VALIDATION OF CLOUD MASKS USING CEILOMETER DATA

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Abstract

The cloud mask is one of the most essential products derived from satellite data. Whereas different cloud analysis applications, such as the cloud top temperature, need information from cloudy pixels, many others require cloud-free conditions. For this reason different organizations and institutes produce their own cloud masks using their own algorithms tuned to serve their particular needs. Being a fundamental product, continuous quality monitoring and validation of the cloud masks is very important. This is a challenging task as good reference data sets are rarely available.

Helsinki Testbed, a joint mesoscale research project of the Finnish Funding Agency for Technology and Innovation, the Finnish Meteorological Institute, Vaisala, and other Finnish industries, has set up an extensive observation network covering the Greater Helsinki area in Finland. The instrumentation includes, for example, several ceilometers and optical backscattering profilers. These data form the baseline in the cloud mask validation.

This study evaluates the performance of the operational EUMETSAT Meteorological Products Extraction Facility Cloud Mask, together with the Nowcasting Satellite Application Facility Cloud Masks provided by Météo-France and the Swedish Meteorological and Hydrological Institute, in high-latitude areas.

INTRODUCTION

Cloud mask is a fundamental product derived from satellite data. Whereas different cloud analysis applications, such as the cloud top temperature, need information from cloudy pixels, others require cloud-free conditions. Due to this, many organizations and institutes have their own cloud mask algorithm tuned to serve their particular needs. Being a fundamental product, continuous quality monitoring and validation of cloud masks is essential. This is a challenging task as good reference data sets are rarely available.

Helsinki Testbed, a joint mesoscale research project of the Finnish Funding Agency for Technology and Innovation, the Finnish Meteorological Institute, Vaisala, and other Finnish industries, has set up an extensive observation network covering the Greater Helsinki area in Finland. The instrumentation includes, for example, several ceilometers and optical backscattering profilers. These data are utilized in this cloud mask validation study. Information about the Helsinki Testbed campaign can be found at http://testbed.fmi.fi.

The study presented in this paper evaluates the performance of three different cloud masks at high-latitudes. The study involves EUMETSAT Meteorological Products Extraction Facility (MPEF) cloud mask, and both Satellite Application Facility in Support to Nowcasting and Very Short Range Forecasting (SAFNWC) cloud masks. The SAFNWC/MSG cloud mask, developed by Météo-France, uses data from SEVIRI, whereas the SAFNWC/PPS cloud masks, developed by the Swedish Meteorological and Hydrological Institute (SMHI), uses data from the Advanced Very High Resolution

Radiometer (AVHRR) onboard NOAA 17 and 18 satellites. The data for the study was collected in August 2006.

CLOUD MASKS

Each of the included cloud masks are based on the thresholding technique. Different spectral channels values, channel differences and/or ratios are compared to pre-defined thresholds to determine whether the examined pixel is cloud contaminated or not. Each separate comparison is called a test. The thresholds in the tests are either fixed or dynamic. In the latter case the thresholds are calculated using numerical weather prediction model (NWP) data together with a radiation transfer model (RTM). The dynamic thresholds allow the cloud mask algorithms to adjust to the prevailing weather conditions. Table 1 summarizes the basic information about the included cloud masks.

Cloud Mask	Instrument	RTM	NWP	Scope
MPEF	SEVIRI	SYNSATRAD	ECMWF	Full Disc
SAFNWC/MSG	SEVIRI	RTTOV	ARPEGE	Full Disc
SAFNWC/PPS	AVHRR	RTTOV	HIRLAM	Local

***Table 1:* The basic characteristics of the different cloud masks.**

The use of the visual channels of an instrument in cloud mask algorithms is commonly determined by the solar zenith angle. Table 2 summarizes the solar zenith angle thresholds for the algorithms. MPEF employs the visual channels only during the “day”, while both of the SAFNWC algorithms use visual channels also during the “twilight”.

Cloud Mask	Day	Twilight	Night
MPEF	$\theta \leq 72$	$72 < \theta < 80$	$\theta \geq 80$
SAFNWC/MSG	$\theta \leq 80$	$80 < \theta < 93$	$\theta \geq 93$
SAFNWC/PPS	$\theta \leq 80$	$80 < \theta < 95$	$\theta \geq 95$

***Table 2:* Solar zenith angle thresholds defining the illumination conditions.**

The pixel sizes of SEVIRI and AVHRR are three kilometres and one kilometre at the sub-satellite point, respectively. Being a geostationary instrument, the pixel size of SEVIRI roughly doubles when scanning high latitude areas (Helsinki ~ 60°N). AVHRR, as a polar orbiting instrument, does not suffer from this. Due to these differences in the viewing geometry and in the pixel sizes, it is clear that only the MPEF and SAFNWC/MSG cloud masks can be directly compared against each other.

More detailed information about the cloud masks is available in the documents EUMETSAT (2006), Météo-France (2007), and SMHI (2004).

CEILOMETERS

Sky condition algorithms depict an image of the sky from automated observations. Some algorithms use only a single point measurement, an example of which is a ceilometer, others adapt to multiple instrument setups (Ravila et al., 2002). It has been shown by Ravila et al. (2002) and Wauben (2002), that sky condition algorithms are giving plausible results even from a single ceilometer measurements.

The Helsinki Testbed ceilometers are manufactured by Vaisala. The setup includes seven CT25K and five CL31 models, both having a measurement range of 0–7500 metres. The sky condition algorithms report the cloud amount in octas, and the cloud base height in metres, but the measuring routines and the number of cloud layers in the output differ depending on the model. The CT25K’s measure every 10 minutes and report the cloud information up to four different layers. An output, which is an average of the measurements over the last 30 minutes, is produced with every measurement. The CL31’s measure every sixteen seconds and report the cloud information up to five different layers. Here the sky condition output is also a 30 minute average, however, the last 10 minutes is given a double weight. Also, as the measuring frequency of the CL31 is very high, an output is not produced with every measurement, but every five minutes. Figure 1 shows the locations and instrument models of the Helsinki Testbed ceilometers.

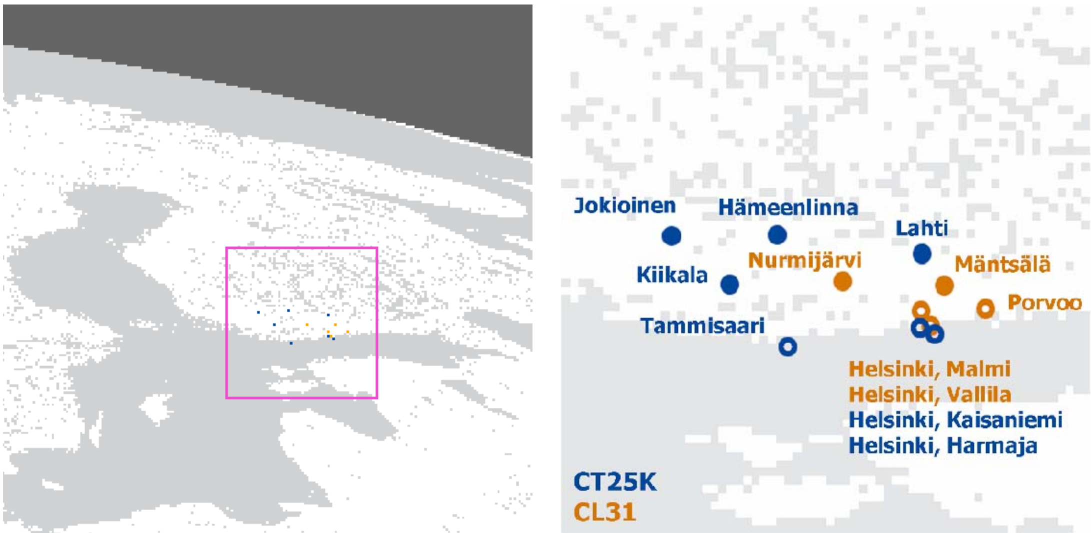

Figure 1: **Locations and instrument types of the Helsinki Testbed ceilometers, coastal stations are marked with circles.**

DESCRIPTION OF THE ALGORITHM

The principle of the comparison algorithm follows the one used by Le Gléau and Derrien (2005). A segment of n×n pixels is extracted around each of the ceilometer stations from the cloud mask data and the total cloud amount (N_{tot}), in octas, is calculated. The segment size for MPEF and SAFNWC/MSG is 3×3, while SAFNWC/PPS uses 21×21 pixels. Taken into account the different pixel sizes of the imaging instruments, these segments roughly represent a geographical area of the same size. The resulting N_{tot} from the cloud mask data is compared to the closest observation in time using a five-minute window. If the ceilometer observation reports multiple cloud layers, minimum overlapping is assumed. The situation is considered to be cloud free if N_{tot} is less than three, and cloudy if N_{tot} is greater than five octas. If the cloud mask or the observation does not meet these requirements, or an observation close enough in time is not found, the comparison is discarded. The purpose of this approach is to filter out the “easy” cases. The results are analysed using a 2×2 contingency table, an example of which is shown in Table 3.

SEVIRI instrument provides an image every 15 minutes, i.e. 00, 15, 30 and 45 of each full hour. The instrument scans from the East to the West and from the South to North. A full disc scan takes roughly twelve minutes, the additional three minutes is used to retrace the instrument to the nominal starting position. The time stamp of a repeat cycle declares the start time of a new scan. With such a measurement routine, the Helsinki Testbed area is scanned approximately eleven minutes after the start. The algorithm adds sixteen (11+5) minutes to the repeat cycle time. The extra five minutes is added so that the double weighting of the last 10 minutes of the CL31 sky condition algorithm better matches the satellite data. The closest ceilometer observation to the modified repeat cycle time, using a five-minute window, is then extracted. Similar approach is used for the AVHRR data. A typical reception at the SMHI, Norrköping, lasts twelve minutes. The area of interest in a received AVHRR swath is in the middle. Therefore, the timestamp, declaring the time of the first received scan line, is modified with eleven (6+5) minutes after which the closest observation is extracted.

		Observation	
		yes	no
Cloud	yes	A	B
mask	no	C	D

Table 3: **2×2 Contingency table.**

The statistical scores used in this study are:

- Proportion Correct (PC) = (A+D)/(A+B+C+D)
- False Alarm Rate (FAR) = B/(A+B)
- Miss Rate (MR) = C/(A+C)
- BIAS = (A+B)/(A+C)

RESULTS

The data used in this study is August 2006. For a few SEVIRI repeat cycles SAFNWC/MSG did not have a result. These cases were discarded from the study. For the SAFNWC/PPS cloud mask 218 AHVRR overpasses were locally received at the SMHI. In some of the overpasses the Helsinki Testbed area was only partially covered.

The first comparison was done including all the ceilometer stations. As coastal areas are typically problematic for cloud mask algorithms, an additional comparison, including only the coastal ceilometer stations (see Figure 1), was also done. The results from the comparisons are shown in Table 4. The SAFNWC/MSG cloud mask has better statistical scores compared to MPEF and is, thus, performing better in this study. The difference is emphasized in coastal areas, because the MPEF algorithm does not identify coastal areas separately and treats them only as land or sea. The SAFNWC/PPS cloud mask algorithm, in general, performs well, but has clear problems over the coastal areas. This is indicated by the drastic increase of FAR and MR scores. The number of comparisons in this study, however, is small. Due to the limited measurement range of the ceilometers, some high clouds may not have been detected. This may lead to incorrect false alarms, so all the FAR and BIAS scores should be interpreted with care.

All Stations	**A**	**B**	**C**	**D**	**PC**	**FAR**	**MR**	**BIAS**
MPEF	8845	4892	926	8207	0.741	0.367	0.099	1.423
SAFNWC/MSG	9129	4445	352	8393	0.785	0.327	0.037	1.432
SAFNWC/PPS	361	154	108	635	0.792	0.299	0.230	1.098
Coastal only								
MPEF	3469	2606	450	4064	0.711	0.429	0.115	1.550
SAFNWC/MSG	3606	2166	254	4487	0.770	0.375	0.066	1.495
SAFNWC/PPS	122	83	82	347	0.740	0.405	0.402	1.005

Table 4: **Statistical parameters calculated from the comparisons.**

Several error sources may be assigned to such a study—parallax error due to the high viewing angle of SEVIRI, comparison of a cloud mask areal-average to a ceilometer time-average etc. Therefore, the absolute values of the statistical scores are not of most importance. Ceilometers are very efficient in cloud detection, so detailed analysis of the cases in which a cloud mask fails (cases C, see Table 3) provide useful information about the problems in a cloud mask algorithm.

Figure 2 shows the case C histograms of MPEF and SAFNWC/MSG analysed by the detected cloud base height (CBH) and by the time (UTC) of the occurrence. In the CBH histograms the situations with fog has been assigned a cloud base height of -200 m. The MPEF algorithm misses many fog and low cloud situations during the night, and especially early in the morning just after the sunrise occurring around 2:30 UTC. These clouds are difficult to detect with the infra-red channels, because the cloud top temperature is very close to the surface temperature. The SAFNWC/MSG algorithm also misses some fog and low clouds slightly more than other cloud types, but the signal here is weak. One reason for the difference in the performance is that the SAFNWC/MSG algorithm uses the visual channels of SEVIRI when the solar zenith angle is less than 93 degrees, the threshold of which is achieved around 2:15 UTC, while the MPEF algorithm does the same when the solar zenith angle is less or equal to 72 degrees. In August this threshold is met in the studied area around 5:30 UTC. The benefit of using the visual channels in low cloud detection is clearly shown in the time histogram of MPEF; after the visual tests are turned on, the number of missed clouds decreases remarkably.

Both of the cloud masks missed almost an identical amount of high clouds around 7000 metres. This could be an indication of the parallax error. However, large number of the cloud mask misses, both with MPEF and SAFNWC/MSG, occurs with low clouds, where the effect of the parallax is negligible.

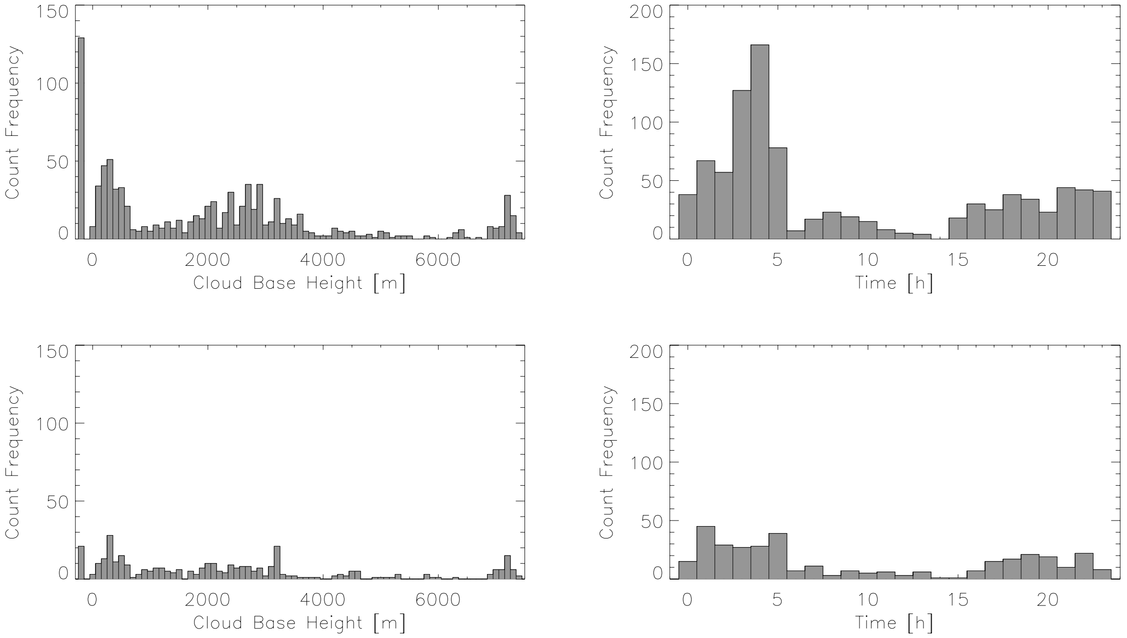

Figure 2: **The MPEF (upper row) and SAFNWC/MSG cases C analysed by Cloud Base Height and time.**

CONCLUSIONS

The purpose of this study was to evaluate the performance of three cloud masks at high latitudes. Moreover, due to the high efficiency of ceilometers in cloud detection, detailed analysis of the situations, where a cloud mask failed, was done. This information is very useful in the development and further improvement of cloud mask algorithms. The selected cloud masks to the study were MPEF, SAFNWC/MSG, and SAFNWC/PPS. MPEF and SAFNWC/MSG are using SEVIRI as the input data, while SAFNWC/PPS uses AVHRR. For this reason only the results from MPEF and SAFNWC/MSG are directly comparable against each other. The area of interest in the study, especially from the SEVIRI point of view, is very small; hence, the results should not be considered to be valid at full disc scale.

Having better statistical scores compared to MPEF, the SAFNWC/MSG cloud mask performs better in this study. The difference is emphasized over coastal areas. The reason for this is two-fold. Firstly, MPEF uses the SEVIRI visual channels rather late in the morning, whereas SAFNWC/MSG utilizes these channels already moments before the sunrise. As a result, some early morning clouds and fog, difficult to detect with IR channels, are missed by MPEF. Secondly, MPEF does not identify coastal areas, but treats them as land or sea.

The SAFNWC/PPS cloud mask performs, in general, well, but has clearly some problems over coastal areas. More detailed analysis would require a bigger data set.

All of the included cloud masks are operational and under continuous development. Due to this, the results presented here are strongly bound to the algorithm versions which were operational at the time of the study. The versions of SAFNWC/MSG and SAFNWC/PPS were 1.2, and 1.1, respectively. The current version of both of these algorithms is 2.0. The MPEF algorithm does not have official version control. Improvements to the algorithm are introduced via patches after an internal validation period. A bigger change to the MPEF algorithm was implemented into the operations 28 August 2007 including improvements in cloud detection especially over the seas, a coastal area check, and modified solar zenith angle thresholds, which improves the early morning cloud detection.

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