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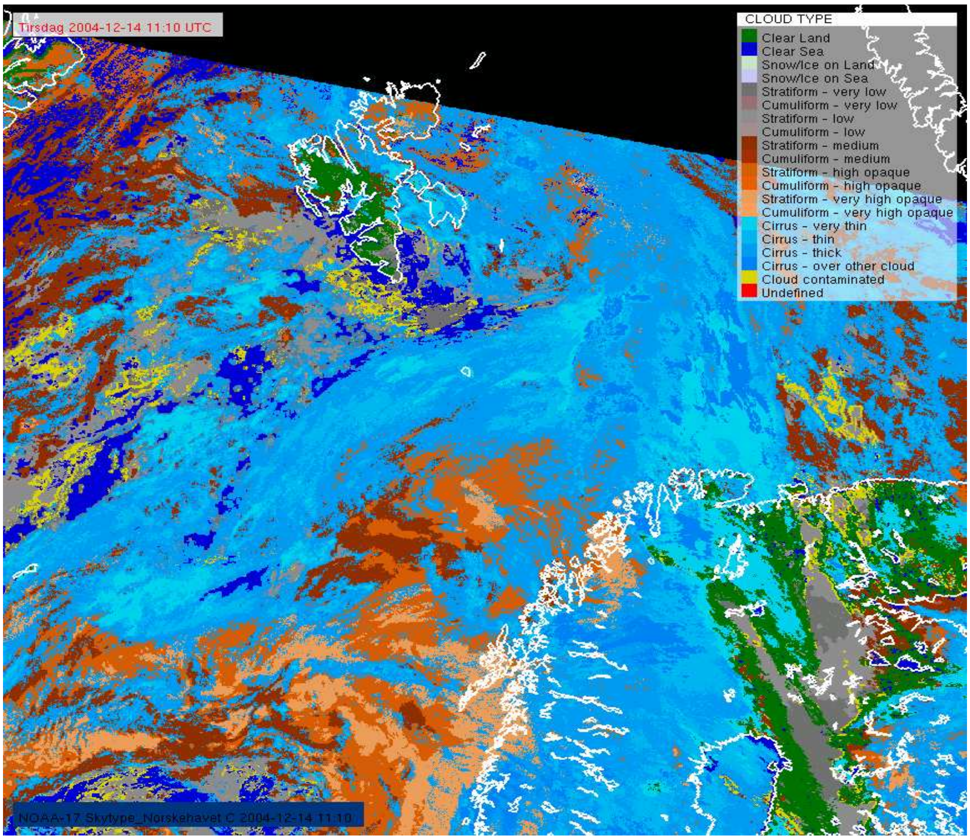
Validation of the NWCSAF PPS cloud products

Øystein Godøy



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Title

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Abstract

The Eumetsat Satellite Application Facility (SAF) in support of nowcasting and very short range forecasting (NWCSAF) delivers software to Eumetsat member states. The software for processing polar orbiting satellites (Polar Platform System - PPS) have been implemented at the Norwegian Meteorological Institute as part of the production system for Eumetsat Ocean and sea Ice for several years. This report presents validation results based upon collocation of NWCSAF PPS products and synoptic weather observations using a collocation software (FMCOL) developed in house. The results gained indicates that the Eumetsat NWCSAF PPS cloud products are reliable concerning detection of clouds, but data are insufficient to validate the classification of cloud types.

Keywords

Satellite Remote Sensing, AVHRR,Eumetsat, SAF, Nowcasting, PPS, objective classification, validation

Disiplinary signature	Responsible signature
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1 Introduction

The Eumetsat Satellite Application Facility (SAF) in support of nowcasting and very short range forecasting (NWCSAF) delivers software to Eumetsat member states. More information on the NWCSAF can be found at Eumetsat's SAF pages: http://www.eumetsat.de/saf/. At those pages an brief introduction to the products is given as well.

Within the NWCSAF software, two production lines are defined. One is dedicated to polar orbiting satellites, this is the Polar Platform System (PPS) and the other one is dedicated to geostationary satellites, this is the Meteosat Second Generation (MSG) system. It is the first one that have been examined at the Norwegian Meteorological Institute (NMI) as this also have been the baseline cloud mask and cloud type generation for the Ocean and sea Ice SAF (OSISAF) which NMI is involved in. The NWCSAF MSG software have not been implemented at NMI yet. Partly due to limited resources during the beta test period, but also due to the fact that the main forecast areas of NMI are at the very far end of the application area of the MSG software. The PPS output was needed in the OSISAF project whereas no immediate need for the MSG software was identified. Implementation of this software during the beta test period would thus not be given adequate attention concerning validation of the products and identification of problematic areas.

This report presents validation data of the current NWCSAF PPS cloud mask and cloud type using synoptic weather reports collocated with NWCSAF PPS output in the FMCOL[1] (Godøy, 2003b) system of NMI.

2 Introduction to the NWCSAF PPS software

2.1 Contents

The NWCSAF PPS software is described in Dybbroe et al. (2000a, 2000b, 2005a, 2005b). Basically the software contains four baseline modules. These are the Product Generating Elements (PGEs), but in order to reach a fully functional software and fulfilling the requirements of processing NOAA POES Level 1B data, some extra modules for map transformations is also contained in the software distribution.

2.1.1 Cloud mask

PGE1 of the NWCSAF PPS software is the cloud mask generation. This produces a cloud mask from AVHRR and NWP input. The cloud mask classifies each pixel as either cloudy, cloud contaminated or clear. Clear pixels are further classified as snow or ice covered. The classes used are described in Table 1.

Table 1 NWCSAF PPS cloud mas numbers and description.

#	*Class description*
0	Unprocessed
1	Cloud free land
2	Cloud free sea
3	Cloud contaminated

1 Collocation software based upon a library (libfmcol), it is further described later in the document.

#	*Class description*
4	Cloud filled
5	Snow/Ice contaminated
6	Unclassified

In order to achieve the classification all available AVHRR channels, observation geometry, NWP temperatures of the surface and the 950 hPa surface as well as the integrated atmospheric water vapour are used. In addition auxiliary data as digital elevation model, surface type database and land/sea masks are used. The methodology used is a threshold method with extensive use of a radiative transfer model in the preprocessing to generate updated threshold values for the specific scene being examined. For further details see Dybbroe et al. (2000a, 2000b, 2005a, 2005b).

2.1.2 Cloud type

PGE2 of the NWCSAF PPS software is the cloud type generation. This requires the cloud mask as input and further classifies the AVHRR data into several cloud types. In total (including cloud free classes) 20 classes are used. These are given in Table 2.

Table 2 Class number and description of the NWCSAF PPS cloud type product.

#	*Class description*
0	Unprocessed
1	Cloud free land
2	Cloud free sea
3	Snow contaminated land
4	Snow or Ice contaminated sea
5	Very low clouds - stratiform
6	Very low clouds - cumuliform
7	Low clouds - stratiform
8	Low clouds - cumuliform
9	Medium level clouds - stratiform
10	Medium level clouds – cumuliform
11	High opaque clouds - stratiform
12	High opaque clouds – cumuliform
13	Very high opaque clouds - stratiform
14	Very high opaque clouds - cumuliform
15	Very thin cirrus
16	Thin cirrus
17	Thick cirrus
18	Cirrus superimposed on low clouds
19	Fractional clouds

#	*Class description*
20	Unclassified

The methodology is the same as for the cloud mask, but more NWP data is used to determine the levels of clouds and to refine the cloud mask product in problematic areas. The extra NWP information used are temperatures of 850, 700, and 500 hPa, and a estimate of the Tropopause temperature. As for the cloud mask a radiative transfer model is used to estimate threshold values.

For further details see Dybbroe et al. (2000a, 2000b, 2005a, 2005b).

2.1.3 Cloud top temperature and height

PGE3 of the NWCSAF PPS software is the cloud top temperature and height generation. This requires the cloud type product as input in addition to AVHRR and HIRS. The radiative transfer model RTTOV (EUMETSAT NWPSAF http://www.met-office.gov.uk/research/interproj/nwpsaf/) is used to compensate for atmospheric effects. The method applied is supposed to improve cloud top temperatures especially in areas with thin Cirrus.

For further details see Dybbroe et al. (2000a, 2000b, 2005a, 2005b).

2.1.4 Precipitating clouds

PGE4 of the NWCSAF PPS software is the precipitating clouds product generation. This applies all available AVHRR channels along with AMSU-A/B (23.8, 89.0 and 150.0 Ghz), and the cloud type. The output is presented as a probability of 3 intensity classes.

For further details see Dybbroe et al. (2000a, 2000b, 2005a, 2005b).

2.2 Implementation at NMI

The present implementation at NMI was performed during the development of the Ocean and Sea Ice SAF. At that time NWCSAF PPS v0.3.0 was available. That is only the cloud mask and cloud type generation is implemented. The main reason for this is that at the time of implementation NMI was operating a AVHRR processing system which only delivered AVHRR on Level 2. The implementation was briefly described in Godøy (2002).

The NWCSAF PPS software requires access to AAPP (EUMETSAT NWPSAF http://www.met-office.gov.uk/research/interproj/nwpsaf/) Level 1B files of AVHRR, HIRS and AMSU. As this was not available at the time, the NWCSAF PPS software of the cloud mask and cloud type generation were slightly modified to accept the AVHRR Level 2 files of AVHRR data. These two modules were required for the OSISAF development and it was also possible with reasonable effort to integrate them in the NMI AVHRR processing system. This was not possible for cloud top temperatures and height and precipitating clouds.

The current implementation is also slightly modified concerning the input of NWP data which is required in WMO GRIB format. The local file format for these data, feltfiles have been filtered to a WMO GRIB standard by modification of software used to generated ECMWF GRIB. The local NWP data used at NMI is from the local implementation of the HIRLAM model (Bjørge et al., 2003).

The current versions in use at NMI are NWCSAF PPS v0.3.0 which contains ACPG v0.66 (ACPG is the cloud mask and cloud type generation, PGEs 1 and 2).

During the implementation of the NWCSAF PPS software a consistency check with SMHI was performed. As partner of the OSISAF project team and responsible for the OSISAF cloud mask/type, SMHI processed the same tiles as NMI. Both use HIRLAM as NWP input, but different versions and different setup. Furthermore, AVHRR data at SMHI were generated by AAPP, while the Kongsberg Spacetec (KSPT) Multimission Earth Observation System (MEOS) generated the AVHRR data used at NMI. Godøy (2002) presents a comparison of both NWCSAF PPS input and output on the OSISAF tiles. That study confirmed that the steps taken to integrate the NWCSAF PPS software in NMI's processing environment were appropriate. The overall resemblance of the output was satisfactory.

Two main areas causing differences were identified, the AVHRR input and the NWP input. Concerning the AVHRR input, insufficient observation geometry handling, channel calibration and handling of channel 3 split at NMI were identified as the major error sources. The differences in NWP input was not believed to be critical, it may affect the result, but are believed to be less important than the error sources identified in the AVHRR data.

As a consequence of the experience described in Godøy (2002) and Godøy (2003a), an internal project – AAPP4AVHRR - was initiated to create an AVHRR processing chain with full control and that fulfils the requirements of the NWCSAF PPS and OSISAF software on the AVHRR input. EUMETSAT offers the ATOVS and AVHRR Processing Package to its member states. This software is now supported by the NWPSAF. It reads HRPT data and creates NOAA Level 1B, but will be expanded with support of EPS METOP. For remapping from the satellite projection to e.g. Polar Stereographic map projection DAMAP, a tool based on USGS PROJ.4 is used. This software was developed by the Danish Meteorological Institute (DMI), using some parts of the NWCSAF PPS software for reading NOAA Level 1B. This software have been further developed at NMI and seems as a common platform for the two Nordic institutes.

2.3 Future plans at NMI

It is planned to upgrade the current implementation of AAPP 3.4 to AAPP 4.4. When this is done NWCSAF PPS v1.0 will be implemented (or v1.1 if that is available). This upgrade will however affect several systems at NMI and care has to be taken in the upgrade process. It is especially important to ensure consistency of the OSISAF products through the upgrade process. The upgrade is likely to take place early 2005. During this upgrade the cloud top temperature and height and precipitating clouds will also be implemented.

2.4 Sample products

Two sample products of the current operational processing chain at NMI are presented within this report. This is one cloud mask product and one cloud type product, both for the Norwegian Sea tile defined for use within the OSISAF project. Further information on the product tiles used can be found in Godøy (2003a). The data presented in this chapter is used for routine production within the Ocean and sea Ice SAF as well as they are distributed to the operational forecasters by NMI's Digital Analysis software (DIANA) where they are collocated with other available meteorological data like synoptic observations, weather radar data, NWP and Ocean Numerical Model output.

Figure 1 shows the cloud mask output generated for AVHRR data received 11:10 UTC 14 December 2004. The classes identified in Table 1 are clearly found.

Figure 2 shows the corresponding cloud type product with the classes identified in Table 2. It is hard to tell which classes that are used from this image, but when these products are presented in

DIANA (the meteorological visualisation software used at NMI) an information area tells which cloud type is under the cursor at any time.

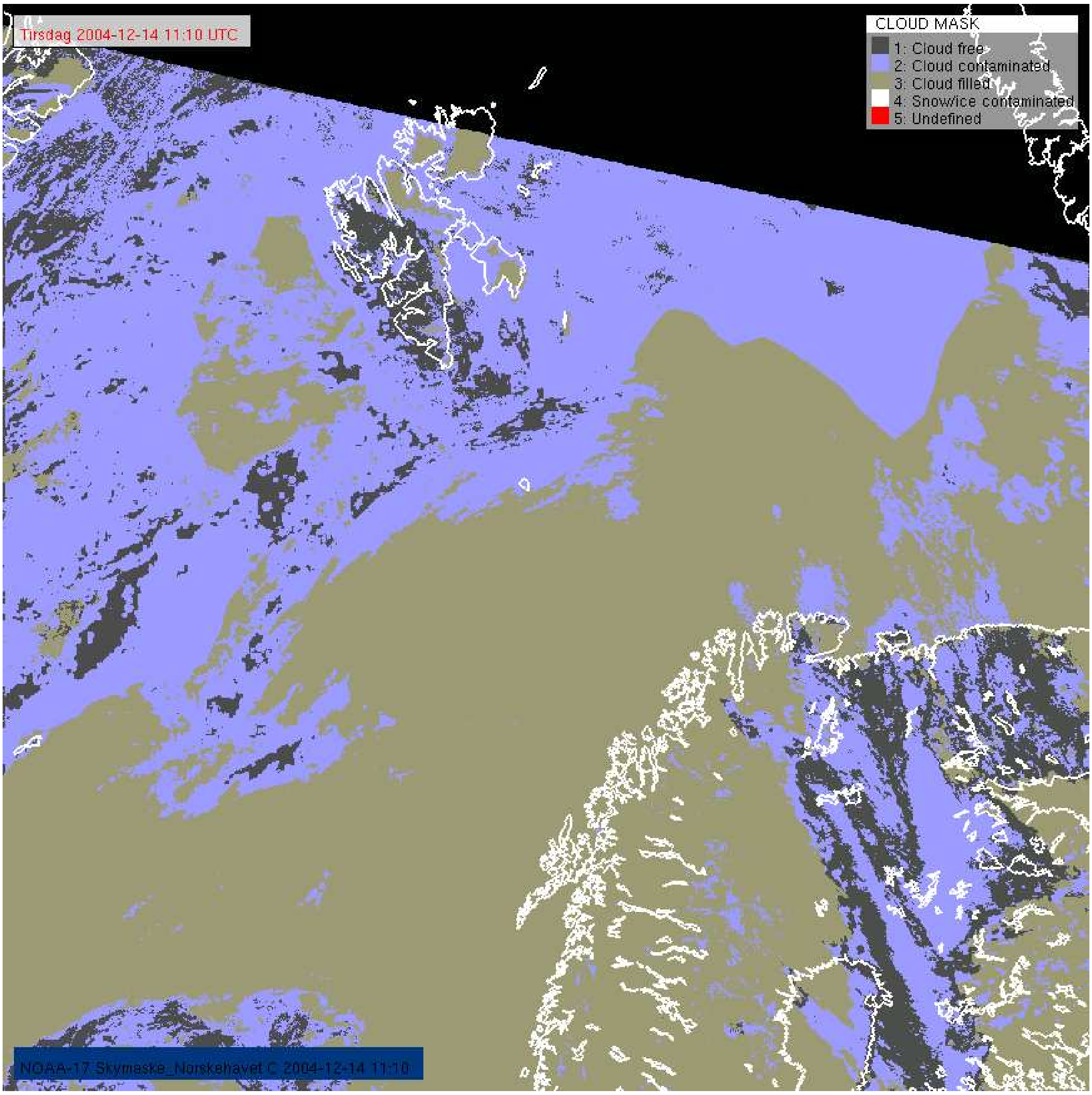

Figure 1 Cloud mask output from the NWCSAF PPS software as implemented at NMI.

3 Validation

3.1 General

Validation is performed using an automatic system (FMCOL) which collocates data from synoptic weather stations, AVHRR Level 2 data, NWCSAF PPS cloud type and HIRLAM NWP output. Collocation is performed using a library *libfmcol* which together with the main software constitues FMCOL v1.0 (Godøy, 2003b). The collocated objects are stored in a NCSA HDF5 file format which is accessible from the statistical software R (R Development Core Team, 2004) using proprietary functions.

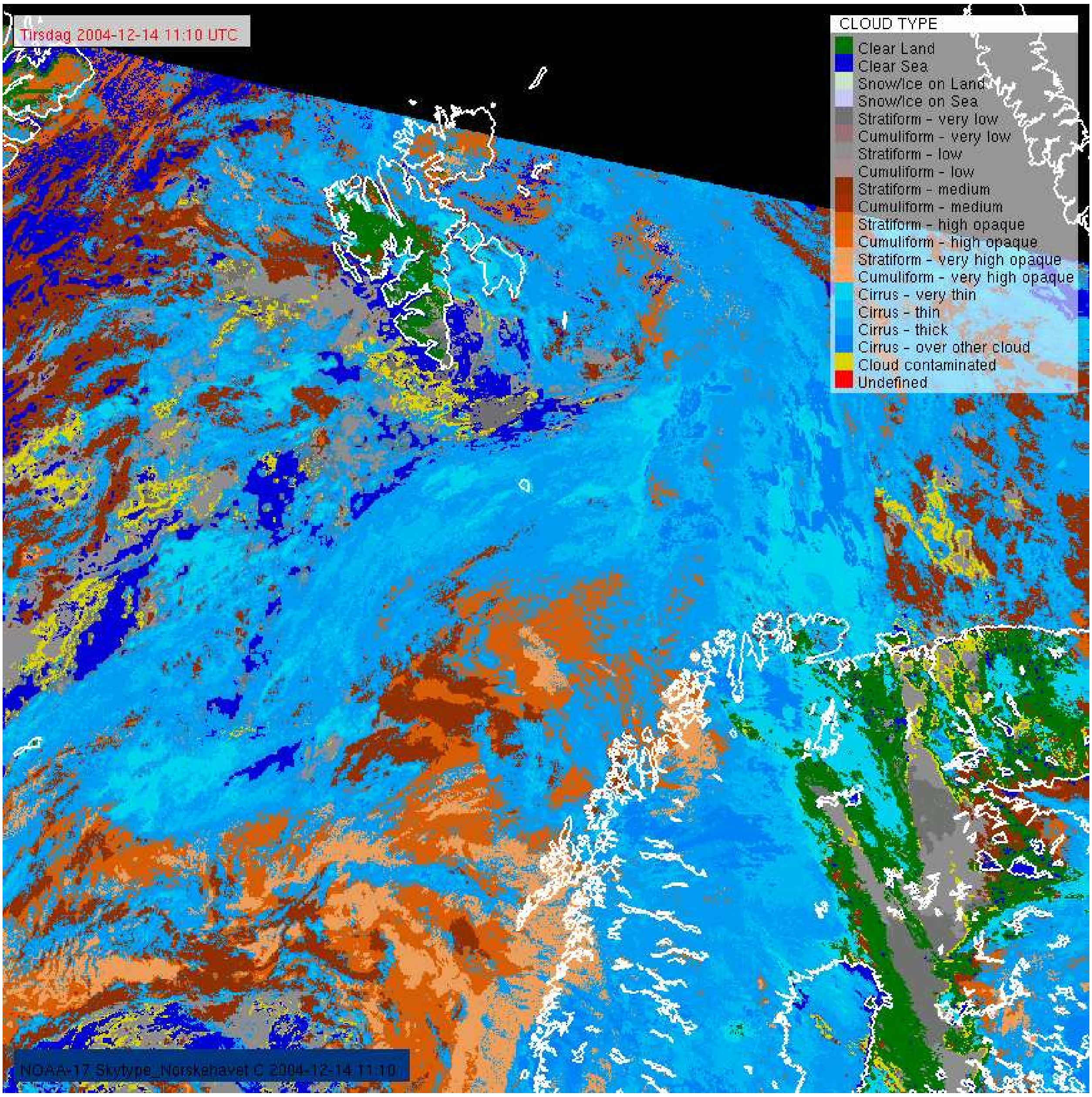

Figure 2 Cloud type output of the NWCSAF PPS software as implemented at NMI.

In the setup used for this validation process a job was set up to run every night processing the available data since the last collocation process. Except for constraints on the maximum time difference between the various data types no further quality control was performed within the collocation process. The maximum time difference allowed for objects to be stored was 1 hour.

In order to compensate for the insufficient quality control of FMCOL v1.0, some extra functionality were built into the R-functions collecting data from the NCSA HDF5 files for further processing. Among the major issues were removal of all out of satellite coverage elements, removal of dubious NWCSAF PPS cloud type results (caused by insufficient string handling in the NWCSAF PPS NDF5 files) and an error caused by file handle overflow due to a programming bug in the FMCOL HDF5 file handling.

The time period being examined were 11 February 2003 through 9 June 2004. During this period 1640 valid satellite scenes were stored.

Within each satellite scene, 18 Norwegian synoptic stations were used for the validation. These are listed in Table 3. Most of these stations have manual cloud observations, but those marked by gsmautomat have not. However, these data have been used for other purposes as well and the stations listed as gsmautomat have not been used in the validation of cloud products. this leaves 15 stations in the validation database. The stations cover most of Norway, from north to south, some stations are airports while the others are mainly placed in uniform areas.

Table 3 Stations used in the NWCSAF PPS validation.

id	*name*	*latitude*	*longitude*	*description*
01317	Bergen / Flesland	60.233N	5.233E	manual
01384	Oslo / Gardermoen	60.200N	11.083E	manual
01415	Stavanger /Sola	58.883N	5.633E	gsmhybrid
01212	Ona	62.867N	6.533E	gsmautomat
01023	Bardufoss	69.067N	18.533E	manual
01199	Sihcajavri	68.750N	23.533E	manual
01028	Bjørnøya	74.517N	19.017E	manual
01047	Kautokeino	69.000N	23.033E	gsmpio
01452	Kristiansand / Kjevik	58.200N	8.083E	gsmhybrid
01210	Ålesund / Vigra	62.567N	6.117E	gsmhybrid
01328	Kvamskogen	60.400N	5.917E	gsmpio
01380	Venabu	61.650N	10.117E	gsmpio
01494	Rygge	59.383N	10.783E	gsmhybrid
01288	Røros	62.567N	11.383E	gsmautomat
01367	Fagernes	60.983N	9.233E	gsmautomat
01274	Selbu-Stubbe	63.200N	11.117E	gsmpio
01134	Fiplingsvatn	65.300N	13.533E	gsmpio
01147	Varnetresk	65.750N	14.183E	gsmpio

3.2 Problems

Most of the problems encountered were connected to the AVHRR processing at NMI. This are documented in Godøy (2003a), but the main issues are repeated below.

The validation presented herein is based upon NWCSAF PPS products generated from KSPT MEOS Level 2 input. Most of the period examined herein the map projection used the MEOS system differs from the NMI standard. This have caused a misalignment of NWCSAF PPS products which might affect the quality as inferred by this study.

Furthermore, the KSPT MEOS processing does not keep both channel 3A and 3B when AVHRR/3 switches during readout. This increases the number of unprocessed pixels in the output of the NWCSAF PPS software.

Quite a few NWCSAF PPS cloud type elements were corrupted due to string and maximum file handles handling in the HDF5 storing process of FMCOL.

3.3 Results

Results are presented as histograms in Figure 3 through Figure 5. In these histograms, classes are represented by numbers. The correspondence between numbers and textual class descriptions are given in Table 2.

Figure 3 shows the validation results of NWCSAF PPS cloud type product using synoptic weather cloud cover observations. The upper panel shows results for totally clear situations , while the lower panel shows results for completely overcast situations. Cloud contaminated observations were discarded from the analysis in this set up. It is readily observed that cloud covered situations are by far the most prominent class.

The overall tendency of Figure 3 supports our expectations, the clear situations shows mostly cloud type indexes below 5. Index 0 is unprocessed, 1-4 are cloud free surfaces, 5-19 are various cloud types and 20 is unclassified as described in Table 2. The lower panel containing fully overcast situations shows that the NWCSAF PPS classification mainly generates cloud types and not clear classifications.

A very small tendency towards false classification of clear pixels as very low stratiform clouds or very thin cirrus is observed in the upper panel. Similarly for overcast pixels some cloudy pixels are classified as clear (especially clear land, but that is probably due to a land biased validation data set). The problem of falsely classifying a pixel as clear when it in fact is cloudy seems to be more frequent than the opposite.

Another important feature of Figure 3 is the lack of the cumuliform cloud types, i.e. classes numbered 6, 8, 10, 12, and 14 (see Table 2). According to Adam Dybbroe (pers. comm.) the separation between stratiform and cumuliform classes were not implemented in NWCSAF PPS v0.3.0.

Figure 4 shows the validation results for overcast situations (as defined by the synoptic weather report). The upper panel shows results for low clouds without other clouds above and the lower panel for medium clouds without other clouds above.

It is easily seen that very few data with low clouds without any clouds above are stored, but for those stored, a clear tendency towards misinterpreting them as cloud free is observed. Furthermore, quite a few are classified as medium or high level clouds, if not fractional clouds. Based on this very sparse data set it might seem as if the method have some problems handling low level clouds.

The lower panel of Figure 4 similarly presents the results for medium level clouds without any clouds above. The NWCSAF PPS cloudtype generation performs better on these clouds, but misclassification of pixels as clear or low level clouds are quite frequent.

Figure 5 shows the results for high clouds. The upper panel shows all high clouds, while the lower panel shows results for thin cirrus. The most obvious feature of Figure 5 is the resemblance of the upper panel with lower panel of Figure 3. This implies that very few synoptic cloud reports are given without high level clouds. This is not a surprising fact given the recommendations of how to perform the cloud cover/type judgement at synoptic weather stations.

The lower panel shows the results for thin cirrus. very situations are stored, but a strong tendency towards misinterpreting them as clear or low or medium level clouds is found.

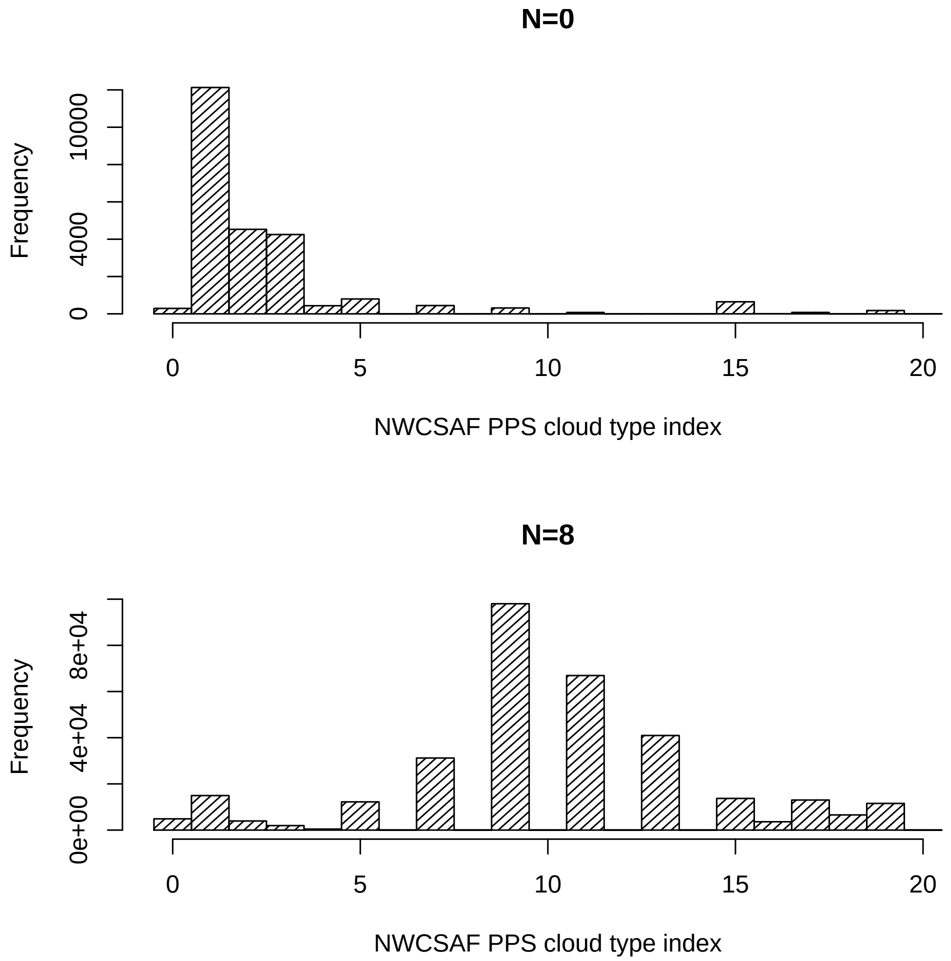

Figure 3 Validation results for clear and overcast situations. See Table 2 for textual description of class numbers.

The results above indicates that the material available can be usable for quantitative validation of cloud detection, but to a lesser extent for quantitative validation of the cloud types. Following the specifications of *WWRP/WGNE Joint Working Group on Verification* (sponsored by WMO and available at http://www.bom.gov.au/bmrc/wefor/staff/eee/verif/verif_web_page.html) examination of the hits, misses, false alarms and correct negatives of the NWCSAF PPS cloud product results in the contingency table given in Table 4.

The quantitative measures described below are computed.

Accuracy (EQ. (1)) which tells us the average fraction of correct estimates (should be close to 1).

$$Accuracy = \frac{hits + correct\ negatives}{total} \tag{1}$$

Bias score (EQ. (2)) which tells us how the frequency of cloudy targets compare to the number of observed cloudy targets (should be close to 1).

$$Bias = \frac{hits + false\ alarms}{hits + misses} \tag{2}$$

Probability of detection (EQ. (3)) which tells how well the method identifies cloudy targets (should be close to 1).

$$Probability\ of\ Detection = \frac{hits}{hits + misses} \quad (3)$$

False alarm ratio (EQ. (4)) which tells how often the method identifies the wrong case (should be close to 0).

$$False\ Alarm\ Rate = false\frac{alarm}{hits + false\ alarms} \quad (4)$$

Table 4 Contingency table representing the relation between satelite classification and synoptic observation of cloudy or clear areas.

		observed		
		cloudy	***clear***	
satellite	***cloudy***	286 163	2 357	288 520
	clear	21 240	21 341	42 581
		307 403	23 698	331 101

Given the results of Table 4 and EQ. (1) - (4) the accuracy is found to be 0.93, the bias is found to be 0.94, the probability of detection is 0.93 and finally the false alarm rate is 0.01. The data used in the computation above includes only full overcast or clear pixels from the NWCSAF PPS product generation and fully clear or cloudy synoptic observations.

4 Discussion

The collocation of data presented herein was performed using the first version of the FMCOL software. During analysis of the data insufficiencies as well as bugs in the software have been revealed. These bugs, e.g. quality control of completely missing targets (out of image coverage), too many open NCSA HDF5 file handles, character string errors in NWCSAF PPS products and insufficient time stamps of synoptic reports have been corrected. However, the presence of these bugs drastically reduced the available collocated data sets for validation.

Given the shortcomings described above of the system the validation results gained were quite encouraging concerning the ability of the NWCSAF PPS software to operate in a complex topography as the Norwegian. That is, the ability to determine whether a pixel is cloudy or not is encouraging, the ability to determine the actual cloud type as described in the synoptic report however, is far less straightforward.

The synoptic report performed by manual inspection is performed by an observer at ground. The observer sees the lowest cloud layer, but observation of higher cloud levels are more difficult and causes an biased observation. On the other hand, the satellite observes clouds from the top and will thus best view the highest cloud layer and will have trouble with lower layers. This is clearly evident from Figure 4 and Figure 5 where very few pixel fulfils the requirement of low or medium clouds only.

Although the data material available for validation of low or medium clouds only is too sparse to make any direct conclusions, it is indicated that the NWCSAF PPS cloud type generation failure increases the lower the clouds become. This result is however complicated by the fact that interpretation of such data often are difficult due to scattered clouds at several layers, a configuration which was not possible to study in detail with current data set.

The value of using synoptic observations for validation of the cloud height is thus questionable. However, the collocation of such data will continue as these data might be easier to interpret in the future when more experience in this field is gained. This is an important aspect concerning the use of the NWCSAF PPS cloud types within the OSISAF SSIFLUX (shortwave surface irradiance) processing.

The quantitative validation results gained for detection of cloud filled pixels seems to be quite good over land with a probability of detection of 0.93 and false alarm rate of 0.01.

One could argue that a simulation of surface made observations from the satellite data (Karlsson, 1993, 1995) should have been made before such a comparison is performed. However, as only fully clear or overcast areas (determined by the synoptic measurement) are used, and no comparison of cloud cover is performed it is believed that the results could provide valuable information anyway.

Dybbroe (2004) shows that cloud cover is artificially increased when no attitude correction of the satellite is performed during navigation. Such attitude correction might be performed using the Meteo France / CMS Automatic Adjustment Software ANA. This software was not installed when the data used in this study were processed. Thus, these data might have a higher number of clear pixels misclassified as cloudy in the coastal region than what would be achieved using the most recent NWCSAF PPS version along with ANA.

One of the intentions of this study was to gain knowledge on how the NWCSAF PPS cloud type generation might affect the OSISAF products Sea Surface Temperature, shortwave surface irradiance, and longwave surface irradiance. As the data base build during this study only contain land stations this is not straightforward but it is believed that the results gained in ocean areas will be better than the results gained on land. The main reasons for this is due to the uniform surface and that the topography usually complicates the use of NWP temperatures on land. However, in order to validate over ocean surfaces where synoptic measurements are sparse, a modification of the forecaster tool at NMI have been implemented. This is the tool that the forecasters use for analysis and visualization of meteorological products. Basically the new modification lets the forecaster look at the NWCSAF PPS output together with synoptic observations, level 2 AVHRR imagery and NWP output. The forecaster can then reclassify areas in the NWCSAF PPS product. The information containing the time of the product, position of the target and the new class is submitted to a parser that makes a coarse quality control and creates an input file for the collocation software (FMCOL). In the collocation file observing geometry, AVHRR, NWP, OSISAF SSI and OSISAF DLI objects are stored. This permits us to rerun the algorithms on the collocated files if needed. These files are directly accessible from R (R Development Core Team, 2004) which allows generation of statistics and graphics. More information on the system is given in Christoffersen et al. (2003) and Godøy (2003b).

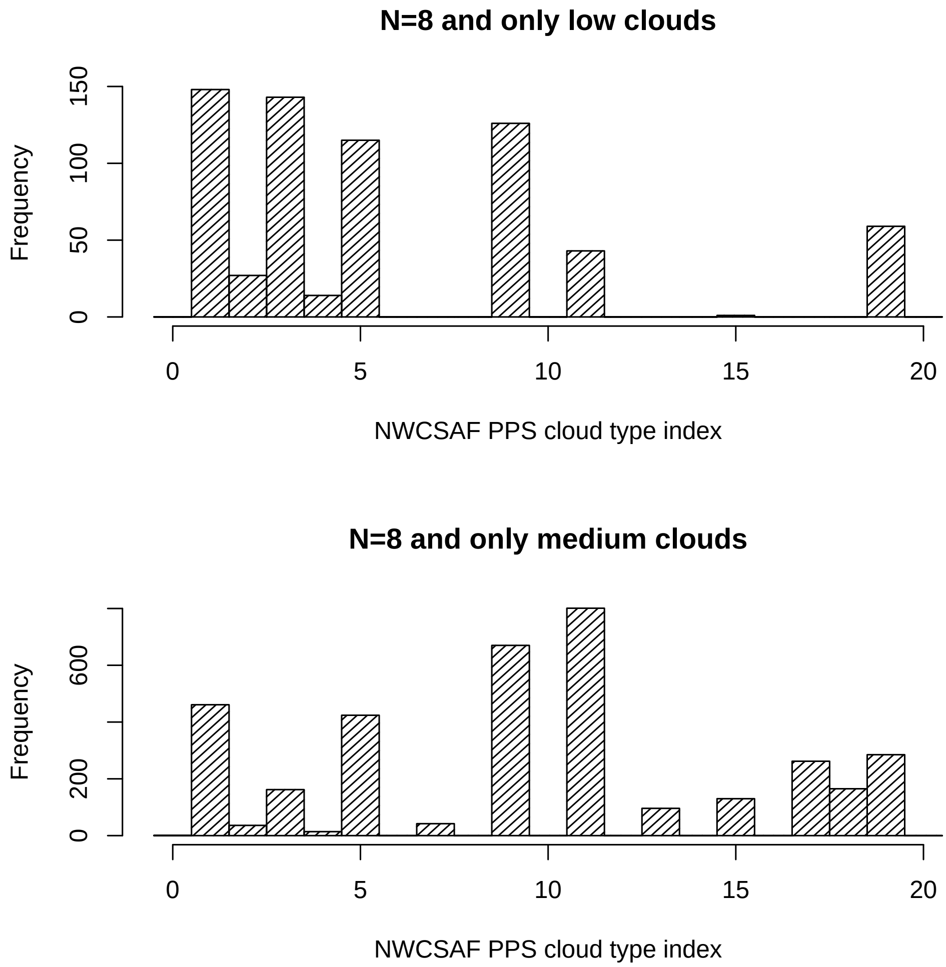

Figure 4 Validation results for cloudy situations containing only low and medium level clouds (upper and lower panel respectively). See Table 2 for textual description of class numbers.

5 Summary

This study has shown that the NWCSAF PPS cloud type generation have a slight tendency towards misclassifying cloudy pixels as clear. The relative effect of this seems to be largest for the low and medium clods (without any clouds above). Some tendency towards classifying clear pixels as cloudy is also observed, but compared to the total number of pixels this problem seems to be less.

The collocated data set is too sparse to conclude on which cloud type that is most affected by misclassification.

In Godøy (2002, 2003a) some problems related to the basic AVHRR processing at NMI were identified. This data set has been built using AVHRR data from the Kongsberg Spacetec MEOS implementation at NMI. However, a new implementation of AVHRR processing based upon Eumetsat AAPP and Danish Meteorological Institute DAMAP software have been operational since mid 2004. This will remove many of the problems encountered in the present study. The new implementation includes the use of ANA which reduces problems in the coastal zone.

No validation have been performed over ocean, an area which is very important for the OSISAF radiative flux and SST products. This will be pursued in the next study by help from the operatinal forecasters at NMI.

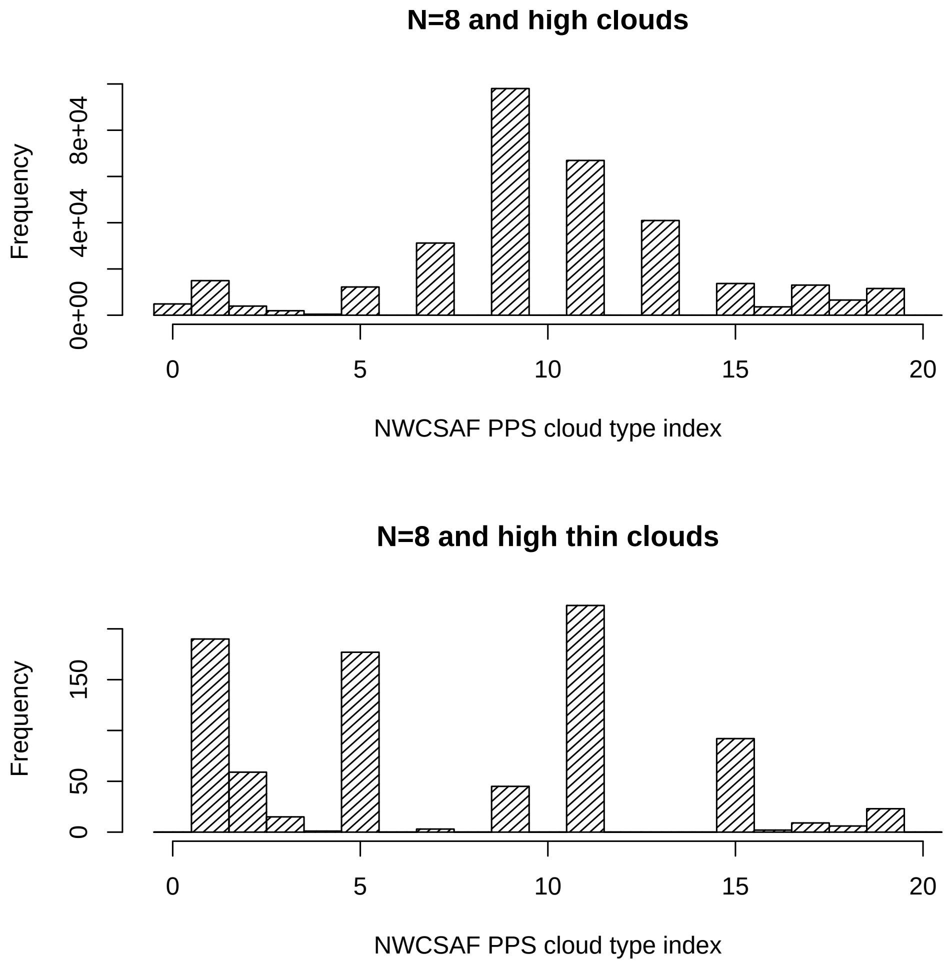

Figure 5 Validation results of cloudy situations containing only high level clouds (upper and lower panel shows all high level clouds and only thin Cirrus respectively). See Table 2 for textual description of class numbers.

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