Narrowband to broadband correction of NOAA/AVHRR data[1]

ØYSTEIN GODØY[2] AND STEINAR EASTWOOD

Norwegian Meteorological Institute[3]

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1 Introduction

To facilitate the production of short−wave irradiance estimates using NOAA/AVHRR data as input several processing steps are required before the observed cloud "albedo" can be related to transmissivity. Basically these steps are :

1. Radiometric calibration transforming instrument count values to reflectance factor (also called scaled radiance and sometimes confusingly albedo)
2. Narrowband to broadband (NTOB) correction transforming the observed narrowband reflectance factors to a broadband reflectance.
3. Anisotropy correction transforming the directional dependent broadband reflectance factor to a directional independent value that can be denoted albedo. This step can also be performed before the NTOB correction but concerning AVHRR there is not much literature on this aspect.

This report addresses the second step, the NTOB correction, and identifies the available methods found in literature and a discussion on which to use. No control data were available (i.e. collocated AVHRR and broadband observations) thus this report is merely a discussion on the NTOB concept, methods found in literature and their feasibility for use in the project Ocean and Sea Ice SAF.

2 Method

2.1 Background

Narrowband observations of the reflected electromagnetic radiation from the Earth usually differs from the broadband observations due to narrowband or line effects in the atmosphere. However, several studies (e.g. Laszlo et al, 1988, Li and Leighton, 1992, Hucek and Jacobowitz, 1995, Li and Trishcenko, 1999) has shown that there is a more or less linear relationship between the narrowband and broadband observations of the reflected radiation. Thus NTOB corrections are usually applied using a relationship like:

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[2] email: o.godoy@met.no

[3] P.O.BOX 43, Blindern, N−0313 OSLO, Norway

$$R_b = a + \sum_{i=1}^{N} b_i R_i$$

where R_b is the broadband reflectance, R_i is the narrowband reflectance (or scaled radiance normalised to overhead Sun and corrected for the varying distance Earth and Sun) of channel i, a and b_i are regression coefficients, and N is the number of available narrowband channels. This is usually applied as

$$R_b = a + b_1 R_1 + b_2 R_2$$

for AVHRR observations.

NTOB corrections can be developed in at least two different ways. Collocated data sets of narrowband AVHRR data and broadband data (e.g. ERBE, ScaRab or CERES) can be analysed with regression methods (e.g. Wydick et al, 1987, Li and Leighton 1992, Hucek and Jacobowitz, 1995) or simulations of NTOB corrections using sophisticated radiation models may be used (e.g. Cess and Potter, 1986, Laszlo et al., 1988). Both methods are facing problems. Regression methods using collocated data violates basic statistical assumptions when the input data is spatially auto correlated (Li and Leighton, 1992). Theoretical simulations avoids this problem, but reproducing the full radiative complexity of the atmosphere and surface is difficult.

In the remaining part of this chapter a simple model study using MODTRAN 3.7 for simulation of AVHRR narrowband and broadband short−wave radiance’s is described. A simple regression model for NTOB correction using these simulated data is given and the result is discussed in light of the results gained by Wydick et al. (1987), Li and Leighton (1992) and Hucek and Jacobowitz (1995).

2.2 Published NTOB conversions for AVHRR data

2.2.1 Wydick et al. (1987)

This is the operational model of NOAA/NESDIS for heat budget products. It was derived using NOAA−7 data which was regressed against broadband NIMBUS−7 ERB data, but has been applied to all successive satellites. No corrections for instrument degradation was performed and more important, the collocated data used for regression was from different time periods and local times (AVHRR data were from 1981 and broadband measurements from 1978−1980). The regression results are presented in Table I.

Table I Regression coefficients of Wydick et al. (1988).

Coefficient	***All scenes***
a	0.746
b_1	0.347
b_2	0.650

2.2.2 Hucek and Jacobowitz (1995)

As sensor degradation became evident from various studies, Hucek and Jacobowitz (1995) analysed various sources of error in the NTOB correction applied at NOAA

(Wydick et al, 1988). Several new NTOB conversions were developed based upon coincident narrowband (AVHRR) and broadband (ERBE) observations made by NOAA−9 using albedo as the regression variable (as suggested by Cess and Potter, 1986). The new models were adjusted for sensor degradation. In this study the surface dependent (Table II) and scene dependent (Table III) models of Hucek and Jacobowitz (1995) were examined.

Table II Regression coefficients for the surface type dependent correction of Hucek and Jacobowitz (1995).

Regression coefficient	***Surface type***						
	snow 1	***ocean 2***	***land 3***	***desert 4***	***land 5***	***ocean 6***	***coast 7***
a	−0.86	3.48	2.65	2.20	3.31	3.52	3.28
b_1	0.1398	0.3617	0.4022	0.4439	0.3994	0.5474	0.4529
b_2	0.6991	0.4496	0.4112	0.3511	0.3984	0.2552	0.3557

Table III Regression coefficients for the surface type and cloud amount dependent model of Hucek and Jacobowitz (1995). Surface types are the same as in Table II.

Coefficient	***Surface type***						
	snow 1	***ocean 2***	***land 3***	***desert 4***	***land 5***	***ocean 6***	***coast 7***
Clear							
a	3.8995	1.78	2.17	2.60	2.95	2.34	2.77
b_1	0.0520	1.3302	0.3999	0.3896	0.2331	1.2062	0.3779
b_2	0.7423	−0.6250	0.4333	0.3873	0.5025	−0.5504	0.4168
Partly cloudy							
a		4.11	4.24	3.12	3.27	5.38	4.65
b_1		0.9029	0.3166	0.2705	0.2063	0.8909	0.3085
b_2		−0.2441	0.3948	0.4811	0.4926	−0.2876	0.3856
Mostly cloudy							
a		5.08	4.75	5.49	9.53	8.51	5.36
b_1		0.4711	0.3757	0.3255	0.2844	0.3664	0.4362
b_2		0.2983	0.3870	0.3961	0.3149	0.3308	0.3227
Overcast							
a	−0.1174	8.19	6.98	7.50	13.28	13.72	7.79
b_1	−0.0650	0.2301	0.2566	0.7564	0.2998	0.0076	0.2930
b_2	0.8671	0.5032	0.4907	−0.0136	0.3530	0.6310	0.4446

Of the surface types described above the ocean areas used for data collection is of special interest. Two ocean areas were chosen, one in the Pacific (along the coast of Peru, numbered 6 above) and one in the Atlantic (off the coast of Ireland and Portugal, numbered 2 above).

2.2.3 Li and Leighton (1992)

Coincident AVHRR and ERBE data from NOAA−9 were used by Li and Leighton (1992) to develop a new method for NTOB correction. Only data north of 60° were used for a period of 4 days in July 1985. Their results are presented in Table IV.

Table IV Statistics summary of Li and Leighton (1992) regression results for NTOB corrections.

Scene	***Sample size***	***a***	***b_1***	***b_2***	***Explained variance***	***RMS error***	***Relative error***
Ocean	401	2.48	0.490	0.699	82.6	1.0	13.8
Land	423	1.25	0.673	0.518	76.7	1.8	10.4
Ice/Snow	1514	4.53	0.389	0.452	97.2	2.0	4.5
Clouds	1140	6.98	0.410	0.448	92.8	3.1	6.5
All	3478	4.42	0.287	0.607	97.7	2.7	7.1

2.3 RTM simulation using MODTRAN 3.7

2.3.1 Comparison of narrowband and broadband reflectance's

In order to examine the relationship between narrowband and broadband reflectance's, AVHRR radiance's was simulated for NOAA 14 and NOAA 15 and compared with broadband radiance's using the radiative transfer model MODTRAN 3.7 (see e.g. Berk et al., 1998). The band output from MODTRAN has been weighted with the response functions of the AVHRR channels and integrated over the band covered by the channel. All simulations have been performed using the Subarctic Summer model atmosphere.

Simulations are performed for solar zenith angles 30° and 60° and surface albedo's 0.07 and 0.3. The satellite zenith angle is varied through 0°, 10°, 20°, 30°, 40°, 50°, and 60° and the azimuth angle is varied through 0°, 45°, 90°, 135°, and 180°.

The results of these simulations are presented in Illustration 1 and Illustration 2 (NOAA−14 and NOAA−15 results respectively))using a surface albedo of 0.07.

The upper left panel in Illustration 1 shows the simulations for NOAA 14 channel 1. The broadband values are represented along the abscissa and the narrowband values along the ordinate. Several clusters are observed. These correspond to various surfaces. The surfaces represented are cloud free ocean (1), stratus (2), altostratus (3) and cirrus (4) clouds. The points within each cluster represents variations in observation geometry (satellite and azimuth angle) for the specific atmosphere and surface albedo used. It is observed that some of the surfaces are represented by one cluster while others like stratus and altostratus clouds are represented by two clusters. The two clusters for each cloud type area caused by the two different solar zenith angles used (smallest reflectances ⇔ largest solar zenith angle, i.e. 60°). The solid line has unity gain and zero intercept. In the lower left corner of the figure, open water is represented. Channel 1 slightly underestimates the broadband value over open water. In this cluster of points high cirrus clouds are also present, though it is not possible to identify them in the figure presented here. The cluster of points identified by the symbol "2", to the right of the cluster representing open water and cirrus, represents low level stratus clouds at a solar zenith angle of 30°. The narrowband reflectivity in channel 1 of these clouds is higher than the broadband reflectivity. Close to the cluster of stratus is a cluster of altostratus found (symbol "3"). The two last clusters in the figure represents stratus and altostratus (highest reflectivity of all) at a solar zenith angle of 30°. Experiments was also performed using a surface albedo of 0.3, resulting in a general increase of the narrowband reflectivity (results are not shown).

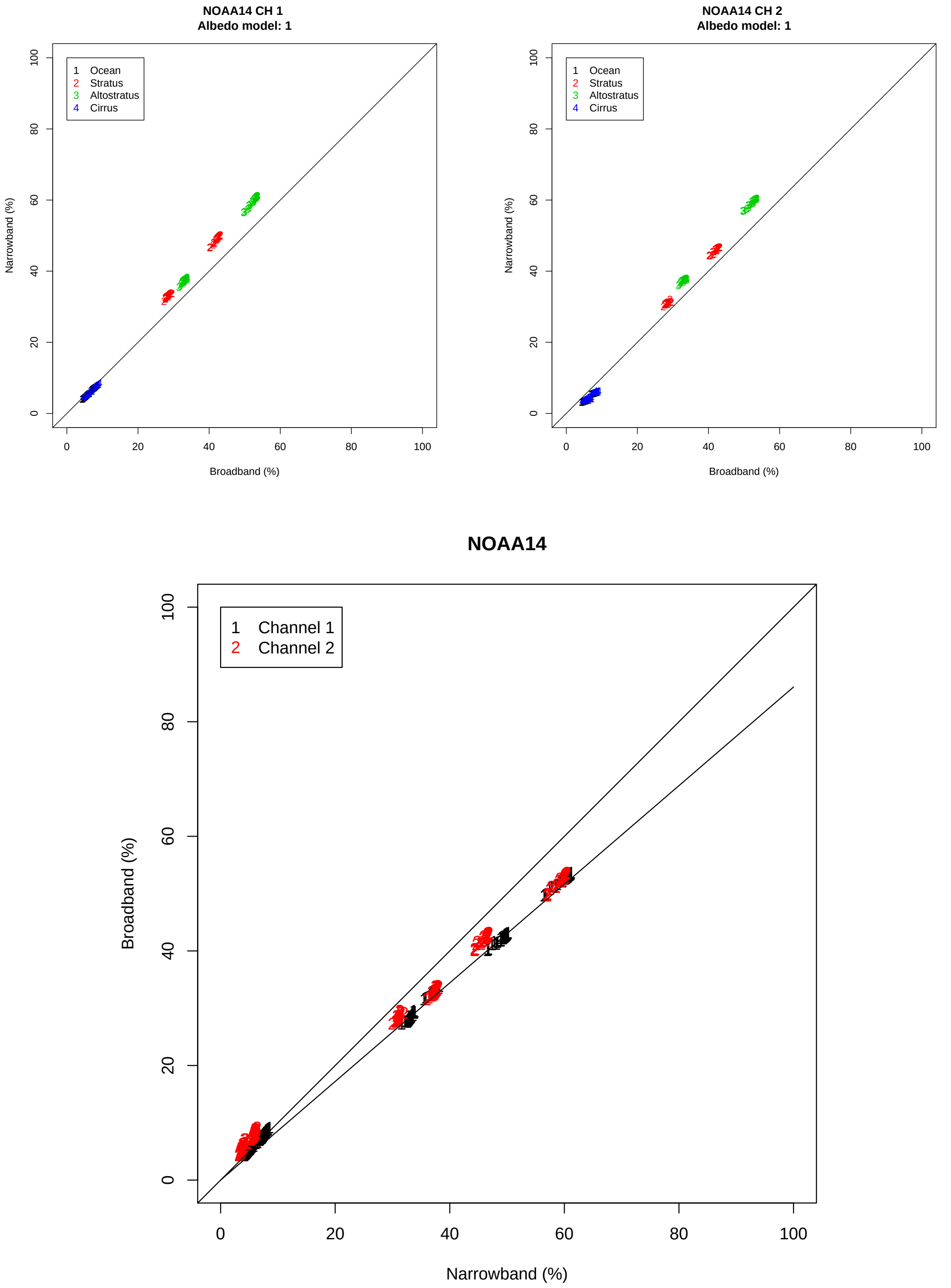


Illustration 1 MODTRAN simulations for NOAA−14.Top left panel shows the relationship between channel 1 reflectances and the broadband reflectance, top right panel shows the same for channel 2 and and the lower panel shows regression of narrowband channels on the broadband.

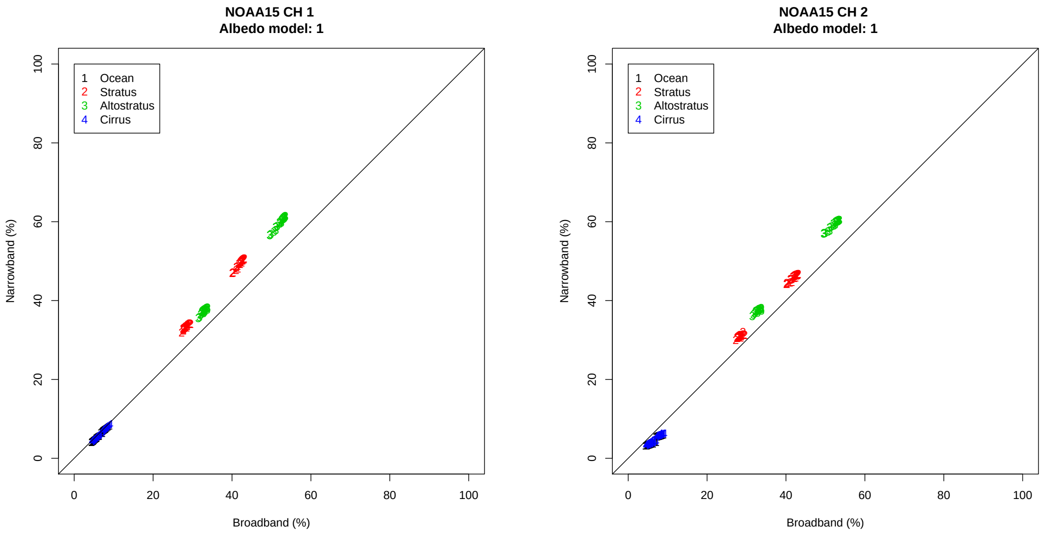
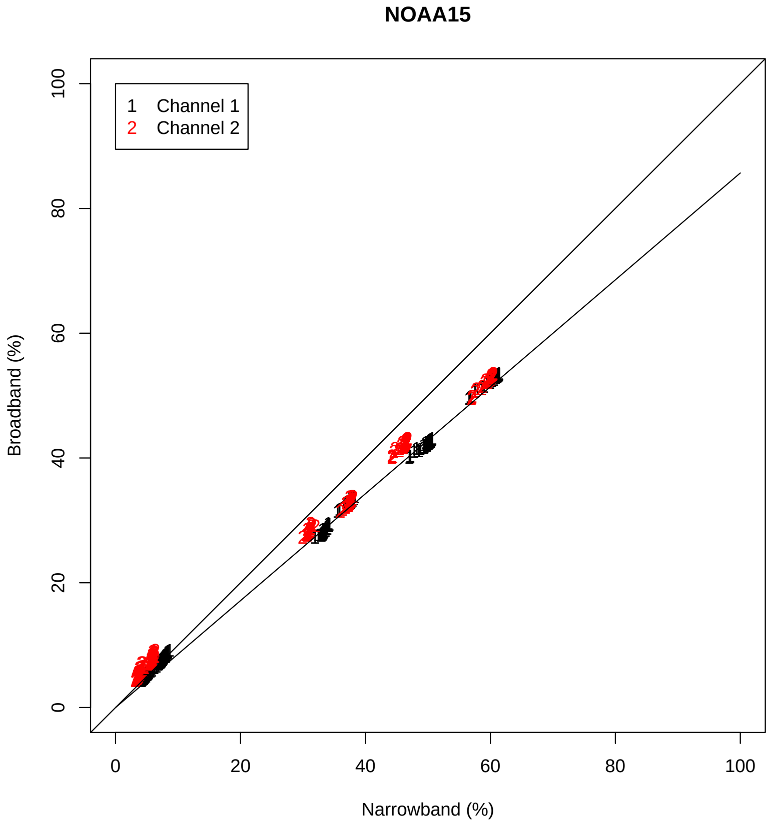


Illustration 2 MODTRAN simulations for NOAA15. Top left panel shows the relationship between channel 1 reflectances and the broadband reflectance, top right panel shows the same for channel 2 and and the lower panel shows regression of narrowband channels on the broadband.



The upper right panel of Illustration 1 presents the results for NOAA 14 channel 2. The results gained for this channel is similar to the results for channel 1 for the clouds, but the reflectivity of open water is less than in channel 1 as it is moderately affected by water vapour absorption.

It is observed that the narrowband reflectances of channels 1 and 2 are higher than the actual broadband value for the different cloud types represented in this study. Thus, the narrowband reflectance is not a good estimate of the broadband reflectance for the surfaces and band examined here.

The results obtained by simulating NOAA−15 is presented in Illustration 2. As for NOAA−14, the upper left panel shows channel 1 and the upper right panel shows channel 2 simulations. The general features of these figures are similar to the description given for Illustration 1, the narrowband reflectances are higher than the broadband values for stratus and altostratus clouds.

2.3.2 Multiple regression

As noted before are NTOB corrections usually presented as linear combinations of narrowband reflectance’s. The coefficients of the linear combination of channels are usually estimated using multiple linear regression were the narrowband AVHRR channels are used as predictors.

As noted in the previous chapter, the narrowband reflectances are higher than the broadband value that would be measured given the same insolation. Thus the broadband value obtained by applying a NTOB correction should be less than both the channel 1 and channel 2 reflectance.

Illustration 1 presents the narrowband reflectance estimates of channel 1 and 2 together with the linear regression of the broadband value on the narrowband values for NOAA 14. The regression was performed using the statistical software packages Splus 3.3 and R (changed to R due to migration from IRIX to LINUX). The results are presented in Table V.

Table V Regression coefficients for clear and cloudy situations over ocean from MODTRAN simulations.

Regression coefficients	***Satellite***	
	NOAA−14	***NOAA−15***
a	1.5279	1.6101
b_1	0.5575	0.5098
b_2	0.2678	0.3309

The regression results show that the present data set is well described by a multiple linear regression and that the estimated broadband value is less than the individual narrowband values.

How these results would perform on real data is yet to be proven. These results are based upon a very limited data set and idealised situation, however, it may help understand the importance of accounting the spectral response of various sensors when performing the narrowband to broadband correction. It is observed that the regression coefficients are very similar for the two sensors. This topic will be further discussed in the next chapter.

2.4 Comparison of correction schemes

The NTOB corrections described earlier are plotted in the same figure (Illustration 3). Along the abscissa the AVHRR channel 1 is plotted and the resulting broadband value is plotted along the ordinate.

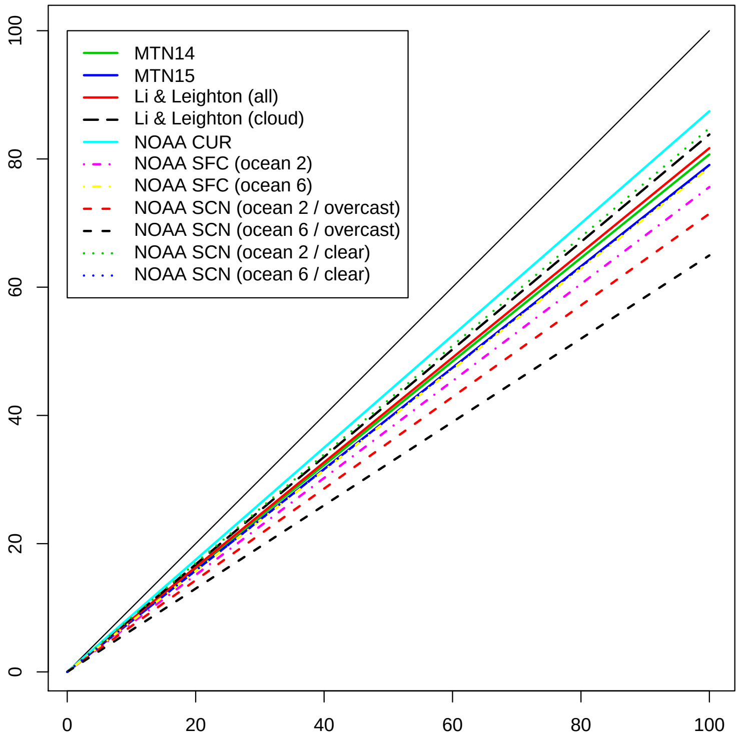


Illustration 3 Comparison of various NTOB corrections described in this document. The abscissa shows the channel 1 reflectance and the ordinate the resulting broadband reflectance.

The comparison is performed using channel 1 values in the range 0−100 as input, and channel 2 values are created by multiplying channel 1 values by 0.8 (a typical relationship over clouds).

It is observed that all methods produce lower broadband values than input narrowband values. The difference between the Li and Leighton (1992) results and the RTM study contained herein is small. The old NOAA method (Wydick et al. 1987) gives the highest broadband albedo.

The regressions for NOAA ocean surfaces numbered 2 are obtained using targets in the northern Atlantic ocean (off the coast of Ireland and Portugal), the ocean surfaces labelled 6 are obtained using targets in the Pacific.

3 Discussion

Laszlo et al. (1988) showed that a linear combination of AVHRR channels gives a better broadband estimate than using AVHRR channel 1 alone, the more channels used, the less error in the broadband estimate. However, they do not provide regression coefficients. As mentioned before, RTM simulations do not reflect all possible radiative property configurations of the Earth−atmosphere system.

NOAA has used the NTOB algorithm of Wydick et al. (1987) since May 1988. This is a two−channel correction developed from AVHRR and ERBE data. However, the input data were from different local times and years. AVHRR data were from 1981 and ERBE data from 1978−1980. No comparison were made with independent data and thus no estimate of the accuracy was available. The coefficients of Wydick et al. (1987) is presented in Table I. Compared to the other methods, this gives the highest broadband albedo (Illustration 3). This was also observed by Hucek and Jacobowitz (1995) who found this method to overestimate the reflected irradiance from the Earth compared to ERBE data. On the two situations they checked, this method overestimated the flux by 37 W/m^2 on one occasion and 22 W/m^2 on another. Following the arguments of Hucek and Jacobowitz (1995) the Wydick et al (1987) is not regarded as a natural choice for NTOB correction.

Li and Leighton (1992) analysed ERBE and AVHRR data from NOAA−9 and summarised the results in a table (reprinted here as Table IV). Li and Leighton (1992) based their regression on a limited data set covering only the dates 1, 10 and 29 July 1985. The region covered was the northern hemisphere north of 60°N, which should make these results interesting for use in the northern Atlantic. The scene independent results (covering both clear and cloudy data) of Li and Leighton (1992) compares well with the results gained in this study using a RTM and a restricted number of cases. When the cloudy subset of Li and Leighton (1992) is chosen the difference gets slightly larger, but then this is compared to a regression including both clear and cloudy RTM targets. The RTM regression result is also expected to change when only cloudy targets are used. However, for operational use the underlying data set used by Li and Leighton (1992) is too small (only 3 days during summer) to rely on these data for operational use. This is also the case for the RTM results. An interesting conclusion made by Li and Leighton (1992) though is that a two channel combination is only expected to improve the broadband prediction significantly when no scene discrimination is performed over ocean (cloud/clear). This is however to some extent in contradiction with the results of Laszlo et al. (1988). Given the small amount of data used by Li and Leighton (1992) it is still open whether or not the NTOB correction would benefit from using more than one AVHRR channel.

Hucek and Jacobowitz (1995) developed scene−dependent NTOB corrections and tested these against the correction of Wydick et al (1987). Input data for the regressions were AVHRR and ERBE data from NOAA−9. Three different scene−dependent corrections were developed, but only two of them are mentioned here. These are a correction depending on surface geography type (Table II) and a correction depending on surface geography type and cloud amount (Table III). Both these correction schemes performed better than the corrections of Wydick et al. (1987), as well as they perform better regardless of latitude (Hucek and Jacobowitz, 1995). At NOAA, the coefficients of Table III have been chosen as the operational

NTOB correction according to the paper, but according to Jacobowitz (pers. comm. 2000) they have not changed yet. Compared to the regression coefficients based upon MODTRAN results, the surface dependent model of Hucek and Jacobowitz (1995) gives similar results. The MODTRAN based model does not differentiate between cloudy and clear targets. However, a surprising feature is that The results for this model compares better when Pacific ocean targets were used for the regression than when Atlantic ocean targets were used. Concerning the scene dependent model of Hucek and Jacobowitz (1995) the MODTRAN simulations are within the results for clear and cloudy regression results obtained using targets in the Atlantic Ocean. Why results are so different for various ocean areas is not fully explained but it is anticipated that various atmospheres (e.g. water vapour and aerosol load) affect the regression results.

The results above show that NTOB results differ according to surface/scene type, spectral response of the instrument etc. Li and Trishcenko (1999) developed also a set of NTOB corrections using RTM calculations and ScaRab observations. In order to use this correction, an adjustment for the spectral response of AVHRR should be performed using a RTM. This should be performed for the coefficients developed for a single AVHRR instrument as well, though NOAA used the correction developed by Wydick et al. (1987) for several satellites regardless of this (Hucek and Jacobowitz, 1995). The argument for this is that 0.01 μm shift in bandwidth changes the reflectance of a scene by less than 1% (reflectance units) in the visible and near infrared (AVHRR channels 1 and 2) (Bowker et al. 1985). To study this the difference in predicted broadband reflectance using the regression relationship developed from MODTRAN simulated NOAA−14 and NOAA−15 data was plotted. This is presented in Illustration 4. It is observed that the maximum difference is about 1.5% (reflectance units). However, most clouds have a reflectance of less than 70% or less, under these conditions the difference due to using various sensors is less than 1%. Thus given the uncertainty of the various NTOB corrections it seems feasible to ignore differences in sensor characteristics. However, as was shown by Hucek and Jacobowitz (1995) sensor drift/degradation should be accounted for.

In addition to the NTOB corrections identified here, a set of AVHRR corrections developed by Jian Feng (pers. comm.) has been tested as well. This correction is based upon the work performed by Li and Trishcenko (1999) and was developed from AVHRR and ScaRab data and use only channel 1 of AVHRR. However, it discriminates between scene types and also use the viewing geometry as input. After some initial testing this method was discarded as it failed in too many situations at high latitudes (lacking data for the viewing geometry in the tables).

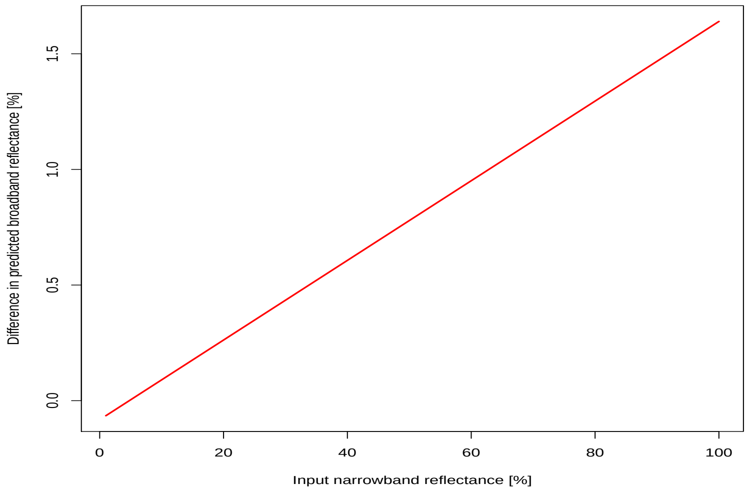


Illustration 4 The difference in predicted broadband reflectivity using regressions determined from NOAA−14 and NOAA−15 data. The difference is plotted along the ordinate as a function of the channel 1 reflectance on the abscissa. All units are in % reflectance.

4 Summary

As no collocated AVHRR and broadband data have been available for testing/control of these models, for the time being the scene dependent corrections of Hucek and Jacobowitz (1995) will be used as these are developed from the largest data base and they compare well with the RTM simulations performed. They did also use re−calibrated AVHRR data, accounting for sensor degradation, as input. This expected to be of greater importance to the accuracy of the predicted broadband value than differences between sensors flown on different platforms (e.g. using NOAA−12, NOAA−14, NOAA−15 and NOAA−16 as input).

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