Validation of the High Latitude SST product for NOAA 16 from the O&SI SAF

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(September 5, 2002)

1 Introduction

This report presents the results from the validation of the High Latitude sea surface temperature (SST) product for the NOAA 16 satellite from the Ocean and Sea Ice Satellite Application Facility (O&SI SAF).

Validation of the SST products from the O&SI SAF is done routinely at the Norwegian Meteorological Institute (met.no) and Meteo-France/CMS. In situ observations from drifting buoys, moored buoys and ships are collocated with the SST products and the satellite data, and collected in matchup databases (MDBs). Using these MDBs the SST product itself can be validated and SST algorithms can be tested. At met.no the high latitude SST product is monitored and at Meteo-France/CMS the low/mid latitude and regional products are monitored.

This report first gives some details about the data in the MDBs in chapter 2. Then the general validation of the High Latitude SST product for NOAA 16 is presented in chapter 3. Data from matching observations from the met.no and CMS MDBs are compared in chapter 4. In chapter 5 different SST algorithms are tested on the MDBs.

2 Matchup database format

The MDB built at met.no collects all in situ SST observations north of 50N in the northern Atlantic and collocates these with the 1.5km resolution SST and AVHRR data within the acquisition area of the met.no receiving station in Oslo. At CMS the similar is done, but with data north of 30N and 2.0km resolution. These MDBs partly cover the same areas, so both MDBs can be used for testing algorithms.

The MDBs of met.no and CMS have the same format. They contain data from the in situ observations, the O&SI SAF SST products and selected AVHRR data. Detailed information is given in Eastwood (2001). Each observation in the MDB contains 73 data fields. The collocating of the in situ observation and the satellite data is done by finding the closest pixel to the in situ point. Then data from a 15x15 pixels box around this pixel is extracted. Both the central pixel values and average from all the cloud free pixels within the pixel box are extracted to the MDB. In this report the

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average values are used if nothing else is stated.

There are some small differences in the criterions for selecting observations for the MDBs at met.no and CMS. One is the maximum time difference between in situ observation and satellite passage. At met.no this value is 120 minutes and at CMS it is 30 minutes. At CMS only pixel boxes with cloud cover less than 60% are selected. At met.no no such criterion is used, only the central pixel needs to be cloud free. The reason for choosing these less restrict criterion at met.no is that few in situ observations are available north of 50N. Filtering of the data is done directly on the MDB instead.

3 Product validation

The met.no MDB contains data from the period January 2002 - July 2002 for NOAA 16. The selection of the algorithm for NOAA 16 is described in Eastwood (2002a). Due to indications that the high latitude algorithm (HLSST) had an increasing bias with satellite zenith angle (Brisson et al., 2001), this algorithm was replaced by the algorithm developed at CMS for global conditions in December 2001. The CMS algorithm is given below:

$$SST = 0.95576 \cdot T4 + (0.92937 \cdot S + 0.07955 \cdot T_{guess}) \cdot (T_4 - T_5) + 0.97607 \quad (1)$$

where: $S = (1/\cos(\theta)) - 1$, θ = satellite zenith angle.

The validation of the SST product is done by studying the error in the estimated temperature, that is the difference between the estimated and observed temperature. Here the observed temperature is denoted Tw and the estimate is denoted SST.

For the validation in this report only the drifting buoys have been used. They are expected to give the most representable observations for the northern Atlantic. Ships have shown more erroneous observations which gives too high standard deviation and the moored buoys in northern Atlantic also show a higher standard deviation than the drifting buoys. Observations with larger error (SST-Tw) than +/- 3 C have also been removed since they are obviously wrong. These errors are considered not to be caused by the SST algorithm, but rather other processing errors such as ie. the cloud mask failing to detect all clouds. The validation results are given in Table 1.

	Number of obs	***std.dev. [C]***	***bias [C]***	***mean Tw [C]***
All obs	845	0.585	-0.578	8.41
Day time	315	0.632	-0.554	7.87
Night time	437	0.517	-0.586	8.73

Table 1: Validation results for the High Latitude SST product from NOAA 16 on the met.no MDB in the period 2002.01 - 2002.07. Number of outliers that have been removed: 11. The CMS global NOAA 16 SST algorithm has been used.

The results show an overall standard deviation in the error of 0.59C, with day time cases having a higher value than night time. The bias is about the same for all cases, around -0.6C. The standard deviation is slightly higher than the expected yearly value of 0.5C (Eastwood, 2002b). Since the MDB only contains data for 7 months, it is too early to say if this goal will be reached. The reason for the large bias is that the algorithm used has not been corrected. As described in Eastwoood (2002b) a correction term should be added to the algorithm to correct for the fact that the algorithm is based on simulated radiances and needs to be tuned for actual conditions. This will be discussed further later in the report.

To see how the algorithm performed on more ideal situations, the MDB was filtered and only situations with cloud cover < 10% within the pixel box was use. This gave an overall standard deviation in the error of 0.48C and a bias of -0.36C, with only 317 matchups. This shows a significant better results, which is probably caused by less noise from cloud contamination.

For comparison all the observations north of 50N have been extracted from the CMS MDB and similar statistics have been calculated. The same algorithm has been used to calculate the SST in the two MDBs, so both MDBs can be used to validate the performance of this algorithm at high latitudes. The results are given in Table 2.

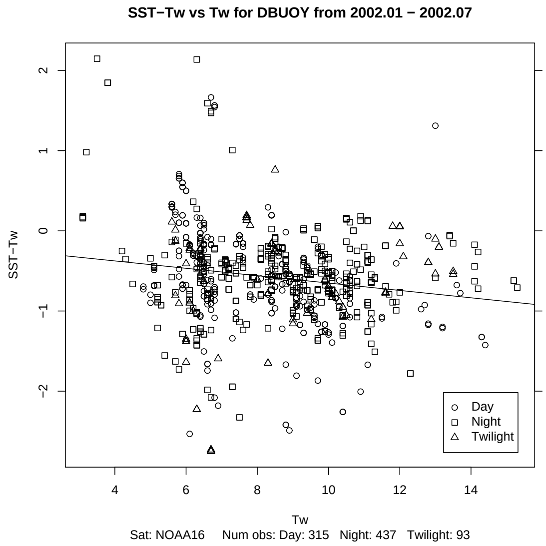
	Number of obs	***std.dev. [C]***	***bias [C]***	***mean Tw [C]***
All obs	965	0.463	-0.429	10.77
Day time	410	0.356	-0.378	10.65
Night time	498	0.508	-0.453	11.06

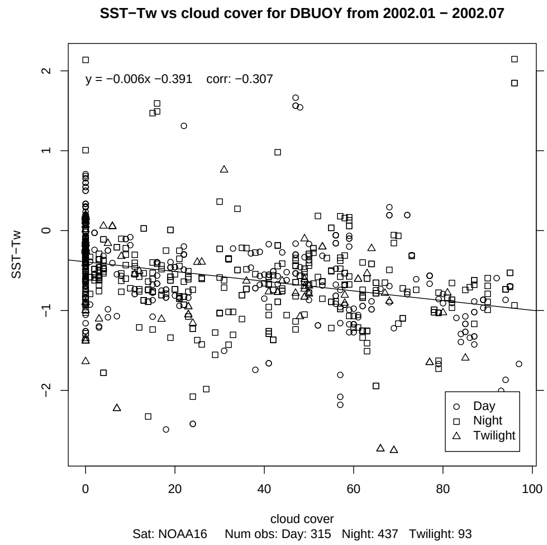
Table 2: Validation results for the CMS global NOAA 16 SST algorithm using the CMS MDB from the period 2001.05 - 2002.04. Number of outliers that have been removed: 6.

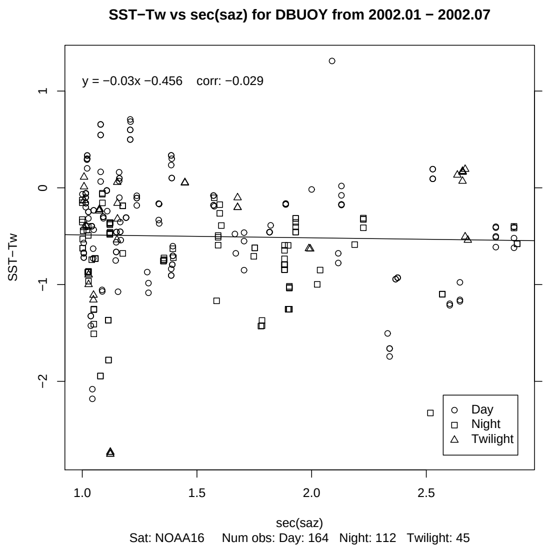
The results from the CMS MDB show smaller standard deviation and less negative bias in the error compared to the results from the met.no MDB in Table 1. The less negative bias can probably partly be explained by the fact that the CMS MDB only have observations with cloud cover less than 60%. There can be several reasons for the lower standard deviation. In chapter 4 coincident matchup observations are compared to see if there are any systematical differences between data from met.no and CMS.

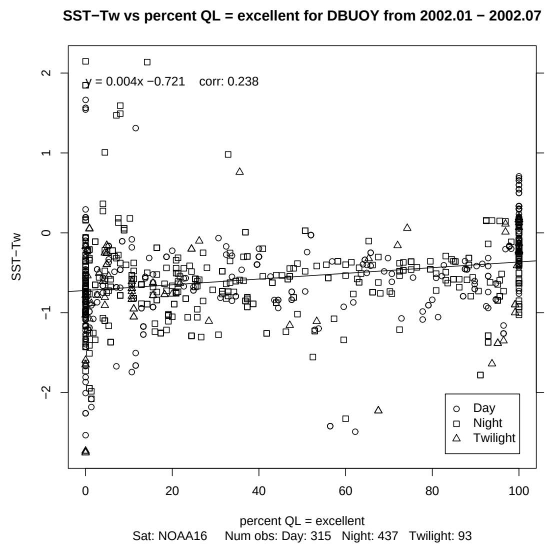
Differences in the validation results between the met.no and CMS MDB must be expected since not the same observations are used and the number of observations are limited. As shown in Eastwood (1998) the standard deviation of such validation varies much with the selection of validation points when few data are used.

To study the error closer the error has been plotted as a function of different parameters. Plots of the error versus Tw, satellite zenith angle, cloud cover and quality level (see Eastwood, 2002b) are given in Illustration 1. The plot with Tw shows that the bias is more negative for higher temperatures. The plot with satellite zenith angle indicates that the bias is independent on satellite zenith angle. The plot of the error versus latitude indicates that the error is least negative for high latitude









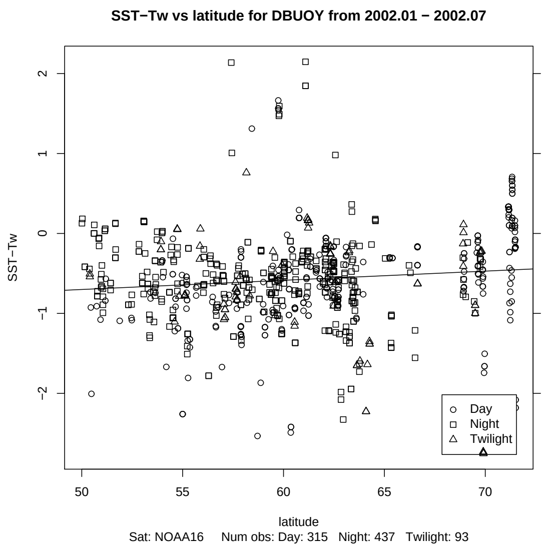


Illustration 1: Plots of error in SST as function of Tw, secant of satellite zenith angle, latitude, cloud cover and percentage of quality level = excellent. The observations are from the met.no MDB.

(~70N) and increases (negatively) towards latitudes around 50N.

In Illustration 1 the plot with cloud cover and quality level have been included to show that a correction term for the algorithm should not simply be chosen from Table 1. A correction term should be chosen so that the algorithm performs best under good conditions, that is with no cloud contamination. Therefor the MDB should be filtered for observations that can be cloud contaminated. In the plot of the error versus cloud cover inside the pixel box it is clear that the error is least negative for cloud cover = 0% and increases with cloud cover. At cloud cover = 0% the bias is 0.39C. In the plot with percentage of quality level = excellent within the pixel box the bias is least negative for 100% excellent pixels, with a bias of 0.36C. These two biases correspond well. To find the exact value to use for a correction term a similar plot was made with the quality level, but only with observations with cloud cover < 10%. This plot showed an error of -0.362 for observations with 100% excellent pixels and cloud cover < 10%, which should be used as correction term for the CMS algorithm at high latitudes.

4 Comparing met.no and CMS data

To compare the AVHRR data at CMS and met.no the two MDBs have been matched so that all observations from the same buoy/ship at the same time can be compared. The satellite times are slightly different since the data are received at different receiving stations, from 2-6minutes. The CMS MDB from 2001.05 - 2002.04 and the met.no MDB from 2002.01-2002.07 was used to find coincident observations/collocation points from 2002.01 - 2002.04 and the results for some parameters are shown in Table 3.

CMS-met.no value	***Number of obs***	***std.dev. [C]***	***bias [C]***	***mean CMS value [C]***
Average T4	422	0.164	0.049	5.76
Average T5	422	0.175	0.042	4.94
Average (T4-T5)	422	0.042	0.008	0.81
SST climatology	557	0.545	0.667	6.68
Cloud cover	557	17.271	3.020	12.63
solar zenith angle	557	0.230	-0.337	95.00
sec(satellite zenith angle)	422	0.003	-0.002	1.13
SST (from CMS alg)	422	0.165	0.102	6.99

Table 3: Comparison of CMS and met.no MDB parameters for observations from the same buoy/ship at the same time in the period 2002.01-2002.04. The values are the difference between the CMS value and the met.no value. T4 and T5 are the brightness temperatures of AVHRR channel 4 and 5, which are averaged over a 15x15 pixel box. The SST in the table has been calculated using the CMS global algorithm and average T4,T5 values and satellite zenith angle from the two MDBs.

Table 3 shows some differences between the CMS and met.no data. The difference in channel 4 and 5 brightness temperatures is not large, but will affect the calculation of SST. So will also the difference in SST climatology. The difference in satellite zenith angle is not large on average, but the difference is larger for higher zenith angles, as shown in Illustration 2.

The effect of these differences on the SST can be seen in the last row of Table 3. A difference of 0.10ºC is observed when the SST is calculated with data from CMS and met.no at the same position. About half of this difference is caused by the difference in T4 and T5, and the other half by the difference in SST climatology.

To check whether the difference in T4 and T5 was cause by cloud contamination the matching observations was filtered and all observations with cloud cover > 10% was removed, both in the CMS and met.no MDB. The results are shown in Table 4. The bias of the differences between CMS and met.no brightness temperatures was reduced to about 0.025C, and the difference between channel 4 and 5 to 0.008C. The resulting difference in SST when using the CMS algorithm was reduced to 0.027C and 0.07C when including the difference in SST climatology. The two MDBs are not completely comparable since they use different pixel size and pixel boxes, and the AVHRR data are processed a differently at CMS and met.no. But the differences must be kept in mind when comparing results.

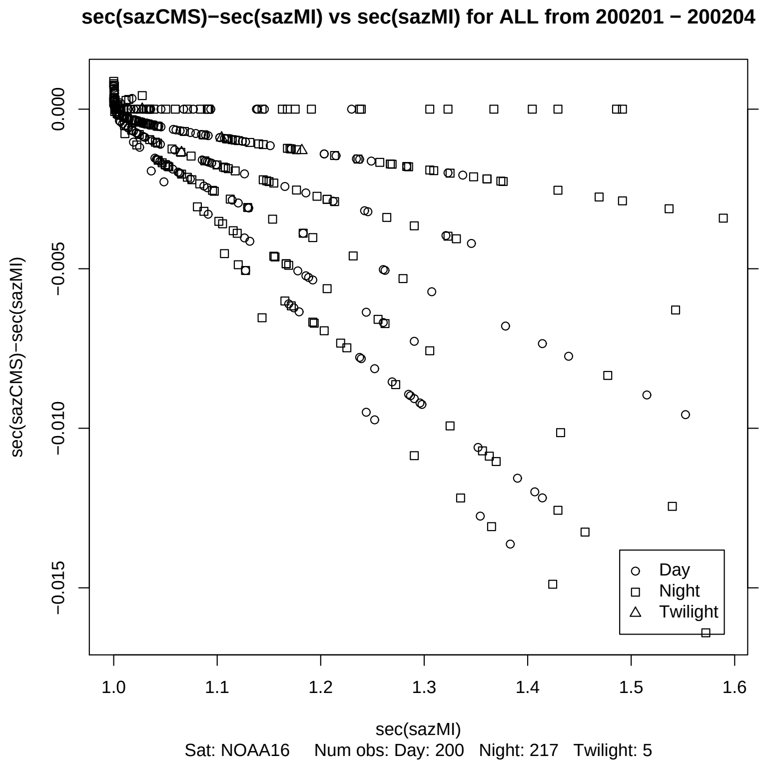


Illustration 2: Difference in satellite zenith angle for data from CMS MDB and met.no MDB as function of satellite zenith angle from met.no MDB.

CMS-met.no value	*Number of obs*	*std.dev. [C]*	*bias [C]*	*mean CMS value [C]*
Average T4	221	0.114	0.026	5.99
Average T5	221	0.115	0.024	5.23
Average (T4-T5)	221	0.022	0.002	0.75
SST (from CMS alg)	221	0.114	0.071	7.17

Table 4: As Table 3, but only observations with cloud cover < 10%.

Table 3 also shows a difference in the cloud cover between the CMS and met.no data. Different cloud mask schemes are used at CMS and met.no, and these results shows that the cloud mask used at met.no seems to underestimate the cloud cover compared to the cloud mask used at CMS.

5 Testing different SST algorithms

The MDBs can be used to test different SST algorithms and compare the results to find the best algorithm for NOAA 16. For high latitudes the OSI SAF has concluded that the best algorithm formalism is the non-linear algorithm. The coefficients for the non-linear algorithm can include different parameters, and four different variants have been defined for high latitudes. These are described in Eastwood (2002a). The coefficients have been calculated using regression analysis on simulated radiances. A set of "noise resistant" coefficients has also been calculated (see Eastwood, 2002a, for details). The four algorithm formalisms are given in (2).

$$
\begin{aligned}
&\text{NL\_1:}\quad SST = A_0 \cdot T_4 + (B_1 \cdot S + B_2 \cdot T_{guess}) \cdot (T4 - T5) + C_0 \\
&\text{NL\_2:}\quad SST = A_0 \cdot T_4 + (B_0 + B_1 \cdot S + B_2 \cdot T_{guess}) \cdot (T4 - T5) + C_0 \\
&\text{NL\_3:}\quad SST = A_0 \cdot T_4 + (B_0 + B_1 \cdot S + B_2 \cdot T_{guess}) \cdot (T4 - T5) + C_0 + C_1 \cdot S \\
&\text{NL\_4:}\quad SST = (A_0 + A_1 \cdot S) \cdot T_4 + (B_0 + B_1 \cdot S + B_2 \cdot T_{guess}) \cdot (T4 - T5) \\
&\qquad\qquad + C_0 + C_1 \cdot S
\end{aligned}
\qquad (2)
$$

The noise resistant algorithms have the same formalisms, but the coefficients have been calculated using simulated radiances with noise. The noise resistant algorithms are labeled as the other algorithms, just with an additional 'n' (e.g. NL_1n). The NL algorithm from CMS was also tested, and it is labeled NL_lml.

	Number of obs	std.dev. [C]	bias [C]	mean Tw [C]
NL_1	276	0.518	-0.492	7.60
NL_2	276	0.491	-0.398	7.60
NL_3	276	0.516	-0.448	7.60
NL_4	276	0.507	-0.452	7.60
NL_1n	276	0.517	-0.495	7.60
NL_2n	276	0.498	-0.452	7.60
NL_3n	276	0.510	-0.509	7.60
NL_4n	276	0.499	-0.520	7.60
NL_lml	276	0.512	-0.405	7.60

Table 5: Validation results for the different non linear algorithm formalisms on the met.no MDB for the period 2002.01 - 2002.07. The averaged brightness temperatures are used. Only drifting buoys are used and observations with cloud cover < 60%. Number of outliers that have been removed: 4.

	Number of obs	std.dev. [C]	bias [C]	mean Tw [C]
NL_1	965	0.464	-0.584	10.77
NL_2	965	0.472	-0.308	10.77
NL_3	965	0.481	-0.268	10.77
NL_4	965	0.484	-0.280	10.77
NL_1n	965	0.464	-0.582	10.77
NL_2n	965	0.463	-0.457	10.77
NL_3n	965	0.467	-0.416	10.77
NL_4n	965	0.482	-0.444	10.77
NL_lml	965	0.462	-0.417	10.77

Table 6: As Table 5, but with the CMS MDB for the period 2001.05 - 2002.04, and latitude > 50N. Number of outliers that have been removed: 6.

The algorithms have been tested on both the CMS MDB and met.no MDB. The results are given in Table 5 and Table 6. It is clear that the differences between the standard deviation of the errors are small, only a variation of 0.02C between the best and worst. The bias varies slightly more, and the NL_1 algorithm gives the worst results. For the other NL formalisms the two MDBs do not show the same trend, but the NL_2 or NL_3 seems to be the best choice.

The validation results show only small differences in standard deviation between the algorithms with noise resistant coefficients and the others. For the bias the noise resistant algorithms have larger negative bias than the others.

An important aspect of the algorithms bias is whether it varies with the satellite zenith

	lat: 30-50N		lat: > 50N	
	normal	noise	normal	noise
NL_1	0.219	0.181	0.035	0.012
NL_2	-0.324	-0.072	-0.134	-0.068
NL_3	-0.503	-0.266	-0.187	-0.123
NL_4	-0.543	-0.406	-0.196	-0.156
NL_lml	0.008		-0.135	

Table 7: Slop values (that is a in y = ax + b) for the linear fit to the error as function of satellite zenith angle for the different NL algorithms, with "normal" and noise r esistant coefficients. The data used is the CMS MDB for NOAA16 from the period 2001.05 to 2002.04. The observations have been split in two latitude groups; 30-50N and >50N.

angle. This can be studied by plotting the error versus the zenith angle and find a linear fit to the points. The slope of the fitted line will then tell how the error varies with the zenith angle. This has been done for all the NL algorithms and the results are shown in Table 7. In this table the observations have been split in two groups, 30-50N and >50N. This is to show how the high latitude algorithms perform outside their intended use. The observations from 30-50N are warmer and more humid than the high latitude algorithms were developed for. When tested on data from 30-50N the high latitude algorithms have a bias that varies with the satellite zenith angle. On data > 50N this dependency on zenith angle is much smaller. It is also clear that the error in the noise resistant algorithms have smaller dependency on zenith angle than the "normal" algorithms. The best choice seems to be the NL_2 algorithm formalism with noise resistant coefficients. The CMS NL algorithm performs well both on data from 30-50N and > 50N.

6 Conclusions

The validation of the High Latitude OSI SAF SST product from the period 2002.01-2002.07 shows that the product error has an overall standard deviation of 0.59C and a bias of -0.68C. The standard deviation is reduced to below 0.5C when only situation with cloud cover < 10% is used in the verification. Similar validation using a MDB from CMS gives better results and indicates that the HL OSI SAF SST product error will fulfill the requirement of a yearly standard deviation less than 0.5C. The validation results also show that a correction term of -0.362C should be added to the NOAA 16 NL algorithm from CMS when used at high latitudes (>50N).

Some differences are found when coincident data from met.no and CMS are compared. The brightness temperatures in channel 4 and 5 seem to be slightly higher at met.no, by 0.025C. The mean climatological SST used for the SST calculations are higher at CMS, by 0.67C. The cloud cover in the MDB from CMS indicates higher cloud cover in the CMS cloud mask. The satellite zenith angle is slightly lower at CMS at high zenith angles. All these differences would give a 0.10C higher SST value with CMS data compared with met.no data.

When different non linear SST algorithm formalisms are validated the differences in the standard deviation of the error are small. There is a more evident variation between the algorithms in the error's bias and the NL_2 algorithm with "noise resistant" coefficients is the best candidate for NOAA16, together with the CMS global NL algorithm.

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