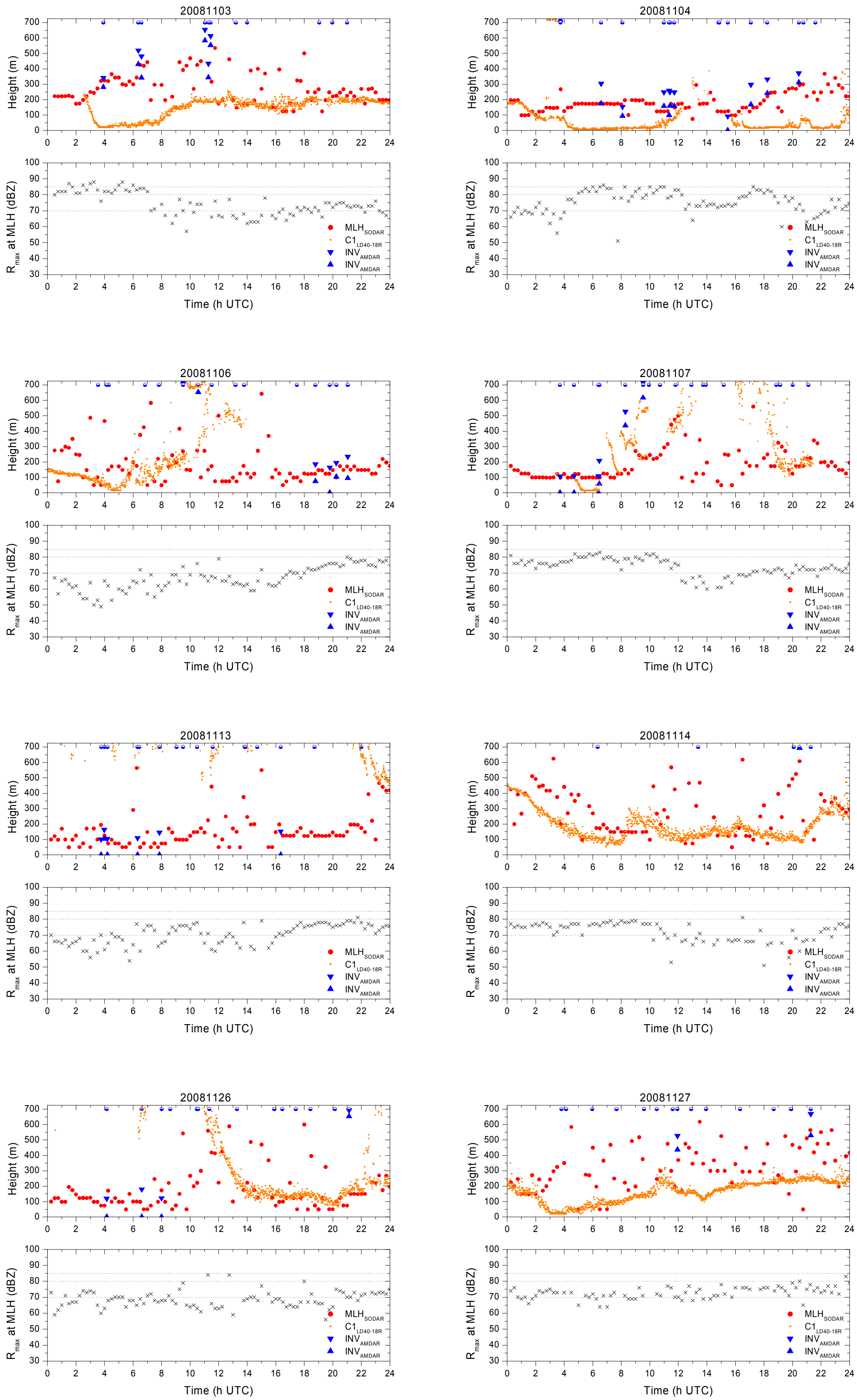

Figure C.1-C.8. Daily time series of automated SODAR MLH [●], ceilometer cloud base at location 18R [●] and the inversion estimate from AMDAR [▲ and ▼] for the cases in November 2008 (see Section 3.3). The max. MLH reflectivity is given in the lower panels.

December

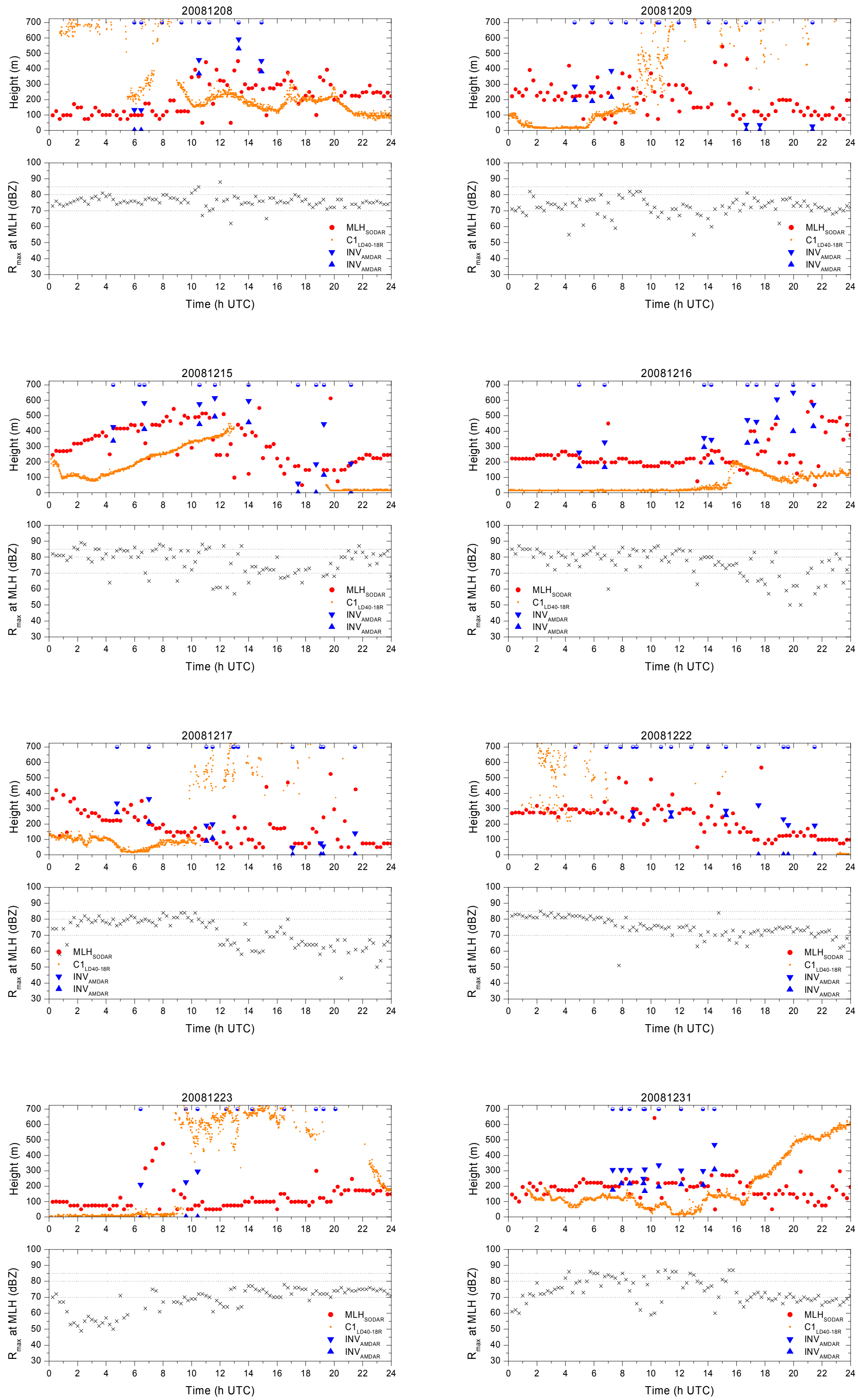

Figure C.9-C.16. Same as Figures C.1-C.8, but for the low visibility cases in December 2008.

January

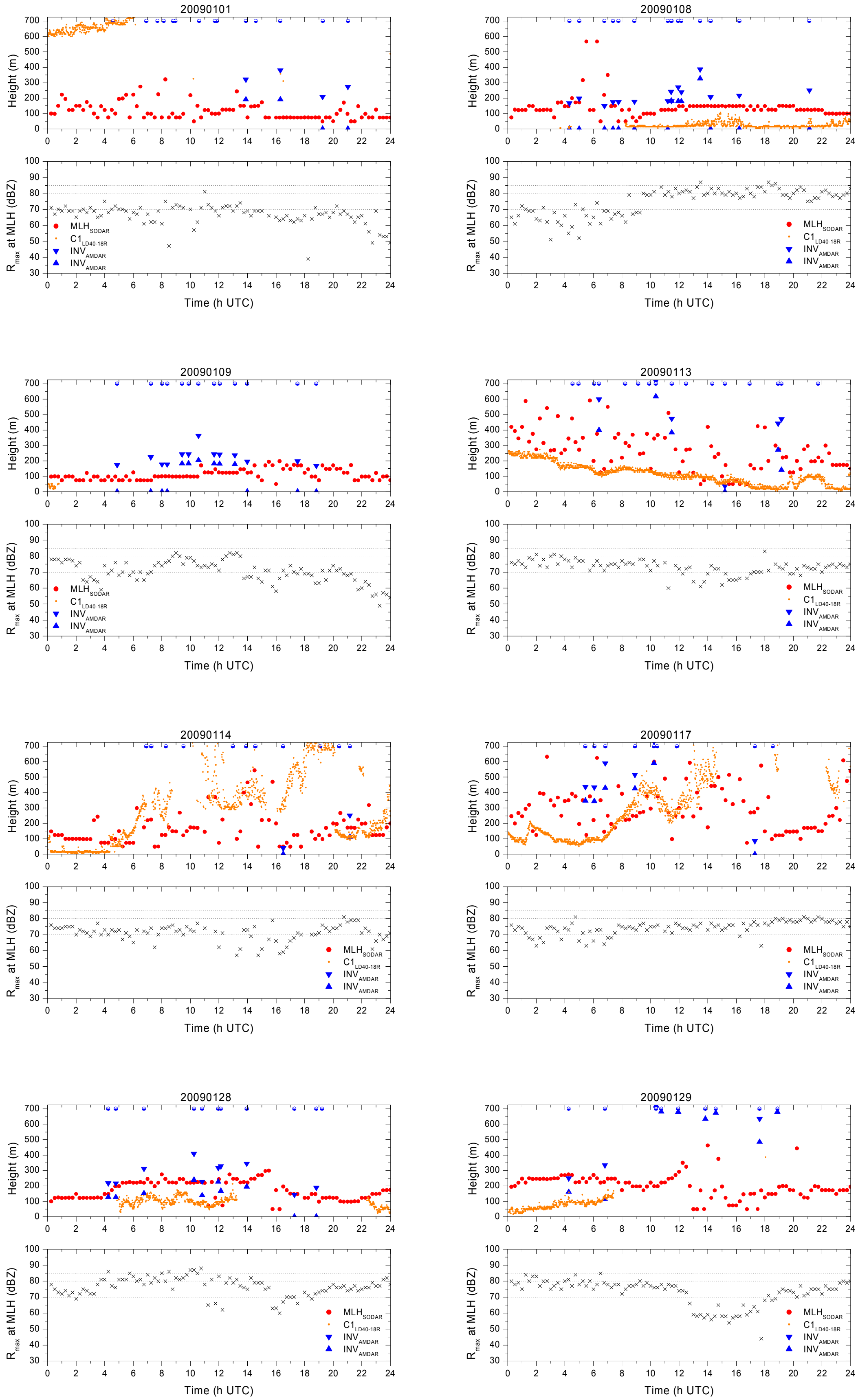

Figure C.17-C.24. Same as Figures C.1-C.8, but for the low visibility cases in January 2009.

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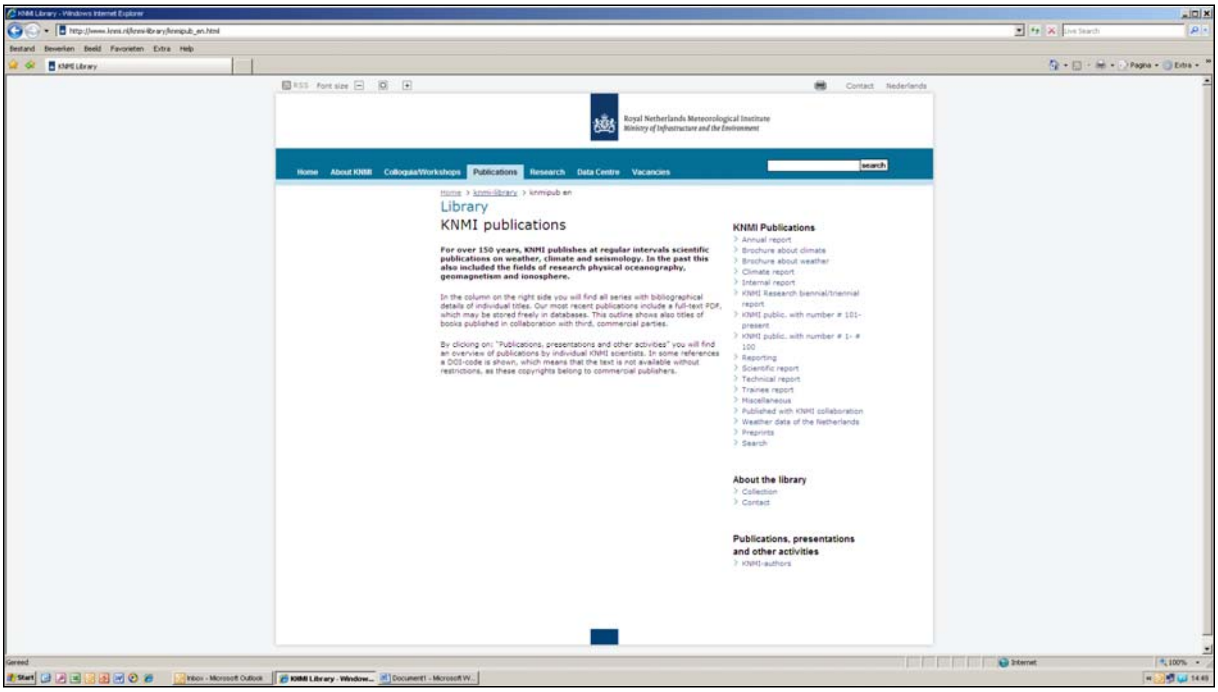

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