# STATUS, EVALUATION AND NEW DEVELOPMENTS OF THE AUTOMATED CLOUD OBSERVATIONS IN THE NETHERLANDS

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## ABSTRACT

All synoptic and climatological cloud observations in the Netherlands are performed automatically since 2003. For that purpose the Royal Netherlands Meteorological Institute (KNMI) employs cloud base ceilometers in combination with a cloud algorithm in its meteorological network. The cloud algorithm converts time series of cloud base heights detected by a ceilometer into cloud layers with corresponding height and amount. In the development phase intercomparisons between visually observed and automated cloud reports were performed. The purpose was to optimize the cloud algorithm and to make the characteristics of the differences between observed and automated cloud reports known to the users.

In this paper the status of the (ceilometer) network in the Netherlands is discussed including the upcoming extension of the network with 7 airbases of the Royal Dutch Air Force and 8 platforms in the North Sea. Recent/new developments include: (i) the introduction, with minor changes to the cloud algorithm, of automated aeronautical cloud observations; (ii) a feasibility study into the determination of the mixing layer height from ceilometer backscatter profiles; (iii) a test with a scanning infrared radiometer. The evaluation of the automated cloud observations addresses: (i) characteristics and problems of automated cloud observations; (ii) the quality of aeronautical cloud products; (iii) the ceilometer derived mixing layer height versus the height of the atmospheric boundary layer as determined from other sources.

## *1. Introduction*

Since the introduction of the new meteorological measurement network of KNMI (including 2 airbases of the Dutch Royal Navy) in November 2002 ALL synoptic and climatological reports are generated fully automatically[1]. KNMI employs observers only at airports, where they only make aeronautical reports. In 2005 the meteorological systems at 9 airbases of the Dutch Royal Air Force were upgraded and connected to the central system so that the synoptic and climatological reports for these stations are also generated fully automatically. The automated cloud observations are performed with LD-40 ceilometers in combination with a cloud algorithm[2]. Currently 16 stations within the Netherlands provide automated cloud observations that are made centrally available every 10 minutes. In 2006 and 2007 LD-40 sensors will replace the old ceilometers at 7 Dutch Royal Air Force airbases. Furthermore, 8 platforms in the North Sea will be equipped with a full sensor set including a LD-40 ceilometer and a FD12P present weather sensor. Hence in the near future about 30 stations in the Netherlands will provide a complete set of automated observations including visibility, weather and clouds that will be made centrally available to internal as well as external users every 10 minutes.

## *2. Automated Aeronautical cloud reports*

### 2.1 Current situation

In 2004 and 2005 functionality was implemented in the meteorological measurement network systems in order to facilitate automated aeronautical observations of visibility, weather and clouds. The automated aeronautical reports are the routine and special aerodrome reports METAR and SPECI and the local routine and special reports ACTUAL and SPECIAL. The fully automated aeronautical reports are used operationally during closing hours of regional airports since mid

2005. Some changes were introduced in the cloud algorithm for the automation of the aeronautical cloud reports. These changes can be activated in the configuration to enable either the aeronautical or the synoptic cloud reports, or both. The differences between aeronautical and synoptic cloud reports, apart from coding differences, are:

- The aeronautical cloud algorithm uses ceilometer cloud base data of the last 10 minutes, instead of 30 minutes, in order to be more sensitive to changes in the cloud amount. This interval also corresponds with the 10-minute delay for reporting improvements of clouds in aeronautical special reports.
- The aeronautical cloud algorithm uses all 12-second cloud base reports of the ceilometer, whereas only 1-minute cloud base reports of the ceilometer (i.e. 1 out of every 5 available) are used for synoptic purposes.
- The allowed separation of individual cloud layers differs between aeronautical and synoptic use and is given by Table 1.

**Table 1. Minimal required separation of individual cloud layers in the cloud algorithm as a function of cloud base height of the lower layer for aeronautical and synoptical usage.**

| *METAR cloud base height (ft)* | *Layer separation (ft)* | *SYNOP cloud base height (ft)* |
|---|---|---|
| ≤1000 | 100 | ≤1000 |
| >1000 and ≤1500 | 200 | >1000 and ≤2000 |
| >1500 and ≤3000 | 300 | >2000 and ≤3000 |
| >3000 and ≤5000 | 400 | >3000 and ≤4000 |
| >5000 and ≤10,000 | 500 | >4000 and ≤5000 |
| - | 3000 | >5000 and ≤15,000 |
| >10,000 | 5000 | >15,000 |

- The vertical visibility (sky obscured) is made available as a separate variable.
- The crucial cloud parameter for aeronautical purposes is the ceiling, i.e. the height of the lowest cloud layer with a cloud amount of at least 5 oktas. When the ceiling height crosses any of the heights 100, 200, 300, 500, 1000 or 1500ft a SPECI report is generated.
- Cloud type is not available and is always encoded as ///.
- NCD (no clouds detected) is reported when no cloud base is detected by the ceilometer in the last 10-minutes. No significant clouds (NSC), sky clear (SKC) and cloud and visibility OK (CAVOK) are not reported in the automated aeronautical reports.
- In case of missing or insufficient ceilometer data ///////// is encoded instead of the cloud group in the METAR.

An evaluation of the automated cloud reports has been performed and results are shown in Table 2[3]. The evaluation is performed on the ceiling height reported by the observer in the METAR and computed from 1-minute ceilometer data of the last 10-minutes using the cloud algorithm described above. In case of vertical visibility, the reported height is treated as ceiling height. The rows/columns with ceiling ≥1500ft also contain the cases in which no ceiling (cloud cover less or equal to 4 okta) is measured or observed.

In Table 2 data of 2001 are displayed in categories according to the national regulations. The boundaries of these categories are also used for generating SPECI reports. Table 2 shows that that about 89% of the AUTOMETAR ceiling heights is in the same category as the observer ceiling height. In about 8% the AUTOMETAR ceiling height is in the adjacent category. AUTOMETAR reports the same or the adjacent category in 97% of all cases. For the other 3% of the cases, it appears that AUTOMETAR reports very often a ceiling height which is 2 categories or more worse than the observer, whereas the opposite is rare. This means that if significant differences between observer and AUTOMETAR occur, AUTOMETAR is in most cases at the safe side (false alarm). It is noteworthy that there are 65 cases in the cell at the lower-left corner of Table 2. This number is high compared to the numbers in the adjacent cells. In most cases these are situations with nocturnal fog. In these cases the fog layer was reported by the AUTOMETAR as very low clouds or vertical visibility less than 100 feet, while the observer, who is situated at a higher position, was able to observe the clear sky or higher clouds.

**Table 2. Contingency table of observed and automated ceiling height for Groningen-Eelde Airport in 2001.**

| ***Ceiling height (ft)*** | ***AUTOMETAR →*** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| ***METAR ↓*** | ***<100*** | ***<200*** | ***<300*** | ***<500*** | ***<1000*** | ***<1500*** | ***≥ 1500*** | ***Sum*** |
| ***< 100*** | 39 | 0 | 0 | 0 | 0 | 0 | 0 | 39 |
| ***100-200*** | 247 | 35 | 2 | 0 | 0 | 0 | 1 | 285 |
| ***200-300*** | 141 | 51 | 55 | 6 | 1 | 0 | 3 | 257 |
| ***300-500*** | 4 | 16 | 86 | 335 | 21 | 0 | 8 | 470 |
| ***500-1000*** | 1 | 1 | 4 | 174 | 896 | 49 | 48 | 1173 |
| ***1000-1500*** | 0 | 0 | 0 | 9 | 182 | 397 | 40 | 628 |
| ***≥ 1500*** | 65 | 5 | 1 | 20 | 190 | 459 | 13328 | 14068 |
| ***Sum*** | 497 | 108 | 148 | 544 | 1290 | 905 | 13428 | 16920 |

| ***Description*** | ***Group*** | ***# Cases*** | ***Percentage*** | ***# Cases*** | ***Percentage*** |
|---|---|---|---|---|---|
| ***Agreement*** | 🟩 | 15085 | 89.2% | 16402 | 96.9% |
| ***Adjacent class*** | 🟨 | 1317 | 7.8% | | |
| ***False alarm*** | 🟦 | 457 | 2.7% | 518 | 3.1% |
| ***Miss*** | 🟧 | 61 | 0.4% | | |
| ***Sum*** | | 16920 | 100.0% | 16920 | 100.0% |

***Subset cases with ceiling METAR < 1500 ft***

| ***Description*** | ***Group*** | ***# Cases*** | ***Percentage*** | ***# Cases*** | ***Percentage*** |
|---|---|---|---|---|---|
| ***Agreement*** | 🟩 | 1757 | 61.6% | 2615 | 91.7% |
| ***Adjacent class*** | 🟨 | 858 | 30.1% | | |
| ***False alarm*** | 🟦 | 176 | 6.2% | 237 | 8.3% |
| ***Miss*** | 🟧 | 61 | 2.1% | | |
| ***Sum*** | | 2852 | 100.0% | 2852 | 100.0% |

The lowest panel of Table 2 gives the scores for a subset of data with METAR ceiling below 1500 ft, i.e. the cases which can be considered as relevant for aviation. Full agreement in ceiling height category is only found in 62% due to the large number of cases that are omitted where both agree that the ceiling is above 1500ft. Together with the adjacent category the score is however still 92%. Again, in this data subset the amount of false alarms is higher than the number of misses.

## 2.2 Recent development

The current automated aeronautical reports do not include cloud type. However evaluations of the automated reports by users showed that information on the presence of convection as given by the reported cloud types of CB (Cumulonimbus) and TCU (Towering Cumulus) is useful. Hence KNMI implemented the automated reporting of CB and TCU using information from the lightning detection network and the precipitation radars. The method was adopted from Météo France and is schematically shown in Table 3. The inputs are the radar reflectivity classes and the number of lightning discharges detected within a radius of 15 (Sfr1) and 20km (Sfr2) around each station. The result is either CB, TCU, no CB/TCU (denoted by "–") or invalid (denoted by "///"). The radar and lightning information are both updated every 5 minutes.

**Table 3. Cloud type decision matrix from radar reflectivity class (BDZ) and lightning discharges (Sfr1 and Sfr2).**

| ***DBZ Class*** | ***Sfr1 >0*** | ***Sfr2 >0*** | ***Sfr1 and Sfr2 =0*** | ***Sfr1 and Sfr2 Invalid*** |
|---|---|---|---|---|
| ***3*** | CB | CB | CB | CB |
| ***2*** | CB | CB | TCU | TCU |
| ***1*** | CB | CB | - | - |
| ***0*** | CB | CB | - | - |
| ***Invalid*** | CB | CB | /// | /// |

Apart from the radar reflectivity class that is determined by the highest reflectivity level observed within a certain radius around a station, the cloud cover is also derived from the fraction of all 'non-zero' radar reflectivities and the cloud base height is estimated by the dew point depression. Next CB-TCU and ceilometer cloud information is combined according to the cases and examples given in Table 4.

**Table 4. Matrix illustrating the combined result of the ceilometer and CB-TCU cloud information in the aeronautical reports for various situations.**

| ***Ceilometer information*** | **CB-TCU information** | | |
|---|---|---|---|
| | ***CB or TCU*** | ***-*** | ***///*** |
| ***Invalid*** | //////CB | ////// | ///////// |
| ***VertVis*** | BKN001 FEW020CB** | VV001 | VV001 REMARK* |
| ***NCD*** | FEW020CB | NCD | NCD REMARK* |
| ***Clouds*** | SCT012 FEW020CB** | SCT012 | SCT012/// |

* In these cases the remark CB INFO NOT AVBL shall be added to the METAR.

** In these cases the cloud layers shall be joined, ordered and/or ignored according to the METAR encoding rules for cloud layers.

The performance of the CB-TCU algorithm has been verified by applying the algorithm on archived precipitation radar and lightning data and by comparing the results with METAR reports for 2005. A radius of 30km and a 29dBz threshold was adopted for reporting CB from radar reflectivity data. This low threshold was required in order to get a probability of detection for CB of maximally 58%, but the associated false alarm rate is about 70%. It should be noted that the scores are better during summer and autumn. It was furthermore found that the discrimination of TCU was rather uncertain and that usage of lightning information had little effect on the performance. The poor quality prevents a smooth introduction of automated CB-TCU reports.

## *3. Status and evaluation of SYNOPIC cloud observations*

The synoptic cloud observations are automated since November 2002. For most locations the introduction of automated cloud observations occurred without an overlap of the automated and manual cloud observations. However, at the airports Schiphol (240), Rotterdam (344), Maastricht-Aachen (380), Groningen-Eelde (280) and De Kooy (235) and at De Bilt (260) LD-40 ceilometers were operated almost 3 years in parallel with manual cloud observations for synoptic purposes.

As an example the results for the test station in De Bilt (261) for 2001 are shown in Table 5. Table 5 compares the observed SYNOP total cloud cover, the cloud cover of the first cloud layer and the cloud base height with the results of the AUTOSYNOP cloud algorithm using 30 1-minute cloud base reports of the ceilometer. The grey cells show the cases without ceilometer data. 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 areas is reported as band0, band 1 and band2. Furthermore, the averaged differences and the averaged absolute differences 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 above results are similar to those of an evaluation of automated versus manual cloud observations using data of 2000 for De Bilt and Schiphol[2].

**Table 5. Comparison of observed and automated total cloud cover, first layer cloud cover and cloud base height for De Bilt Test in 2001.**

**Total cloud cover (n in okta)**

| | **AUTOSYNOP →** | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **SYNOP ↓** | **NA** | **0** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **Sum** | **<n>** |
| **NA** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| **0** | 16 | 151 | 91 | 41 | 15 | 7 | 2 | 4 | 3 | 1 | 1 | 332 | 1.01 |
| **1** | 13 | 308 | 252 | 84 | 58 | 20 | 14 | 14 | 10 | 2 | 0 | 775 | 1.20 |
| **2** | 9 | 90 | 106 | 78 | 59 | 48 | 23 | 26 | 10 | 4 | 2 | 455 | 2.29 |
| **3** | 6 | 65 | 94 | 36 | 66 | 47 | 57 | 32 | 34 | 12 | 2 | 451 | 3.10 |
| **4** | 2 | 25 | 51 | 24 | 39 | 44 | 48 | 71 | 58 | 35 | 1 | 398 | 4.43 |
| **5** | 13 | 22 | 36 | 19 | 30 | 35 | 47 | 51 | 98 | 79 | 2 | 432 | 5.21 |
| **6** | 13 | 42 | 57 | 33 | 22 | 33 | 73 | 89 | 167 | 336 | 4 | 869 | 5.97 |
| **7** | 42 | 18 | 55 | 23 | 42 | 43 | 63 | 105 | 276 | 1713 | 2 | 2382 | 7.26 |
| **8** | 92 | 1 | 10 | 10 | 11 | 10 | 11 | 24 | 91 | 2278 | 42 | 2580 | 7.85 |
| **9** | 11 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 9 | 64 | 86 | 8.79 |
| **Sum** | 217 | 722 | 752 | 348 | 342 | 287 | 339 | 417 | 747 | 4469 | 120 | 8760 | |
| **<n>** | | 1.77 | 2.58 | 2.81 | 3.49 | 4.14 | 4.82 | 5.21 | 6.05 | 7.36 | 8.12 | | |

Band0 = 39.2% Band1 = 75.5% Band2 = 88.0% <Δn> = 0.13 <|Δn|> = 1.10 Miss = 7.1% False = 4.9%

**Cloud cover first layer (n in okta)**

| | **AUTOSYNOP →** | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **SYNOP ↓** | **NA** | **0** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **Sum** | **<n>** |
| **NA** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| **0** | 16 | 151 | 134 | 11 | 5 | 5 | 3 | 4 | 2 | 0 | 1 | 332 | 0.80 |
| **1** | 55 | 432 | 1597 | 429 | 244 | 151 | 86 | 67 | 68 | 128 | 2 | 3259 | 1.92 |
| **2** | 25 | 67 | 701 | 330 | 199 | 87 | 51 | 50 | 38 | 40 | 4 | 1592 | 2.22 |
| **3** | 34 | 35 | 380 | 244 | 170 | 111 | 64 | 38 | 29 | 48 | 8 | 1161 | 2.69 |
| **4** | 21 | 14 | 162 | 108 | 93 | 75 | 53 | 49 | 23 | 39 | 4 | 641 | 3.27 |
| **5** | 23 | 6 | 100 | 82 | 67 | 53 | 49 | 40 | 36 | 55 | 0 | 511 | 3.80 |
| **6** | 20 | 12 | 82 | 50 | 43 | 29 | 41 | 46 | 30 | 65 | 5 | 423 | 4.18 |
| **7** | 9 | 4 | 39 | 27 | 22 | 21 | 17 | 16 | 39 | 140 | 2 | 336 | 5.61 |
| **8** | 3 | 1 | 43 | 20 | 26 | 19 | 35 | 39 | 48 | 155 | 30 | 419 | 5.99 |
| **9** | 11 | 0 | 0 | 1 | 1 | 0 | 1 | 3 | 1 | 4 | 64 | 86 | 8.57 |
| **Sum** | 217 | 722 | 3238 | 1302 | 870 | 551 | 400 | 352 | 314 | 674 | 120 | 8760 | |
| **<n>** | | 1.20 | 1.98 | 2.55 | 2.86 | 3.08 | 3.73 | 3.99 | 4.30 | 5.09 | 7.58 | | |

Band0 = 31.3% Band1 = 64.1% Band2 = 78.9% <Δn> = 0.01 <|Δn|> = 1.53 Miss = 9.9% False = 11.2%

**Cloud base height (h in height class)**

| | **AUTOSYNOP →** | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **SYNOP ↓** | **NA or n=9** | **<50m** | **<100m** | **<200m** | **<300m** | **<600m** | **<1000m** | **<1500m** | **<2000m** | **<2500m** | **> or n=0** | **Sum** | **<h>** |
| **NA or n=9** | 75 | 10 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 86 | |
| **<50m** | 42 | 53 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 11 | 112 | 1.50 |
| **<100m** | 34 | 65 | 126 | 12 | 1 | 2 | 1 | 0 | 0 | 1 | 1 | 243 | 0.88 |
| **<200m** | 25 | 9 | 129 | 448 | 27 | 10 | 3 | 3 | 1 | 2 | 4 | 661 | 1.95 |
| **<300m** | 33 | 2 | 8 | 200 | 335 | 64 | 10 | 3 | 3 | 0 | 3 | 661 | 2.84 |
| **<600m** | 48 | 3 | 3 | 40 | 157 | 879 | 133 | 43 | 21 | 9 | 53 | 1389 | 4.24 |
| **<1000m** | 25 | 4 | 2 | 10 | 19 | 233 | 1156 | 333 | 115 | 57 | 257 | 2211 | 5.66 |
| **<1500m** | 8 | 3 | 0 | 0 | 3 | 19 | 94 | 559 | 86 | 25 | 183 | 980 | 6.54 |
| **<2000m** | 10 | 3 | 1 | 1 | 1 | 4 | 18 | 99 | 269 | 49 | 127 | 582 | 7.21 |
| **<2500m** | 2 | 0 | 0 | 0 | 2 | 0 | 2 | 4 | 15 | 83 | 38 | 146 | 7.99 |
| **> or n=0** | 35 | 27 | 3 | 3 | 3 | 3 | 15 | 25 | 25 | 45 | 1505 | 1689 | 8.67 |
| **Sum** | 337 | 179 | 278 | 715 | 548 | 1214 | 1432 | 1069 | 535 | 271 | 2182 | 8760 | |
| **<h>** | | 2.38 | 1.67 | 2.45 | 3.38 | 4.17 | 5.02 | 5.76 | 6.38 | 6.97 | 7.95 | | |

Band0 = 64.3% Band1 = 85.6% Band2 = 91.2% <Δh> = 0.21 <|Δh|> = 0.68 Miss = 7.3% False = 1.5%

An overview of the intercomparison at the other locations mentioned above and for the years 2000, 2001 and 2002 is given in Table 6. Table 6 gives the above-mentioned scores for the total cloud cover for all 6 stations for each year. There is some variation in the scores between the years and stations. Generally the scores for 2002 are better than for 2000 and 2001. The reason for this difference is unclear. Some improvements have been introduced to the ceilometer, but it could also be that the observers made more frequent use of the ceilometer data or that the meteorological situation was different in 2002. Table 6 also shows that the scores for the synoptic station De Bilt are generally better than for the airports. This could be the result of better conditions for performing manual observations at airports. The scores for the total cloud cover averaged for all stations and over 3 years are: band0=39±5%, band1=75±3%, band2=87±3%, <Δn>=–0.2±0.3, <|Δn|>=1.2±0.2, Miss=10±3%, False=4±2%. For the cloud amount of the first cloud layer the averaged scores are: band0=34±4%, band1=67±3%, band2=81±2%, <Δn>=0.3±0.4, <|Δn|>=1.5±0.1, Miss=7±3%, False=12±3%; and for the cloud base height the averaged scores are: band0=68±5%, band1=86±3%, band2=91±3%, <Δh>=0.3±0.2, <|Δh|>=0.6±0.1, Miss=8±3%, False=1.2±0.4%.

**Table 6. The scores of the intercomparison between observed and automated total cloud cover for several stations and years. The first column denotes the WMO station number and the year.**

| ***Case*** | ***Band0*** | ***Band1*** | ***Band2*** | $\langle\Delta n\rangle$ | $\langle\lvert\Delta n\rvert\rangle$ | ***Miss*** | ***False*** | ***Valid*** |
|---|---|---|---|---|---|---|---|---|
| 235_00 | 33.5% | 74.5% | 85.4% | 0.08 | 1.21 | 8.7% | 5.9% | 64.0% |
| 235_01 | 35.0% | 73.8% | 85.4% | 0.33 | 1.22 | 6.6% | 8.0% | 99.5% |
| 235_02 | 37.8% | 74.6% | 86.1% | 0.13 | 1.15 | 7.6% | 6.4% | 93.7% |
| 240_00 | 34.1% | 74.3% | 85.5% | -0.36 | 1.25 | 11.4% | 3.0% | 99.8% |
| 240_01 | 35.0% | 74.5% | 85.4% | -0.48 | 1.25 | 12.3% | 2.4% | 99.6% |
| 240_02 | 39.1% | 77.0% | 86.7% | -0.33 | 1.12 | 10.6% | 2.8% | 99.1% |
| 260_00 | 40.5% | 75.7% | 86.2% | -0.19 | 1.18 | 10.0% | 3.8% | 97.4% |
| 260_01 | 40.5% | 77.1% | 88.5% | 0.04 | 1.06 | 7.6% | 3.9% | 99.1% |
| 260_02 | 57.1% | 86.1% | 94.1% | 0.19 | 0.68 | 3.3% | 2.7% | 97.9% |
| 280_00 | 38.6% | 73.1% | 84.5% | -0.41 | 1.23 | 11.8% | 3.7% | 91.0% |
| 280_01 | 37.9% | 71.3% | 83.5% | -0.48 | 1.29 | 12.9% | 3.6% | 99.5% |
| 280_02 | 43.5% | 77.6% | 88.6% | -0.02 | 1.01 | 6.6% | 4.8% | 99.4% |
| 344_00 | 33.0% | 72.4% | 84.9% | -0.37 | 1.27 | 11.7% | 3.4% | 93.7% |
| 344_01 | 34.8% | 72.8% | 84.8% | -0.34 | 1.26 | 11.8% | 3.4% | 99.1% |
| 344_02 | 39.9% | 76.5% | 86.7% | -0.28 | 1.12 | 10.2% | 3.1% | 98.9% |
| 380_00 | 35.2% | 72.5% | 84.3% | -0.53 | 1.28 | 13.6% | 2.1% | 90.9% |
| 380_01 | 37.7% | 75.2% | 87.3% | -0.26 | 1.13 | 9.8% | 2.9% | 99.5% |
| 380_02 | 42.1% | 78.1% | 89.0% | -0.24 | 1.02 | 8.6% | 2.4% | 99.3% |
| 261_01 | 39.2% | 75.5% | 88.0% | 0.13 | 1.10 | 7.1% | 4.9% | 97.5% |
| 261_12sec | 41.8% | 78.1% | 88.1% | -0.19 | 1.06 | 9.1% | 2.8% | 97.5% |
| 261_10min | 37.6% | 73.1% | 84.8% | -0.18 | 1.24 | 10.9% | 4.3% | 97.5% |
| 261_1zero | 38.9% | 75.1% | 87.8% | 0.11 | 1.12 | 7.3% | 4.9% | 97.5% |
| 261_lowmid | 57.8% | 88.1% | 94.6% | 0.41 | 0.64 | 0.6% | 4.8% | 44.5% |
| 261_wind | 43.3% | 76.8% | 88.7% | 0.07 | 1.04 | 7.4% | 3.9% | 41.4% |
| 261_calm | 36.1% | 74.5% | 87.5% | 0.18 | 1.15 | 6.9% | 5.6% | 56.1% |
| 261_day | 35.1% | 74.0% | 87.0% | -0.02 | 1.19 | 9.4% | 3.7% | 53.0% |
| 261_night | 44.0% | 77.3% | 89.2% | 0.31 | 1.00 | 4.4% | 6.3% | 44.5% |
| 261_wet | 77.8% | 97.0% | 98.9% | 0.20 | 0.27 | 0.1% | 1.0% | 13.8% |
| 261_dry | 32.8% | 71.9% | 86.2% | 0.12 | 1.24 | 8.3% | 5.5% | 83.7% |

Table 6 contains the scores of the operational station 260 in De Bilt and of the test station 261 in De Bilt for 2001. Apart from the score of the default AUTOSYNOP total cloud cover for De Bilt test in 2001, the scores are also given for:

(i). Usage of 150 12-second cloud base measurements in the last 30 minutes instead of 30 1-minute readings gives generally a slight improvement of the overall scores. The number of false alarms reduces significantly, but the effect on the faulty sky obscure (9 okta) cases is negligible. Further investigation showed that the backscatter profile generally gives no clear indication of shallow fog situations and cannot provide information on the cloudiness above. Usage of multi-ceilometer algorithms might partially overcome this problem[2], but this more or less selects the least exposed sensor. Since the parameter prevailing cloud is unknown, one can only consider positioning the ceilometer at the operationally relevant location and height.

(ii). Usage of 50 12-second cloud base measurements in the last 10 minutes instead of 30 1-minute readings gives generally a slight deterioration of the overall scores. However, since the response to sudden changes is faster this shorter interval is still preferred for aviation.

(iii). Treating 1 cloud base hit in the last 30 minutes as no cloud cover reduces the number of automated cases with total cloud cover equal to 1 by about 150, but has little effect on the overall scores. Hence, isolated faulty cloud base measurements by the ceilometer that sometimes occur, can be filtered out, but has little effect on the overall score. However, such a optimisation of the cloud cover boundaries has a positive effect on the frequency distribution of total cloud cover, which since the introduction of the automated cloud reports shows significantly less cases with 1 and 7 okta. This has been expected since due to the lesser spatial representativeness of a single (and even 3) ceilometer the automated system cannot detect an isolated cloud or gap in an overcast situation as frequent as an observer.

(iv). Restricting the intercomparison to low and middle cloud layers improves the scores for total cloud cover significantly. The ceilometer is less sensitive for high cloud even when integration over 20 minutes is possible. A combination of ceilometer cloud with satellite cloud information should be considered to overcome this problem.

(v). Considering only situation with wind speed above 2.5m/s, improves the scores for total cloud cover and cloud base. A situation dependent integration interval has been proposed, but this might confuse the interpretation of the automated cloud observations for a user.

(vi). Considering only night situations improves the scores for total cloud cover and cloud base. This might be expected since during night time an observer has a difficult job and has to rely more on available ceilometer measurements.

(vii). Considering only situations with precipitation improves the scores for total cloud cover and cloud base. This is contrary to the sometimes observed reduction of cloud cover during precipitation. The improvement is the results of the predominant stratiform nature of precipitation in which case the spatial representativeness of the ceilometer cloud observations is good, and hence the scores are better.

## *4. Test of the Nubiscope scanning infrared radiometer*

A known limitation of the automated ceilometer cloud observations is the lack of spatial representativeness. In order to overcome this problem a test has been performed at KNMI with the scanning infrared radiometer Nubiscope that measures every 15 minutes the sky temperature in 1080 directions. From (variations in) the sky temperature the presence of clouds can be determined, whereas the observed temperature gives some information on the cloud base height. Usage of an infrared radiometer allows daytime as well as night time cloud observations. Figure 1 shows an example of a measurement of the Nubiscope, and illustrates the spatial information of the Nubiscope observations.

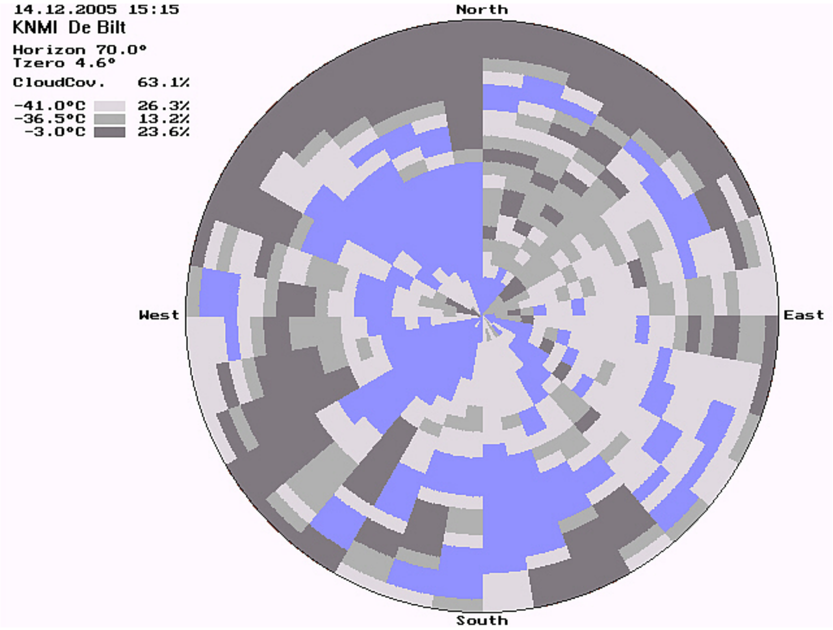

**Figure 1. The sky at De Bilt on 14 December 2005 15:15 UT as observed by the Nubiscope. Shown is a cloud mask in a colour scheme that simulates a visual observation.**

Table 7 shows an intercomparison of the Nubiscope and automated ceilometer total cloud cover and cloud base height for De Bilt Test. Table 7 shows that the overall scores between Nubiscope and ceilometer for total cloud cover is good. This is what could have been expected since mostly stratiform clouds were present during which spatial representativeness is no real issue. The interesting cases were Nubiscope and ceilometer differ need to be studied in more detail, because in these cases the Nubiscope provides additional information. The results for the cloud base height are not so good. It should be noted that the Nubiscope determines the height from the observed sky temperature by using the ambient temperature, as derived from a scan along the horizon, a correction of the sky temperature involving the observed blue sky temperature which has an elevation dependency, and adopting a fixed lapse rate. Therefore it is not surprisingly that the agreement between the cloud base heights is not so good. In addition, the cloud base temperature sometimes seems to be affected by partial and or semi-transparent clouds. As a result the cloud base temperature is too low and hence the derived cloud base height is too high. Furthermore, the distribution between low, middle and high clouds obtained from the ceilometer and Nubiscope show large differences, the Nubiscope reporting a larger fraction of middle and high clouds. The differences need to be investigated in more detail using additional measurements (e.g. cloud camera, satellite cloud top temperatures and actual temperature profiles). Furthermore the combination of Nubiscope with ceilometer data might partially overcome the problems with the height determination. A KNMI technical report on the evaluation of the Nubiscope is available[4].

**Table 7. Comparison of Nubiscope and ceilometer total cloud cover and cloud base height observed at De Bilt Test 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 | 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%

***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%

## 5. Mixing layer height determination from ceilometer backscatter

The presence of aerosol can be detected in the backscatter profiles of ceilometers. Aerosols are mainly emitted at the surface and the concentration of aerosol is therefore generally higher in the atmospheric boundary layer than in the free troposphere. Hence the mixing layer height (MLH) can be derived from backscatter profiles. KNMI developed an algorithm and executed a feasibility study into the routine determination of the MLH from a commercial ceilometer. For that purpose a six year backscatter profile data set obtained at De Bilt has been processed and evaluated by comparison with MLH estimations from radiosonde data, as well as from wind profiler observations. The top panel of Figure 2 shows an example where the first mixing layer heights (•) show a characteristic increase during the day whereas clouds (×) prevent detection in the afternoon. At night a residual layer is present that is reported as a second mixing layer (•). The red curve denotes the height at which SNR=1 is reached. The red squares give the MLH derived from the wind profiler at Cabauw during day time and show good agreement with the ceilometer MLH data. The coloured bullets just above the x-axis indicate the quality of the LD-40 MLH determinations. The quality ranges from good (green) to ambiguous (red) and is related to the difference in averaged ceilometer backscatter below and above the MLH.

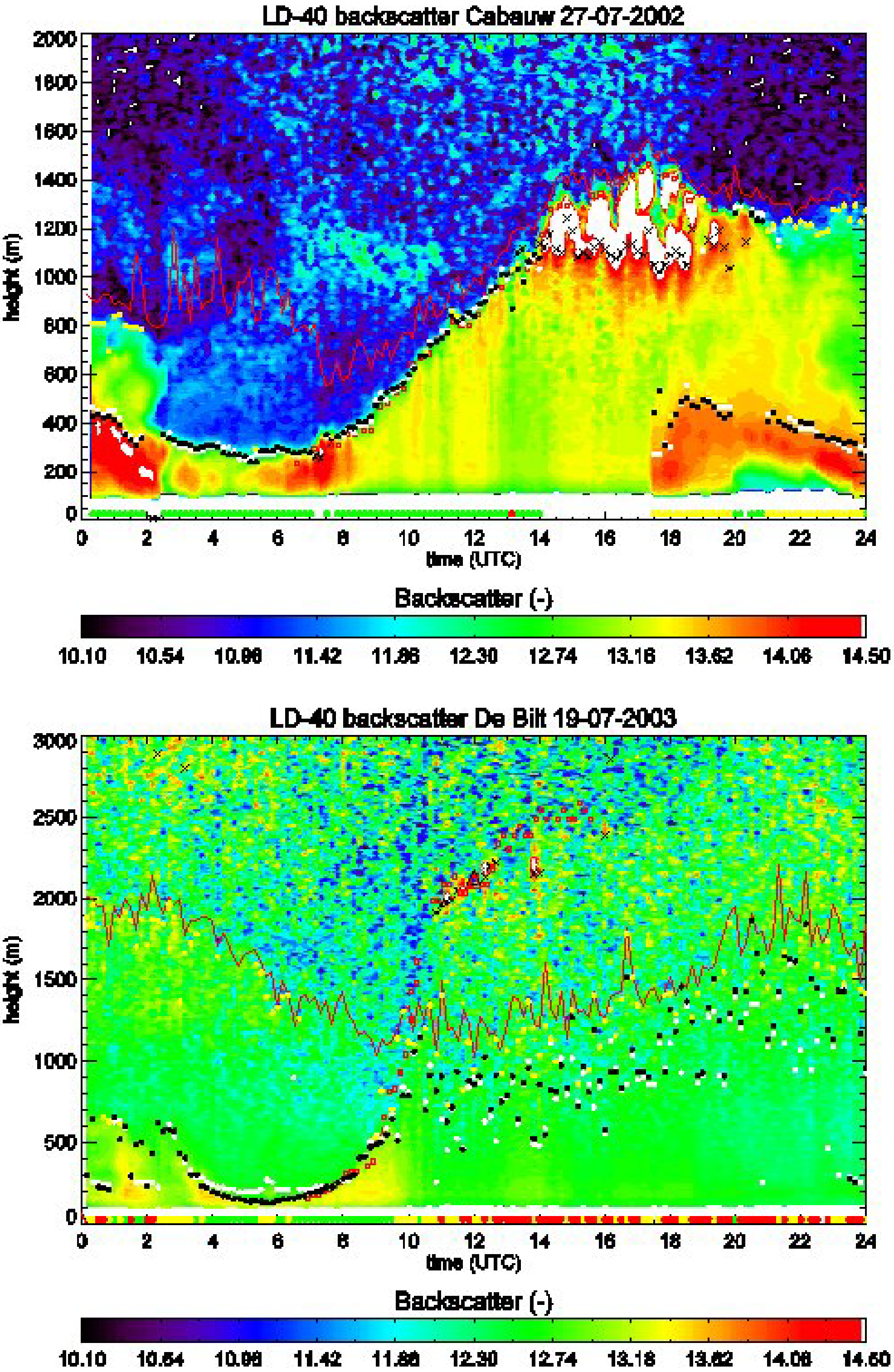

**Figure 2. A contour plot of the observed backscatter profiles of the LD40 ceilometer and the derived mixing layer heights at Cabauw July 27, 2002 (top) and at De Bilt July 19, 2003 (bottom).**

The detection of very shallow MLHs, e.g. observed during periods with a nocturnal (stable) layer is often problematic because of by the lowest detection height of the LD-40 (i.e. 90 m). A reliable detection of MLH requires a fairly constant and sufficient amount of aerosol backscatter in the mixing layer. This mainly occurs when the mixing layer grows not too deep, e.g. in a shallow wintertime mixing layer. During strong convective conditions in spring and summer, the MLH detection can be limited by the vertical range of the LD-40. This is illustrated in the bottom panel of Figure 2. The ceilometer MLH is correct up to 10UT. Around noon the MLH values reported by the wind profile and radiosonde (triangles) reach values up to about 2500m. The ceilometer reports some clouds near that level, but in the absence of clouds the vertical range is limited to about 1500m. After 10UT the MLH algorithm reports isolated MLH detections with ambiguous quality varying rapidly in time. The users of the LD-40 MLH product should therefore use the MLH estimates with care. The quality index can be used as a first check on the reliability. Furthermore, a visual inspection of variability of the MLH time series provides useful information.

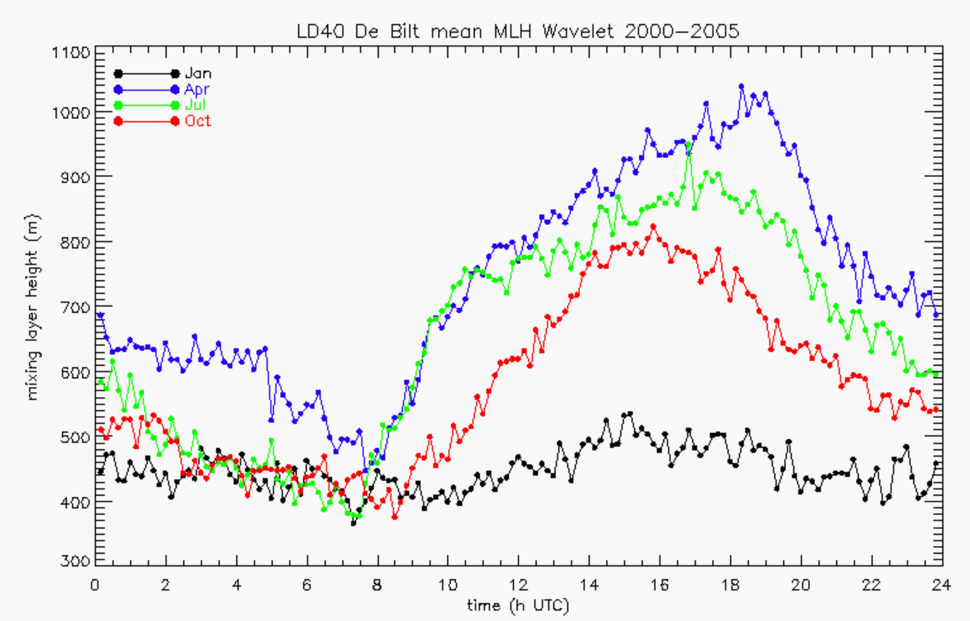

**Figure 3. Diurnal cycle of the mixing layer height derived from ceilometer backscatter data for De Bilt in 2000-2005 for the months Jan, Apr, Jul and Oct.**

Figure 3 shows the diurnal cycle of the derived MLH and its seasonal dependence. The observed behaviour shows the characteristics of the atmospheric boundary layers and supports the possibility of the MLH derivation from an aerosol gradient in the ceilometer backscatter profile. However, the monthly mean MLH during daytime observed for spring and summer months is lower than expected. This is related to the inability of the algorithm to detect most of the deep mixing layers heights. Statistics furthermore show that generally the MLH detection is not possible due to the presence of fog or precipitation in respectively 2 to 7% of the cases, whereas no MLH detection threshold was met up to the height of a cloud base or the signal-to-noise level in 34% and 1% of the cases. In about 56% of the cases a MLH can be determined, distributed as 25%, 23% and 8% for detections with good, weak and ambiguous quality, respectively. A KNMI scientific report on the ceilometer backscatter MLH determination is available[5].

## *6. References*

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[5] De Haij, M.J., Wauben, W.M.F., Klein Baltink, H.: Continuous mixing layer height determination using the LD-40 ceilometer: a feasibility study, KNMI scientific report, in press, De Bilt, 2006.