COMPARISON OF MACROSCOPIC CLOUD DATA FROM GROUND-BASED MEASUREMENTS USING VIS/NIR AND IR INSTRUMENTS AT LINDENBERG, GERMANY

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1. INTRODUCTION

Long-term ground-based observations of macroscopic cloud data such as cloud cover and cloud-base height have been used in studies to derive climate statistics and in attempts to recognize signs of climate change. Ground-based cloud observations have provided valuable macroscopic cloud data over several decades. On the other hand, automation of cloud observations is required worldwide to improve both reliability and - by higher sampling rates – representativeness of cloud data. Automated imagers and sky scanners have the potential to provide not only cloud cover in higher time resolution than conventional cloud observations, but in addition also cloud distribution in the sky.

Different types of instruments and observations have been compared referring to cloud cover over a four-months time period from May 9, 2006 to September 5, 2006 at the Meteorological Observatory Lindenberg. In addition to cloud cover, cloud-base heights derived from signals measured by passive and active sensors were analyzed. A few typical features and capabilities of the individual types of instruments will be discussed. They use different ranges of the radiation spectrum to measure either scattered visible and NIR solar radiation, IR radiation emitted from the atmosphere, or signals that are emitted by the instruments and backscattered from the atmosphere.

2. INSTRUMENTS AND MEASUREMENT CAMPAIGN

In addition to hourly cloud observations of the Lindenberg weather station, measurements from the following instruments were used in the comparison: a Nubiscope (IR scanner), the VIS/NIR Whole Sky Imager (WSI), a Laser ceilograph Tropopauser LD-40, and a Ka-Band cloud radar. The first three instruments were installed on the rooftop of the DWD Radiation Central Station at Lindenberg 52.2086°N, 14.1213°E, 127 m asl), which provides an unobstructed horizon. The Ka band radar was located on the ground close to the radiation platform. The site's weather station, where visual cloud observations were performed, is less than 200 m apart from the sensor on the rooftop.

The *Nubiscope* consists of an infrared sensor (pyrometer) that receives infrared radiation emitted from the atmosphere in the spectral region 8 to14 µm with a full viewing angle of 3°. The pyrometer is sensitive to measured brightness temperatures down to –100 °C. A sky tracker directs the tube containing the pyrometer at 30 different zenith angle steps of 3° between zenith and horizon, and at 36 azimuth steps shifted by 10° each. It takes about 6 minutes to perform one spatial sky scan that consists of 1,080 individual spot measurements. During the campaign, the Nubiscope instrument performed scans every ten minutes for 24 hours. A cloud decision algorithm provides cloud fraction (total and for three height

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levels), cloud-base heights, and a 'cloud description' parameter (overcast, broken clouds, Cirrus, fog) either in real-time mode or by manual data post-processing.
The *DAY VIS/NIR Whole Sky Imager (WSI)* manufactured at the University of California San Diego (UCSD) has been in operation at DWD since 2000 (Feister and Shields, 2005). Images of the upper hemisphere (180° viewing angle) are acquired every ten or 5 minutes in up to 7 different spectral ranges in the visible and near infrared (NIR) region. Cloud fractions of optically thin and opaque clouds for the upper hemisphere and for selected regions of interest are derived by a cloud decision algorithm from images in two different spectral regions. In this study, images acquired in the blue region (434 – 480 nm) and NIR (845 – 942 nm) were used for cloud post-processing. Time distances between two images of one sequence are less than 30 s for most of the daylight time, but can be longer for very long exposure times with thick clouds and high solar zenith angle.
The *Laser ceilograph Tropopauser LD-40* (Ceilometer, 1995) sends signals at a wavelength of 855 nm in the zenith direction and receives radiation backscattered from a cloud. Cloud-based heights (CBH), which are derived for up to three levels at time steps of 15 s, were averaged for intervals of 6 minutes to be compatible with the time resolution of the Nubiscope.
The *Ka band cloud radar MIRA 36* (Görsdorf and Handwerker, 2006) measures atmospheric backscattered signals of electromagnetic waves sent out by the instrument in the 35.5 GHz (8 mm) band. Parameters such as reflectivity, Doppler velocity and its variation, and linear depolarisation ratios are calculated for the height range of 0.25 to 14 km with 10 s averaging time and 30 m vertical resolution. Cloud-base and cloud-top heights as well as droplet size distribution, liquid and ice water content of the cloud can be derived usually by combination with measurements of other systems. For the time of the campaign, the reflectivity signal averaged for time periods of 10 minutes was used as a parameter that provides information on CBH. Due to interfering effects of aerosol particles and insects in the atmospheric boundary layer and the disproportionate scattering by larger water droplets during precipitation events, CBH values were not derived, but the reflectivities of the lowest three layers were used to derive estimates of the CBH for comparison with Nubiscope values.

3. RESULTS

In this study, we have focussed on the comparison between cloud data of the Nubiscope and the site's macroscopic cloud data that are routinely measured by the Whole Sky imager, the ceilometer and the radar as well as values obtained from conventional cloud observations. Data of each instrument were selected, and if necessary, averaged for the observation times of the Nubiscope to get a consistency in time as close as possible.

3.1 CLOUD COVER FROM NUBISCOPE AND FROM OBSERVATIONS

The Nubiscope cloud fractions (CF in per cent) selected for times of cloud observations, which are performed around minute 40 after the hour, were converted to 8 bins of cloud cover (CC) given in Okta. CF values of less than 1% were defined as 0 Okta (cloudless) and more than 99% as 8 Okta (overcast). The frequency plot of differences between total CC from the Nubiscope and observations is shown in Fig. 1. More than 50% of the differences are within ±1 Okta, which is the estimated uncertainty of CC observations, and about 2/3 of the differences are within ±2 Okta. If only the two types cloudless (CC=0) and cloudy (CC>0) are considered, which evaluates the capabilities of detecting clear sky, the Nubiscope and observer yielded the same decision for those two options in 93.5% of all hourly cases. In 16% of our comparisons, the Nubiscope did not make a decision on CF. The Nubiscope CC also shows a tendency of more frequently underestimating CC compared to observed CC. The results for high-level clouds are shown in Fig. 2. Due to the smaller difference of brightness temperatures between cloudless sky sections and thin clouds, they are more difficult to be detected from measurements in the infrared than low-level thick clouds. Nevertheless, the differences plotted in Fig. 2 between Nubiscope CC and observed CC show a close correspondence in most cases, but also large differences up to -8 Okta in some cases. Similar to total CC, the Nubiscope tends to slightly underestimate high-level clouds. We mention that systematic differences can be reduced by modifying thresholds in cloud decision algorithms.

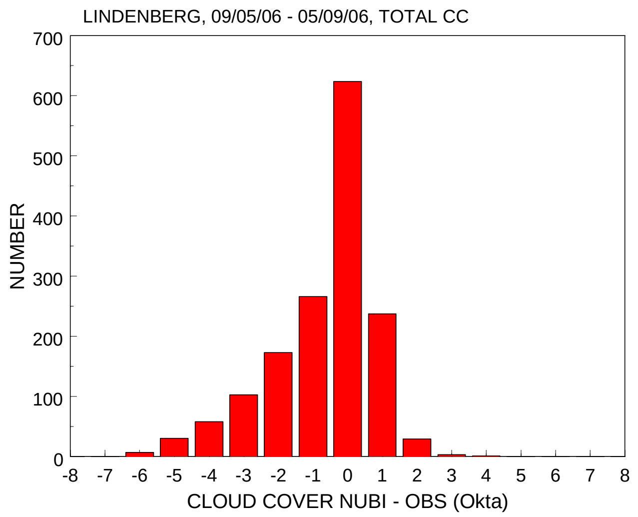

Fig.1 Frequency of differences of total CC from Nubiscope measurements and cloud observations (2,207 day and night values for comparison in the period May to September 2006

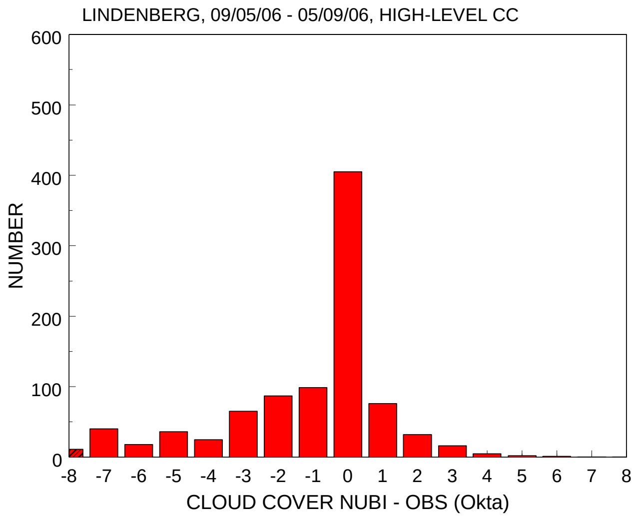

Fig. 2 Frequency of differences of high-level CC from Nubiscope measurements and cloud observations (2,207 day and night values for comparison in the period May to September 2006

3.2 CLOUD COVER FROM NUBISCOPE AND WSI

Due to the small time step of WSI image grabbing of 5 or 10 minutes, the overall number of daylight comparison cases was 7,671. In 991 of them (13%), the Nubiscope did not make a cloud decision. To make a first rough comparison, we defined cloud free as CF < 1%, and cloudy as CF ≥ 1%. We found that 2.6% of cases were defined by both instruments to be cloud free, and 94.8% were found by both instruments to be cloudy. Thus there was agreement between the two instruments in this course comparison, of 97.4%. A more detailed classification of differences in CF is shown in Fig. 3. It can be seen that in more than 50% of cases cloud fractions differ by less than ±5%. More than ¾ of differences of cloud fractions are within ±15%, and about 90% of all cases show CF differences of less than ±25%.

Analogous to the comparison between Nubiscope and observed cloud cover, the number of overestimated cloud fractions from the Nubiscope compared to the Whole Sky Imager is slightly larger than the number of underestimations.
The effect of the limited field of view used by the Nubiscope algorithm (view angles less than 70° corresponding to about 66% of the upper hemisphere) was tested by comparing Nubiscope CF with WSI CF values that were analyzed for this limited view angle. There is still a good correspondence between both CF on the average, though there can be larger differences in individual cases. The individual CC occurrences for each of 8 Okta bins for Nubiscope and WSI are shown in Fig. 4. Differences in frequencies are obvious only for a CC of 1 Okta and for 7 and 8 Okta. Due to the conversion from CF in per cent to CC in Okta, small differences in CF resulted in an apparent larger systematic deviation of CC. In many cases, when the Nubiscope decided on CF=0%, the WSI showed a very small CF of 1% to about 4% that according to our definition of CC was not cloud free any more, i.e. CC=1 Okta. Similarly, due to our definition of CC=8 Okta (overcast, i.e. closed cloud deck without gaps), corresponding to CF = 100%, there were many cases with a WSI decision on CF of 100% (CC = 8 Okta), while the Nubiscope CF of about 98% to 99% resulted in a CC = 7 Okta. It should be noted that threshold settings in both cloud algorithms themselves, and finally the area close to the horizon that is not part of the Nubiscope scan may have also contributed to those differences.

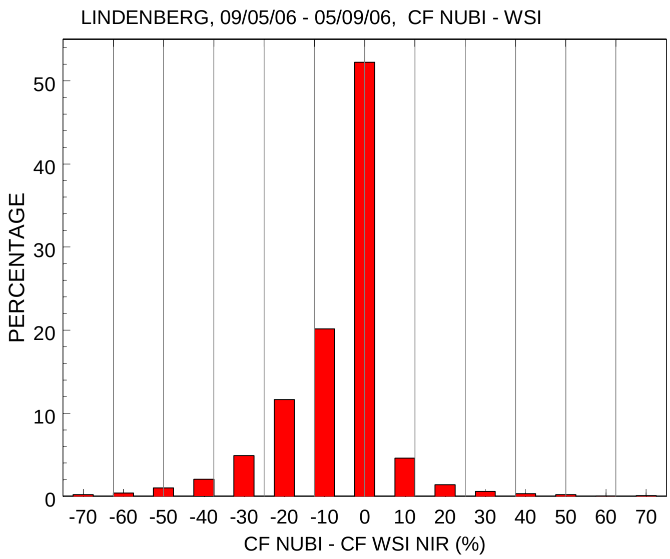

Fig. 3 Frequency of differences of total cloud fraction from Nubiscope and WSI measurements (6,681daylight values for comparison in the period May to September 2006)

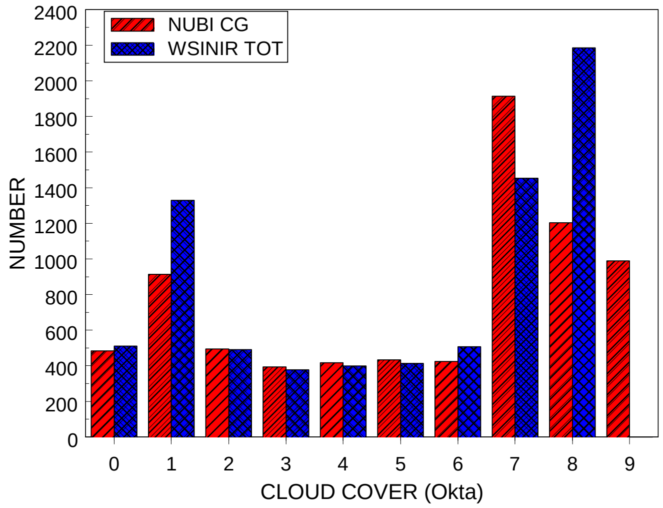

Fig. 4 Number of CC values per Okta from Nubiscope and WSI for the period May to September 2006. CC=9 means no decision by the Nubiscope

3.3 CLOUD-BASE HEIGHTS COMPARISON

The Nubiscope cloud algorithm also derives cloud-base heights (CBH) from IR sky radiances and from measurements of the surrounding surface emission. It does not include external data such as measured vertical temperature profiles and/or air mass characteristics that might be useful to improve the estimated CBH. We have not tried to include CBH estimates from cloud observers, because they may have been affected by the information they take from the ceilometer display.

Day and night CBH values from the Nubiscope and the ceilometer LD-40 are shown in Fig. 5 as differences of CBH between them in dependence of solar zenith angle. In general, CBH from the Nubiscope is somewhat smaller than the ceilometer CBH. A comparison between zenith cloud fraction from WSI and ceilometer performed in another study had shown that the uncertainty of this type of ceilometer becomes larger at higher cloud levels such that high clouds that are recognized in WSI images and are also identified as such by the WSI cloud algorithm, are not detected by the ceilometer or, that the ceilometer detects clouds that are not seen in the WSI image (Feister and Shields, 2005). Therefore, part of the larger CBH differences between Nubiscope and ceilometer especially at higher height levels may be due to erroneous ceilometer signals.

The comparison between nubiscope and radar was performed by using the height of the lowest border of radar reflectivity signals instead, because a radar CBH algorithm working independent of other instruments was not available at the time of the campaign. The radar reflectivities at the lowest height-level are still affected by ground clutter from boundary layer aerosols. Differences between Nubiscope CBH and radar 'CBH' in Fig. 5 show more frequently slightly higher Nubiscope CBH values than the corresponding radar reflectivities. A systematic dependence on the time of the day cannot be recognized, but it appears that large differences between Nubiscope and both ceilometer and radar are less frequent during night time. It cannot be decided yet, to what extent this feature is due to atmospheric stability, because during night time, the chance of stable atmospheric conditions is higher than during day time, or if it is an effect of the instruments.

The dependence of CBH from the Nubiscope and from the active sounders at different height levels can be seen in the scatter plot of Fig. 6. Part of the ground clutter of radar signals has been removed for this plot. The correspondence between CBH from Nubiscope and the active sounders shows a closer correspondence with smaller scatter for low-level and mid-level clouds below about 3 km. Systematic differences are more pronounced between Nubiscope CBH and ceilometer CBH up to levels of about 5 km than between Nubiscope and radar. There is still some remaining ground clutter at low height levels in the radar data left. More scatter between CBH from the instruments can be seen at higher levels. It is generally larger between Nubiscope and ceilometer CBH than between Nubiscope and radar CBH. We mention that the definition of cloud-base height is also determined by the type of instrument and observation method as well as the thresholds used in cloud algorithms (Pal et al. 1992, Seiz et al. 2007).

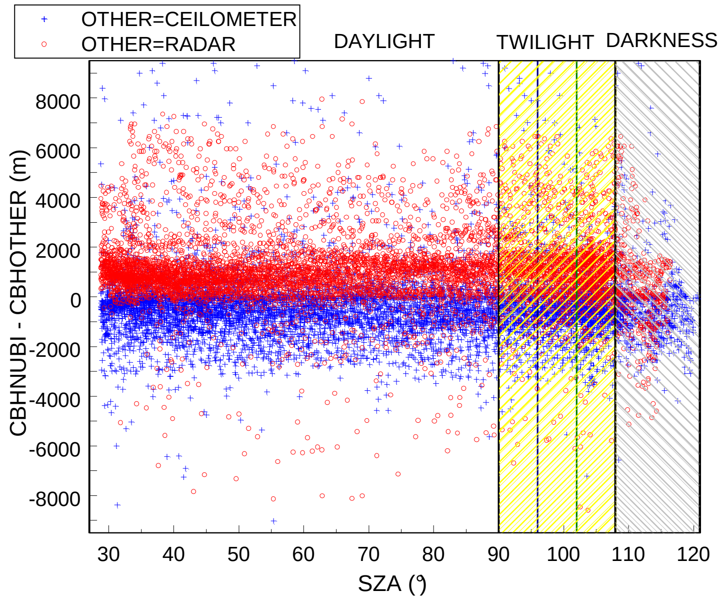

Fig. 5 Differences of cloud-base heights between Nubiscope and ceilometer (plus) or radar (circles) of non-zero signals in dependence of solar zenith angle (SZA) from May to September 2006. Radar is not CBH, but lowest-layer reflectivity signal. Dashed areas mark daylight, twilight (civil, astronomical, nautical), and darkness periods.

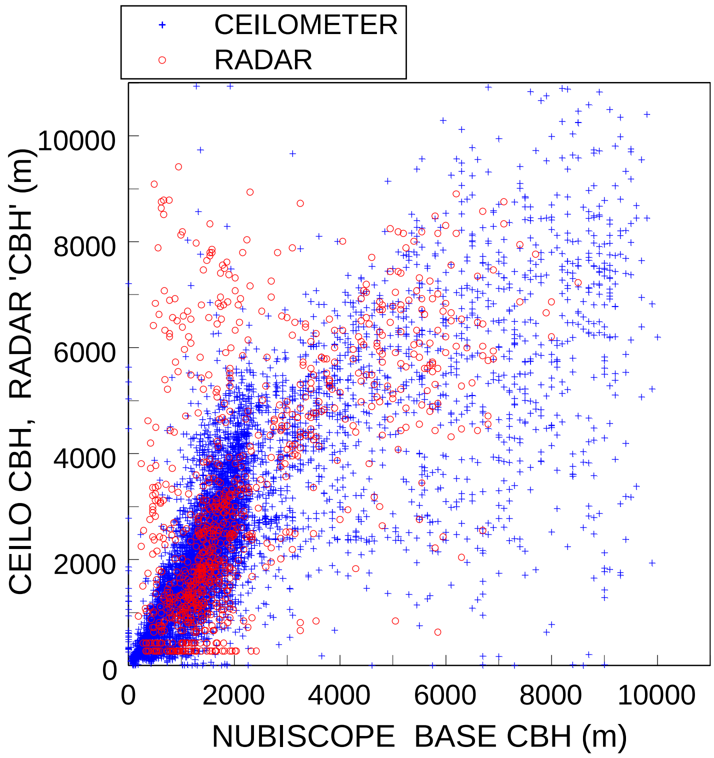

Fig. 6 Cloud-base heights (CBH) from Nubiscope compared to CBH from ceilometer (plus) or lowest-level radar reflectivity (circle) for the period May to September 2006.

4. CONCLUSIONS

A comparison between different types of passive and active sensors that are operated in different spectral ranges in the VIS/NIR (WSI), NIR (ceilometer), infrared (Nubiscope), and mm-wave region (radar) to provide macroscopic cloud parameters was performed in a field campaign. The results are valid mainly for summer conditions at a mid-latitude site, where the upper tropospheric temperatures did not drop below -60 °C, and integrated water path derived from microwave radiometer data ranged between 0.6 and the high value of 4.0 cm with an average of 2.1 cm during the four-months campaign.

For cloud cover, only slight systematic differences have been found between the Nubiscope and WSI as well as between the Nubiscope and cloud observations. In individual cases, cloud detection in the IR is difficult in particular for cold and thin clouds having brightness temperatures close to clear sky temperatures. Their detection requires a high sensitivity of the

receiver. The same decision on cloud or no cloud for the whole sky was taken by both instruments in 95% of cases. In individual cases, larger differences can occur.
The percentage of cases, where the Nubiscope provides no decision on CC would need to be reduced for many applications. Due to the spatial scanning and the smaller time resolution, the Nubiscope cannot provide high resolution cloud structures, as they are provided by the spot measurements of imagers, but it provides data during darkness that are not acquired by the Daylight VIS/NIR WSI. We mention that there is a Day/Night WSI available that provides cloud decisions during day and night (Shields et al. 1998). Referring to cloud-base heights, the comparison shows reasonable agreement between Nubiscope and ceilometer as well as between Nubiscope and cloud radar up to height levels of about 3 km. CBH differences between the instruments in the lower height range are mainly due to the different principles of measurement including the geometries of measurements (zenith looking versus scanning), the assumption on lapse rate used in the Nubiscope cloud algorithm, and the definition of CBH for the respective instrument.

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