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Evaluation of the Nubiscope

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De Bilt, 2006

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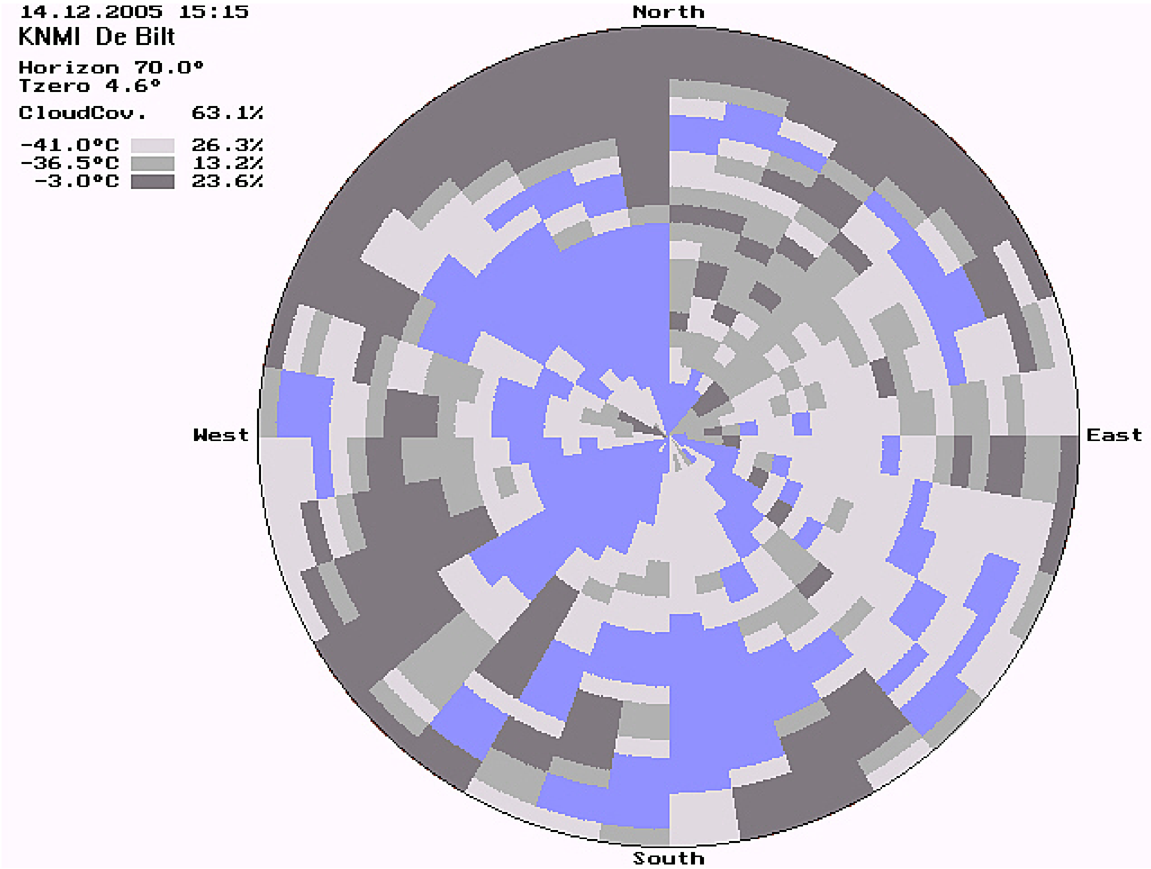

The title page shows the cloud mask of the Nubiscope measurement of December 14, 2005 at 15:15UT in De Bilt in false colors simulating a visual observation of the full sky. Graph provided by IMK/Sattler-SES.

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1. Introduction

Cloud observations are performed routinely for synoptic and aeronautical purposes (WMO, 1996; ICAO, 2004). The cloud observations are traditionally performed by human observers. Several cloud layers can be reported and for each layer the cloud amount, height and type are estimated. While cloud cover and particularly cloud type are determined visually, the determination of the cloud base height can be enhanced by using radio soundings, tethered balloons or balloons with a known ascent rate, and/or searchlights. More recently, ceilometers are employed that provide the observer with frequent readings, typically every 15 seconds, of the cloud base height directly overhead. Presently, several countries, e.g. Sweden, USA and the Netherlands, perform automated cloud observations using a ceilometer in combination with a cloud algorithm that transforms the ceilometer cloud base readings in a certain time interval into cloud layers with corresponding amount and height. The automated cloud observations have been compared to visual observations (e.g. Ramsay and Nadolski, 1998, Perez et al., 2002; Wauben et al., 2006). The overall agreement is generally good, but as could be expected, situations with large differences between visual and automated cloud observations do occur. The main reason for these differences is the lack of spatial representativeness of the ceilometer measurements.

A study showed that the combination of the results of 3 instead of 1 ceilometer in the cloud algorithm did not significantly improve the overall results (Wauben, 2002; Ravilla et al., 2002). Observing systems that can provide spatial cloud information are e.g. radiometers on board satellites, camera systems and scanning systems. The space-borne instruments provide useful cloud information particularly for high clouds, but has limitations for low clouds and experiences difficulties with partially clouded pixels and semi-transparent situations. In addition satellite instruments do not give information on the cloud base height. Camera systems are currently often used as remote observing systems (e.g. Mammen and Wienert, 2005), although systems are available that automatically evaluate the images and provide an automated total cloud cover (e.g. Long et al., 2006). However, visual camera systems only give useful information during daytime and twilight and they do not give information on the cloud base height, although stereoscopy using 2 wide-angled cameras makes it possible to obtain cloud base height (and wind) information (cf. e.g. Seiz et al., 2002). Infrared camera systems require regular maintenance and are currently too expensive to be considered for operational use (Keogh et al., 2000). Several scanning systems are available. Scanning ceilometer systems are expensive and since a ceilometer measurement requires an integration time, scanning the entire sky is too time consuming. Scanning infrared radiometers (pyrometers) are less expensive and make nearly instantaneous measurements. Furthermore scanning infrared (IR) radiometers can be operated during day- and night-time and provide, through the observed temperature, information on the height of the observed clouds. Furthermore the observed cloud base temperature itself is a useful quantity that can be combined with the cloud top temperature obtained from satellites. Hence scanning pyrometers seem promising observation systems that can give useful information on clouds.

Currently 2 types of scanning IR radiometers are commercially available. The first one is the Cloud Infrared Radiometer (CIR) manufactured by Atmos Sarl. This instrument (see e.g. Genkova et al., 2004), consists of up to 13 pyrometers attached to an arc to cover the various elevations. The arc rotates 360 degrees in order to measure the whole sky. A measurement in 30 azimuth directions takes about 3 minutes. The field of view of each IR radiometer is 6 degrees. The other scanning IR radiometer is the so-called Nubiscope manufactured by IMK/Sattler-SES (http://Sattler-SES.de/Nubiscope-US.html). This sensor consists of a single IR radiometer mounted on a pan and tilt unit. A measurement of the whole sky, every 3 degrees in elevation and every 10 degrees in azimuth takes about 6 minutes. The field of view of the IR radiometer is 3 degrees. Both scanning IR radiometers have been tested by users and give promising results. The advantages of the Nubiscope are the smaller FOV, the employment of a single radiometer and the statement that the system is weather proof and requires little maintenance. Therefore the Nubiscope was selected for a test.

In this report no detailed evaluation of the above mentioned observing systems for spatial cloud observations will be performed. The evaluation will be restricted to the Nubiscope. During a brief field test the technical aspects of the system will be investigated e.g. reliability, robustness, weather proof, required maintenance, sensitivity to contamination. A comparison of the Nubiscope results with the automated cloud observations using a ceilometer gives an indication of the quality of the results and the added value of the Nubiscope.

2. Test setup and Nubiscope details

2.1. Test setup

The Nubiscope was loaned for a 2 month period from November 29, 2005 to February 21, 2006. The Nubiscope was installed on the radiation platform on top of KNMI building B in De Bilt (52° 06' North, 05° 11' East, surface elevation +2.0m msl). The radiation platform, which placed the Nubiscope at a height of 24.5m msl, was selected since it has a nearly free horizon. The only significant obstruction is caused by a radar tower to the North with an elevation of 16° extending maximally 8° in azimuth. Figure 1 shows a picture taken from the radiation platform towards North. The pole in the lower right corner, which was formerly used for a sun photometer, was used for mounting the Nubiscope. Another reason for using this site was that it could easily be accessed for inspection of the instrument and the "computer room" directly underneath the radiation platform provided the power supply and a location a PC for retrieving the data from the Nubiscope. The automated weather stations of De Bilt (06260) and De Bilt Test (06261) are located about 150m to the South. The evaluation of the Nubiscope results was performed by comparison with meteorological data from these 2 stations.

Figure 1: The view to the North as observed from the radiation platform on top of the South-East corner of KNMI building B in De Bilt showing the radar tower.

2.2. Nubiscope system

The Nubiscope system consists of a pyrometer, a pan-and-tilt unit (PTU) and an electronics box. In addition, a precipitation detector is connected to the system, but this detector is not used in the generation of the results. A picture of the setup of the Nubiscope system during the test at De Bilt is shown in Figure 2.

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Figure 2: The Nubiscope system on the radiation platform during the test in De Bilt with a view to the South-East.

The pyrometer is a Heitronics KT 15.82D which measures in the spectral range of 8-14µm, i.e. in the atmospheric IR window. The sensor has a temperature range of −100 to 50°C with an accuracy of ±0.5°C+0.7% of the temperature difference between target and housing. The long term stability of the sensor is better than 0.01%/month. The response time is 300ms and the field of view is 3°. The pyrometer is mounted at the end of a tube with baffles that shield the lens from contamination by precipitation. Any precipitation that enters the tube can escape through venting hole at the back. The range of operation of the pyrometer is between −20 and +60°C. The pyrometer (and PTU) can be heated so that the operating range is extended to −40 and +60°C.

The pyrometer is mounted on a BEWATOR P16 pan and tilt unit which gives the azimuth and elevation with an accuracy of ±0.1. The range of operation of the PTU is between −20 and +60°C. At the start of a new measurement cycle the PTU is moved along the horizon to the North. Next, upward and downward elevation scans between horizon and zenith are performed. During an elevation scan the position of the PTU is continuously sampled and the pyrometer signal is read at zenith angles 1.5° to 88.5° in steps of 3°. An elevation scan takes about 10 seconds. The PTU moves 10° in azimuth after completion of each elevation scan, i.e. each time a zenith angle 88.5° or 1.5° is reached. The azimuth movement is from North to East. A full scan of the sky at 30 zenith and 36 azimuth angles, i.e. 1080 directions in total, takes about 6 minutes. At the end of a full scan the PTU moves to a downward orientation in order to perform a measurement of the surface temperature and then the PTU moves to a neutral position. These 2 orientations are user configurable. For the surface temperature measurements the PTU was pointed towards the East with zenith angle 97.4°, which is in the direction of the allotments visible in Figure 2, and the neutral position was horizontally towards the East, i.e. opposite to the prevailing wind direction.

A Lambrecht 15152 conductive precipitation detector is optionally connected to the Nubiscope system. The occurrence of precipitation at any time during the full sky scan is reported in the results file of the Nubiscope, although this indicator is not used in the cloud discrimination of the Nubiscope.

The Nubiscope system operates fully automated. The CPU in the electronic box controls the PTU and performs the measurements of the pyrometer. The settings of various parameters controlling the measurements are stored in parameters files. The raw temperature readings, as well as the derived products are stored on a flash memory card. Via a serial interface a connection can be made to the Nubiscope system. An elevation scan cannot be interrupted. Only when the PTU is horizontal again, i.e. after an upward and downward elevation scan, control over the system can be obtained. This can give a delay in the communication with the Nubiscope system of up to 20 seconds, but it prevents the PTU remaining in an upwards and hence minimizes the exposure of the lens of the pyrometer. During the period of the remote connection the measurement scheme of the Nubiscope is interrupted. When the interruption extends into the next measurement interval a scan is omitted. Via the interface the measurements scheme can be configured and several processing parameters can be adjusted. Raw and processed data can also be obtained via this interface.

The default measurements schedule of the Nubiscope a was applied during the test at KNMI. Every 15 minutes a full scan of the sky was performed which takes about 6 minutes. The results were manually extracted from the Nubiscope on a weekly basis. Since there is only a period of 9 minutes between 2 full scans, only the processed data were retrieved. The extraction of a daily raw data files takes about 3.5 minutes. These files were only extracted for interesting days. At the end of the test the entire data set was copied from the flash disk.

An overview of the main Nubiscope characteristics and system parameter settings is given in Table 1.

Table 1: Overview of the Nubiscope characteristics and system parameter settings.

Characteristics Pyrometer	
Spectral range	Atmospheric IR window 8-14μm
Temperature range	–100 to 50ºC
Temperature accuracy	±0.5ºC+0.7%
Repeatability	±0.1ºC+0.1%
Response time	300ms
Field of view	3º
Characteristics Pan-Tilt unit	
Azimuth scan angles	10 to 360º step 10º
Zenith scan angles	1.5 to 88.5º step 3º
Accuracy	±0.1º
Time for full scan	6min
Operating temperatures	–20 to 60ºC (–40 to 60ºC)
System parameters	
Maximum zenith angle for cloud evaluation	70º
Threshold for sky clear	total cloud cover < 0.5%
Limits for low/middle/high clouds	2100/5400m

2.3. Nubiscope data

The basic measurements of the Nubiscope system are the sky temperature measurements consisting of elevation scans with measurements at 30 zenith angles for 36 azimuth directions. In addition the surface temperature T_{gnd} is measured by the pyrometer and the internal pyrometer temperature T_{ref} is monitored. The raw temperature data are stored locally in daily binary files with name convention NYYMMDD.dat where YYMMDD denotes the year, month and day of the measurements. The raw data files can be transferred to a PC via the serial interface. The files are stored a monthly subdirectory structure denoted YYMM. A windows executable is provided by the manufacturer that transforms the daily binary file into individual ASCII files for each full scan using the file name convention NYYMMDDh.hmm where h.hmm denotes the start time in hours and minutes of the observation with mm=00, 15, 30 or 45 for a 15 minute measurement cycle. These ASCII files are stored in daily subdirectories YYMMDD.

The pyrometer temperature measurements are processed by the Nubiscope system. The exact details of the internal processing are unknown. Below a qualitative description of the processing and the derived products is given. The measurements near the horizon are analyzed in order to obtain the "zero" temperature (T_{zero}) which corresponds to the ambient temperature and serves as the starting point for the altitude determination. The cloud height is calculated by assuming a dry adiabatic lapse rate of 0.98°C/100m in the mixing layer, the height of which was fixed to 150m. Above the mixing layer a lapse rate of −6.5°C/km for the free atmosphere is used, which is within limits adjusted by the actual measurements of the Nubiscope. The temperature measurements near the horizon are also used to identify situations with fog in which case the variability of the temperature near the horizon will be relatively small. When the entire sky show hardly any temperature gradients the Nubiscope reports dense fog (DF) whereas otherwise light fog (LF) is reported. The measured sky temperatures in case of a clear sky situation show a characteristic dependence with zenith angle, with increasing temperatures towards the horizon as a results of IR emission by water vapor. This behavior is shown in Figure 3, which shows the sky temperature distribution observed at De Bilt on January 28, 2006 at 12:00UT. The zenith angle dependence of the clear sky temperature measurements is described by a polynomial. This polynomial is used to convert the observed clear sky temperatures to a clear sky temperature directly overhead (T_{blue}). The clear sky temperature directly overhead is updated whenever at least 6 clear spots at various elevations are observed. If not, the previous value is persisted.

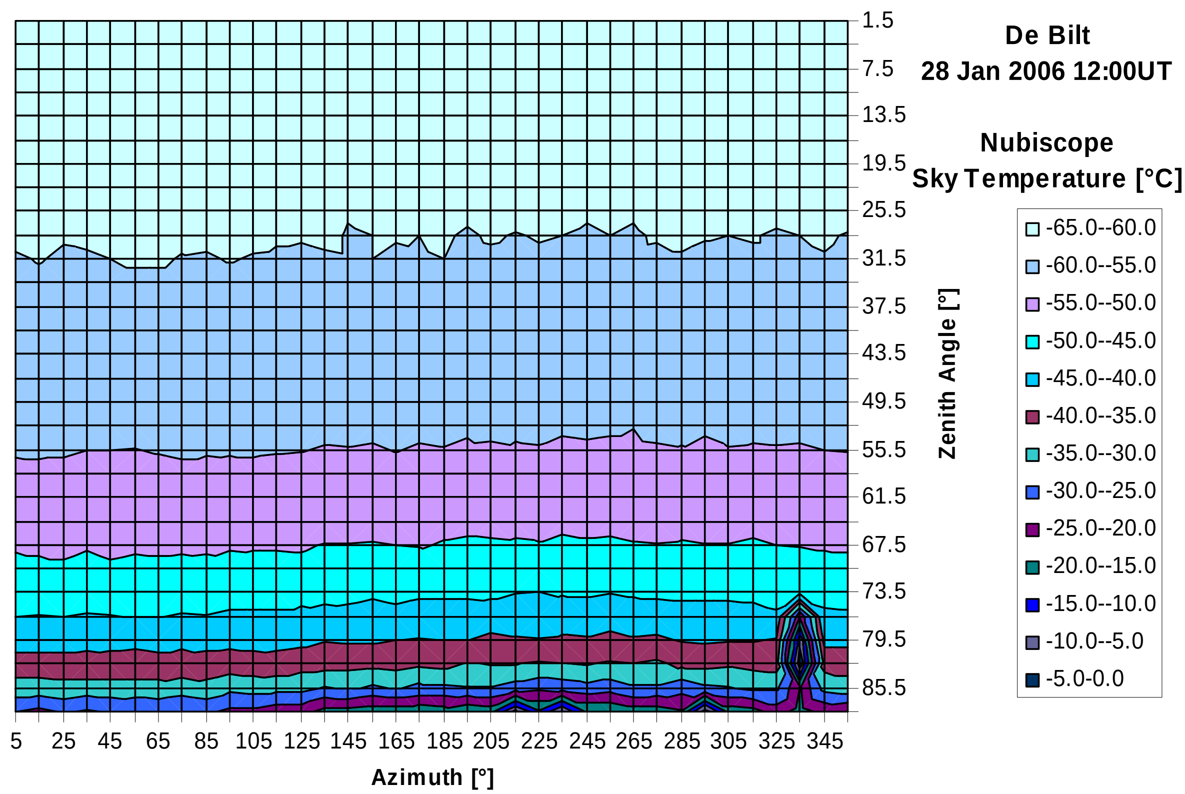

Figure 3: The zenith angle dependency of a clear sky observed at De Bilt on January 28, 2006 at 12:00UT. Note the increased temperatures near the North horizon that is caused by the radar tower. [1]

The presence of clouds leads to a increase of the sky temperature in that direction. The lower the cloud, the higher the temperature. The exact thresholds for cloud detection and the vertical range for cloud detection are unknown. Apart from instrumental limitations (such as temperature resolution, temperature range -in particular the lower limit- and the sensitivity to contamination) and software thresholds, the presence of water vapour, partially clouded scenes within the field of view of the pyrometer and semi-transparent clouds will affect the determination of the presence of clouds and the associated temperature. The sky temperature measurements with a zenith angle below 70° are

[1] To my knowledge, Excel does not support a polar surface plot, nor a surface plot without contour interpolation. My apologies for this clumsy graph and my thanks to IMK/Sattler-SES for providing the graph on the title page.

processed for the determination of clouds. The Nubiscope distinguishes the following sky conditions: clear sky (CS) situations with less than 0.5% cloud cover; overcast (OC) situations with 100% cloud cover in the lowest layer; broken cloud (BC) situations were clouds are observed in more than one layer; cirrus (CI) clouds only; identification unknown (IU) situations where distinction between clouds or fog cannot be made; light fog (LF) and dense fog (DF) situations.

The results of the processed Nubiscope data are stored in daily files with name convention RYYMMDD.dat. These processed files can be transferred to a PC via the serial interface. A windows executable is provided by the manufacturer that reprocesses the daily binary file and generates the results files. This allows the reprocessing of the raw data with a new set of parameters. Since the parameters were changed several times during the test period all raw data were reprocessed after the test using the latest software settings. The results files give for every sky scan:

- Date and time of the start of the scan.
- Precipitation indicator (Y/n).
- The temperatures T_{gnd}, T_{ref}, T_{zero}, T_{blue} (°C).
- The sky condition classification (CS, CI, BC, OC, IU, LF, DF)
- The total cloud cover and the fraction of clouds below the main cloud base (%).
- Cloud cover (%), temperature (°C) and height (m) of the main cloud base (MCB), i.e. the cloud layer below 2100m that exceeds 30% cloud cover.
- The cloud cover (%) of low (<2100m), middle and high (>5400m) clouds.
- Temperature (°C) and height (m) of the lowest cloud layer.
- Temperature (°C) and height (m) of ceiling, i.e. the lowest cloud layer exceeding a cover of 55%.

Note that in situations of light or dense fog or identification unknown (i.e. LF, DF or IU) no cloud cover amounts, temperatures or heights are reported. For the other sky conditions the parameters are reported as far as applicable for that particular situation. Figure 4 shows a example of several of the derived parameters at De Bilt for December 14, 2005.

In addition to this 2 new output files have been constructed. These 2 additional output files were generated off-line after completion of the test and, currently, cannot be obtained directly via the remote connection. The first new output file, denoted MYYMMDDh.hmm, contains the derived cloud mask where for each pixel is indicated whether it contains 0=no cloud, 1=high cloud, 2=medium cloud, 3=low cloud, or 4=margin of a cloud. The cloud mask is gives for all pixels above 20° elevation, i.e. 23*36 pixels and can be used for presentation purposes. The second additional output file, denoted ZYYMMDDh.hmm, reports the 36 measurements around the zenith. The file reports the time, observed temperature and the derived height. The file is suitable for a direct comparison with cloud ceilometer data. The cloud mask and zenith files are generated in daily subdirectories in the monthly directory structure. Examples of the Nubiscope results, cloud mask and zenith files are given in the Appendix.

Finally, the Nubiscope system generates a monthly log-file, denoted LYYMM.dat, which reports start and end of each remote connection, the update of parameter files and any errors.

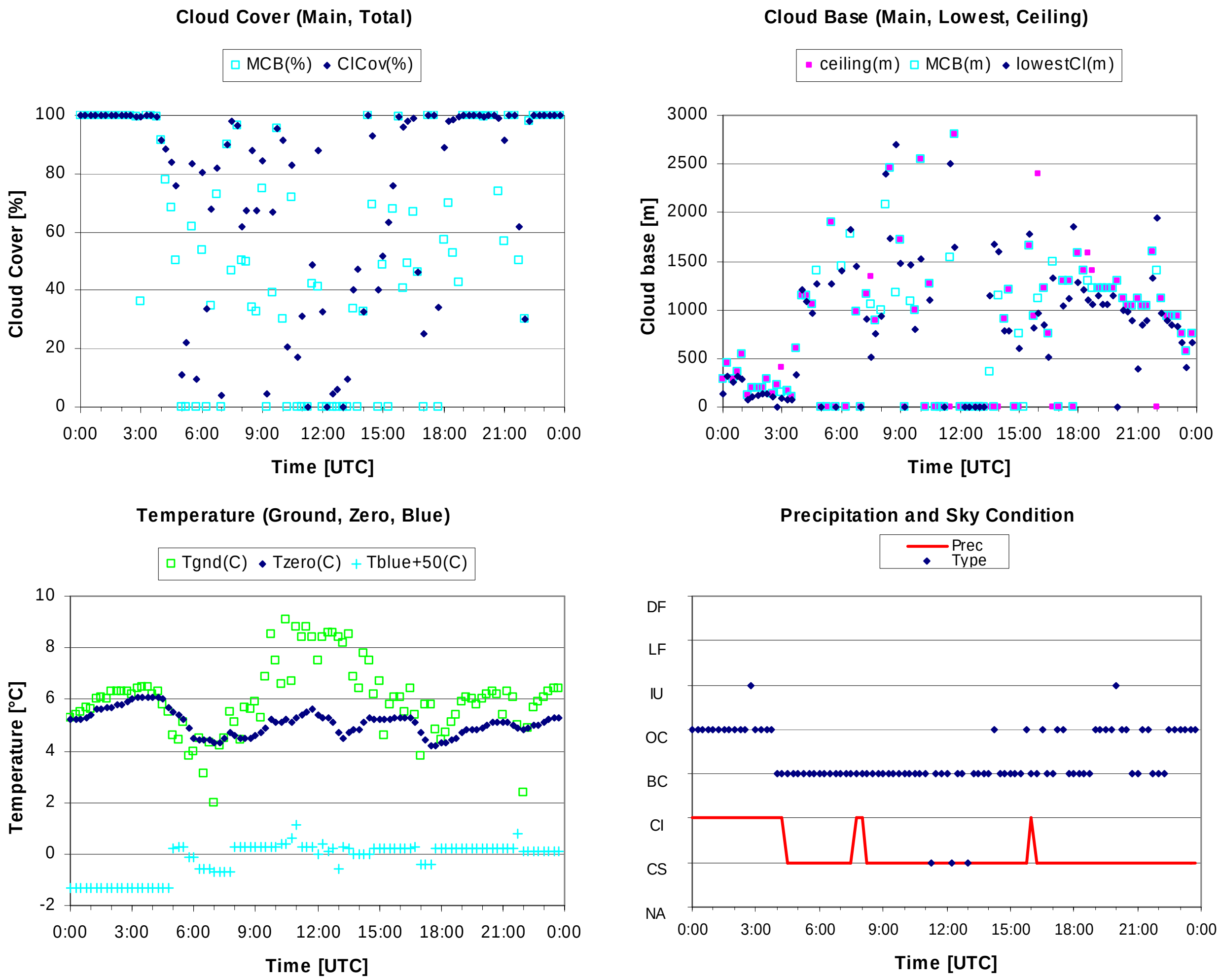

Figure 4: Derived Nubiscope parameters obtained at De Bilt on December 14, 2005.

3. Results and discussion

In this section results of the Nubiscope will be shown and when possible compared to other sources.

3.1. Overall technical performance

The Nubiscope was installed at De Bilt on November 29, 2005 by the manufacturer. An interface was made by KNMI that was fastened to the top an existing pole on which the pan-and-tilt unit of the Nubiscope system could be mounted. The electronics box was attached to the pole. The interface was aligned manually so that the PTU was roughly oriented to the North direction. After this fairly easy installation the Nubiscope system was operated from De Bilt from November 29, 2005 to February 21, 2006. During this period no technical problems occurred. The sensor software and settings were updated several times during the test. Below an overview of the changes are given:

November 29, 2005	Nubiscope installed at KNMI
December 3, 2005	New coefficients for zero temperature derivation
January 20, 2006	New coefficients for fog identification (due to free/homogeneous horizon)
February 20, 2006	New software with additional output (temperature and height of lowest cloud layer)
February 20, 2006	New off-line software with additional output (cloud mask and temperature and height information of zenith measurements).
February 26, 2006	New limit for clear sky (0.1% instead of 10%)
February 28, 2006	New boundaries for low, middle and high clouds (2100 and 5400m)
June 27, 2006	New off-line software with ceiling and revised cloud base height.

The overview shows that the zero temperature and the fog identification coefficients depend on local conditions and needed to be determined based on measurements. Furthermore some coefficients were changed in order to perform the derivations more in line with the KNMI practice for reporting cloud observations. The additional output for the lowest cloud layer was added since this is a fundamental parameter. Similarly, the ceiling, i.e. the height of the cloud base below 1500ft where a cloud cover of 4 okta is exceeded, has been added.

The data analyzed in this report are form the period December 1, 2005 to February 20, 2006, i.e. the first 2 days and the last day are omitted during which the sensor was installed and removed. The analysis covers a period of 82 days so that a total of 7872 scans of the full sky should have been performed. However, 37 scans were not available. On 31 occasions an PTU error was reported in the log-file. This error is caused by a missing reading of the PTU, which is sampled continuously during an elevation scan (see section 2.2). After missing a single readout of the PTU the scan is terminated and the other measurements of the corresponding full sky scan are rejected. The PTU errors occurred during the entire period of the test. Generally only one error occurs per day, but on February 2, 2006 three such errors occurred, although during different hours. The rejection of an full scan when a single PTU reading is missed, without a retry, is rather crude and leads to unnecessary loss of data even if it is only 0.4%. The other 6 missing scans resulted from remote connections for software changes or data retrieval that lead to omission of a scan when the connection time extended into the next measurement interval.

The software and configuration changes were activated from a laptop via a serial RS232 connection. This connection was also used to retrieve the processed data on a weekly basis. The communication with the serial was performed manually by using a Windows executable provided by the manufacturer. The data retrieval is based on daily files. The setup worked for the purpose of this test, but for operational usage the data should made available on a near real-time basis. For KNMI this means using a 10-minute cycle for the full sky scans followed by a retrieval of the results (i.e. overall results, but also cloud mask and if possible raw data). The retrieval of the data will be performed by a KNMI application that needs to be synchronized with the Nubiscope system. The communication protocol of the Nubiscope system is available, but it is unclear whether all recent raw and processed data can be made available.

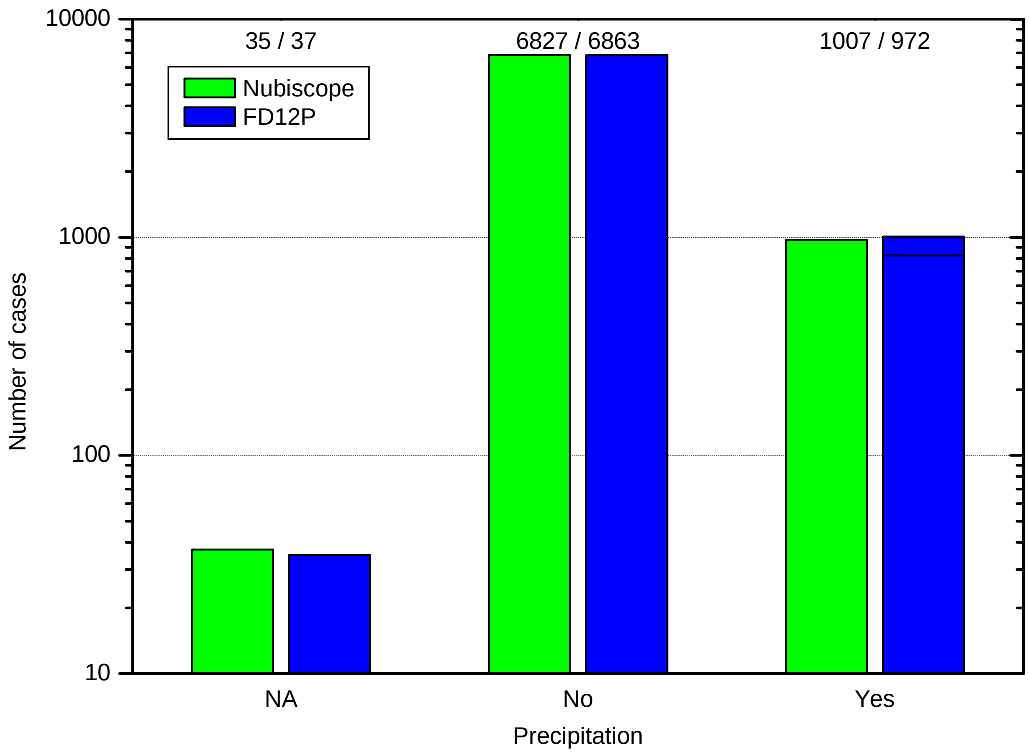

Figure 5: Histograms of the precipitation events reported by the Nubiscope and the FD12P present weather sensor during the period of the Nubiscope test in De Bilt.

Figure 5 shows a histogram of the number of precipitation events reported by the Nubiscope and the FD12P present weather sensor during the period of the test. The number of precipitation events reported by the Nubiscope system and the FD12P show good agreement. The precipitation detector is not used in the Nubiscope system, hence the precipitation events only give information on the conditions during which the test was performed. During 1007 15-minute intervals the FD12P reported precipitation of which 825 were considered light (averaged intensity below 1mm/h), 174 moderate, and 8 high (averaged intensity above 4mm/h) precipitation events. As discussed in section 3.2, it is believed that these precipitation events did not lead to any contamination of the lens of the pyrometer. The temperatures experiences during the test are given in section 3.2.

3.2. Ground and zero temperature

The Nubiscope reports the ground temperature (T_{gnd}) and the zero temperature (T_{zero}), which is a measure for the ambient temperature. These temperatures have been compared to the ambient temperature (T_{amb}), the so-called grass temperature (T_{grass}), and the soil temperature (T_{soil}) measured at 1.5m, 10cm and −5cm above a grass surface, respectively, at the operational station of De Bilt. Figure 6 shows a histogram of all valid temperature measurements obtained during the period of the Nubiscope test at De Bilt. The figure shows that the Nubiscope ground temperature for the allotments resembles the grass temperature the most. The soil temperature is much higher. The Nubiscope zero temperature shows very low values that are not reported by the ambient temperature.

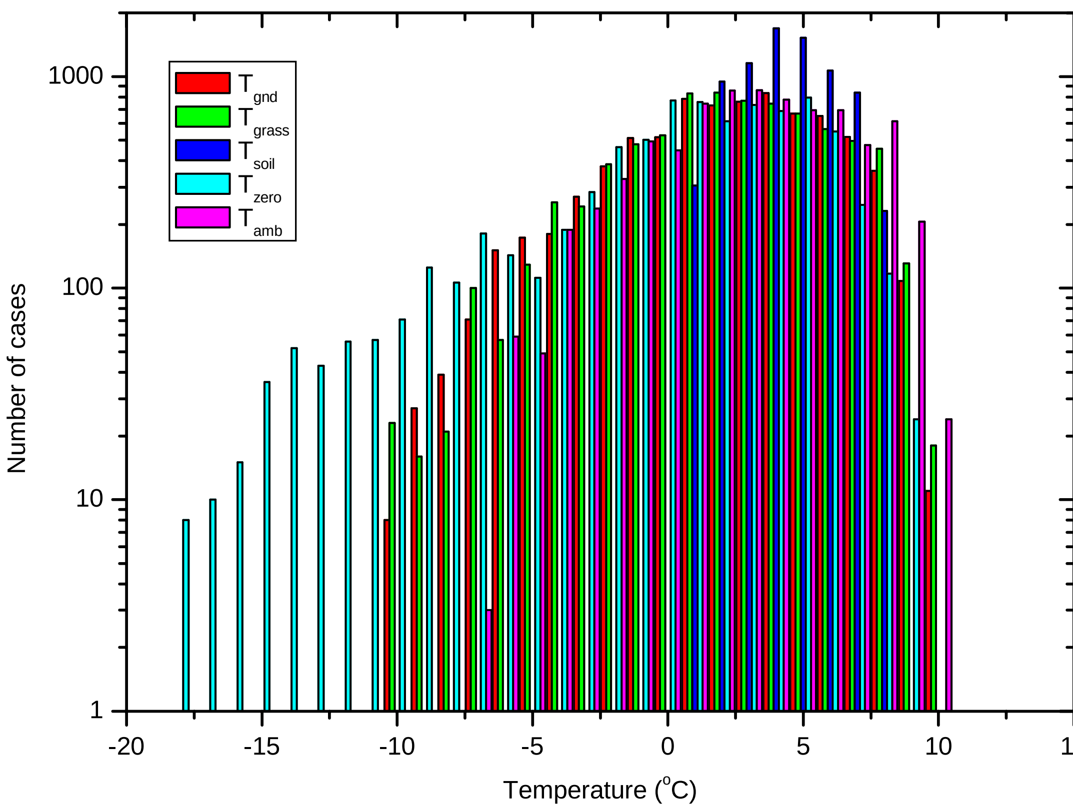

Figure 6: Histograms of the observed temperatures during the period of the Nubiscope test in De Bilt.

In Figure 7 the ground temperature observed by the Nubiscope is compared to the grass temperature. The agreement between T_{gnd} and T_{grass} is good. The differences $T_{gnd}-T_{grass}$ range between −4.0 and 5.3°C with an averaged difference of −0.1°C and a standard deviation of 0.71°C. The scatter plot shows that the data can be fitted rather well by a linear line with an offset of b=0.17°C and a slope of a=0.97. The correlation between T_{gnd} and T_{grass} is 0.96. The observed allotment probably has an emissivity close to unity and does not exhibit a so-called skin temperature (Knuteson et al., 2004). When a scatter plot is made for 2 separate data sets containing the temperatures before and after 10 January 2006, the linear fit is nearly on the x=y line for the first period (b=0.04, a=1.00) and slightly worse for the second period (b=0.26, a=0.94) and the averaged difference is −0.05 and −0.17°C, respectively, whereas the standard deviation is better for the second period (0.55 versus 0.82). This difference is caused by a small number of outliers in the region denoted by the ellipses, which mainly occur in the first period. Since there are no significant differences between the temperature results for the first and second half of the test period, one can conclude that any effect of contamination was negligible. In fact, the reduction of the averaged difference by about −0.1°C between the first and second period is contrary to a contamination since any contamination would result in higher Nubiscope temperatures. When the Nubiscope ground temperature is compared to the ambient temperature the results are slightly worse. The differences range between −5.9 and 4.1°C with an averaged difference of −0.75°C and a standard deviation of 1.00°C. The linear fit has an offset of 1.01°C and a slope of 0.88 and the correlation between T_{gnd} and T_{amb} is 0.97.

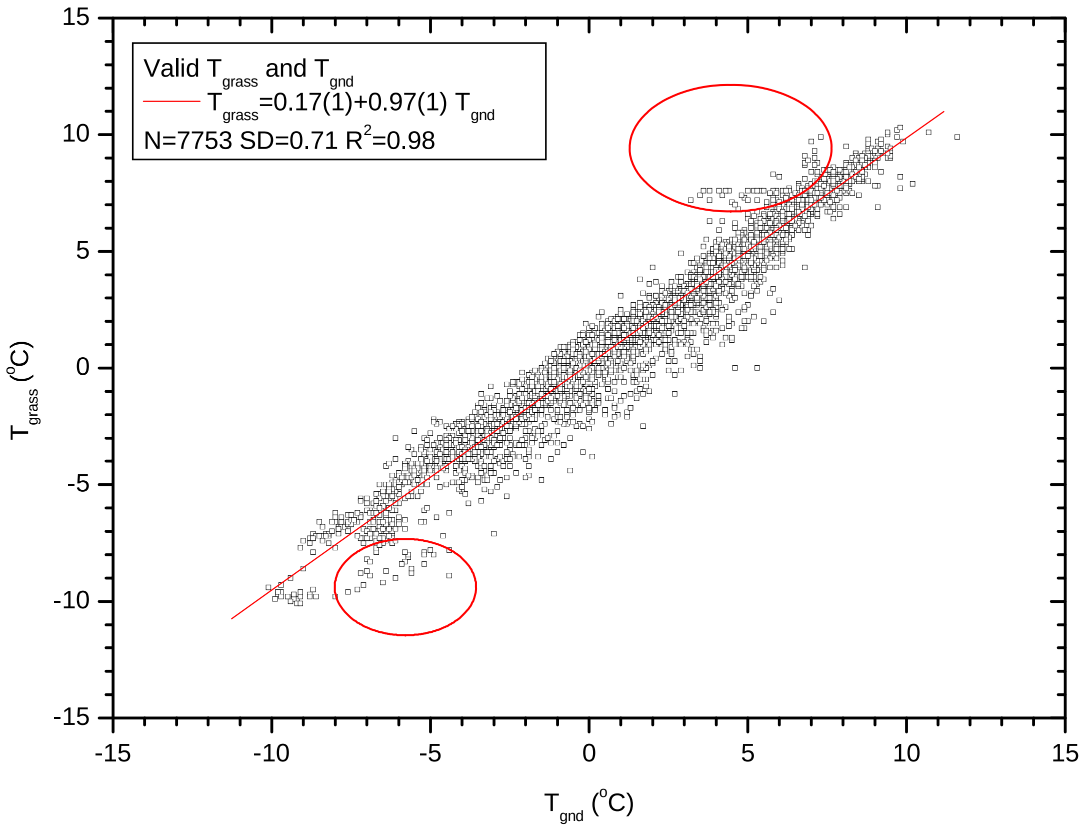

Figure 7: Scatter plot of Nubiscope ground temperature versus the 10cm grass temperature observed at De Bilt.

Next the zero temperature derived by the Nubiscope is compared to the ambient temperature in Figure 8. The scatter is much larger than for the ground temperature and the zero temperature reports much lower values (cf. Figure 7). The scatter plot also shows arc-shaped structures (denoted by the ellipses) which seem to indicate daily variations of the differences. The differences between T_{zero}–T_{amb} range between −15.4 and 4.9°C with an averaged difference of −2.3°C and a standard deviation of 2.6°C. The linear fit has an offset of 2.5°C and a slope of 0.61. The correlation between T_{zero} and T_{amb} is 0.85. According to the manufacturer the derivation of the zero temperature should be better during clouded conditions. In order to investigate this effect a scatter plot was made including only the temperature data when the total cloud cover reported by the Nubiscope exceeded 30%. The differences now range between −9.9 and 4.9°C with an averaged difference of −1.4°C and a standard deviation of 1.3°C. The linear fit for the clouded situations has an offset of 1.7°C and a slope of 0.87 and the correlation between T_{zero} and T_{amb} is 0.91. Hence during clouded situations the agreement between the Nubiscope zero temperature and the ambient temperature is better, but the errors in the zero temperature still are considerable and should only be used if no ambient temperature measurement available. An error of 0.6°C corresponds to an error of about 100m in altitude for a standard atmosphere.

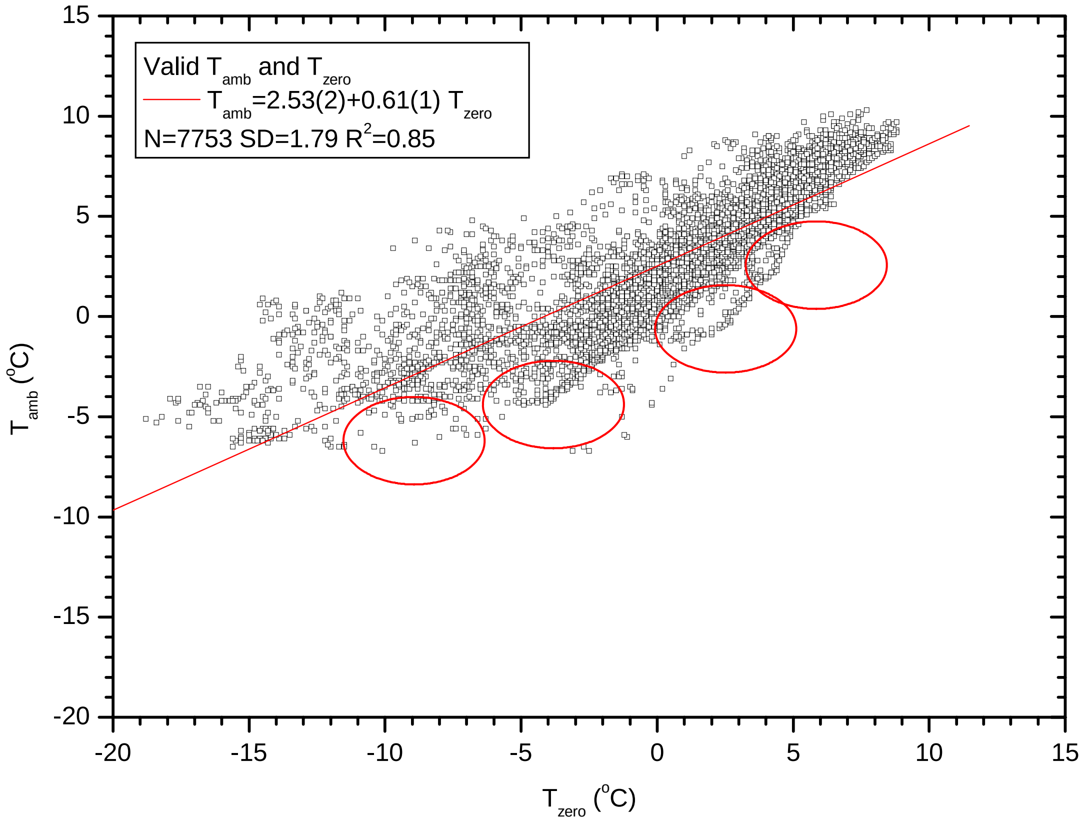

Figure 8: Scatter plot of Nubiscope zero temperature versus the ambient temperature observed at De Bilt.

3.3. Sky obscuration types

The Nubiscope makes a distinction of the sky obscuration based on the sky temperature measurements. The measurements near the horizon are used for the discrimination of fog events while the dependence with elevation is used to distinguish between light and dense fog. In the absence of fog the sky obscuration is given in relation to the cloud cover. An overview of the sky obscuration types reported by the Nubiscope during the test in De Bilt is given in Figure 9. The figure shows again the 37 cases where the Nubiscope provided no data (NA). It should be noted that the classification of clear sky (CS) and overcast (OC) are directly related to the cloud cover of 0 and 8 okta, respectively, as is the case in synoptic and aeronautical applications. The classification of broken (BC) is not like in aeronautical applications directly related to the cloud cover (5 to 7 okta), but the Nubiscope uses broken in order to indicate clouds that are distributed over more than 1 layer. In these cases the cloud cover is reported and allows direct comparison with other results. This will be discussed in section 3.4. The cirrus clouds only classification (CI) means that none of the three previous cloud classifications applies. However, since no cloud cover, temperature and height information is provided these 83 cases cannot be considered in section 3.4. The fog cases are separated in light and dense fog. No light fog cases were reported during the test of the Nubiscope at De Bilt. In case of fog the Nubiscope total cloud cover is set to 9 okta and the associated cloud base height is, in the absence of a reported temperature and base by the Nubiscope system, set to 9m. The identification unknown (IU) occurs 50 times and denotes the cases where discrimination between fog and clouds was not possible. In this situation the Nubiscope reports the total cloud cover and main cloud base, but not the temperature nor the cloud base height of the lowest cloud layer.

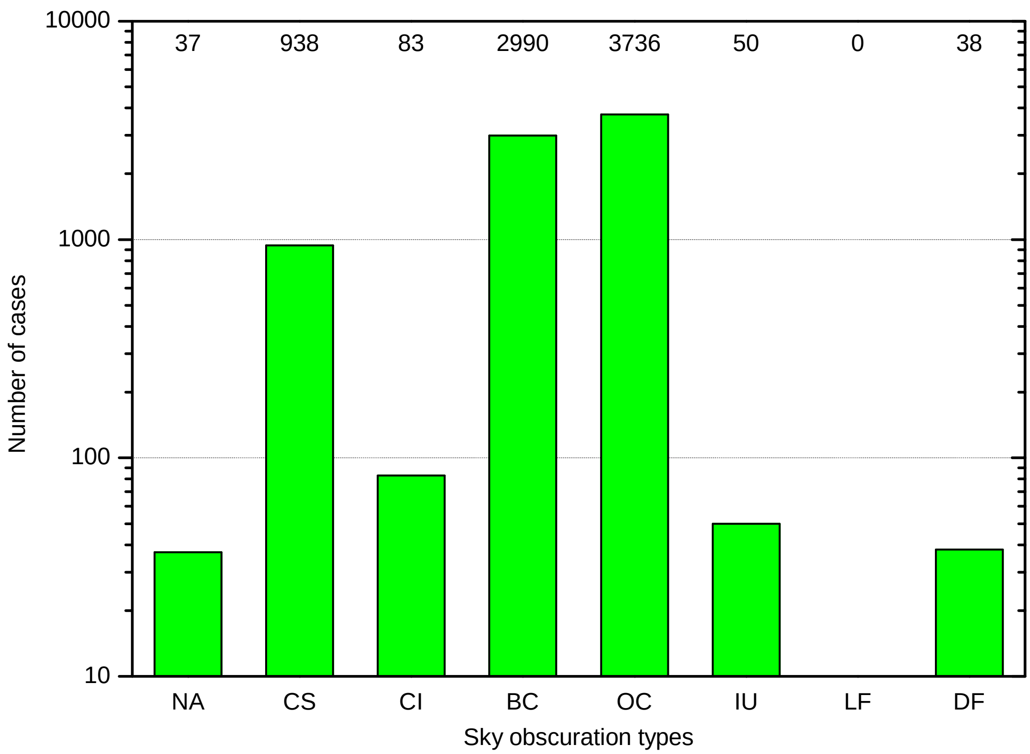

Figure 9: histogram of the sky obscuration types reported by the Nubiscope during the test at De Bilt.

The relatively few cases with unknown classification and fog are considered here in more detail. The Nubiscope reported 38 cases with dense fog (DF). Of all 38 cases, only 11 were reported by the ceilometer algorithm as situations with sky obscure, i.e. only 1 cloud layer detected with base below 500ft, total cloud cover 8 okta and visibility below 1km. In one case the ceilometer reported a total cloud cover of 7 okta, with a low cloud base, but in all other 26 cases the situation was reported by the ceilometer as overcast (8 okta) with a cloud base below 500ft. The visibility was below 1km in only 5 cases whereas in the other 21 cases it was between 1 and 6km. In the 5 cases with overcast and visibility below 1km the ceilometer reported more than one cloud layer, which de-classifies these case as sky obscured. Hence only 42% of the Nubiscope reports of DF agree with a visibility below 1km, whereas nearly all DF cases occurred during overcast situations with a low cloud base height. Figure 10 shows the measurements obtained on January 19, 2006 at de Bilt. The ceilometer cloud base and visibility measurements show that the sky obscured situation occurred between 1 and 6 UT, whereas the Nubiscope reports broken and overcast situations with 2 unknown identification events between 1 and 2 UT. Between 6 and 10 UT the low cloud base reported by the ceilometer lifts and dissipates and a second cloud layer is detected above 2000ft. The Nubiscope reports 4 cases of dense fog between 17 and 22 UT during which the FD12P sensor reports visibilities above 1km, although the visibility values are close to 1km between 17 and 19UT.

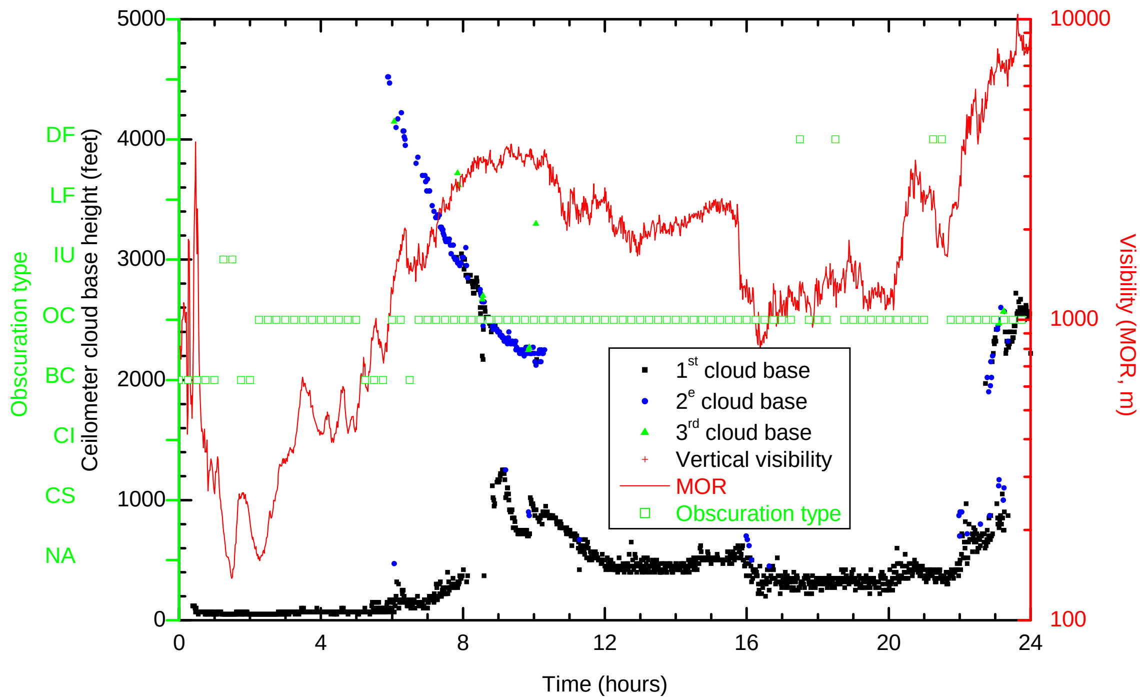

Figure 10: The cloud base reports of the ceilometer, the visibility measured by the FD12P and the sky conditions reported by the Nubiscope on January 19, 2006 in De Bilt.

There are 50 cases where the Nubiscope reports unknown identification (IU) and in all of these cases the cloud cover reported by the Nubiscope is above 98%. 2 cases on January 19, 2006 correspond with sky obscured situations according to the ceilometer and FD12P results, in 1 case the ceilometer reports a total cloud cover of 6 okta, but the other 47 cases correspond with overcast situations. The 47 overcast cases according to the ceilometer results all have a visibility above 1km and in 29 and 45 cases the cloud base is below 500 and 2000ft, respectively. The 83 cases where the Nubiscope reports cirrus cloud only (CI) occur over the full range of cloud cover according to the ceilometer. Mostly the ceilometer cloud cover is low (44 and 16 cases with 0 and 1 okta, respectively), but 3 cases with 8 and 9 okta also occur during the unknown classification. The 39 cases where the ceilometer detects clouds can be divided in 23 cases with a low cloud base (<2100m), 10 cases with a middle cloud base, and 6 cases where only clouds with high cloud base are detected (>5400m).

Hence, the Nubiscope performs not well in the detection of fog cases. In fact, the FD12P reported a total of 427 15-minute intervals with an averaged visibility below 1km, whereas the Nubiscope only reports 38 cases of fog and even then the agreement with actual fog cases, according to the FD12P present weather sensor, is only 42%. The differences in the reported visibility cases of Nubiscope and present weather sensor can partially be ascribed by the difference in altitude of these 2 instruments. On the other hand, almost all dense fog and unknown identification cases reported by the Nubiscope correspond with situations where the ceilometer reports overcast with a low cloud base, but structures in the cloud base and particularly the visibility prevent a classification of these cases as sky obscured or fog.

3.4. Total cloud cover

An intercomparison of the total cloud cover results obtained by the Nubiscope and the ceilometer for De Bilt between December 2005 and February 2006 is shown in Table 2. The AUTOSYNOP results denote the results of the cloud algorithm using 30 1-minute cloud base reports of the ceilometer. The algorithm is evaluated every 15-minutes with a 5 minute shift so that the Nubiscope measurements obtained from the time interval hh:15*n - hh:15*n+6 is compared with the ceilometer results of hh:15*n-25 - hh:15*n+5. The grey cells show the cases without valid Nubiscope or ceilometer data. Note that apart from the 37 cases of missing Nubiscope data also the 83 unknown classification cases do not report a total cloud cover. The green cells indicate the cases with perfect agreement, whereas the yellow and white cells indicate the cases within ±1 and ±2 reporting classes, respectively. The relative number of valid cases within these three areas is reported as band0, band1 and band2. Furthermore, the averaged differences $\langle n_{ceilo}-n_{nubi} \rangle$ and the averaged absolute differences $\langle |n_{ceilo}-n_{nubi}| \rangle$ are reported as well as the relative number of valid cases denoting a miss (red area) and a false alarm (blue area). Finally the averaged automated cloud cover and cloud base height per observed class is reported and vice versa.

The results can be compared to the results obtained for the evaluation of automated versus manual cloud observations for 3 years at 6 locations (cf. Wauben et al., 2006). This evaluation showed averaged scores of: band0=39±5%, band1=75±3%, band2=87±2%, $\langle \Delta n \rangle = -0.2 \pm 0.3$, $\langle |\Delta n| \rangle = 1.2 \pm 0.2$, Miss=10±3%, False=4±2%. The intercomparison of the Nubiscope with the automated ceilometer results gives better scores for band0, band1, band2, $\langle |\Delta n| \rangle$ and miss. These differences could be expected since the evaluation of the Nubiscope was based on only 2½ months of measurements during which mostly stratiform clouds were present. In these situations the spatial representativeness of the ceilometer measurements is not really a problem. Still, many cases occur where the Nubiscope and ceilometer show large differences and where the Nubiscope might provide additional information. The ceilometer reports 239 cases with sky obscured of which only 11 are characterized as such by the Nubiscope. In 200 cases the Nubiscope reports overcast and in 1 case the Nubiscope reports no clouds at all. The latter is probably a situation with shallow fog that obstructed the measurement of the ceilometer on the field whereas the Nubiscope observed a clear sky from the top of the building. The number of cases with overcast situations is large for the Nubiscope and particularly the ceilometer measurements. The Nubiscope reports much more cases with 7 okta then the ceilometer since the chance of observing a hole in a cloud deck is larger due to the spatial information. The higher frequency of occurrence of 7 and 1 okta can also be observed when comparing the ceilometer total cloud cover with manual cloud observations. However, the values in the low cloud cover range of Table 2 do not show this behavior. The ceilometer data show many cases with 1 okta. This is the result of a problem with the ceilometer operated at De Bilt during this test. As a result the ceilometer reports isolated faulty cloud reports between 10,000 and 15,000ft during clear sky conditions. When instead the ceilometer data of station De Bilt Test (06261) are used the isolated faulty cloud hits are not present and the behavior of the results at 0 and 1 okta is more as could be expected (cf. Table 3), i.e. the Nubiscope shows (slightly) less cases with 0 and more cases with 1 okta compare to the ceilometer. The absence of the faulty hits have little effect on the overall scores.

Table 2: Comparison of Nubiscope and ceilometer (260) total cloud cover observed at De Bilt between December 2005 and February 2006.

Total cloud cover (n in okta)

	AUTOSYNOP →												
NUBI ↓	***NA***	***0***	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***Sum***	***<n>***
NA	0	10	43	13	11	6	2	1	4	29	1	120	
0	1	157	679	55	19	11	11	2	1	1	1	938	1.05
1	4	32	129	45	35	37	27	16	12	6	0	343	2.46
2	6	12	42	14	29	28	17	18	10	10	0	186	3.40
3	5	7	29	11	20	15	14	14	19	13	0	147	3.96
4	3	2	22	14	13	14	17	16	21	23	1	146	4.66
5	9	0	11	6	12	8	15	22	39	34	0	156	5.73
6	11	0	3	3	12	10	16	24	60	86	0	225	6.62
7	72	1	16	11	13	32	63	80	289	1327	25	1929	7.47
8	63	0	0	1	4	6	12	16	115	3227	200	3644	7.99
9	1	0	0	0	0	0	0	0	0	26	11	38	8.30
Sum	175	221	974	173	168	167	194	209	570	4782	239	7872	
<n>		0.44	0.62	1.84	2.93	3.52	4.58	5.29	6.49	7.61	7.89		

Band0 = 51.5% Band1 = 87.6% Band2 = 93.6% <Δn> = 0.40 <|Δn|> = 0.73 Miss = 2.1% False = 4.3%

Table 3: As Table 2, but now the ceilometer and visibility data of station De Bilt Test (06261) is used.

Total cloud cover (n in okta)

	AUTOSYNOP →												
NUBI ↓	***NA***	***0***	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***Sum***	***<n>***
NA	0	48	19	11	3	2	2	1	2	31	1	120	
0	0	800	87	19	13	5	9	2	0	1	2	938	0.28
1	0	133	77	30	29	23	25	14	11	1	0	343	1.78
2	0	47	32	16	29	15	14	16	10	7	0	186	2.70
3	0	21	21	18	18	14	9	16	18	12	0	147	3.61
4	0	10	30	12	2	14	20	18	17	23	0	146	4.29
5	1	9	8	8	10	11	16	19	41	33	0	156	5.44
6	1	3	5	5	10	13	16	19	61	92	0	225	6.49
7	22	9	16	26	26	44	71	91	289	1310	25	1929	7.32
8	6	3	2	5	9	11	9	15	128	3246	210	3644	7.96
9	0	0	0	0	0	0	0	0	1	26	11	38	8.26
Sum	30	1083	297	150	149	152	191	211	578	4782	249	7872	
<n>		0.46	1.88	3.28	3.51	4.53	4.79	5.39	6.56	7.63	7.88		

Band0 = 58.4% Band1 = 87.3% Band2 = 93.0% <Δn> = 0.18 <|Δn|> = 0.68 Miss = 3.5% False = 3.5%

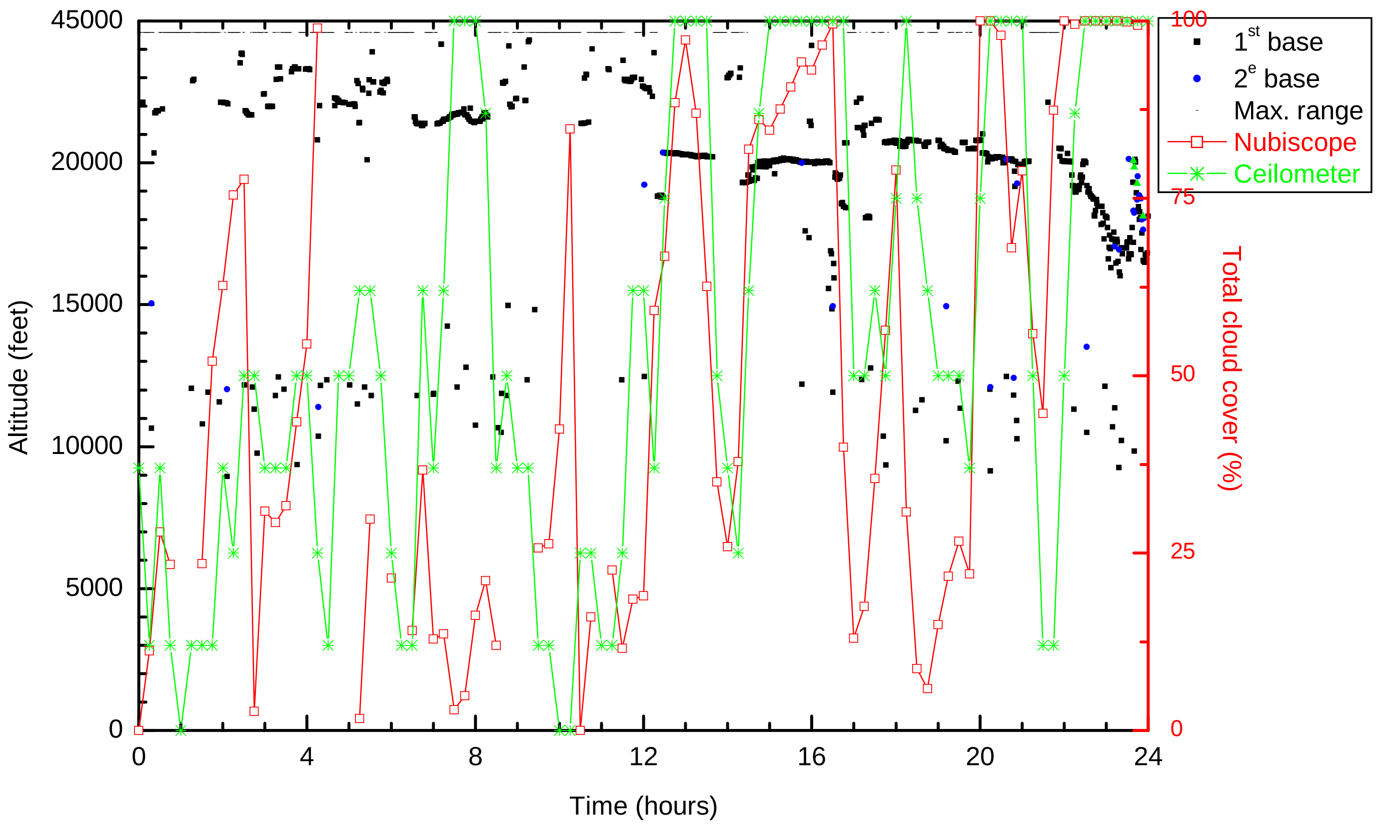

Figure 11: The cloud base reports of the ceilometer (260) and the total cloud cover reported by the Nubiscope and cloud algorithm on January 24, 2006 in De Bilt.

The day with the largest averaged absolute difference between Nubiscope and ceilometer total cloud cover is shown in more detail in Figure 11. On January 24, 2006 the averaged absolute difference was 2 okta. The figure clearly shows the isolated faulty cloud reports of the ceilometer at De Bilt 260. Furthermore only high clouds are observed (note the different vertical scale between 20,000 and 45,000ft). The Nubiscope only reports middle and high clouds. In some case the Nubiscope total cloud cover closely follows the main cloud layers observed by the ceilometer, e.g. around 13, between 14-16, between 20-21 and after 22 UT. However, the ceilometer features around 8 and 18 UT are not reproduced by the Nubiscope. The results for January 24, 2006 are also typical for situations where the Nubiscope results less total cloud cover than the ceilometer. The maximum averaged daily underestimation by the Nubiscope is 0.9 okta and occurs on 3 days with many faulty ceilometer reports. On January 24 the averaged underestimation by the Nubiscope underestimation is 0.8 okta. If the evaluation is limited to cases where the ceilometer cloud base is below 15,000ft the averaged scores hardly change. With a properly working ceilometer the differences are less. The ceilometer and visibility data of station De Bilt Test (261) will be considered in the remaining part of this report.

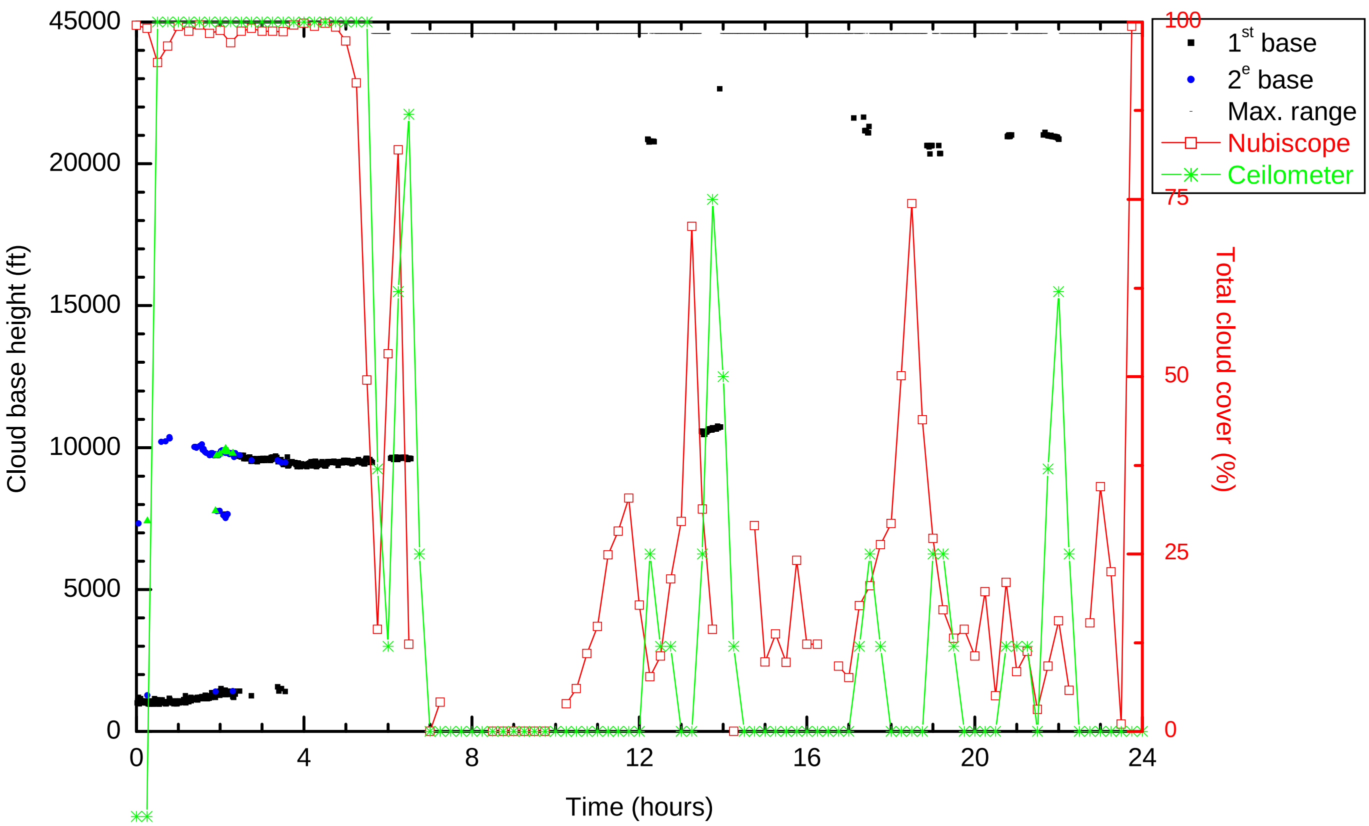

Figure 12: The cloud base reports of the ceilometer (261) and the total cloud cover reported by the Nubiscope and cloud algorithm on December 1, 2005 in De Bilt.

It should be noted that for high clouds the spatial representativeness of the ceilometer data need not be good and the sensitivity of the ceilometer as well as the Nubiscope is less for high, and especially thin, clouds. For January 24, 2006 (cf. Figure 11) the gaps in the Nubiscope cloud base height results before up to 11UT (8 measurements in total) are all situations where the Nubiscope reported cirrus only (CI classification), and hence did not report cloud base height. During the field test there were 2 other days with a large number of CI classifications. On December 1, 2005 (cf. Figure 12) the Nubiscope reports cirrus around 8UT while the ceilometer reports no clouds at all, whereas the 2 cirrus classifications around 14 and 22UT occur around times when the ceilometer reports high clouds. In fact the ceilometer reports a several isolated situations with high clouds during the afternoon with clear sky otherwise, while the Nubiscope almost continuously reports about 2 okta. On December 28, 2005 the Nubiscope reports cirrus around 11, 16 and 20UT during which the ceilometer reports no clouds at all. The ceilometer reports solely high clouds between 13 and 14UT while the Nubiscope reports 1 to 2 okta of clouds between 12:30 and 14:40UT.

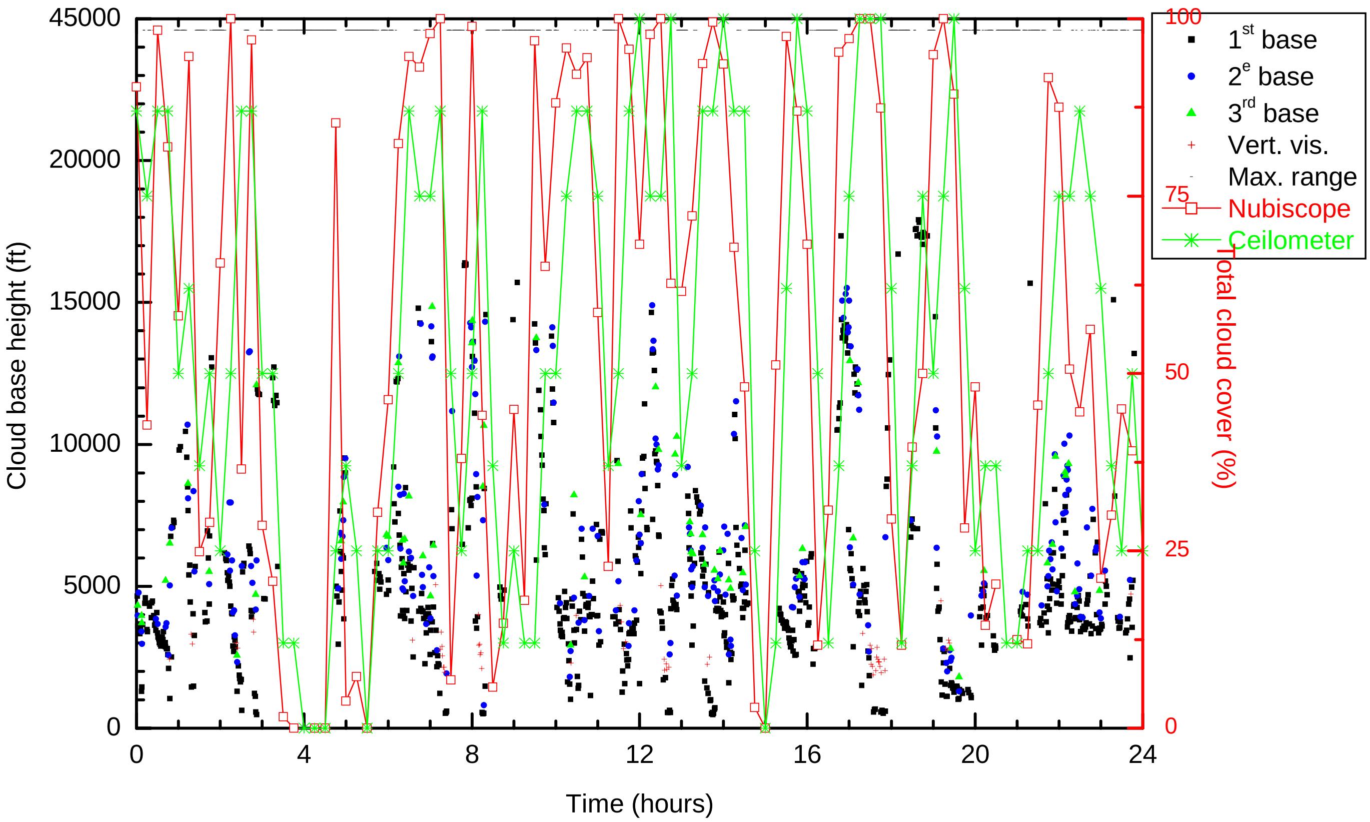

Figure 13: The cloud base reports of the ceilometer (261) and the total cloud cover reported by the Nubiscope and cloud algorithm on December 17, 2005 in De Bilt.

In Figure 13 the ceilometer and Nubiscope results are shown for December17, 2005, i.e. a day with cumulus clouds. In these situations large differences can also be expected. The behavior of the curves for the total cloud cover of the Nubiscope and ceilometer show, however, large similarities. The amount of clouds passing over the ceilometer in 30-minutes is in this particular cloudy situation rather representative of the cloud cover of the entire sky as reported by the Nubiscope, although differences up to 6 okta occur. The Nubiscope often reports the changes earlier compared to the ceilometer, which might be expected since the Nubiscope observes the cloud in all direction whereas the ceilometer can only report what already passed over the instrument. The delay that can be observed is typically about 15 minutes and is related to the 30-minute history used in the ceilometer cloud algorithm and the 15-minute scan interval of the Nubiscope. The

Nubiscope results show large variations in total cloud cover from one 15-minute scan to the next. In the ceilometer results the variations from one to the next 15- minute interval are smoothed by the 30-minute history.

3.5. Lowest cloud layer

In this section the cloud cover and height of the lowest reported cloud layer is compared. The ceilometer cloud algorithm generates a new layer when the difference in height between individual cloud layers exceeds a threshold, which is a function of the cloud base height of the lower layer and increases with height. The Nubiscope reports the lowest detected cloud layer. However, sometimes a lowest layer is not reported and the corresponding cloud cover is not clear. Therefore the lowest layer of the Nubiscope is determined as follows. The lowest layer cloud cover is the smallest (if existing) of the fraction of cloud below the main cloud deck or the main cloud deck and the fraction of low clouds. If none of these exist then the fraction of middle, or high clouds, or else the total cloud cover is used instead. In case of fog the fraction of low clouds is set to 9 okta. The base of the lowest cloud is the either the main cloud base height or the height of the lowest layer and if both exist then the lowest value. In case of fog a cloud base height of 9m is adopted. The upper part of Table 4 shows the contingency table of the cloud cover of the lowest layer reported by the ceilometer and the Nubiscope. The agreement is less good than for the total cloud cover. The ceilometer tends to report lower cloud amount for the lowest layer than the Nubiscope. This could be expected, because for cloud base heights below 5000ft the ceilometer algorithm uses a layer separation of 100-500ft, which is much finer than can be obtained for the sky temperature measurements, given the uncertainty of the cloud base temperature as a function of zenith angle and the corresponding height determination. However, there are also quite a lot of cases where the lowest layer cloud cover of the Nubiscope is smaller than the corresponding ceilometer results. This is probably caused by spatial information of the Nubiscope, which enhances detection of a separate cloud layer. Hence the cloud amounts of the lowest layer show missed and false alarm percentages of 31 and 11%, respectively, whereas they were 4% for the total cloud cover.

The middle and lower part of Table 4 show the contingency table for the lowest cloud base heights reported by the ceilometer and the Nubiscope in the reporting steps for the cloud base in the SYNOP reports, which focuses on the low cloud base heights, and the ceiling height, i.e. the cloud base height at which a cloud amount of 4 okta is exceeded, that is used in aviation. The tables show that the ceilometers generally gives lower cloud base and ceiling heights than the Nubiscope. In this case this least to more false alarms compared to misses, particularly for the lowest cloud base height. Again the differences are larger than when ceilometer results are compared to a visual observer. When the main cloud amount and base of the Nubiscope are compared to the first ceilometer layer the results are nearly the same as for the lowest layer. The lesser agreement between ceilometer and Nubiscope for the cloud amount and cloud base height of the lowest layer and ceiling compared to ceilometer and observer is probably caused by the fact the when comparing ceilometer results with the Nubiscope, not only the spatial information leads to differences, but also the uncertainties in the height information of the Nubiscope. The latter does not affect the results of the total cloud amounts. However, the differences could also be the results of the better spatial information for the Nubiscope during night time, when a visual observation can be rather restricted and probably relies more on the available ceilometer readings. The effect of spatial information and the uncertainties in the height determination of the Nubiscope are discussed in section 3.7.

Table 4: Comparison of Nubiscope and ceilometer cloud cover and cloud base height of lowest cloud layer and the ceiling height observed at De Bilt between December 2005 and February 2006.

Total cloud cover (n in okta)

	AUTOSYNOP →												
NUBI ↓	**NA**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Sum**	**<n>**
NA	0	4	10	4	1	2	2	3	2	9	0	37	
0	0	844	126	25	13	3	6	0	1	0	3	1021	0.29
1	9	149	377	127	90	68	51	43	38	67	20	1039	2.59
2	2	49	213	78	56	38	32	32	23	62	11	596	3.03
3	3	15	135	74	37	28	21	25	40	72	16	466	3.80
4	7	9	108	48	22	32	16	24	24	52	18	360	3.88
5	0	5	58	28	19	11	15	11	10	33	11	201	3.93
6	1	2	40	18	14	17	5	7	13	30	16	163	4.49
7	5	5	195	122	69	37	39	27	30	147	7	683	3.83
8	3	1	619	310	276	266	199	194	210	1054	136	3268	5.03
9	0	0	1	0	1	3	1	5	5	11	11	38	7.18
Sum	30	1083	1882	834	598	505	387	371	396	1537	249	7872	
<n>		0.38	4.54	5.16	5.49	5.82	5.77	5.87	6.00	6.88	6.22		

Band0 = 31.8% Band1 = 49.5% Band2 = 59.2% <Δn> = -1.22 <|Δn|> = 2.44 Miss = 30.8% False = 10.0%

Cloud base height (h in height class)

	AUTOSYNOP →												
NUBI ↓	**NA or n=9**	**<50m**	**<100m**	**<200m**	**<300m**	**<600m**	**<1000m**	**<1500m**	**<2000m**	**<2500m**	**> or n=0**	**Sum**	**<h>**
NA or n=9	0	0	1	5	4	8	6	6	1	1	5	37	
<50m	38	38	88	127	32	60	13	4	1	0	87	488	3.46
<100m	16	20	33	174	68	96	25	5	0	0	0	437	2.67
<200m	20	17	22	153	145	140	45	3	0	0	0	545	2.98
<300m	24	16	11	39	64	139	53	6	1	1	0	354	3.49
<600m	54	14	31	114	206	541	279	28	5	1	1	1274	3.82
<1000m	36	23	6	74	194	390	331	207	13	1	4	1279	4.29
<1500m	32	18	7	44	73	186	187	292	43	7	7	896	4.82
<2000m	26	15	2	21	14	89	87	65	42	12	27	400	5.08
<2500m	10	6	1	5	10	29	28	25	12	10	44	180	5.92
> or n=0	23	43	32	63	49	125	133	97	55	31	1331	1982	7.49
Sum	279	210	234	819	859	1803	1187	738	173	64	1506	7872	
<h>		4.39	2.64	3.00	3.98	4.46	5.25	6.09	7.16	7.89	8.39		

Band0 = 37.5% Band1 = 65.4% Band2 = 80.6% <Δh> = -0.43 <|Δh|> = 1.47 Miss = 5.3% False = 14.1%

Ceiling height (ft)

	AUTOSYNOP →									
NUBI ↓	**NA**	**<100m**	**<200m**	**<300m**	**<500m**	**<1000m**	**<1500m**	**> or n<5**	**Sum**	**<h>**
NA	0	0	0	0	2	5	6	24	37	
<100m	0	19	12	12	36	35	19	92	225	4.14
<200m	0	19	5	11	34	32	9	16	126	3.16
<300m	0	11	9	8	19	56	9	24	136	3.64
<500m	0	21	12	5	61	138	64	70	371	4.04
<1000m	2	36	13	5	37	190	127	149	559	4.35
<1500m	1	41	2	5	22	105	117	214	507	4.68
> or n<5	27	183	21	22	74	342	467	4775	5911	5.55
Sum	30	330	74	68	285	903	818	5364	7872	
<h>		4.70	3.34	3.22	3.38	4.34	5.07	5.73		

False = 5.4%

Band0 = 66.3% Band1 = 81.2% Band2 = 90.3% <Δh> = -0.11 <|Δh|> = 0.77 Miss = 4.4%

3.6. Zenith measurements and cloud base height errors

A more direct way to compare the Nubiscope and the ceilometer results is by considering the 36 zenith measurements of the Nubiscope only. The cloud base temperature, cloud mask and cloud base height determinations of the Nubiscope are compared to the ceilometer results. Since the Nubiscope measurements are performed between hh:m*15-hh:m*15+6 only 7 1-minute cloud base reports of the ceilometer corresponding to this time interval are considered in order to get a better agreement. The results are reported in Table 5. The agreement between ceilometer and Nubiscope is better compared to the case when 30-minutes of ceilometer and the Nubiscope results below a zenith angle of 70º are used. The agreement is, however, largely determined by the large fraction of overcast situations which is large as a result of the smaller time interval of the ceilometer data and the reduced spatial coverage of the Nubiscope data. Some situations where either Nubiscope or ceilometer report overcast and the other reports clear sky also occur. These cases with 8 okta difference in total cloud cover include some situations where the ceilometer is situated in shallow fog, but mostly the situations are cases with high clouds. On January 24, 2006 (cf. Figure 11) 3 cases with ceilometer and 2 with Nubiscope overcast situations occur while the other sensor reports clear sky. The collocation of the ceilometer and the Nubiscope is probably not easy because of the differences in field of view and sensitivity. In addition, the ceilometer is tilted 5º from the vertical to the North in order to reduce its sensitivity to precipitation (Giles, 2001) so that the zenith measurements of the Nubiscope do not overlap with the ceilometer The cloud base height of the Nubiscope and the ceilometer in Table 5 show less agreement for the zenith results than for the overall results. In situations with a low ceilometer cloud base the Nubiscope quite often reports a higher cloud base. However, in general the cloud base reported by the Nubiscope zenith measurements is lower than the ceilometer cloud base.

The reasons for these differences is illustrated in Figure 14, which shows the ceilometer cloud base and the Nubiscope main cloud base temperature and height on December 30, 2005. This day was selected since the cloud base varies between 20,000 and 500ft during the day. Between 0-6 UT and 17-24 UT the cloud base is about 500ft. After 17 UT the agreement of the cloud base height of Nubiscope and ceilometer is good although the Nubiscope reports a decreasing cloud base at the end of the day. Between 0-6 UT the differences between ceilometer and Nubiscope are larger and the Nubiscope generally overestimated the cloud base height. The reason for this is probably that the cloud base is partly transparent, the ceilometer sometimes detects a second cloud base, which means that the observed temperature is colder and hence the derived altitude of the Nubiscope is higher. Between 11 and 17 UT the cloud base decreases from 20,000 to about 1000ft. This decrease is also observed by the Nubiscope, but the decrease is much steeper. Around 9 UT a cloud is present at 16,000ft. The height of this cloud is underestimated by the Nubiscope, but another striking feature of the Nubiscope is that before and after the cloud is observed by the ceilometer the Nubiscope reports a much colder/higher main cloud base. The ceilometer cloud base height and the Nubiscope cloud base main cloud base temperature are shown on a temperature profile plot in Figure 15. The temperature profiles of the radio soundings of December 30, 2005 at 0 UT, 12 UT and December 31, 2005 at 0 UT are also shown. The temperature data are generally within the limits determined by the radio sonde profiles. However, at low cloud base heights many too cold temperatures are reported and about 5 such cases occur around 5km. These are probably all cases with partial or semi transparent clouds in the field of view of the Nubiscope. Only in 1 case (at 12:30 UT) is the reported cloud base temperature much higher than could be expected from the associated observed cloud base height and the temperature profile. In this case the Nubiscope detected a lower cloud layer. The ceilometer shows some lower cloud base hits after 12:50UT.

Table 5: Comparison of Nubiscope and ceilometer cloud cover and cloud base height observed at De Bilt between December 2005 and February 2006 using the zenith measurements and the corresponding 7 minutes of ceilometer data.

Total cloud cover (n in okta)

	AUTOSYNOP →												
NUBI ↓	**NA**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Sum**	**<n>**
NA	0	7	0	0	0	0	0	0	0	30	0	37	
0	0	1271	63	32	17	0	7	5	3	14	0	1412	0.27
1	0	67	25	13	22	0	19	14	5	9	0	174	2.32
2	0	18	7	7	9	0	18	18	6	7	0	90	3.82
3	0	12	7	7	12	0	9	11	16	10	0	84	4.29
4	0	9	3	3	7	0	10	17	19	25	0	93	5.54
5	1	9	3	1	5	0	5	11	16	34	0	85	5.89
6	0	2	1	1	4	0	7	4	21	69	0	109	7.09
7	10	8	1	2	5	0	12	33	55	870	0	996	7.73
8	15	26	11	19	21	0	20	24	83	4573	0	4792	7.85
9	0	0	0	0	0	0	0	0	0	0	0	0	#DIV/0!
Sum	26	1429	121	85	102	0	107	137	224	5641	0	7872	
<n>		0.35	1.55	2.79	3.49	#DIV/0!	4.05	4.77	6.23	7.74	#DIV/0!		

Band0 = 76.2% Band1 = 91.7% Band2 = 94.7% <Δn> = 0.16 <|Δn|> = 0.46 Miss = 2.0% False = 3.3%

Cloud base height (h in height class)

	AUTOSYNOP →												
NUBI ↓	**NA or n=9**	**<50m**	**<100m**	**<200m**	**<300m**	**<600m**	**<1000m**	**<1500m**	**<2000m**	**<2500m**	**> or n=0**	**Sum**	**<h>**
NA or n=9	1278	5	1	0	1	7	18	11	14	14	100	1449	
<50m	0	6	19	19	17	99	52	17	16	7	2	254	4.14
<100m	0	10	2	8	6	129	110	45	47	10	4	371	4.90
<200m	0	11	8	7	2	95	173	111	36	20	15	478	5.20
<300m	4	17	11	9	1	25	98	77	63	34	18	357	5.55
<600m	7	47	9	3	8	70	202	293	208	200	104	1151	6.19
<1000m	8	19	9	4	0	41	159	158	166	196	392	1152	7.15
<1500m	8	20	9	8	2	23	66	61	76	84	457	814	7.61
<2000m	4	18	4	3	0	12	32	27	43	26	198	367	7.36
<2500m	2	11	6	5	0	3	13	17	15	8	94	174	7.03
> or n=0	144	78	24	15	17	79	93	75	72	77	631	1305	7.01
Sum	1455	242	102	81	54	583	1016	892	756	676	2015	7872	
<h>		5.92	4.73	4.01	3.96	3.19	3.92	4.34	4.71	5.10	6.80		

Band0 = 15.8% Band1 = 29.8% Band2 = 47.8% <Δh> = 1.42 <|Δh|> = 2.61 Miss = 42.6% False = 9.6%

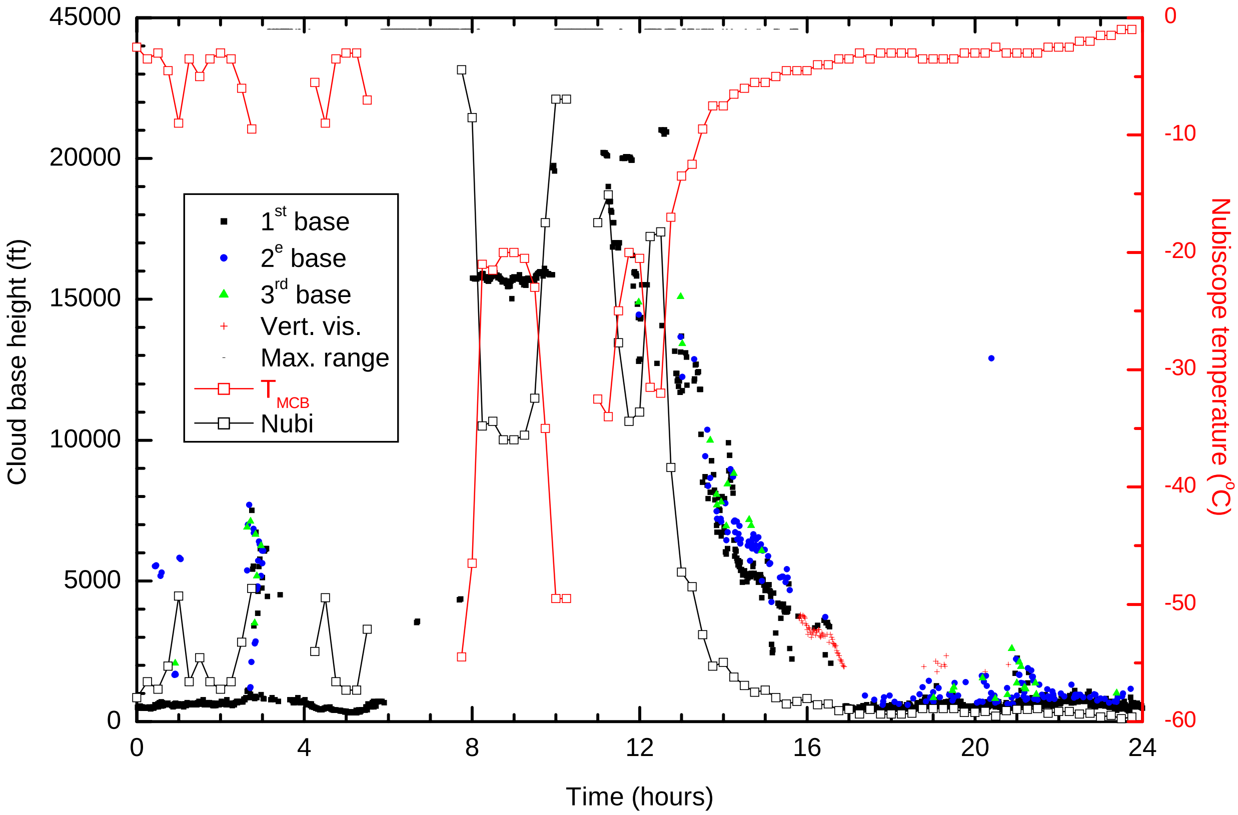

Figure 14: The cloud base reports of the ceilometer and temperature and altitude of the main cloud base reported by the Nubiscope on December 30, 2005 in De Bilt.

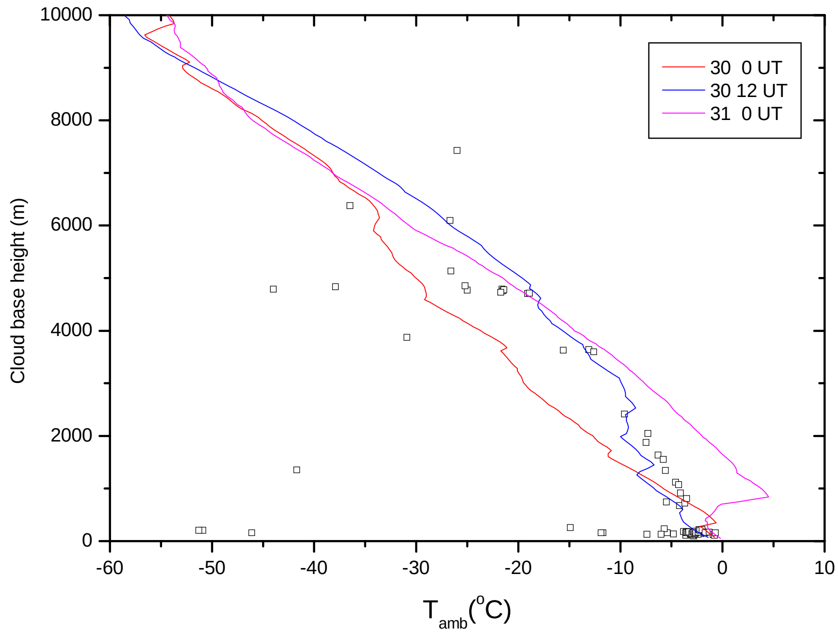

Figure 15: The ceilometer cloud base heights versus the Nubiscope main cloud base temperatures for the measurements of December 30, 2005 in De Bilt. The temperature profiles of the radio soundings are also shown.

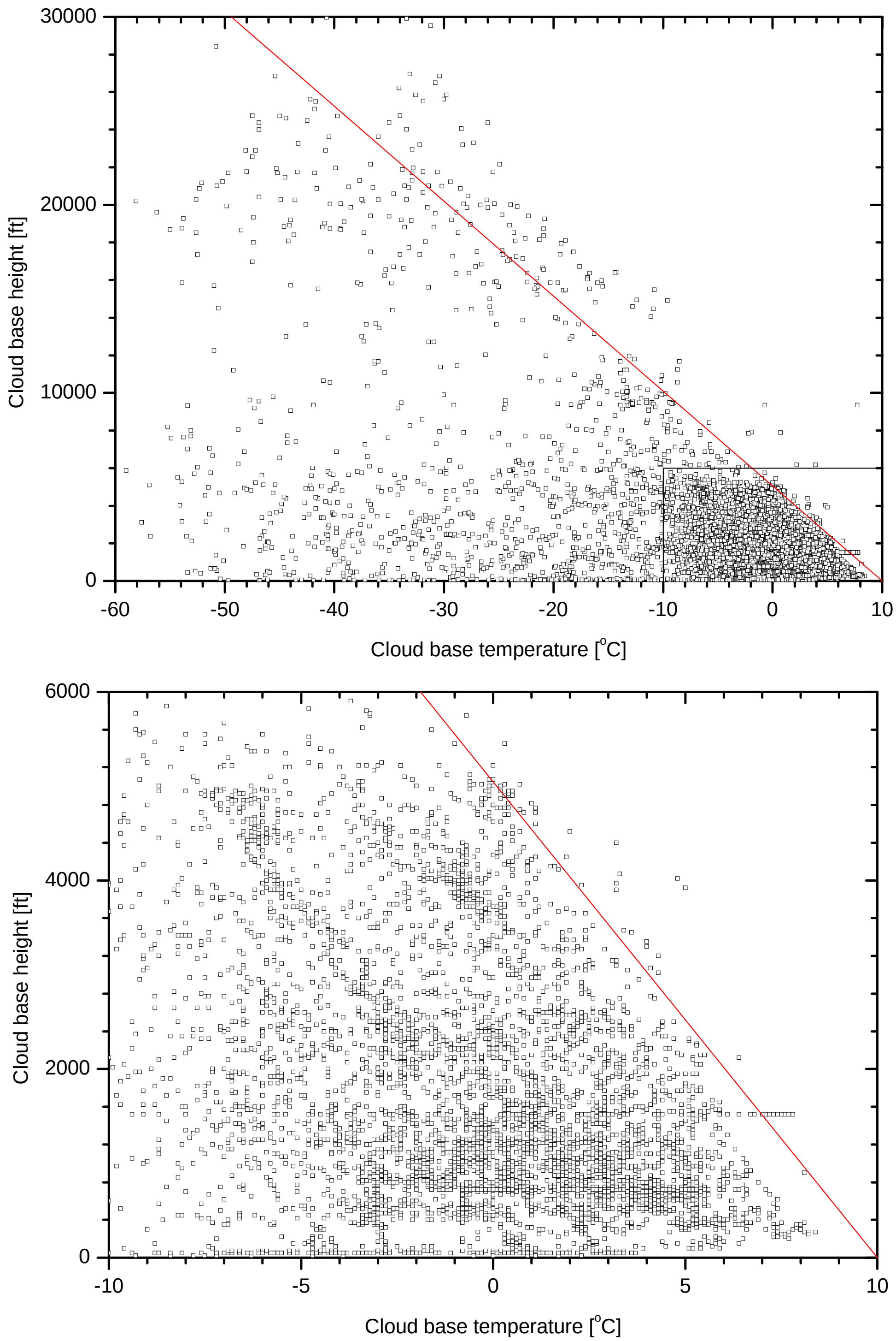

Figure 16: The cloud base temperature of the Nubiscope zenith measurements versus the ceilometer cloud base height. The adiabatic lapse rate of 6.5ºC per km is denoted by the red line. The lower panel shows the data below 6000ft.

Finally, the cloud base temperature of the zenith measurements of the Nubiscope are plotted against the ceilometer cloud base height in Figure 16. The data shows a large amount of scatter. Although the results are generally below and to the left of the red line denoting the adiabatic lapse rate, even is this is a crude representation of the actual temperature profile, it seems that only in a few cases the Nubiscope reports a cloud base that is warmer and hence below the base reported by the ceilometer. In most cases the Nubiscope cloud base temperature is too low as a report of partially clouded scenes or semi-transparent clouds. Even if the zenith sky measurements of the Nubiscope and ceilometer are restricted to overcast situations the behavior is the same. The plot also show many cases below 1000ft with cloud base temperatures as low as −50 ºC. The results below 6000ft also show much scatter, but this can partly be ascribed to the variations in the ambient temperature, which ranged within −10 en +10ºC during the period of the evaluation.

3.7. Cloud mask and effect of spatial information

The cloud mask files can be used to make the cloud cover available to users. An example of a cloud mask plot is given on the cover of this report. It should be noted that the 15 minute update interval of the Nubiscope is generally not fast enough in order to generate pictures that can be used to track cloud movements. For that purpose an update interval of about 1 minute is needed, and requires a camera system.

The effect of spatial information is investigated by considering the cloud mask data. The total cloud cover is determined from the cloud mask files by adding the amount of low, middle and high clouds and by counting the partially clouded cells half. The total cloud cover is determined for all zenith ranges between 1.5º and 67.5º in steps of 3º. Figure 17 shows the distribution of the total cloud cover of the okta intervals. The first entry given the results for the ceilometer. Next the results of the cloud mask are given whereby an increasing fraction of the sky is considered. The number of 0 and 8 okta cases decreases with increasing fraction of the sky used for determining the total cloud cover because the chance of the single cloud/hole detection increases. The ceilometer distributions obtained by using 30-minutes of data are generally similar to the Nubiscope results for a zenith angle of up to about 45º and show better agreement with the Nubiscope results for the full sky than the Nubiscope zenith measurements. Only the ceilometer results for 8 and 7 okta results show larger deviations from the Nubiscope measurements with increasing zenith angle range.

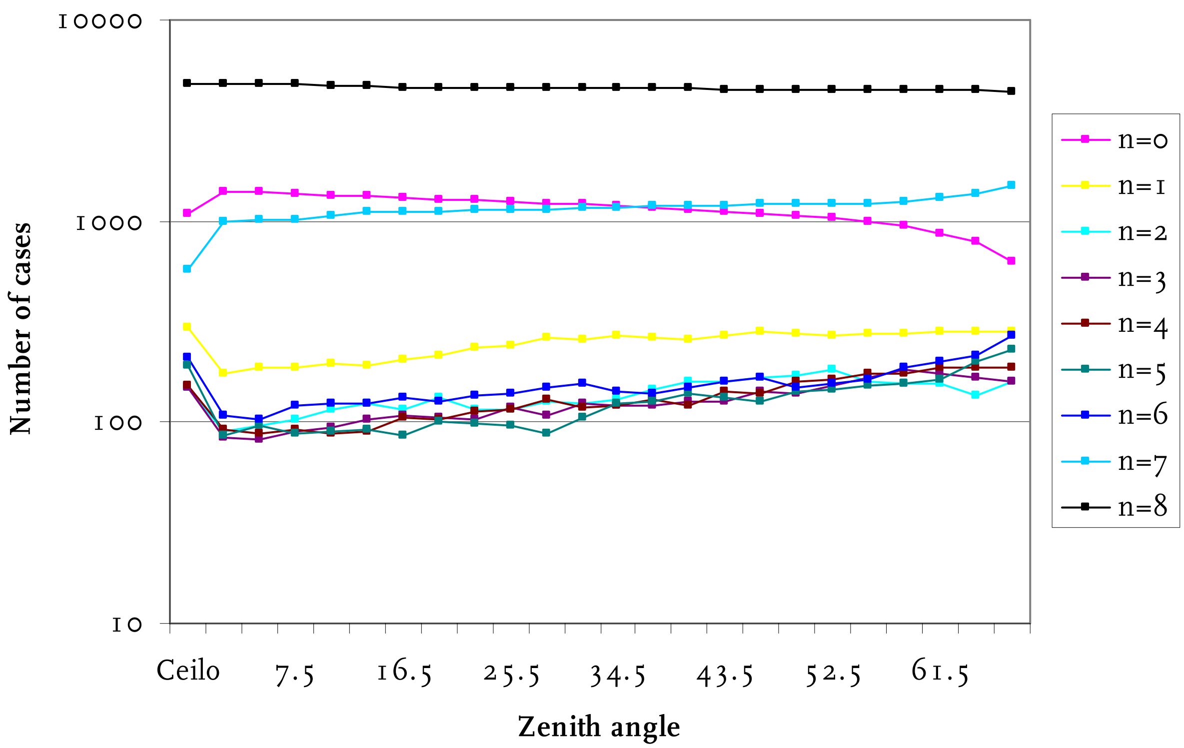

Figure 17: The number of cases per okta interval for the ceilometer results (first entry) and the number of cases per okta interval as a function of the zenith angle range used for the full sky total cloud cover evaluation.

Contingency matrices of ceilometer versus Nubiscope total, low, middle and high cloud cover are given in Table 6. Nubiscope cloud mask data up to zenith angles 34.5º are processed in this case. The total cloud cover results are already discussed before. Note however, that in about 85% of the time the ceilometer and Nubiscope report clouds. When a larger fraction of the sky is processed (cf. Table 7) the fraction of clouded Nubiscope cases increases slightly. As a result the fraction of false alarm cases decreases at the expense of the number of missed cases. Furthermore, the fraction in the bands decreases and the averaged difference $<n_{ceilo}-n_{nubi}>$ decreases and becomes negative. When only low clouds are considered the ceilometer reports more cases than the Nubiscope (80 versus 67%). The false alarm rate is 17% and 3% of the cases are in the missed category. Enhancing the zenith angle range of the Nubiscope increases the number of cases with low clouds and improves nearly all scores. For middle and high cloud the Nubiscope reports much more cases than the ceilometer. The fraction of missed cases is about 20% whereas the false alarms only constitute about 1-2% of the cases. The Nubiscope already reports much more middle and high cloud cases for the zenith measurements and this increases slightly with increasing zenith angle range. Hence the larger fraction of middle and high clouds can only partly be ascribed to the better spatial coverage, although the larger field of view of the Nubiscope compared to the ceilometer can also give a better coverage. On the other hand, partial and or semi-transparent clouds contribute to the larger amount of middle and high clouds in the Nubiscope measurements. The agreement between ceilometer and Nubiscope for high clouds deteriorates with increasing zenith angle range.

Table 6: Contingency matrix of ceilometer versus Nubiscope total, low, middle and high cloud cover. Nubiscope data up to zenith angles 34.5 are processed.

Total cloud cover (n in okta)

	AUTOSYNOP →												
NUBI ↓	**NA**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Sum**	**<n>**
NA	0	4	3	0	0	0	0	0	1	29	0	37	
0	0	903	149	45	33	17	20	10	6	4	3	1190	0.56
1	0	103	45	18	29	22	22	17	9	5	0	270	2.11
2	0	24	25	12	17	6	10	13	12	10	0	129	3.22
3	0	18	22	14	9	13	10	15	11	9	0	121	3.45
4	0	13	15	14	4	11	15	13	22	14	0	121	4.28
5	1	5	16	10	6	11	12	8	28	26	0	123	5.00
6	0	3	5	7	13	10	12	12	32	48	1	143	5.92
7	13	2	8	10	17	29	58	71	221	738	0	1167	7.25
8	16	8	9	20	21	33	32	52	236	3899	245	4571	7.85
9	0	0	0	0	0	0	0	0	0	0	0	0	#DIV/0!
Sum	30	1083	297	150	149	152	191	211	578	4782	249	7872	
<n>		0.35	1.56	3.08	3.36	4.60	4.85	5.52	6.80	7.76	7.90		

Band0 = 65.7% | Band1 = 87.6% | Band2 = 92.2% | <Δn> = 0.10 | <|Δn|> = 0.64 | Miss = 3.8% | False = 4.0%

nceilo= 86% nnubi= 85%

Low cloud cover (n in okta)

	AUTOSYNOP →												
NUBI ↓	**NA**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Sum**	**<n>**
NA	0	6	2	0	0	0	2	2	2	23	0	37	
0	2	1526	273	58	126	60	130	81	101	142	52	2551	1.75
1	0	12	15	3	28	17	55	37	49	90	6	312	5.73
2	4	5	3	1	4	6	29	25	31	59	6	173	6.38
3	0	2	3	0	4	2	20	15	24	43	0	113	6.42
4	1	3	1	0	3	0	32	29	32	53	3	157	6.53
5	2	2	1	0	5	2	13	17	22	57	2	123	6.77
6	3	1	1	0	5	2	28	28	43	87	2	200	6.84
7	3	7	0	1	3	1	61	63	68	254	4	465	7.02
8	15	6	2	2	6	3	176	213	312	2832	174	3741	7.68
9	0	0	0	0	0	0	0	0	0	0	0	0	#DIV/0!
Sum	30	1570	301	65	184	93	546	510	684	3640	249	7872	
<n>		0.10	0.20	0.43	1.00	0.95	4.35	5.21	5.35	7.13	5.91		

Band0 = 57.5% | Band1 = 73.2% | Band2 = 80.1% | <Δn> = 0.85 | <|Δn|> = 1.30 | Miss = 2.9% | False = 17.0%

nceilo= 80% nnubi= 67%

Middle cloud cover (n in okta)

	AUTOSYNOP →												
NUBI ↓	**NA**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Sum**	**<n>**
NA	0	36	0	0	0	0	0	0	0	1	0	37	
0	15	5465	50	10	18	14	13	14	17	16	0	5632	0.10
1	0	202	1	1	5	0	6	8	13	9	0	245	1.06
2	1	138	1	0	2	1	3	5	11	7	0	169	1.13
3	0	77	0	0	0	2	1	3	2	2	0	87	0.70
4	0	132	1	1	2	3	3	3	2	9	0	156	0.90
5	2	108	0	1	2	0	2	4	1	5	0	125	0.72
6	5	207	0	0	0	1	2	3	5	9	0	232	0.61
7	6	598	0	0	1	1	2	2	4	33	0	647	0.50
8	1	430	1	0	1	2	4	5	22	76	0	542	1.52
9	0	0	0	0	0	0	0	0	0	0	0	0	#DIV/0!
Sum	30	7393	54	13	31	24	36	47	77	167	0	7872	
<n>		1.45	0.28	0.77	1.35	2.04	2.64	2.79	3.74	5.92	#DIV/0!		

Band0 = 71.2% | Band1 = 75.4% | Band2 = 77.7% | <Δn> = -1.24 | <|Δn|> = 1.51 | Miss = 20.0% | False = 2.3%

nceilo= 6% nnubi= 28%

High cloud cover (n in okta)

	AUTOSYNOP →												
NUBI ↓	**NA**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Sum**	**<n>**
NA	0	36	1	0	0	0	0	0	0	0	0	37	
0	17	5469	30	5	5	0	2	1	5	5	0	5539	0.03
1	0	244	14	6	6	5	0	2	1	0	0	278	0.30
2	0	119	10	4	2	0	1	0	2	1	0	139	0.37
3	0	117	4	3	0	1	1	1	0	2	0	129	0.32
4	1	117	5	3	0	2	2	2	3	1	0	136	0.52
5	0	108	3	2	0	1	2	1	1	1	0	119	0.35
6	2	209	4	1	2	2	0	2	3	7	0	232	0.47
7	10	922	2	3	4	2	4	6	12	10	0	975	0.26
8	0	218	0	4	8	12	7	11	18	10	0	288	1.34
9	0	0	0	0	0	0	0	0	0	0	0	0	#DIV/0!
Sum	30	7559	73	31	27	25	19	26	45	37	0	7872	
<n>		1.50	1.65	3.35	4.22	5.72	5.63	6.15	5.96	5.65	#DIV/0!		

Band0 = 70.7% | Band1 = 75.0% | Band2 = 77.1% | <Δn> = -1.45 | <|Δn|> = 1.53 | Miss = 22.4% | False = 0.5%

nceilo= 4% nnubi= 29%

Table 7: The scores for the contingency matrices of ceilometer versus Nubiscope cloud cover for total cloud cover and low, middle and high cloud layers as a function of the zenith angle range of the Nubiscope.

	Zenith	Band0	Band1	Band2	<Δn>	<|Δn|>	Miss	False	nceilo	nnubi
Total	1.5	67.2%	87.6%	91.7%	0.13	0.65	3.7%	4.6%	86.2%	81.9%
	34.5	65.7%	87.6%	92.2%	0.10	0.64	3.8%	4.0%	86.2%	84.8%
	67.5	62.2%	85.2%	90.2%	-0.26	0.75	8.2%	1.5%	86.2%	92.0%
Low	1.5	57.1%	71.9%	78.3%	0.97	1.41	3.0%	18.8%	80.0%	65.0%
	34.5	57.5%	73.2%	80.1%	0.85	1.30	2.9%	17.0%	80.0%	67.3%
	67.5	60.4%	77.2%	84.8%	0.50	1.01	3.0%	12.1%	80.0%	72.7%
Middle	1.5	72.2%	76.0%	77.5%	-1.23	1.53	20.0%	2.5%	5.7%	26.7%
	34.5	71.2%	75.4%	77.7%	-1.24	1.51	20.0%	2.3%	5.7%	28.0%
	67.5	70.7%	76.2%	78.9%	-1.16	1.38	19.3%	1.8%	5.7%	29.4%
High	1.5	73.3%	76.6%	78.4%	-1.38	1.47	21.0%	0.6%	3.6%	25.8%
	34.5	70.7%	75.0%	77.1%	-1.45	1.53	22.4%	0.5%	3.6%	29.3%
	67.5	65.4%	69.9%	72.7%	-1.65	1.70	26.9%	0.4%	3.6%	34.8%

4. Conclusions and recommendations

The conclusions of the evaluation of the Nubiscope are:

- The Nubiscope is technically in order. Some minor problems with the communication between the CPU and the PTU occurred, which led to the rejection of a full sky scan.
- During the 2½ month test of the Nubiscope at KNMI there was no sign of any (effect of) contamination.
- The Nubiscope ground temperature, T_{gnd}, showed good correlation with grass temperature and the ambient temperature.
- The Nubiscope ambient temperature, T_{zero}, shows large deviations from the ambient temperature. Consider usage of T_{gnd} instead or perform temperature into altitude conversion afterwards using the ambient temperature in combination with other sources. One should note, however, that, apart from the uncertainty in the zero temperature, the actual vertical structure, the moisture content of the atmosphere and the existence of a well mixed boundary layer also lead to errors in the altitude determination by using the Nubiscope cloud base temperature. In addition, fractionally cloudy pixels and semi-transparence of the clouds contribute to errors of the cloud base height determination.
- Fog cases are not often correctly identified by the Nubiscope mainly because the visibility does not meet the fog criterion. However, in nearly all cases a overcast, low cloud layer was observed by the ceilometer.
- The unknown identification cases mostly consist of overcast situation with a low cloud base.
- Total cloud cover derived by Nubiscope shows good agreement with ceilometer data, although in some situations differences can be large.
- The effect of spatial information of Nubiscope is small on the overall scores, but changes in cloud deck are reported earlier and sometimes a new cloud deck is reported.
- The cloud base height derived by the Nubiscope shows less agreement with the ceilometer data than an observer. Cloud base temperature seems often to be affected by partial and or semi-transparent clouds. As a result the cloud base temperature is too low and the derived cloud base height is too high.
- The distribution between low, middle and high clouds obtained from the ceilometer and Nubiscope show large differences. The Nubiscope reports a larger fraction of middle and high clouds. This can partly be ascribed to the overestimation of the cloud base height by the Nubiscope.

The recommendation based on the technical performance of the Nubiscope instrument which showed no sign of contamination, and the good results for the total cloud cover, with some larger differences between Nubiscope and ceilometer showing the added value, is to perform a further test with the Nubiscope system. This test should span a larger time period and should focus more on the comparison with other independent cloud cover and cloud base height or temperature sources, in order to investigate of the problem of partially and/or semi-transparent clouds, and to perform the test under semi-operational conditions. Specific recommendations are:

- Operate Nubiscope with a 10-minute scan cycle.
- Use RS422 communication with the Nubiscope system.
- Control the timing of the Nubiscope from PC.
- Use near-real time communication between the Nubiscope and a PC in order to make the raw and processed Nubiscope data available every 10 minutes.
- The Nubiscope processing should give temperature and height information for the sky conditions IU, CI, LF and DF so that after any possible readjustment of the obscuration type data is available.
- Perform a test at Cabauw in co-location with various other instruments e.g.: ceilometer (the current system for automated cloud observations), IR radiometer (as a reference for the calibration and the effect of contamination), WSI (visible camera system for daytime cloud observations) radiometer (system for continuous temperature profile measurements); and cloud radar. The co-location not only allows a better evaluation of the Nubiscope, but the threshold settings in the Nubiscope processing software can be optimized and the situations when the Nubiscope performs good or not can possible be identified.
- The co-location should also include visibility measurements in order to facilitate an evaluation and possible optimization of the fog classification. Note that the contamination of the horizon by objects might improve the fog classification of the Nubiscope.
- Perform a supervised test where the processed data is near-real time made available to a local and remote user preferably at an airport.
- Monitor long term contamination of Nubiscope by comparison with calibrated IR radiometer and by comparison soil temperature measurements.
- Process the Nubiscope data in combination with satellite data for validation and detection of partial and/or semi-transparent situations.
- Combination the Nubiscope with ceilometer data in order to improve cloud base height after a selection of the partial and/or semi-transparent situations.
- Evaluate the Nubiscope blue sky temperature with the integrated water vapor column.

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Appendix

Results file R051214.dat

Date	Time	Pr	Tgnd	Tbase	Tzero	Tblue	Type	ClCov	<MCB	MCB	MCB	MCB	LLC	MLC	HLC	lowestCl		ceiling	
2005-12-14	00:00	Y	5.3	5.7	5.2	-51.3	OC	100.0	0.0	100.0	3.5	280	100.0	0.0	0.0	4.3	140	3.5	280
2005-12-14	00:15	Y	5.4	5.7	5.2	-51.3	OC	100.0	0.0	100.0	2.5	450	100.0	0.0	0.0	3.3	310	2.5	450
2005-12-14	00:30	Y	5.5	5.7	5.2	-51.3	OC	100.0	0.0	100.0	3.5	280	100.0	0.0	0.0	3.6	260	3.5	280
2005-12-14	00:45	Y	5.7	5.7	5.3	-51.3	OC	100.0	0.0	100.0	3.0	360	100.0	0.0	0.0	3.3	310	3.0	360
2005-12-14	01:00	Y	5.6	5.7	5.4	-51.3	OC	100.0	0.0	100.0	2.0	540	100.0	0.0	0.0	3.4	290	2.0	540
2005-12-14	01:15	Y	6.0	5.7	5.6	-51.3	OC	100.0	0.0	100.0	4.5	120	100.0	0.0	0.0	4.9	80	4.5	120
2005-12-14	01:30	Y	6.1	5.7	5.6	-51.3	OC	100.0	0.0	100.0	4.0	190	100.0	0.0	0.0	4.7	100	4.0	190
2005-12-14	01:45	Y	6.0	5.7	5.7	-51.3	OC	100.0	0.0	100.0	4.0	190	100.0	0.0	0.0	4.5	120	4.0	190
2005-12-14	02:00	Y	6.3	5.7	5.7	-51.3	OC	100.0	0.0	100.0	4.0	190	100.0	0.0	0.0	4.3	140	4.0	190
2005-12-14	02:15	Y	6.3	5.8	5.8	-51.3	OC	100.0	0.0	100.0	3.5	290	100.0	0.0	0.0	4.3	140	3.5	290
2005-12-14	02:30	Y	6.3	5.8	5.8	-51.3	OC	100.0	0.0	100.0	4.5	130	100.0	0.0	0.0	4.7	110	4.5	130
2005-12-14	02:45	Y	6.3	5.9	5.9	-51.3	IU	99.5	0.0	99.5	4.0	220	99.5	0.0	0.0	-	-	4.0	220
2005-12-14	03:00	Y	6.2	6.0	6.0	-51.3	OC	99.7	0.0	36.1	4.5	150	99.7	0.0	0.0	5.1	90	3.0	410
2005-12-14	03:15	Y	6.4	6.1	6.1	-51.3	OC	100.0	0.0	100.0	4.5	160	100.0	0.0	0.0	5.4	70	4.5	160
2005-12-14	03:30	Y	6.5	6.1	6.1	-51.3	OC	100.0	0.0	100.0	5.0	110	100.0	0.0	0.0	5.4	70	5.0	110
2005-12-14	03:45	Y	6.5	6.1	6.1	-51.3	OC	99.7	0.0	99.7	2.0	610	99.7	0.0	0.0	3.6	330	2.0	610
2005-12-14	04:00	Y	6.2	6.1	6.1	-51.3	BC	91.7	0.0	91.7	-1.0	1140	91.7	0.0	0.0	-1.3	1200	-1.0	1140
2005-12-14	04:15	Y	6.3	6.1	6.1	-51.3	BC	88.5	0.0	78.1	-1.0	1140	88.5	0.0	0.0	-0.6	1080	-1.0	1140
2005-12-14	04:30	n	5.8	6.1	6.0	-51.3	BC	83.9	1.5	68.5	-0.5	1060	70.0	0.0	13.9	0.0	960	-0.5	1060
2005-12-14	04:45	n	5.5	6.1	5.7	-51.3	BC	75.8	0.0	50.3	-2.5	1400	50.3	0.0	25.5	-1.7	1260	-46.5	9200
2005-12-14	05:00	n	4.6	6.1	5.5	-49.8	BC	11.3	-	-	-	-	-	-	-	-	-	-	-
2005-12-14	05:15	n	4.4	6.1	5.4	-49.7	BC	22.2	0.0	0.0	-	-	22.2	0.0	0.0	-20.0	4600	-	-
2005-12-14	05:30	n	5.1	6.1	5.2	-49.7	BC	83.5	21.7	61.8	-5.0	1900	83.5	0.0	0.0	-1.4	1260	-5.0	1900
2005-12-14	05:45	n	3.8	6.1	4.9	-50.1	BC	9.5	-	-	-	-	-	-	-	-	-	-	-
2005-12-14	06:00	n	4.0	6.1	4.5	-50.1	BC	80.2	0.0	53.7	-2.5	1440	53.7	26.5	0.0	-2.3	1400	-24.0	5300
2005-12-14	06:15	n	4.5	6.1	4.4	-50.6	BC	33.9	0.0	0.0	-	-	0.0	8.9	25.0	-21.0	4700	-	-
2005-12-14	06:30	n	3.1	6.1	4.4	-50.6	BC	67.8	0.0	34.5	-4.5	1780	34.5	0.0	33.3	-4.7	1820	-30.0	6300
2005-12-14	06:45	n	4.3	6.1	4.4	-50.6	BC	81.7	0.0	73.1	0.0	980	81.7	0.0	0.0	-2.6	1440	0.0	980
2005-12-14	07:00	n	2.0	6.1	4.3	-50.7	BC	4.1	-	-	-	-	4.1	-	-	-	-	-	-
2005-12-14	07:15	n	4.2	6.1	4.3	-50.7	BC	90.2	0.0	90.2	-1.0	1160	90.2	0.0	0.0	0.4	900	-1.0	1160
2005-12-14	07:30	n	4.5	6.1	4.5	-50.7	BC	97.8	4.1	46.7	-0.5	1060	97.8	0.0	0.0	2.6	510	-2.0	1340
2005-12-14	07:45	Y	5.5	6.1	4.7	-50.7	BC	96.6	0.0	96.6	0.5	890	96.6	0.0	0.0	1.3	750	0.5	890
2005-12-14	08:00	Y	5.1	6.1	4.6	-49.7	BC	61.9	0.0	50.1	0.0	990	61.9	0.0	0.0	0.3	930	-38.0	7900
2005-12-14	08:15	n	4.4	6.1	4.5	-49.7	BC	67.1	0.0	49.7	-6.0	2080	49.7	0.0	17.4	-7.7	2400	-38.0	7900
2005-12-14	08:30	n	5.7	6.1	4.5	-49.7	BC	87.8	25.5	34.4	-8.0	2450	25.5	62.3	0.0	-4.1	1740	-8.0	2450
2005-12-14	08:45	n	5.6	6.1	4.5	-49.7	BC	67.1	0.0	32.6	-1.0	1180	32.6	34.5	0.0	-9.5	2700	-21.0	4800
2005-12-14	09:00	n	5.9	6.1	4.6	-49.7	BC	84.2	9.3	74.9	-4.0	1720	84.2	0.0	0.0	-2.7	1480	-4.0	1720
2005-12-14	09:15	n	5.3	6.1	4.7	-49.7	BC	4.7	-	-	-	-	-	-	-	-	-	-	-
2005-12-14	09:30	n	6.9	6.1	4.9	-49.7	BC	67.0	0.0	39.0	-0.5	1080	39.0	0.0	28.0	-2.6	1460	-31.0	6600
2005-12-14	09:45	n	8.5	6.1	5.2	-49.7	BC	95.6	0.0	95.6	0.0	990	95.6	0.0	0.0	1.0	800	0.0	990
2005-12-14	10:00	n	7.5	6.1	5.1	-49.7	BC	91.4	36.0	30.1	-8.5	2550	36.0	55.4	0.0	-3.0	1520	-8.5	2550
2005-12-14	10:15	n	6.6	6.1	5.1	-49.6	BC	20.4	0.0	0.0	-	-	0.0	20.4	0.0	-41.0	8400	-	-
2005-12-14	10:30	n	9.1	6.1	5.2	-49.6	BC	82.8	0.0	71.9	-1.5	1260	82.8	0.0	0.0	-0.6	1100	-1.5	1260

2005-12-14	10:45	n	6.7	6.1	5.1	-49.4	BC	17.3	0.0	0.0	-	-	0.0	17.3	0.0	-37.4	7800	-	-
2005-12-14	11:00	n	8.8	6.1	5.3	-48.9	BC	31.0	0.0	0.0	-	-	31.0	0.0	0.0	-12.9	3400	-	-
2005-12-14	11:15	n	8.4	6.1	5.4	-49.7	CS	0.0	0.0	0.0	-	-	0.0	0.0	0.0	-	-	-	-
2005-12-14	11:30	n	8.8	6.1	5.5	-49.7	BC	48.8	0.0	42.1	-3.0	1540	48.8	0.0	0.0	-8.4	2500	-	-
2005-12-14	11:45	n	8.4	6.1	5.6	-49.7	BC	88.0	46.9	41.1	-10.0	2800	17.0	71.0	0.0	-3.5	1640	-10.0	2800
2005-12-14	12:00	n	7.5	6.1	5.4	-50.0	BC	32.7	0.0	0.0	-	-	0.0	18.0	14.7	-31.5	6700	-	-
2005-12-14	12:15	n	8.4	6.1	5.3	-49.6	CS	0.0	0.0	0.0	-	-	0.0	0.0	0.0	-	-	-	-
2005-12-14	12:30	n	8.6	6.1	5.3	-49.9	BC	4.6	-	-	-	-	-	-	-	-	-	-	-
2005-12-14	12:45	n	8.6	6.1	5.1	-49.8	BC	5.8	-	-	-	-	5.8	-	-	-	-	-	-
2005-12-14	13:00	n	8.4	4.7	4.7	-50.6	CS	0.0	0.0	0.0	-	-	0.0	0.0	0.0	-	-	-	-
2005-12-14	13:15	n	8.2	4.5	4.5	-49.7	BC	9.5	-	-	-	-	9.5	-	-	-	-	-	-
2005-12-14	13:30	n	8.5	4.7	4.7	-49.8	BC	40.1	0.0	33.6	2.0	360	40.1	0.0	0.0	-2.2	1140	-	-
2005-12-14	13:45	n	6.9	4.8	4.8	-50.0	BC	47.2	0.0	0.0	-	-	21.7	0.0	25.5	-5.0	1680	-	-
2005-12-14	14:00	n	6.4	4.8	4.8	-50.0	BC	32.7	0.0	32.7	-2.0	1140	32.7	0.0	0.0	-4.6	1600	-	-
2005-12-14	14:15	n	7.8	5.1	5.1	-50.0	OC	100.0	0.0	100.0	-0.5	910	100.0	0.0	0.0	0.2	780	-0.5	910
2005-12-14	14:30	n	7.5	5.3	5.3	-50.0	BC	93.1	23.8	69.3	-2.0	1200	93.1	0.0	0.0	0.3	790	-2.0	1200
2005-12-14	14:45	n	6.2	5.3	5.2	-49.8	BC	40.1	0.0	0.0	-	-	18.9	0.0	21.2	-30.7	6500	-	-
2005-12-14	15:00	n	6.7	5.3	5.2	-49.8	BC	51.6	0.0	48.5	0.5	750	51.6	0.0	0.0	1.2	610	-	-
2005-12-14	15:15	n	4.6	5.3	5.2	-49.8	BC	63.1	0.0	0.0	-	-	20.6	0.0	42.5	-21.5	4800	-44.0	8900
2005-12-14	15:30	n	5.8	5.3	5.2	-49.8	BC	76.1	1.3	67.9	-4.5	1660	76.1	0.0	0.0	-5.2	1780	-4.5	1660
2005-12-14	15:45	n	6.1	5.3	5.3	-49.8	OC	99.3	0.0	99.3	-0.5	930	99.3	0.0	0.0	0.1	820	-0.5	930
2005-12-14	16:00	Y	6.1	5.3	5.3	-49.8	BC	96.1	4.6	40.8	-1.5	1120	45.4	50.7	0.0	-0.6	960	-8.5	2400
2005-12-14	16:15	n	5.5	5.3	5.3	-49.8	BC	98.2	20.5	49.0	-2.0	1220	98.2	0.0	0.0	0.0	840	-2.0	1220
2005-12-14	16:30	n	6.4	5.3	5.3	-49.8	OC	98.8	0.0	66.7	0.5	760	98.8	0.0	0.0	1.8	520	0.5	760
2005-12-14	16:45	n	5.4	5.3	5.1	-49.7	BC	46.4	0.0	46.4	-3.5	1500	46.4	0.0	0.0	-2.6	1320	-	-
2005-12-14	17:00	n	3.8	5.3	4.7	-50.4	BC	25.3	0.0	0.0	-	-	25.3	0.0	0.0	-18.9	4250	-	-
2005-12-14	17:15	n	5.8	5.3	4.4	-50.4	OC	100.0	0.0	100.0	-2.5	1300	100.0	0.0	0.0	-1.1	1040	-2.5	1300
2005-12-14	17:30	n	5.8	5.3	4.2	-50.4	OC	100.0	0.0	100.0	-2.5	1300	100.0	0.0	0.0	-1.5	1120	-2.5	1300
2005-12-14	17:45	n	4.8	5.3	4.2	-49.8	BC	34.0	0.0	0.0	-	-	19.6	0.0	14.4	-5.5	1860	-	-
2005-12-14	18:00	n	4.4	5.3	4.3	-49.8	BC	88.8	0.0	57.4	-4.0	1580	57.4	31.4	0.0	-2.4	1280	-4.0	1580
2005-12-14	18:15	n	4.7	5.3	4.3	-49.8	BC	97.8	0.0	69.7	-3.0	1400	97.8	0.0	0.0	-1.9	1200	-3.0	1400
2005-12-14	18:30	n	5.1	5.3	4.4	-49.8	BC	98.7	0.0	53.0	-2.5	1300	98.7	0.0	0.0	-1.3	1100	-4.0	1580
2005-12-14	18:45	n	5.4	5.3	4.5	-49.8	BC	99.6	0.0	42.5	-2.0	1220	99.6	0.0	0.0	-1.2	1060	-3.0	1400
2005-12-14	19:00	n	5.9	5.3	4.7	-49.8	OC	99.8	0.0	99.8	-2.0	1220	99.8	0.0	0.0	-1.5	1140	-2.0	1220
2005-12-14	19:15	n	6.1	5.3	4.8	-49.8	OC	99.9	0.0	99.9	-2.0	1220	99.9	0.0	0.0	-1.2	1060	-2.0	1220
2005-12-14	19:30	n	6.0	5.3	4.8	-49.8	OC	100.0	0.0	100.0	-2.0	1220	100.0	0.0	0.0	-1.2	1060	-2.0	1220
2005-12-14	19:45	n	5.8	5.3	4.8	-49.8	OC	99.9	0.0	99.9	-2.0	1220	99.9	0.0	0.0	-1.6	1140	-2.0	1220
2005-12-14	20:00	n	6.0	5.3	4.9	-49.8	IU	99.7	0.0	99.7	-2.5	1300	99.7	0.0	0.0	-	-	-2.5	1300
2005-12-14	20:15	n	6.2	5.3	5.0	-49.8	OC	100.0	0.0	100.0	-1.5	1120	100.0	0.0	0.0	-0.8	1000	-1.5	1120
2005-12-14	20:30	n	6.3	5.3	5.1	-49.8	OC	100.0	0.0	100.0	-1.0	1040	100.0	0.0	0.0	-0.7	980	-1.0	1040
2005-12-14	20:45	n	6.2	5.3	5.1	-49.8	BC	98.9	2.3	74.0	-1.0	1040	98.9	0.0	0.0	-0.2	890	-1.0	1040
2005-12-14	21:00	n	5.4	5.3	5.1	-49.8	BC	91.7	24.4	56.6	-1.5	1120	91.7	0.0	0.0	2.5	390	-1.5	1120
2005-12-14	21:15	n	6.3	5.3	5.1	-49.8	OC	100.0	0.0	100.0	-1.0	1040	100.0	0.0	0.0	-0.0	850	-1.0	1040
2005-12-14	21:30	n	6.1	5.3	5.0	-49.8	OC	100.0	0.0	100.0	-1.0	1040	100.0	0.0	0.0	-0.2	890	-1.0	1040
2005-12-14	21:45	n	5.0	5.3	4.9	-49.2	BC	61.8	11.4	50.4	-4.0	1600	61.8	0.0	0.0	-2.5	1320	-4.0	1600
2005-12-14	22:00	n	2.4	5.3	4.8	-49.9	BC	30.2	0.0	30.2	-3.0	1400	30.2	0.0	0.0	-6.0	1940	-	-
2005-12-14	22:15	n	4.9	5.3	4.9	-49.9	BC	98.0	0.0	98.0	-1.5	1120	98.0	0.0	0.0	-0.6	960	-1.5	1120
2005-12-14	22:30	n	5.7	5.3	5.0	-49.9	OC	100.0	0.0	100.0	-0.5	940	100.0	0.0	0.0	-0.2	890	-0.5	940
2005-12-14	22:45	n	5.9	5.3	5.0	-49.9	OC	100.0	0.0	100.0	-0.5	940	100.0	0.0	0.0	0.0	840	-0.5	940
2005-12-14	23:00	n	6.1	5.3	5.1	-49.9	OC	100.0	0.0	100.0	-0.5	940	100.0	0.0	0.0	0.1	830	-0.5	940
2005-12-14	23:15	n	6.3	5.3	5.2	-49.9	OC	100.0	0.0	100.0	0.5	750	100.0	0.0	0.0	1.0	670	0.5	750
2005-12-14	23:30	n	6.4	5.3	5.3	-49.9	OC	100.0	0.0	100.0	1.5	570	100.0	0.0	0.0	2.4	400	1.5	570
2005-12-14	23:45	n	6.4	5.3	5.3	-49.9	OC	100.0	0.0	100.0	0.5	760	100.0	0.0	0.0	1.0	670	0.5	760

Cloud mask file M0512141.515

14.12.2005 15:15
CloudMask: 0=blue, 1=high, 2=medium, 3=low, 4=margin

Angle	5	15	25	35	45	55	65	75	85	95	105	115	125	135	145	155	165	175	185	195	205	215	225	235	245	255	265	275	285	295	305	315	325	335	345	355
1.5	0	0	0	0	1	1	1	1	0	0	0	0	0	1	1	1	1	1	0	0	0	1	0	0	0	0	1	1	1	1	1	1	1	1	0	0
4.5	0	0	0	0	1	1	1	1	1	1	0	0	1	0	1	1	1	1	0	0	0	1	0	0	0	0	1	1	1	1	1	1	1	1	0	0
7.5	0	0	0	0	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0	0
10.5	1	1	0	4	1	1	1	1	1	1	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1	0	0	0
13.5	1	1	1	1	1	1	1	1	0	1	1	1	0	0	1	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	0	1	0	0	0	0
16.5	4	1	1	4	1	1	1	1	1	1	1	1	0	0	0	1	1	1	1	1	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0
19.5	1	1	1	1	1	1	1	1	1	1	0	1	1	0	0	1	1	1	1	1	0	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0
22.5	1	1	1	1	1	1	1	1	0	1	1	0	1	4	0	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
25.5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	4	0	1	1	1	1	1	1	0	0	1	1	0	0	0	1	0	0	0	0	0	0
28.5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0	0	1	1	1	0	0	1	0	0	0	0	0	0
31.5	4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	0	0	1	1	1	1	1	1	0	0	0	0	0	0
34.5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	1	1	0	0	1	1	1	1	1	1	0	0	0	0	0	0
37.5	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0	0	0	0	1	1	1	0	1	1	1	1	1	0	0	0	0	1	1	1
40.5	1	1	1	4	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	2	1	1	1	1	1	1	1	0	0	0	0	1	0	2
43.5	1	1	1	4	1	1	1	1	1	1	0	0	1	1	0	0	0	0	1	1	0	2	1	1	2	2	1	1	4	0	0	1	1	0	0	2
46.5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	1	1	0	2	1	1	2	2	1	1	4	1	0	1	0	0	4	2
49.5	0	4	1	1	1	0	0	0	1	1	1	1	0	1	1	0	0	0	1	1	0	1	1	1	2	2	4	1	1	1	1	1	1	1	1	2
52.5	0	0	0	1	0	0	0	1	1	1	1	1	0	1	1	4	0	0	1	1	1	1	1	4	2	1	4	1	1	2	1	1	4	1	1	3
55.5	1	0	4	1	4	1	0	1	1	1	1	1	1	0	2	4	0	0	0	1	1	0	1	2	2	4	1	1	1	2	1	1	4	2	2	3
58.5	4	4	1	1	1	4	1	1	1	1	1	0	1	1	2	2	4	0	0	4	1	0	1	1	1	4	0	0	1	1	1	4	4	2	2	3
61.5	4	2	2	3	4	1	1	1	1	1	1	0	0	0	2	2	2	1	0	0	1	0	4	2	1	1	1	0	1	1	4	2	2	3	3	3
64.5	3	4	4	3	3	2	4	1	1	1	1	1	1	0	4	2	4	1	0	0	1	1	4	2	1	1	1	0	4	1	2	2	3	3	3	3
67.5	4	4	3	3	4	2	4	1	1	1	1	4	4	1	4	1	4	1	1	1	1	4	2	4	1	1	1	4	4	2	2	2	3	3	3	3

Zenith measurements file Z0512141.515

14.12.2005 15:15
Zenith points

time	T(øC)	H(m)
15:15:10	-47.6	-
15:15:12	-47.3	-
15:15:30	-49.0	-
15:15:32	-48.8	-
15:15:50	-39.4	8096
15:15:52	-38.2	7858
15:16:10	-37.0	7637
15:16:12	-36.8	7600
15:16:32	-46.3	-
15:16:34	-47.6	-
15:16:52	-48.9	-
15:16:54	-49.0	-
15:17:12	-47.0	-
15:17:14	-46.2	9346
15:17:33	-39.1	8041
15:17:35	-40.8	8354
15:17:53	-41.8	8537
15:17:55	-42.9	8739
15:18:13	-47.2	-
15:18:15	-47.8	-
15:18:33	-47.5	-
15:18:35	-46.1	9327
15:18:53	-47.5	-
15:18:55	-49.7	-
15:19:13	-49.4	-
15:19:15	-49.5	-
15:19:33	-45.1	9144
15:19:35	-43.6	8868
15:19:53	-29.8	6315
15:19:55	-30.4	6425
15:20:13	-35.4	7343
15:20:15	-38.5	7913
15:20:34	-42.6	8684
15:20:36	-41.4	8464
15:20:54	-46.4	-
15:20:56	-48.3	-