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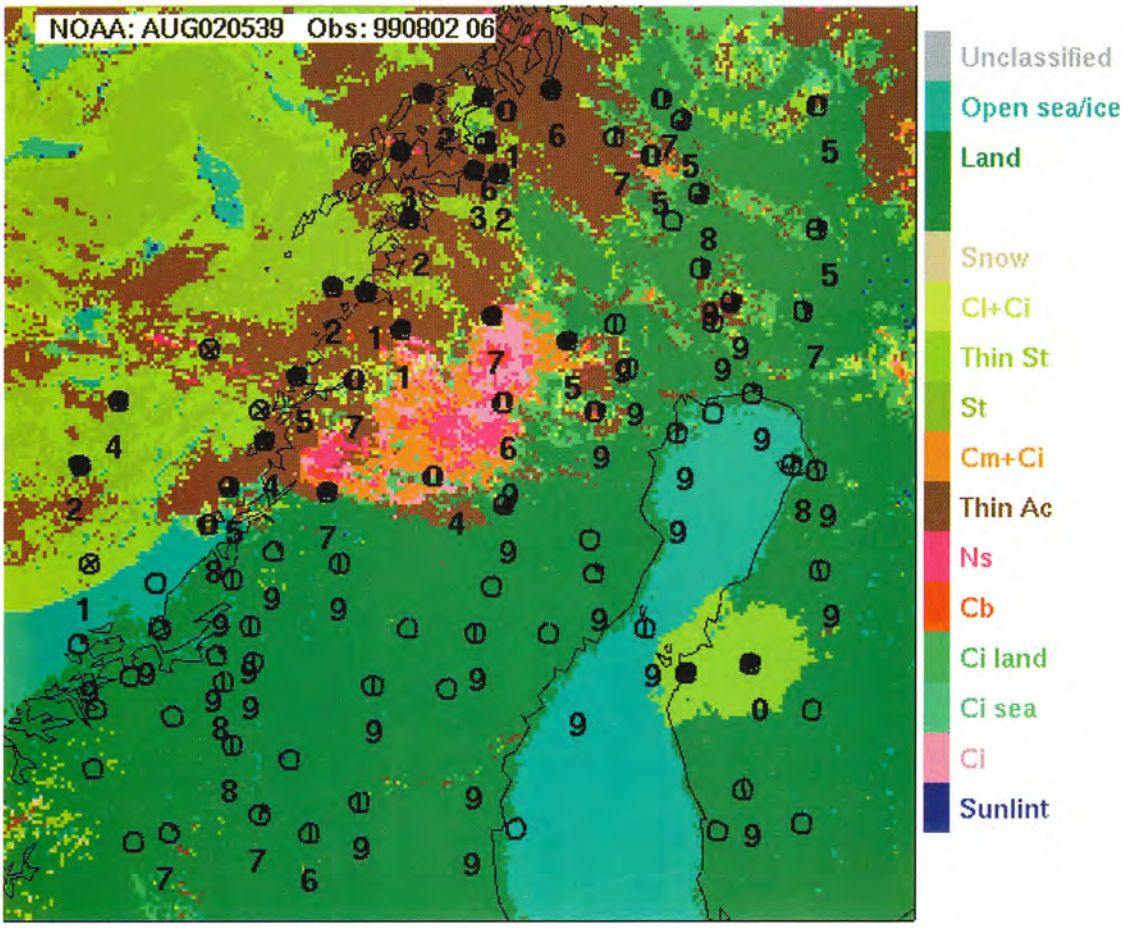

SCANDIA
-its accuracy in classifying
LOW CLOUDS

Pia Hultgren, Adam Dybbroe and Karl-Göran Karlsson
An exchange-work between The Swedish Airforce and SMHI

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Front cover: SCANDIA cloud classification from 2 August 1999 at 05:39 UTC compared to SYNOP observed total cloud cover (circular symbol) and significant cloud base altitude (below circular symbol) at 06 UTC.

1. INTRODUCTION

Low clouds are of great interest for the airborne users of weather forecasts. Therefore it is important to improve the techniques of forecasting low clouds. One valuable way to detect low clouds is through the information from satellite images. A cloud classfication model (named SCANDIA – described by Karlsson, 1996) is used since many years at SMHI. Cloud classification results are distributed to users at the central forecasting office, at local forecasting offices and at forecasting offices of the Swedish Airforce. Since there are still improvements to make in cloud classification applications, the Swedish Airforce started this project to join the development and research going on in this area at SMHI.

The study focuses on low clouds. As we know from long term experience and earlier studies, the SCANDIA cloud classification model has problems in specific conditions. These situations are:

- Low level inversion with no significant cloud signature (due to dawn/dusk illumination or mixed water & ice phases).

- Sunglint in combination with cold sea.

- Forward scattering, particularly in moist and hazy atmospheres.

This document reports on the general performance of the SCANDIA cloud classification scheme concerning the treatment of low clouds. Validations and verifications have been made to identify and focus on the specific problems. A database (MSMS = Matching Satellite Model & SYNOP data) was constructed and is continuously being updated and expanded. MSMS is used for the validations and verifications. By studying the information in the database from surface observations, NOAA AVHRR satellite data, and the SCANDIA classification, the problems can be identified, and some ways to improve the classification model might be found and suggested. In a wider scope, it can be seen as a preliminary study for the purpose of improving the analysis of low cloudines inferred from satellite data in the SMHI mesoscale analysis model MESAN (Häggmark, 1997).

2. OBJECTIVES

The main objective with this work is to use the created database MSMS for validations in order to learn and understand more how SCANDIA behaves concerning low clouds. To fulfil this the intention is:

To build a database containing collocated SYNOP observations, AVHRR satellite data, SCANDIA data, and NWP-model data for a selected set of surface observation stations.

To use the database (MSMS) to study and validate the performance of the SCANDIA model concerning the analysis of low clouds. The investigations focus on the specific conditions of sunglint and presence of low level inversions where it is well known that SCANDIA has problems. In addition to the objective assessment of the general reliability of SCANDIA in these problematic situations it is of importance to know if the reliability show any significant and systematic dependency that might be possible to correct for in a future objective classification scheme. The parameters that come to mind are

- The HIRLAM data. The forecasted surface temperature and the layer temperature on 700 hPa are the parameters used for the low-cloud-analysis in SCANDIA.
- Solar zenith angle.
- Satellite zenith angle.
- Sun-satellite azimuth difference-angle (determining possible anisotropic scattering).
- Vertical temperature profile.
- The total atmospheric water vapour content.
- The location of the station (if the orography or the land/sea environment play any role).
- Surface temperature.

3. BACKGROUND

3.1 Low clouds

The Definition of low clouds varies depending on the situation. The official definition is that low clouds are the clouds that exist below 2500m, which is also the limit for low clouds in the SYNOP code. The reason for focusing on low clouds is that the accuracy of the low cloud classification in SCANDIA today, is not satisfactory, and that they play an important role in weather forecasting especially for the aviation customers. The very low clouds, Stratus & fog (clouds below 300 m) are the cloud types that can highly effect the starting and landing procedures, which are the most critical part of a flight. These low clouds are relatively common at high latitudes and especially during the darker half of the year.

3.2 Low cloudiness in SCANDIA

The basic idea of a cloud classification of satellite images can be summarised by the following:

1. To reduce the amount of data presented to the forecaster and at the same time provide the optimal amount of information for the specific meteorological problems (the clouds).
2. To provide an automatic and objective digital product, which is easy to incorporate into an objective (mesoscale) analysis or forecast model.

The SCANDIA classification model use calibrated and geometrically transformed image data from the five AVHRR channels. The model uses a classical box model with a set of unique thresholds defined for each of the specific categories. A general description of the model is found in the SMHI RMK No.67 (Karlsson, 1996).

SCANDIA is operationally executed in two version at present (1999). The first version (original SCANDIA) is run with full AVHRR horizontal resolution (1 km) in areas covering south and north Sweden and the second version (updated SCANDIA) is run on a coarse resolution (4 km) covering northern Europe.

The studied version of the model (updated SCANDIA) uses 12 eight bit image layers to segment a scene into a number of different classes depending on the sun elevation and the season:

The low clouds in SCANDIA is treated by using the layers:

1. AVHRR channel1

4. AVHRR channel 3 - AVHRR channel 4 + 127

6. AVHRR channel 5 - AVHRR channel 4 + 127

7. Channel 4 temperatures – HIRLAM surface temperatures + 127

8. Channel 4 temperatures – HIRLAM 700 hPa temperatures + 127

10. HIRLAM surface temperatures – HIRLAM 700 hPa temperatures + 127

12. HIRLAM surface temperatures

Notice that the value 127, which is added to the differences, defines the zero level in an eight-bit representation.

The procedure to sort out low clouds from other cloud types and surface types can shortly be described by the following steps:

Step1: General cloud detection

Step 2: Identification of low clouds

Step 3: Quality check

Analysis of layers 1, 4 and 7 form the backbone of the general cloud detection in step 1 during day-time. Clouds are basically identified if values in layer 1 exceed a reflectance threshold and if layer 4 values are below a temperature difference threshold (denoted ct4 which regulates how much warmer a cloud should appear in AVHRR channel 3). In addition, an extra check of values in AVHRR channel 4 is made by comparing with forecasted surface temperatures in layer 7. Clouds are here identified if AVHRR channel 4 brightness temperatures are significantly colder (as described by the TEMPADD parameter –currently set to 8 K) than the forecasted surface temperature. The test in layer 7 is very important for cases when cloud reflectance's (affecting layers 1 and 4) are very low (e.g. in twilight and in shadows). At night the cloud detection relies mainly on tests of layers 4 and 7. The threshold for layer 4 has now a reversed sign (water clouds are colder in AVHRR channel 3 at night). Layer 6 is used in addition at night (a negative difference indicates semi-transparent Cirrus clouds).

To extract only the low clouds in step 2 layers 8 and 6 are used. Low clouds are here defined to be warmer than the temperature in 700 hPa, thus a positive difference is required in layer 8. Cirrus clouds (which often have this property) are sorted out by using layer 6.

The final quality check in step 3 is motivated by the fact that the existence of low-level temperature inversions often violates the test with layer 8 in step 2. Thus, a simple check of if inversions are present is made by use of layer 10 (discussed further in section 3.4). When a low level inversion exists due to the quality check, the pixels are being labeled unclassified

It is already mentioned that SCANDIA is less reliable in situations with sunglint and with low level inversions. Here follows a little background to these problems.

3.3 Sunglint

Sunglint can be observed in imagery from polar orbiting satellites. It occurs over water surfaces when solar radiation is reflected by direct specular reflection. The direct reflection is possible when the incident angle of the sun equals the satellite-viewing angle over a calm water surface. Water surfaces outside sunglint areas, have normally very low reflectance's, especially at longer wavelengths.

In the VIS region of the spectra (0.4-1.0 μm) the sun produces a bright spot in the calm ocean (or the sea) at the specular point (the critical angle). In a windy situation, a larger area around the specular point is lit up by sunglints from waves and ripples.

Low-level clouds like Stratus and fog may be difficult to separate from sun glints if the cloud top temperatures are very close to the ocean temperatures.

To classify sunglint SCANDIA first uses a geographical map, to ensure there are no land pixels. Then layer 7 is used in an attempt to distinguish cloudy pixels from cloud free. The cloud processing in step 1 in the previous section is then carried out. The strength of the sunglint is divided into four categories and these are determined using layers 1 and 4.

3.4 Inversions

In the atmosphere inversions exist when the temperature lapse-rate increases with height in a specific layer. Radiative cooling of the surface, subsidence due to a high pressure or a frontal situation may cause inversions to form.

One problem is that the low-level stratiform clouds, which are very common at high latitudes (especially during night and during the winter season) are closely linked to a surface inversion or a low-level inversion (normally between 1-3 km). If inversions are very strong this often leads to very low cloud top temperatures for low level clouds implying a risk for misinterpreting the cloud as a mid-level or even high-level cloud.

Another problem is related to the cloud test based exclusively on AVHRR channel 4 brightness temperatures (the TEMPADD test described earlier). The basic idea of this test is to try to improve classification results (compared to the original SCANDIA model) when no typical cloud signature is available in visible and infrared channels (excluding AVHRR channel 4). In cases of inversions, the local variation of surface temperatures within a HIRLAM grid square is generally larger than in other cases. Thus, the risk to mistake a cloudfree and cold pixel for being cloudy is then large. This is especially serious in areas with a large topographical variation and the problem naturally increases in strength if forecasted surface temperatures are too high.

The SCANDIA model uses both static thresholds and forecasted temperatures from HIRLAM to treat potential classification problems due to inversions. The following processing steps are utilised:

1. Inversions are generally assumed to be present if the forecasted surface temperature is colder than a predefined parameter (*COLDLAND*). This parameter is currently set to –2.5 °C. The COLDLAND test is used for precaution reasons, i.e, inversions are very common at these situations and it has been shown that HIRLAM often fails to correctly describe inversion in very cold weather situations. In addition, even if the surface temperature forecast is correct the local variation within a gridpoint is likely to be large at low temperatures which may lead to a misclassification of very cold pixels.

2. If the *COLDLAND* test fails, inversions may still be detected if the forecasted surface temperature is colder than the forecasted temperature at 700 hPa + the parameter *TSURBIAS* (which is set to 10 °C). The *TSURBIAS* parameter may be regarded as a correction for the known warm bias in the HIRLAM surface temperature in very cold winter situations.

3. When inversions are indicated by the first test above, unclassified pixels are NOT produced but erroneous low clouds due to single infrared tests (discussed later in sections 6.2.3 and 6.2.6) are prohibited.

   If the second test is positive, SCANDIA labels the actual pixels unclassified in order to avoid misclassifications (misinterpreting cloudy pixels as cloudfree). These unclassified values are set to 2 or 3 in SCANDIA. In practice, this means that when inversions are so strong (i.e., the surface temperature is below the 700 hPa temperature), there will be a zone in the lower troposphere where clouds may exist without being detected and this would justify to label the pixel as unclassified.

4. The DATA

4.1 The database

To be able to investigate and validate the SCANDIA classification model, a database was built.

The database, MSMS (Matching Satellite Model & SYNOP data) is used as the unique source of information for the investigations in this report.

For the database AVHRR data, SCANDIA results and HIRLAM data are stored for each matching SYNOP report. Matchup-data have been added continuously since June 1998. The data used for the validations in this report are from June the 7th 1998 to June the 1st 1999. The almost one year data set have small interruptions, but also it includes a week of data from March 1998. The investigations might focus primarily on the darker half of the year, since most of the earlier mentioned problems occur during low sun elevations and during inversion situations.

The time deviation between the satellite pass and the SYNOP had to be less than one hour to be saved as a "match".

The used version of the SCANDIA (the updated SCANDIA) classification model that is used in the database has a resolution of 4 km, while the basic AVHRR (imagery has a resolution of 1 km). More details on the MSMS database may be found in a manual by Dybbroe & Hultgren (1999).

4.2 Selected stations

A selection of surface observations from Synoptic and automatic observation stations is displayed on a map in figure 1. The selected observations are spread out over the area, which are mainly over Sweden, but also stations in Norway, Denmark, Finland, Great Britain, Poland and the Baltic states are included in the database. The geographic selection of the stations were chosen to represent the area well, but also to include locations near the coast and in the mountains.

Synop stations for the SMHI matchup database (MSMS) - Feb 99

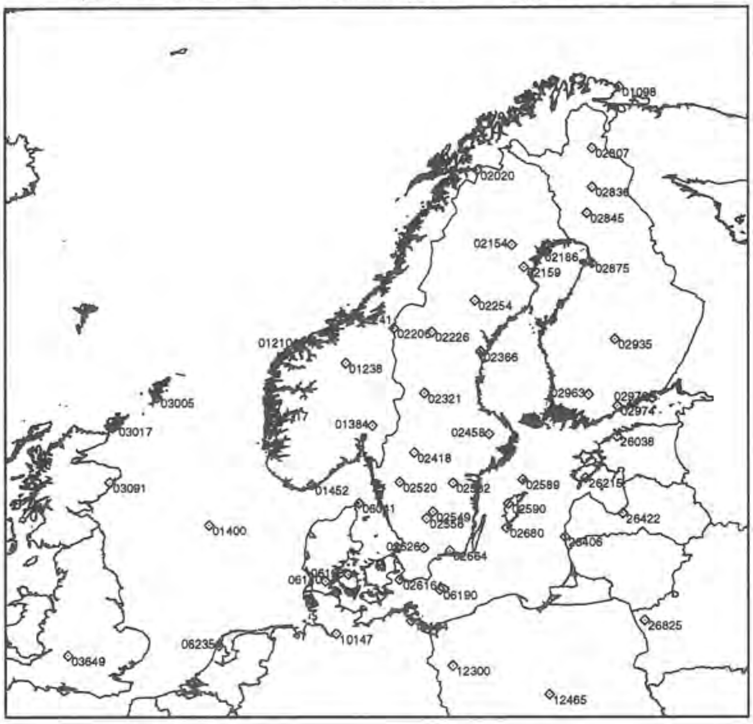

Figure 1 The SYNOP stations for the MSMS database.

The observations are saved every third hour. The surface observation stations consist of both manual and automatic stations, and were selected out of a quality point of view. The selected manual SYNOP stations are mainly from airports where a high quality on cloud observations is usually performed. The automatic stations were except for the location, chosen because they were equipped with ceilometer and present weather sensors. The automatic stations do not give the total cloud cover, low cloud cover or cloud type parameters. The cloud information is instead reported in four different layers, adding the cloud amount to the highest layer parameter. The cloud amount and the ceiling for each layer are reported (cloudiness for each layer is calculated from an algorithm connected to the ceilometer – see Frankenberg, 1997). The maximum measurement height for the automatic SYNOP reports is 3800 m.

4.3 Treatment of the data

The method used in this study is to build up a database, investigate and validate the data by doing statistics and selections of the data trying to map the problems. There are many ways to "cut" in the database. The validation of the parameters connected with clouds is a delicate problem since the clouds are dynamic and it is not possible to measure the parameters (amount, height and type) in exact terms. Several sources of error are likely to appear. Here follow some aspects that have to be considered in the study:

- Time difference between the satellite measurement and the surface observation in rapidly changing weather conditions and during sunrise and sunset.
- Clouds may be hidden by another cloud layer for either the satellite, for the observer or for both.
- Dark conditions for the observer on the ground, which could cause difficulties to observe high clouds.
- Geometrical errors in the used satellite images.
- Geometrical differences between the observations and the HIRLAM and/or the satellite data.

Before data are used in the statistical analysis a basic quality assurance has to be applied. First of all it is checked that all the necessary information is available in the MSMS file (not every MSMS file includes a classification result). But more important, the surface observations (SYNOP reports) and the coverage of the satellite data are checked to be reasonable. The surface-satellite observation in MSMS is ignored if

- The observed cloud cover is missing in the SYNOP observation. In cases when fog or heavy snowfall occurs, cloudiness is generally not reported but this has then been treated as an overcast situation.
- The satellite path is not covering the requested area (32x32 pixels) around the observation. The cloud cover calculations could then be mis-leading.
- The SYNOP data that is inconsistent. An example of this is when the total cloud amount is less than the amount of low, medium and high clouds together.
- If the AVHRR data is unreliable due to too high (>320K) or too low (< 220K) brightness temperatures. Unreliable data are normally sorted out in the MSMS database, but this is an extra check to remove data that have slipped through.

4.4 Definition of cloudiness from satellite – SCANDIA data

In SCANDIA, the **low clouds** are coded as the pixel-values **79-90**, the **medium clouds** as pixel values **146-179** and the **high clouds** as pixel values **179-223**. Behind every pixel value there is an algorithm and thresholds to define the specific cloud. The **unclassified values of 0-3** are also extracted from MSMS. They have to be taken into account since they mean that SCANDIA has identified a difficult situation. The area around the SYNOP station where the satellite data is taken and where the cloud cover is defined, is a square of 32x32 km with the selected surface observation in the middle. The area corresponds to 8x8 pixels in the classification image, with a grid space of 4 km (which is almost as an observation with radii of 16 km). Cloud cover is calculated in percent of "cloudy-pixels" (the pixel intervals above) of the total pixels.

The **size of the selected area** has been defined, considering the range the clouds that are seen from the SYNOP station, for the validation to be as close to the reality as possible. The higher the clouds are, the longer is the distance they can be seen from. The surface visibility does also effect the distance that a cloud can be seen from. In situations with Stratus (which is a cloud type that is very important in this study) the visibility often decrease below 10 km, which means that the satellite-derived cloudiness might cover a larger area than the surface observation does. On the other hand medium and high clouds will be seen further out than 16 km from the surface observation on a very bright day. The clouds far away will anyway only cover a small fraction of the total sky. An area of 8x8 pixels was decided to be a reasonable area for the "satellite observations" and it was then used in the investigations having in mind that we are focused on studies of low level clouds. Tests were made with a smaller "satellite-observation" area of 16x16 km (4x4 pixels in a SCANDIA 4km picture). The validation of SCANDIA using the smaller area showed almost the same result as for the 32x32km area. Maybe the smaller area would have been more accurate for the automatic stations, since they report a cloud amount according to an algorithm using data for 30 minutes intervals. The larger area allows the SCANDIA cloud cover to be scattered in a higher degree than a smaller area.

For most of the validations the SCANDIA-class pixel value that are referred to, is the most frequent value in the "observation"-area (in the 8x8 array). For the sunglint studies though, the pixels on the coastal stations were chosen to be as much over sea as possible. Furthermore, "cloudy" was defined to be a cloud cover > 70 % (≥6/8) and "cloud-free" as a cloud cover < 30% (≤2/8). Of course, the optimal definition would have been 100% cloudiness for "cloudy" and 0% of cloudiness for "cloud free", but according to the nature of clouds, the definition cannot be chosen too strict.

5. METHOD

The cloud validation must be seen as an *estimation of the quality* of the cloud classification due to the sources of errors that exists. The inexact nature of the cloud parameters, should be taken into account when analysing the results. The validation is primarily a study of when the SCANDIA classification result significantly deviates from the cloud report of the SYNOP observations, and a study of the role of the input data to the model. To find any tendencies and significant problems the following was to do:

- Investigate the indata used for the classification (i.e. the satellite information, the HIRLAM data, and the time & location information).

- Try to find and extract the situations from the MSMS database when SCANDIA has classification problems.

- Study the cases when SCANDIA classification gives cloud free, while the surface observation reports cloudy.

- Study the cases when SCANDIA gives cloudy and the SYNOP reports cloud free.

The data are divided and analysed in different sun angle intervals. The results for different data sets are presented in contingency tables where the observed cloud amount and the SCANDIA cloud amount for each case are counted as one hit for the specific combination of octas. The "hit-score" for each octa-combination is presented in percent of all cases in the table.

Since the occurrence of clouds and the cloud amount have not "digital" properties, a measure that relates the results to each other would be accurate to use, in order to get an objective result of the classification performance. From the tables (1a-1e and 4a-4e) an objective measure of the accuracy of the SCANDIA model is calculated. SCANDIA is for this purpose considered as providing a forecast of the cloud amount, and the SYNOP observation is regarded as giving the true cloud amount. Of course, the SYNOP observations do not always show the true picture of the cloudiness (see section 4.3), but it is used in this study in order to have an objective measure of the accuracy.

The objective measure used is the Ranked Probability Score (RPS). RPS is a standard measure of the accuracy of a probabilistic forecast model where the predictant can be considered as ordinal, and it is commonly applied within meteorology to verify forecast models (Dybbroe, 1996).

In order to explain what is meant by an ordinal predictant it, is perhaps easiest to give an example: A good example of an ordinal predictant is the temperature. The temperature is normally given as a real number (e.g. 283.2 K) and the output space is coherent. If the true/observed temperature is 280.0K a forecasted temperature can for instance take the values 280.5 K and 279.4 K Both temperatures are not correct, but they are rather close, and one is only a bit closer/better than the other. Since the temperature is an ordinal parameter it is possible to estimate how far the forecast is from the truth. With a nominal predictant this is not the case. The cloud type can be considered as nominal. It is not relevant to distinguish the forecast event "Cirrus" and "Cumulus Humilis" when the observation gives "Cumulonimbus". Both forecasts are equally wrong.

Now it should be clear that the cloud amount as given by SCANDIA can be considered an ordinal predictant, just like the temperature above. SCANDIA can also be considered as a probability forecast, though a rather crude such: The probability distribution will always give 100 percent probability for the cloud amount which is actually deduced from the SCANDIA cloudiness, and taking the value zero for all other cloud amounts. Contrary to the case of a nominal predictant, to derive a measure for the accuracy of a probability forecast with ordinal predictants, it is necessary to establish a connection between the events. This is done by considering the forecasts and observations as cumulative. So in the case of temperature, for instance, instead of giving the probability for the temperature being inside some interval the probability will correspond to the temperature being higher (or lower) than a given value.

The RPS ranges from zero for completely accurate forecast (or other estimated or modelled values) to N-1 for complete inaccurate forecasts (N being the total range of possible forecast values). Here the RPS ranges from 0 to 9. RPS is calculated as:

$$RPS_N = (1/K) \cdot \sum (\underline{R}_k - \underline{D}_k) \cdot (\underline{R}_k - \underline{D}_k)'$$

K is the total number of compared forecast/observation pairs.

$\underline{R}_k = (\underline{R}_{1k},\ldots,\underline{R}_{Nk})$ denote the k'th cumulative forecast, where $\underline{R}_{nk} = \Sigma\, \underline{r}_{mk}$ for m = 1 to n. r_mk represents the forecast probability of the n'th event on the k'th occasion. r_nk is between 0 and 1, and all the $\underline{r}_{nk}$'th sum to 1.

An example: If we consider the cloud amount in octas R_1k may be the k'th probabilistic forecast of the cloud amount having 0 octas, R_2k is then the k'th probabilistic forecast of the cloud amount having 1 octas or lower, etc. In the case of evaluating SCANDIA a R_k may look like this: (0,0,0,0,0,0,1,1,1). This should be the result when SCANDIA gives 6/8 partially overcast.

$\underline{D}_k = (D_{1k},\ldots, D_{Nk})$ denote the k'th cumulative observation, where each D_{nk} is the sum of the corresponding observations for the n'th event on the k'th occasion.

6. RESULTS

6.1 General quality of SCANDIA cloudiness

When going through *all* available data from June 1998 to June 1999, the number of matching satellite and SYNOP cases that passed the quality controls described in section 4 ("The Data") were 23787. These cases are used in the general investigation and in the statistics of the data followed below.

One of the objectives was to find out how the SCANDIA model performs depending on the **sun-zenith angle**. As mentioned in section 3 it is well known that the model has difficulties in separating clouds during low sun angles. In SCANDIA the sun elevation is divided into 12 different intervals but according to earlier investigations (Karlsson,1993), this study focus on the lowest sun angle intervals, which have showed to be the most critical.

1. Sun angles < 0.5° ("night")
2. Sun angles = 0.5 ° and < 5.2°
3. Sun angles = 5.2 and < 9.8°
4. Sun angles = 9.8 and < 14.5°
5. Sun angles = 14.5° ("day")

The higher sun angle classes in SCANDIA (5-12), were in this study treated as "day cases" (interval 5.). The SCANDIA performance in the different sun-zenith intervals is shown in contingency tables below (tables 1a to 1e). In all the tables the observed total cloud amount (the "octas") is presented on the rows, and the SCANDIA cloud amount ("octas") on the columns. In each square is the representation in percentage for the data set. Notice that we are here exclusively examining total cloud cover and not specifically low level clouds (although being the main subject of this report). The reason is that it was considered too difficult to extract the single contribution from low level clouds in both the satellite and the SYNOP observation. However, it is assumed that most of the problems for SCANDIA is connected to the detection of low level clouds (which is well-known from operational experience).

A special treatment of situations with unclassified pixels was applied. According to section 4.4, unclassified pixels are given four possible values (0,1,2 and 3). Here, cases when the dominating pixel value is unclassified due to detected inversions (pixel values 2 and 3) are discarded. Also cases including pixels lying outside of the satellite swath (resulting in pixel value 0) are discarded. However, the unclassified pixel value 1 is treated as a cloudfree pixel in this study. The reason is that these pixels were only introduced to alert the user that this cloudfree pixel is deduced during twilight conditions (category 2 above) when SCANDIA is known to underestimate low level clouds (see Karlsson, 1996).

The consequence of this treatment of unclassified pixels is that the results given later should show if errors or problems remain for SCANDIA also in "normal" situations (i.e., when no inversions have been detected by the SCANDIA inversion detection scheme).

Table 1a: All cases for the sun angle class 1 (night). The number of occasions of each individual event has been normalised by the total number of night cases (9215).

clds\sat	0/8	1/8	2/8	3/8	4/8	5/8	6/8	7/8	8/8	SUM
0/8	0,1	0	0	0	0	0	0	0	0	0,1
1/8	4,9	1	0,7	0,3	0,3	0,2	0,2	0,1	0,4	8,1
2/8	2,5	0,6	0,4	0,2	0,3	0,3	0,2	0,2	0,6	5,3
3/8	1,7	0,6	0,5	0,3	0,3	0,3	0,3	0,3	0,8	5,1
4/8	0,9	0,5	0,3	0,3	0,2	0,3	0,3	0,3	0,7	3,8
5/8	0,9	0,4	0,4	0,3	0,3	0,4	0,3	0,4	1,2	4,6
6/8	0,5	0,6	0,5	0,5	0,6	0,5	0,6	0,7	2,1	6,6
7/8	1,4	0,7	0,8	0,8	0,8	1,4	1,5	2,2	12,7	22,3
8/8	1,5	1	0,7	0,7	1,1	1,6	2,4	3,6	31,3	43,9
SUM	14,4	5,4	4,3	3,4	3,9	5	5,8	7,8	49,8	99,8

Table 1b: All cases for the sun angle class 2. The number of occasions of each individual event has been normalised by the total number of class 2 cases (2562).

clds\sat	0/8	1/8	2/8	3/8	4/8	5/8	6/8	7/8	8/8	SUM
0/8	0,1	0	0	0	0	0	0	0	0,1	0,2
1/8	4,2	0,7	0,5	0,6	0,1	0,5	0,3	0,6	1,5	9
2/8	2,2	0,5	0,6	0,3	0,2	0,3	0,2	0,5	0,7	5,5
3/8	1,1	0,8	0,4	0,2	0,5	0,3	0,5	0,3	0,8	4,9
4/8	0,7	0,6	0,2	0,1	0,3	0,4	0,1	0,4	1,2	4
5/8	0,4	0,4	0,4	0,2	0,4	0,4	0,7	0,6	1,9	5,4
6/8	0,4	0,4	0,4	0,5	0,3	0,6	0,8	1,2	3,9	8,5
7/8	0,8	0,7	0,3	0,7	0,5	0,7	1,4	2,5	18,3	25,9
8/8	0,6	0,4	0,4	0,4	0,9	0,7	0,7	1,8	31	36,9
SUM	10,5	4,5	3,2	3	3,2	3,9	4,7	7,9	59,4	100,3

Table 1c: All cases for the sun angle class 3. The number of occasions of each individual event has been normalised by the total number of class 3 cases (2245).

clds\sat	0/8	1/8	2/8	3/8	4/8	5/8	6/8	7/8	8/8	SUM
0/8	0,1	0	0	0	0	0	0	0	0	0,1
1/8	2,9	0,8	0,5	0,4	0,6	0,3	0,4	0,8	1,8	8,5
2/8	1,3	0,4	0,5	0,4	0,4	0,4	0,4	0,5	1,1	5,4
3/8	0,9	0,7	0,4	0,2	0,4	0,2	0,7	0,7	1	5,2
4/8	0,1	0,4	0,2	0,4	0,2	0,4	0,3	0,5	1,2	3,7
5/8	0,2	0	0,2	0,4	0,4	0,3	0,7	0,8	1,2	4,2
6/8	0,1	0,3	0,3	0,4	0,4	0,7	1	0,9	4,5	8,6
7/8	0,1	0,2	0,3	0,4	0,8	1,2	1,2	3,1	20,5	27,8
8/8	0,1	0	0	0,1	0,1	0,3	0,6	1,2	33,4	35,8
SUM	5,8	2,8	2,4	2,7	3,3	3,8	5,3	8,5	64,7	99,3

Table 1d: All cases for the sun angle class 4. The number of occasions of each individual event has been normalised by the total number of class 4 cases (1856).

obs\sat	0/8	1/8	2/8	3/8	4/8	5/8	6/8	7/8	8/8	SUM
0/8	0	0,1	0	0	0	0	0,1	0,1	0	0,3
1/8	3,5	0,7	0,5	0,6	0,2	0,1	0,8	0,4	0,8	7,6
2/8	1,2	0,8	0,4	0,5	0,5	0,3	0,3	0,3	1,1	5,4
3/8	1	0,6	0,4	0,2	0,4	0,4	0,5	0,8	1,2	5,5
4/8	0,9	0,4	0,3	0,4	0,2	0,3	0,5	0,3	0,5	3,8
5/8	0,3	0,4	0,3	0,5	0,5	0,6	0,7	0,8	2	6,1
6/8	0,2	0,5	0,3	0,7	0,4	0,5	0,6	1,4	3,5	8,1
7/8	0,1	0,2	0,2	0,5	0,7	1	1,1	3	22,2	29
8/8	0,1	0	0	0,1	0,1	0,3	0,4	0,9	32,4	34,3
SUM	7,3	3,7	2,4	3,5	3	3,5	5	8	63,7	100,1

Table 1e: All cases for the sun angle class 5 – 12 (day). The number of occasions of each individual event has been normalised by the total number of class 5 cases (6346).

[illegible]	0/8	1/8	2/8	3/8	4/8	5/8	6/8	7/8	8/8	SUM
0/8	0	0	0	0	0	0	0	0	0	0
1/8	5,4	1	0,5	0,4	0,3	0,3	0,2	0,2	0,8	9,1
2/8	2,7	1,1	0,7	0,3	0,3	0,4	0,2	0,2	0,7	6,6
3/8	1,9	1,3	1	1	0,9	0,6	0,9	1,2	4,1	12,9
4/8	0,7	0,6	0,7	0,5	0,7	0,6	0,9	0,8	2,3	7,8
5/8	0,6	0,5	0,6	0,7	0,7	0,7	0,7	1,2	3,9	9,6
6/8	0,3	0,3	0,4	0,5	0,6	0,7	1	1,6	4,8	10,2
7/8	0,2	0,2	0,2	0,5	0,5	0,9	1,5	2,6	17,1	23,7
8/8	0	0	0,1	0,1	0,1	0,1	0,3	0,6	19	20,3
SUM	11,8	5	4,2	4	4,1	4,3	5,7	8,4	52,7	100,2

The optimal contingency table would have all values gathered across a straight line from the upper left corner to the lower right corner. As shown in the tables above there is a relative high accuracy for the 8/8 and 7/8 observed cloud amount in all the sun angle classes. There is an under estimation of the SCANDIA cloud amount, when the surface observation gives cloudy (7-8/8) for low sun angles. An over estimation of the SCANDIA can be seen in the table for the higher sun angles.

Except for the values along the "straight line", the results are for the lower sun angles dominating along the bottom line.

The cloud free situations during daytime (or in reality, sun angle intervals 4 and 5) are subdivided into snowfree and snow- or ice covered situations (the latter resulting in pixel values 30 or 40 in SCANDIA). These classes are not over-represented in the studied cases with under-estimated cloudiness which could have been suspected (clouds should have a rather high reflectance more similar to snow than a snow-free surface). The situations when SCANDIA classify 30 or 40 as dominating classes corresponded to cases with almost cloud free observations.

The over estimated cases along the right column at the higher sun angles, consist mainly of the following SCANDIA classes: low; 80 and 82, medium; 165, 170 and high; 190, 200, 210, 220 and 222. Since it is the total cloud amount that is shown in the tables, an "over-estimation" for the sun angles interval 1 could be explained by the darkness for the surface observation. The satellite can more easily detect the clouds during the night. This explanation is indeed valid for the medium and high clouds (have in mind that the ceilometer at the automatic SYNOP stations only reaches up to 3800m). The over estimation that is seen for the higher sun angles has probably to do with enhanced reflection at high satellite zenith angles (anisotropic enhancement).

In table 2, RPS (The Ranked Probability Score) gives a value of the SCANDIA accuracy relative to the ground observation for each sun angle interval. The results are rather encouraging indicating a reasonable accuracy for SCANDIA even at night and twilight conditions. However, the trend of improving performance at higher sun angle intervals is quite clear.

The data was also divided into summer (May-August) and winter (December-February) situations for night cases exclusively (also included in Table 2). The most significant results were the relatively high accuracy even for scattered cloudiness for the summer and the under estimation similar to the low sun angles for the winter situations.

Table 2: The Ranked Probability Score (RPS) for the different sun intervals. RPS ranges from 0 to 9.

Sun angle interval	RPS
< 0,5	1,64
0,5-5,2	1,51
5,2-9,9	1,31
9,8-14,5	1,26
>14,5	1,23
SUMMER < 0,5	1,39
WINTER < 0,5	1,77

6.2 Specific problems

Here follows the analysis of the MSMS data, which are connected to the specific problems with the low clouds in SCANDIA.

6.2.1 The sunglint studies

The SCANDIA classification was validated in order to find if the data show any tendencies on specific parameters in sunglint situations. A better knowledge of such tendencies may then help to minimise miss-classification in a new classification model.

As a first step the observation and the matching satellite scene around Gotska Sandön (02589) was studied. The station is situated on a small island with a diameter around 5 km. That makes it relatively easy to find a pixel that for a high percentage of occasions is over the sea (considering the inherent uncertainty in the exact location of a pixel due to the navigation problems). The station is situated on the north west corner of the island, so the pixel in the upper left corner of the picture was extracted. Also the pixel in the viscinity of the station were of interest and extracted in order to search for any land-sea differences within the same "satellite observation". Another station where a sunglint pixel easily should be found is Rønne (Bornholm) (06190), which was treated as Gotska Sandön and used in the study. To get a land (no sunglint!) reference the data from these coastal stations were compared to the two inland stations, Uppsala (02458) and Tomtabacken (02549).

From the theory we know that sunglint depend on the sun and the satellite angles, the integrated water vapour content in the atmosphere and the surface wind speed and direction. The sun- and satellite angles can be calculated in advance (before the satellite passage) if we know the time table and the path of the satellite. Also the surface wind speed and integrated water vapour may be available in advance by using NWP data.

The MSMS database (June 1998 till May 1999) contain totally 1314 cases from Gotska Sandön and 1173 cases from Bornholm (2487 altogether). Among these there were 126 respectively 69 cases that fulfilled the sun- and satellite angle criteria for sunglint appearance and the criteria for having cloud free in the observation and no higher clouds in SCANDIA. There were 155 cases from both stations where SCANDIA gave low clouds (mostly the SCANDIA class 81 but also 82, 85 and 89 and a few 80 and 84) in the upper left corner.

The same selection of data was made for the two inland stations Uppsala and Tomtabacken. When dividing the cases into inland and coastal stations there were almost twice as often low clouds at the coastal stations than at the inland ones. This result is anyway very difficult to deduce from sunglint appearance over the sea only. The relative frequencies of low clouds were compared for the two coastal stations and for two inland stations. It clearly shows that low clouds occur more often in the SCANDIA classifications over the coastal stations than over the inland ones. When looking at the possible sunglint situations, which are when the sun and the satellite azimuth differ by approximately 180°, the figures were 28% of low clouds at sea and 14% on the inland stations. When comparing all situations the figures were 18% against 16%.

Also the SCANDIA classification for haze or sub-pixel cloudiness had clearly a larger frequency over the sea than over the inland stations. It is probably true that the relative frequency of low clouds is larger over sea due to the larger avalibility of water vapour in lower levels but some of these situations are certainly low clouds due to the sunglint phenomenon.

6.2.2 The temperature inversion problem – a background

According to Godøy (1998), the problems with the SCANDIA classification during inversions need to be further investigated. The problems and uncertainties during inversions are highlighted here and some new suggestions are presented. Special attention has been given to the forecasted HIRLAM temperatures that are used in the inversion study and in the inversion test in SCANDIA.

The SCANDIA model uses forecasted temperatures (9- or 12-hour forecasts at the surface and 700 hPa levels) from HIRLAM to identify inversions according to section 3.4. The success of the SCANDIA model in treating inversions is strongly related to the quality of these temperatures in HIRLAM.

The temperature profiles from HIRLAM which are saved in the MSMS data base were analysed to get an idea of **how often** inversions exist, **how many** inversions that "normally" occur vertically, and **the maximum number** that can occur vertically in such profile. The HIRLAM profiles in MSMS are difficult to verify, since radio soundings are not saved in the database. It is important to note that the profile levels in MSMS are fixed pressure levels and therefore interpolated from the model levels from HIRLAM. Another defect in this comparison to be mentioned is that some differences between the forecast lengths stored in MSMS and the used forecast lengths in SCANDIA may exist occasionally. However, since the time difference normally is limited to one hour the error is considered as marginal. It is believed that most of the well-known spinup problems in HIRLAM is related to shorter forecast lenghts (although this assumption is not indisputable – compare later with cloud forecast results in table 3!).

Godøy (1998) made a comparison of HIRLAM temperature profiles against radio soundings. It showed that the quality of the HIRLAM profiles was acceptable, and that the profiles are worth using, being aware they are coarser than the radio soundings. Surface inversions might occur in HIRLAM when there **is no** inversion in reality. The incorrect inversion forecast could be due to an unrealistic cloud forecast, to an erroneously analysed snow/ice cover, or to a misleading temperature forecast.

6.2.3 General quality of HIRLAM temperature profiles

An estimation of the quality of the profiles was made. The used profiles were plotted and studied for different situations and an example from December 1998 is shown in figure 2. The study of the profiles showed that the inversions usually occur below 900 hPa and for only a few cases up to 800 hPa. This is also in accordance to a climatological study presented in "Klimathandbok för Försvarsmakten", which showed that a normal depth of temperature inversions in the north of Scandinavia is about 1 km. Normally there are only one inversion, including the surface inversions. There are situations when HIRLAM have two inversions in below 800 hPa, but more than two is very rare. The profiles shown in figure 2 below were selected from situations when SCANDIA made a incorrect analysis.

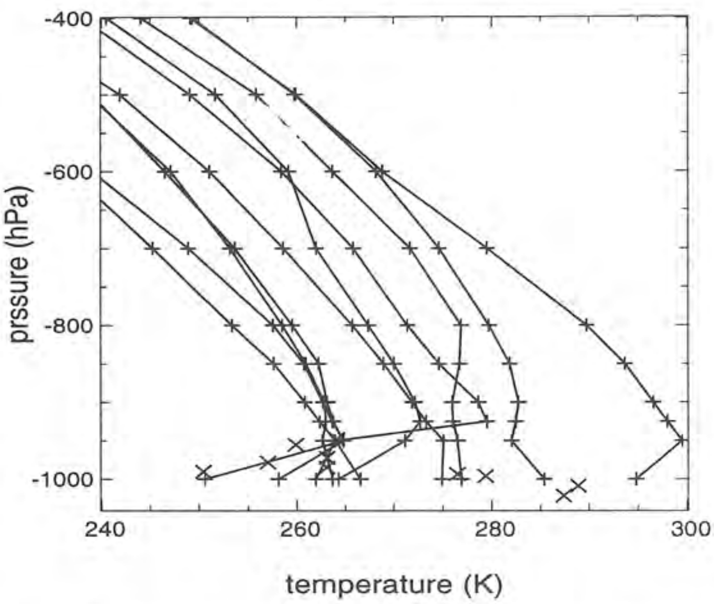

Figure 2: Some selected HIRLAM forecasted temperature profiles with inversions (December 1998) for cases with noticed problems for SCANDIA. The profile levels from MSMS are clearly shown.

To estimate the quality of the surface inversions, the HIRLAM **surface temperature** is central and it was here validated against the observed 2m temp. Of great importance here is the fact that the surface temperature is indirectly depending on the cloudiness (if it is clear or cloudy). Thus, the forecasted temperature is related to the forecasted cloudiness. For the HIRLAM temperature saved in MSMS, it is unfortunately only possible to check the relation against the cloudiness indirectly by using the surface observations, since the cloudiness from HIRLAM is not saved.

A validation of the HIRLAM cloudiness parameter is made operationally and some specific validation results are shown in table 3. The table shows that for HIRLAM 44 (which is used in SCANDIA), the total cloud cover deviates 3/8 or more in 24,5% of the cases. Notice also the negative bias (underestimated cloud cover) which is a known systematic error for almost all available NWP models today (e.g., see Karlsson, 1996). This is certainly features that may influence the formation of surface inversions in HIRLAM profiles.

Table 3: The "total cloud cover" parameter (not saved in the MSMS database) from the HIRLAM 12-hours forecasts during 1998 has been validated against SYNOP from 5143 cases (Karl-Ivar, SMHI).

"Measure" / Forecast	H 44	ECMWF	H 22	Persistent
Average absolute deviation	1.8	1.6	1.9	2.0
RMS	2.6	2.4	2.8	2.9
Bias	-0.7	-0.1	-0.5	-0.9
"Hit score" max deviation 2/8	75.5	75.7	70.1	69.1

6.2.4 Differences between inland and coastal stations

It is also of interest to see if the HIRLAM surface temperatures show any differences between coastal stations and inland stations. Figure 3 shows observed temperature against HIRLAM surface temperature for a typical inland station (Tomtabacken, synop station 02549), and figure 4 shows temperatures for a typical coastal station (Uleåborg, synop station 02875).

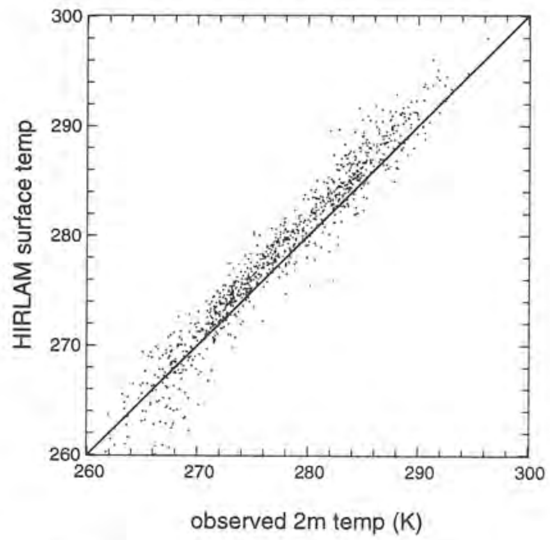

Fig 3: The observed 2m temperatures versus the HIRLAM surface temperatures for a typical inland station "Tomtabacken". Data covers the period June 1998 – June 1999.

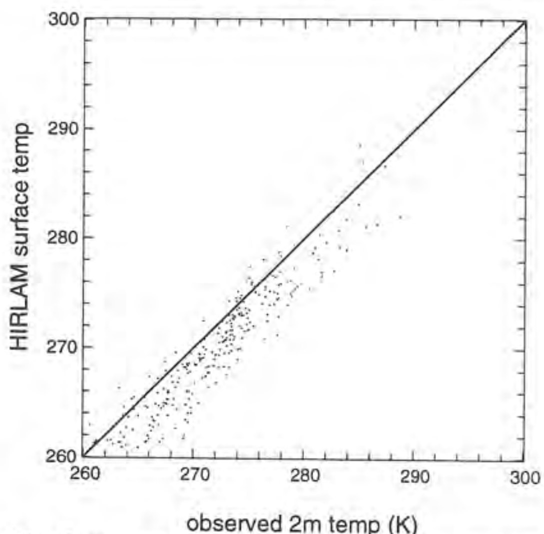

Fig 4: The observed 2m temperatures versus the HIRLAM surface temperatures for the coastal station Uleåborg. Data covers the period June 1998 – June 1999.

Before discussing the results, it is important to explain how the used surface temperature parameter is defined in HIRLAM forecasts. The exact parameter definition is "land surface temperature" and it is computed in two possible ways:

Alternative 1: The land fraction in a grid square exceeds a threshold (currently set to 1%)

=> The temperature is strictly the temperature of the land fraction (i.e., not influenced by temperatures of the sea).

Alternative 2: The land fraction in a grid square is below a threshold (currently set to 1%)

=> The temperature is strictly the sea surface temperature of the sea fraction

The station Tomtabacken shows a relative straight line in fig. 3 with a slight warm bias in HIRLAM for high temperatures and a slight cold bias for low temperatures. The scatter plot for Uleåborg (fig. 4) shows a slight cold bias on the HIRLAM temperature for most of the temperature range. The coastal stations showed in general larger deviation (both positive and negative) for the whole temperature range than the stations situated over land. The negative bias increased to almost 10 degrees for temperatures below the freezing point, a feature that more common for inland stations than for coastal stations. There were no systematic differences between stations situated at higher levels (in the mountains) and lower situated stations.

These results are somewhat unambiguous since similar deviations could be expected in reality. The surface temperature should have a larger variability than the 2 meter temperature (i.e., surface temperatures are generally lower during night and in the winter season and higher during day and in the summer season). Thus, the noticed biases may have natural reasons. However, it was found that the difference between the forecasted surface temperature and the 2-meter temperature was quite small (normally less than 0.5K difference) during the studied period. Consequently, it is concluded that the indicated negative bias for low temperatures and the positive bias for high temperatures are real for HIRLAM. Thus, the use of a compensating bias parameter (presently denoted TSURBIAS) in SCANDIA can be questioned, at least for coastal areas. Thus, the need of TSURBIAS and the appropriate value (today set to as high as 10K) must be examined further.

6.2.5 An unexpected HIRLAM problem

One specific and surprising problem that occurred was the HIRLAM ground temperature at the grid point for Falsterbo (synop station 02616, see figure 1). The forecasted temperature is mainly set to two discrete values (282.5 K and 284 K) for most of the cases during the year. This is shown in figure 5, where the observed 2m temperature is plotted versus the HIRLAM ground temperature. In the next figure (fig 6), the observed temperature is plotted against the HIRLAM 2m temperature, where the problem does not occur (only a small tendency).

Figure 7 presents the conditions for the neighbouring station Bornholm (synop station 06190) which does not show this problem at all. The two stations are referring to different grid points in the HIRLAM domain. The problem seems to be an error in specific HIRLAM grid points. Figure 8 shows the observed 2m temperature for GOTSKA SANDÖN (synop station 02589) compared to the forecasted HIRLAM ground temperature. The same horizontal line structure as could be seen in figure 5 appears also here, however somewhat less distinct.

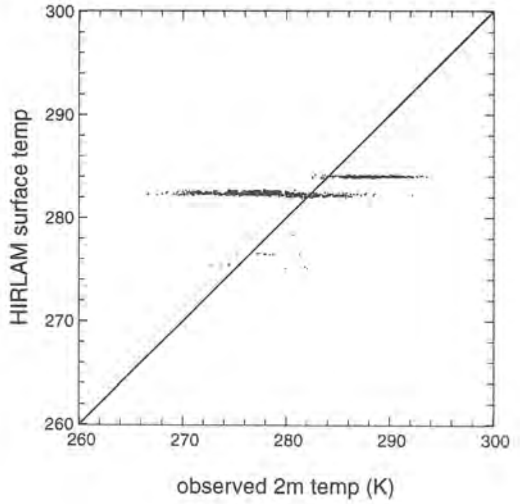

Figure 5: The observed 2m temperature against the HIRLAM **surface (ground)** temperature for Falsterbo for all files June 1998-June 1999.

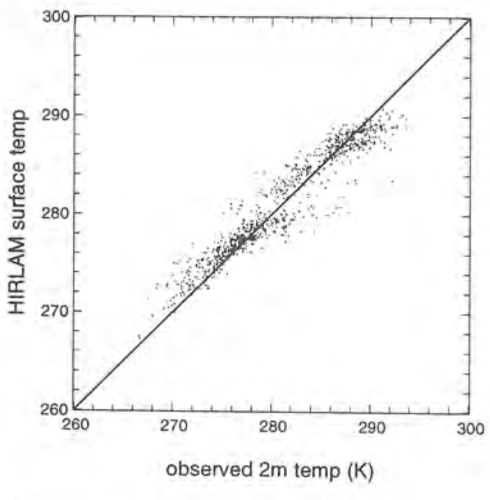

Figure 6: The observed 2m temperature against **HIRLAM 2m temperature** for FALSTERBO for all files June 1998-June 1999.

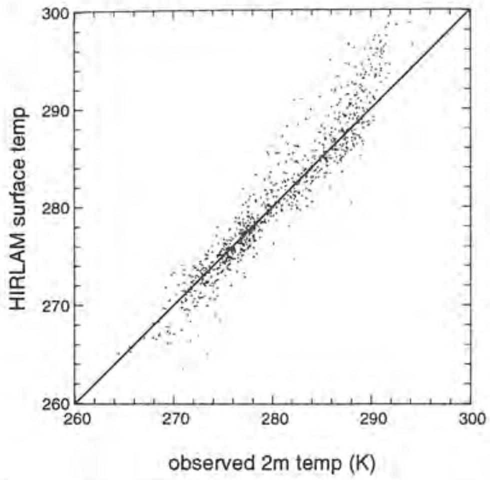

Figure 7: The observed 2m temperature versus the HIRLAM surface temperature for Bornholm for all files June 1998-June 1999.

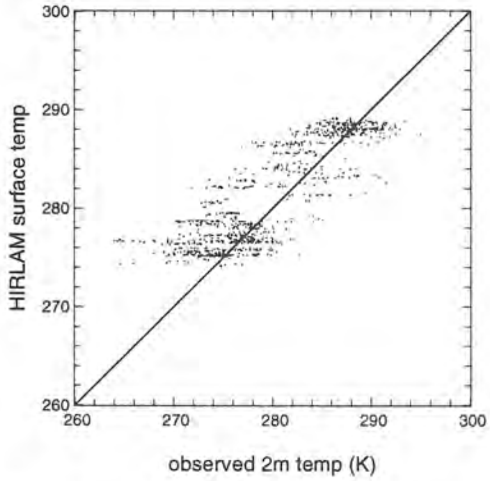

Figure 8: The observed 2m temperature and the HIRLAM ground temperature for all files from GOTSKA SANDÖN June 1998-June 1999.

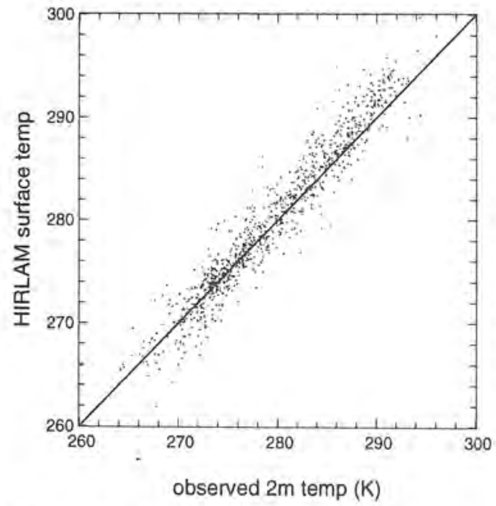

Figure 9: The observed 2m temperature and the HIRLAM ground temperature for all files from VISBY June 1998-June 1999.

The same plot for the neighbouring station VISBY (synop station 02590) is plotted in figure 9. The two stations in figs 8 and 9 are covered by different grid points in HIRLAM. Going through all the used coastal stations in the MSMS, Falsterbo and Gotska Sandön were the only stations where this feature could be observed.

The results indicates a bug in the code of the present operational HIRLAM model since the shown result values are totally unrealistic and fictious. This error seems to occur only for the case when the land fraction is equal to the earlier mentioned land fraction threshold (1%) in a grid square.

6.2.6 SCANDIA performance in situations with inversions

To find cases with existing inversions in the HIRLAM profiles for each matching synop-satellite observation, the lapse rate and the derivative of the lapse rate with respect to pressure was calculated. Extreme values are found when the lapse rate is zero and the derivative of the lapse rate then determines if it is a maximum or a minimum. The inversion test is made up to the fifth pressure level (850 hPa), which is assumed to be sufficient since very few inversions above this level are encountered.

In November and December 1998 there were a period with high pressure over Scandinavia which created many good cases with inversions which have been used for the investigations.

Table 4a – 4e shows how the cloud amount (in octas) for the observation (in columns) and the satellite (in rows) coincide case by case for all five sun elevation categories (listed in section 6.1) in cases of HIRLAM inversions. Thus, notice that the studied data is a subset of the data previously studied in section 6.1. The number of cases gathered in one square is displayed in percentage of all selected cases for the specific table.

Table 4a: All inversion cases (i.e., inversions given by HIRLAM) for the sun angle class 1 (night). The score for each event is in percent of all inversion night cases (3334).

cldsat	0/8	1/8	2/8	3/8	4/8	5/8	6/8	7/8	8/8	SUM
0/8	0,2	0,1	0	0,1	0	0	0	0	0	0,4
1/8	5,4	0,8	1	0,2	0,5	0,2	0,3	0,1	0,5	9
2/8	2,8	0,4	0,6	0,2	0,3	0,3	0,2	0,2	0,8	5,8
3/8	1,9	0,4	0,6	0,4	0,2	0,2	0,4	0,4	1,1	5,6
4/8	1,2	0,4	0,2	0,2	0,3	0,2	0,3	0,3	1	4,1
5/8	1	0,6	0,3	0,1	0,3	0,1	0,3	0,4	1,1	4,2
6/8	0,7	0,5	0,4	0,5	0,4	0,6	0,5	0,5	1,9	6
7/8	2,4	1	1,1	1,2	0,9	1,9	1,6	2,3	10,4	22,8
8/8	2,6	1,6	1	1	1,5	2,2	3,2	4,3	24,2	41,6
SUM	18,20	5,8	5,2	3,9	4,4	5,7	6,8	8,5	41	99,50

Table 4b: All inversion cases (i.e., inversions given by HIRLAM) for the sun angle class 2. The score for each event is in percent of all inversion class 2 cases (852).

cldsat	0/8	1/8	2/8	3/8	4/8	5/8	6/8	7/8	8/8	SUM
0/8	0,1	0	0	0,1	0	0	0	0	0,2	0,4
1/8	3,4	0,8	0,4	0,9	0,4	1,2	0,5	0,9	2,7	11,2
2/8	2,2	0,4	0,7	0	0,2	0,4	0,1	0,8	1,4	6,2
3/8	1,1	0,7	0,2	0,1	0,6	0,2	0,9	0,5	1,2	5,5
4/8	0,7	0,4	0,1	0	0,4	0,6	0	0,4	1,3	3,9
5/8	0,2	0,7	0,4	0,1	0,5	0,1	0,9	0,5	1,6	5
6/8	0,4	0,4	0,4	0,1	0,6	0,4	0,5	1,1	3,5	7,4
7/8	1,2	0,6	0,4	0,6	0,6	0,7	1,3	2,2	19,7	27,3
8/8	1,2	0,7	0,2	0,6	1,1	0,8	0,8	1,8	26,3	33,5
SUM	10,5	4,7	2,8	2,5	4,4	4,4	5	8,2	57,9	100,4

Table 4c: All inversion cases (i.e., inversions given by HIRLAM) for the sun angle class 3. The score for each event is in percent of all inversion class 3 cases (1085).

obs\est	0/8	1/8	2/8	3/8	4/8	5/8	6/8	7/8	8/8	SUM
0/8	0,3	0	0	0	0	0	0	0	0,1	0,4
1/8	3,2	0,8	0,7	0,4	0,8	0,3	0,5	1,2	3,2	11,1
2/8	1,2	0,4	0,1	0,1	0,5	0,5	0,3	0,5	1,9	5,5
3/8	0,9	0,3	0,7	0,3	0,1	0	1,1	1,1	1,9	6,4
4/8	0,1	0,4	0	0,3	0,4	0,4	0	0,5	1,3	3,4
5/8	0,1	0	0	0,3	0,4	0,3	0,5	0,8	0,9	3,3
6/8	0	0,3	0,4	0,5	0,1	0,8	1,2	0,9	4,5	8,7
7/8	0,3	0,3	0,3	0,7	0,9	1,2	1,3	1,7	21,3	28
8/8	0,3	0,1	0,1	0,4	0,3	0,5	1,1	1,2	29,5	33,5
SUM	6,4	2,6	2,3	3	3,5	4	6	7,9	64,6	100,3

Table 4d: All inversion cases (i.e., inversions given by HIRLAM) for the sun angle class 4. The score for each event is in percent of all inversion class 4 cases (678).

obs\est	0/8	1/8	2/8	3/8	4/8	5/8	6/8	7/8	8/8	SUM
0/8	0	0,2	0	0	0	0	0,2	0,2	0	0,6
1/8	2,9	1	0,8	1	0,6	0,2	1,4	0,4	1,5	9,8
2/8	0,6	0,8	0,4	1,2	0,8	0,4	0,4	0,2	2,3	7,1
3/8	0	0,8	0,2	0,2	0,2	0,6	0,4	0,2	1,5	4,1
4/8	0,6	0,2	0,2	0,2	0	0,2	0	0	0,2	1,6
5/8	0	0,2	0,6	0,8	0,6	0,6	0,4	0,8	2,5	6,5
6/8	0	0,2	0,4	0,6	0,2	0,6	0,2	0,6	3,7	6,5
7/8	0	0	0	0	0,4	0,8	1	3,1	24,4	29,7
8/8	0	0	0	0,2	0	0,8	0,8	1,2	31,9	34,9
SUM	4,1	3,4	2,6	4,2	2,8	4,2	4,8	6,7	68	100,8

Table 4e: All inversion cases (i.e., inversions given by HIRLAM) for the sun angle class 5. The score for each event is in percent of all inversion class 4 cases (836).

obs\est	0/8	1/8	2/8	3/8	4/8	5/8	6/8	7/8	8/8	SUM
0/8	0	0,1	0	0	0	0	0	0	0	0,1
1/8	5,4	1,4	0,2	0,5	0,2	1	0,2	0,1	0,7	9,7
2/8	3,1	0,7	0,5	0,2	0,4	0,2	0,2	0,2	0,6	6,1
3/8	1,4	0,6	0,4	0,2	0,5	0,2	0,2	0,1	0,6	4,2
4/8	1	0,4	0,4	0,5	0,7	0,1	0,4	0,5	0,4	4,4
5/8	1,2	0,8	0,1	0,4	0,6	1	0,6	0,6	2	7,3
6/8	0,4	0,1	0	0,6	0,2	0,8	0,7	1,4	2,8	7
7/8	0,2	0,4	0,4	0,7	0,8	1,7	2,2	3,6	17,3	27,3
8/8	0	0,2	0,1	0,2	0,1	0	0,8	1,2	31	33,6
SUM	12,7	4,7	2,1	3,3	3,5	5	5,3	7,7	55,4	99,7

As a measure of the accuracy of the inversion cases for the different sun angle intervals RPS calculated and show in table 5.

Table 5: The Ranked Probability Score (RPS) for the data shown in tables 4 a-e. RPS ranges from 0 to 9, where 0 is total accuracy.

Sun angle interval	RPS
< 0,5	2,06
0,5-5,2	1,84
5,2-9,8	1,6
9,8-14,5	1,31
>14,5	1,26
ALL	1.89

It is obvious from table 5 that it is during night conditions that SCANDIA have most problems. An interesting fact is that approximately a third of the night cases (table 4a compared to table 1a) represents cases when HIRLAM do have inversions while the SCANDIA inversion detection scheme fail. This means that, after comparing tables 2 and 5, one may conclude that the present SCANDIA inversion detection scheme is not capable of taking care of all errors introduced by the presence of inversions. The main point is that for this subset of the data, the probability to face a forecasted surface temperature below –2.5ºC (the COLDLAND parameter – see section 3.4) is high which increases the risk that true low clouds are discarded by SCANDIA (see also discussion below).

Table 4a show this feature, i.e., the high value for the underestimation of clouds in SCANDIA) for sun class 1 and the relatively low percent of coincidence for the large cloud amount. The SYNOP reported cloud amount consisted here of low clouds in 95% of the cloudy cases.

Also sun class 2 (table 4b) show similar results. In addition, the overestimation of large cloud amounts has increased. The reason for this is probably that inversions were much stronger than indicated by HIRLAM in reality so that cold ground pixels was mistaken for mid-level clouds.

According to how the thresholds in SCANDIA are defined (described in section 3.4), it is worthwhile to investigate the conditions for these situations in more detail. A known weakness in the implementation of the SCANDIA cloud tests is that the precautionary inversion test (the COLDLAND parameter test) does not automatically produce unclassified pixels as output. It is mainly used to prohibit any use of the basic cloud test in channel 4 (the TEMPADD test) when there is a risk for mistaking a cloud pixel for a cold ground pixel. In this situation, the pixel is now left unclassified only if, in addition, the channel 4 brightness temperature is colder than 700 hPa and the second inversion test (using forecasted surface and 700 hPa temperatures) is positive. Thus, there is a possibility for missing low-level clouds completely if the following criteria are valid for a pixel without a typical cloud signature in any AVHRR channel except channel 4:

- The channel 4 brightness temperature is warmer than the temperature at 700 hPa.
- The surface temperature from HIRLAM is below –2.5° C
- The channel 4 brightness temperature is 8 degrees colder than the surface temperature.

A special test was made investigate further if this potential defect could explain a significant part of the missed cloud pixels. When checking the validity of these criteria on the cases that were cloud free in SCANDIA and cloudy in the SYNOP (the bad cases in table 4a) it was found that 68% (256 cases of 379) matched the criteria above. For all the 379 cases the forecasted inversions were too weak to be detected by SCANDIA. For these cases, the surface temperature would still be warmer than the 700 hPa temperature. The inversions were in most of the cases below 800 hPa. By lowering the SCANDIA upper level for the inversion test from 700 hPa to 900 or 950 hPa more cases with inversions would have been detected. This should then lead to that a large portion of these misclassified pixels could be labelled unclassified instead of cloudfree.

6.2.7 Analysis of the SCANDIA class 82 – low clouds form infrared information exclusively

The SCANDIA class 82 consist of low clouds derived from only the temperature information in channel 4 and the surface temperature from HIRLAM in cases when no typical cloud signature is found in all AVHRR channels except channel

4. This class was added in the updated version of SCANDIA in order to improve the analysis of low clouds. It is thus interesting to see if the introduction of this class lead to an improvement. For 1998 there were 599 cases that gave SCANDIA class 82 as the most frequent pixel. Among these, only 41 cases (6.9%) were clearly unacceptable (the observed cloud cover < 30% and SCANDIA cloud cover > 70%). A closer study of these 41 cases revealed that 7 of them were in the sun angle interval of 0-15 degrees, while the rest (34 cases) were from when the sun angle was below 0 (night cases).

To find out if the problematic cases had some relation to the location of the station (i.e., if it is an inland station or a coastal one), the relative frequency of the involved stations were studied. The most frequent stations showing this result, were Sundsvall (7), Malmslätt(4), Uppsala(3), Hoburg(3), Skrydstrup(3), Osby(2) and Såtenäs(2). Sundsvall is situated close to the sea and relatively far north, which can make the site more sensitive due to the humidity from the sea and to the high frequency of low surface inversions. Many other of the stations are also situated near a coast of the sea or a major lake.

We may thus conclude that the introduction of class 82 have indeed improved results despite the problems that were earlier seen associated with inversions (discussed in previous sections). For the remaining problematic fraction of the cases, it is indicated that locations close to the coast are overrepresentated. Thus, the treatment of the forecasted land surface temperature (as described in section 6.2.4) seems to be critical and sensitive for a coastal HIRLAM grid point.

6.2.8 Analysis of the SCANDIA class 165 – medium clouds from infrared information exclusively

Another interesting class to investigate in SCANDIA is class 165 - medium clouds from temperature information only. Because of the close relation to class 82 some attention must be given to this class. During 1998 there were 956 cases having 165 as the most frequent SCANDIA class. Among these only 64 were "unacceptable" (6.7%). Here all cases except 2 were during night-time (sun angle < 0). Thus, as for class 82, the result show in general an improvement after introduction of class 165 in the updated SCANDIA.

As have been shown previously, the HIRLAM surface temperature has a warm bias which can be one explanation for the remaining incorrect cases (meaning that ground temperatures are generally colder in reality which could give this class if the inversion test is negative).

The most frequent stations for the remaining incorrect cases were: Sodankylä (14), Storlien(5), Frösön(5), Rovaniemi(4), Luleå(4), Sundsvall(4), Malmen(4), Gardemoen(3), Katterjåkk(3), Osby(3) and Såtenäs(3). Thus, we can see a tendency that the problem is concentrated to the northern part of the area. Probably this has to do with the very low temperatures and a high frequency of surface inversions.

7. DISCUSSION

This study concentrated on situations where the used version of SCANDIA did not already indicate specific classification problems due to inversions, i.e., cases with unclassified pixels due to detected inversions were excluded. The intention was that this would give indications if the present SCANDIA inversion detection method adequately removed errors caused by very cold ground temperatures (i.e., if there are remaining problems due to inversions which are not detected by SCANDIA). The exclusion of the unclassified cases means that it is here assumed that these cases were correctly identified which is motivated by the fact that the scheme only identifies very strong inversions.

Results indicated a reasonable overall accuracy. Best results were seen at daytime with high sun angles which perhaps could be expected. Also results at night and in twilight appeared to be quite acceptable. However, it is clear that situations with large differences between the SYNOP and satellite occur. For example, SCANDIA classified about 3% of all cases during night as totally cloudfree when SYNOP reported 7 or 8 octas. Furthermore, for twilight cases and for low sun elevations SCANDIA classified about 3% of the cases as being totally cloud covered while SYNOP reported less than three octas. Also for higher sun elevations, some overestimation of cloud amounts was noticed.

SCANDIA often classified cloud-free when the observations showed the existence of low level clouds. The reason is that SCANDIA normally uses a simple infrared temperature test to complement the tests in other AVHRR channels. Here, the idea is that a pixel that is significantly colder than the forecasted surface temperature must be treated as cloudy even when typical cloud signatures in other AVHRR channels are not found. This would guarantee that a pixel is classified as cloudy in cases of shadows on other clouds and during night when transparent Cirrus clouds are superposed over low water clouds (discussed in more detail by Karlsson, 1996). However, this method must of course be avoided in cases of inversions. In the studied version of SCANDIA, this cloud test is not used when forecasted surface temperatures are below –2.5°C resulting in a cloudfree pixel. For the pixel to be labelled unclassified, the SCANDIA inversion test must in addition be positive.

The overestimation of clouds that occurred in SCANDIA for twilight and low sun angle conditions has two main explanations: an enhanced reflection at high satellite zenith angles (anisotropic enhancement – satellite viewing towards the direction of the sun) and mis-classified mid-level clouds in very cold situations where inversions were too weak in HIRLAM profiles.

The SCANDIA low level cloud class 82 (resulting from the simple complementary infrared temperature test mentioned earlier) has improved the classification as compared to the original version of SCANDIA. Especially encouraging is that the problem with underestimation of low-level clouds at twilight has been reduced significantly. However, also new problems have occurred due to the introduction of this class. The results indicated an overrepresentation of this class in coastal areas. This is related to the SCANDIA treatment of the forecasted surface temperature for a coastal HIRLAM gridpoint (due to interpolation of coarse HIRLAM grid point values to high resolution image pixels) and improvements in how these temperatures are used must be considered. In connection to this, it was also noticed a special problem with unrealistic temperatures at some specific HIRLAM grid points along the Swedish coast. This turned out to be caused by an unfortunate bug in HIRLAM and it will be removed in future HIRLAM versions.

The SCANDIA mid level cloud class 165 (originating from the same type of test as class 82 but for very cold temperatures) was occasionally overestimated.

There was a tendency for this problem to be concentrated to the northern part of the studied area. Most probably, this was caused by very low surface temperatures occurring in cases when inversions in HIRLAM were too weak.

The possible confusion between sunglints and low clouds in the database for the actual period was difficult to verify. The investigation showed that the relative frequency of low clouds was larger over sea than over land for a few selected stations. The larger availability of water vapour in the lower levels naturally favours low cloud formation. When extracting cases under sunglint conditions (equal satellite and sun zenith angles) some overestimation of the amount of low level clouds were indicated. However, more sunglint cases need to be sampled to be able to draw more firm conclusions.

Since many of the mentioned deviations between SCANDIA and SYNOP clearly are related to parts of the SCANDIA scheme dealing with temperature inversions, a further focusing on inversion cases was made. It was shown that as much as one third of the investigated cases occurred when an inversion (however, only weak or moderate) was found in the HIRLAM profile. For this subset of the data, it was seen that the large deviations mentioned above were increasing their relative frequency. Thus, it is likely that problems due to inversions cause a significant part of the large deviations.

From earlier experience we know that SCANDIA has problems during situations with inversions. In the studied version of SCANDIA an inversion control is implemented to label pixels as unclassified (shown in black) when surface inversions are very strong. This test is apparently not capable of detecting all cases when inversions may confuse SCANDIA results. The problem with inversions results obviously in both an underestimation and an overestimation of cloudiness.

HIRLAM seems to identify the low-level inversions rather well and can therefore be used to detect inversions for the cloud classification. This study shows that SCANDIA did not identify a significant part of the occurring inversions. To improve results it is proposed to use a combination of the lowest HIRLAM levels or possibly only one of them in combination with the surface temperature. The final choice depends on the required computer time and memory limits for the execution of the classification model. Inversions were shown to extend up to the 950 or 900hPa levels in most of the cases. These levels are thus suggested for use in any inversion detection scheme.

The use of ancillary data provided by NWP (HIRLAM) in the cloud classification model open many new possibilities to solve difficult situations. On the other hand, the use of NWP affects the cloud classification with its inhered errors. This dilemma was shown when studying the surface temperature from HIRLAM for different stations. The HIRLAM surface temperature deviated significantly from the observed 2-meter temperature, in some cases up to 10K. A positive bias for warm temperatures and a negative bias for cold temperatures were also indicated. This behaviour could be natural since surface temperature could be expected to be colder than 2-meter temperature at low temperatures and reversed at high temperatures. However, since the forecasted 2-meter temperature rarely deviated more than 0.5K from the forecasted surface temperature, the bias seemed to be real. It was evident that for coastal SYNOP stations the forecasted surface temperature was too cold whereas inland stations often showed a positive bias, especially in northern Scandinavia. The consequences for SCANDIA are thus expected to be different for coastal and inland areas, respectively. Specifically, the use of the warm bias correction of HIRLAM surface temperatures (the TSURBIAS correction) seems only to be motivated for inland areas at present. This means that recent improvements in HIRLAM surface temperature forecasts must be taken into account when implementing any new version of SCANDIA.

The MSMS database is shown to be a rich source for validation and verification of the quality of the SCANDIA cloud classification. However, the SCANDIA model was here validated against SYNOP reports and this means that potential errors in SYNOP observations consequently affected the achieved results. This also concerns sources of error in the basic AVHRR- and HIRLAM datasets. The full effect of these specific errors may not have been entirely covered in this report. In addition, the choice to study exclusively total cloud cover has obscured some interesting aspects of the SCANDIA performance. For example, it is well known that SCANDIA often mis-classifies low-level clouds as mid-level clouds in cases of temperature inversions. Notice that this occurs when there is no need for the surface temperature test (the TEMPADD test) for cloud detection, i.e., clouds have already been detected by tests using other AVHRR channels than channel 4. The reason for the mis-classification is here that cloud top temperatures are generally much colder than the 700 hPa level. In this particular study, this circumstance has not been considered as an error since it has not affected the estimation of total cloud cover.

As a final remark, MSMS is considered to highly serve its purpose with all its different data that can be used for validations in order to develop a new classification model. The tables and the objective measures that are presented in the study show a general high performance of the SCANDIA cloud classification. However, problems exist causing serious errors in critical situations for the forecaster and there is still a need for improvement.

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