

# Report about Visiting Scientist stay at CMS, Météo-France

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Steinar Eastwood  
DNMI, P.O.BOX 43, Blindern, N-0313 OSLO, NORWAY



**DNMI**

Det norske meteorologiske institutt

As a visiting scientist for the Ocean and Sea Ice SAF I worked at CMS, Meteo-France in Lannion, France for 6 weeks from 29/5 to 10/7. I lived close to CMS and had an office at CMS where I worked closely together with Pierre Le Borgne. I also worked together with Alain Brisson and Anne Marsouin.

In the visiting scientist proposal which had been approved by EUMETSAT Council, the stay was supposed to be divided in two parts, 1 month in 1997 and 4 months in 1998. The first stay was in September last year. For practical reasons the stay in June/July 1998 was only for 6 weeks. We however hope that the remaining fundings can be used for a third stay next year if necessary.

DNMI and CMS are both involved in the Ocean and Sea Ice SAF and cooperate on the development of algorithms for SST (sea surface temperature) retrieval from satellite data over the Atlantic Ocean. DNMI has the responsibility of developing an algorithm for the high latitudes (in cooperation with DMI) and CMS for low and mid latitudes. A close cooperation between these SAF teams is necessary to assure a good final product, and this was the framework for my visit at CMS. The stay was sponsored by EUMETSAT as part of the Ocean and Sea Ice SAF visiting scientist program.

The main objectives of this visit was to:

- Compare the research done on developing algorithms for SST retrieval at CMS and DNMI. This includes studying the radiosonde databases used in the radiative simulations and the results from these simulations, comparing the algorithms that had been developed at CMS and DNMI and testing these algorithms on different matchup databases (MDBs).
- Studying differences between conditions for SST retrieval on low/mid latitudes and high latitudes.
- Work with the task of merging of the low/mid latitudes product with the high latitudes product to the final Merged Atlantic Product, that is a transition between the high latitudes algorithm and the low/mid latitudes algorithm.

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## *Work done during the visiting scientist stay at CMS*

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The Ocean and Sea Ice SAF team at CMS worked mainly on radiative fluxes during my stay. I had however frequent and thorough discussions with Pierre Le Borgne on the SST matters all through my stay. It was very convenient to work at CMS. Databases and climatological datasets were easily available and also tools to extract and interpret these data. This made it possible to work efficient and concentrate on the scientific matters. The broad expertise on remote sensing at CMS was also helpful for discussions.

### *2.1 Comparing the research on SST retrieval at CMS and DNMI*

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Since my last visiting scientist stay at CMS (September, 1997) the Ocean and Sea Ice SAF team at CMS had finished their work on the development of algorithms for SST retrieval at low and mid latitudes for NOAA AVHRR and GOES. This work is summarized in a report (Brisson et al., 1998) which presents some preliminary algorithms and conclusions. At DNMI similar algorithms had been developed for high latitudes using an equivalent approach.

In this approach a radiosonde database was used for radiative simulations of different atmospheric conditions to simulate the satellites response to various surfaces and atmospheric conditions. These kinds of simulated satellite radiances were then used to develop algorithms by regression analysis. Finally the algorithms were tested using matchup databases (MDBs). At CMS the TIGR database was used to simulate the atmospheric conditions at low and mid latitudes (for details, see Brisson et al., 1997). At DNMI a special radiosonde database, CADR, was built containing only cloud free radiosoundings (Eastwood, 1998). From this database all maritime radiosoundings from high latitudes (north of 50N) were used for the radiative simulations. As discussed in Brisson et al. (1997) the TIGR database is geographically unbalanced with few radiosondes in the tropics and many at mid latitudes. The dataset used for radiative simulations at high latitudes is also unbalanced with many radiosondes at mid/high latitudes and few radiosondes at high/polar latitudes. This gives more weight to simulations against mid latitude conditions. This problem is further discussed later.

For the radiative simulations MODTRAN 3.5 (Berk et al., 1989) was used both at CMS and DNMI. This was to assure the same constraints. MODTRAN was selected since it is a commonly used model and suitable for these kind of simulations. The results from the simulations seemed satisfactory both at CMS and DNMI.

To study the performance of different SST algorithms a MDB was built using the Pathfinder Ocean Matchup Database for NOAA-14 (Podesta et al., 1997). All matchups from 1995 and 1996 were used. A complementary empirical cloud filter was applied to this MDB to minimize the number of cloud contaminated matchups (as described in Brisson et al., 1997). Values of climatological total water vapour content were added to this MDB from the monthly climatology of Oort (1983). For this purpose temporal and spatial interpolation were used.

The preliminary SST algorithms for NOAA-14 developed at CMS (for low/mid latitudes) and DNMI (high latitudes) were compared to investigate the difference in performance,

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and especially for investigating the variation in performance with latitude. It was expected that the CMS algorithms would perform best at low and mid latitudes and that the DNMI algorithms would perform best at high latitudes. From the developments at both CMS and DNMI three types of algorithms gave the most promising test results;

- total water vapour content dependent algorithms (WV-alg), with this formalism:

$$SST = A(\theta) \cdot T_{11} + B(wvc) \cdot (T_{11} - T_{12}) + C(\theta, wvc) , \quad (1)$$

- non linear algorithms (NL-alg):

$$SST = A(\theta) \cdot T_{11} + B(\theta, T_{guess}) \cdot (T_{11} - T_{12}) + C(\theta) , \quad (2)$$

- algorithms based on use of the 3.7  $\mu\text{m}$  radiative temperature (TRI-alg):

$$SST = A(\theta) \cdot T_{3,7} + B(\theta) \cdot (T_{11} - T_{12}) + C(\theta) , \quad (3)$$

where A, B, and C are coefficients, constant or depending on the satellite zenith angle,  $\theta$ , the total water vapour content, WVC, and/or a first guess sea surface temperature,  $T_{guess}$ . The climatological SST is used for the  $T_{guess}$ .

A main conclusion from the development of WV and NL-algorithms both for low/mid and high latitudes was that the WV-algorithms gave better results than the NL-algorithms on the simulated radiances and that the NL-algorithms gave better results on the MDBs (see Table 1). The NL-algorithms were between 5 and 10% better in standard deviation depending on which MDB used. One explanation for this is that the simulated radiances have accurate measures of the total water vapour content from the radiosoundings, while the MDBs have only coarse climatological values. This affects the atmospheric correction term in the WV-algorithms but not the NL-algorithms. The effect of this will be studied later by using climatological values for WVC (instead of the accurate measures) and see how the WV-algorithms perform on the simulated radiances. The WV-algorithms also had a larger bias which can be explained the same way. This will also be further discussed later.

The TRI-algorithm developed for low/mid latitudes gave the best results both for simulated radiances and MDBs at low/mid latitudes. This was not the case for the TRI-algorithm developed for high latitudes. This might be because the TRI-algorithms use the 3.7  $\mu\text{m}$  radiative temperature which is less sensitive to the atmospheric water vapour than the window channels around 10  $\mu\text{m}$  (T11 and T12). This will have largest impact in conditions with high total water vapour content as at low latitudes (the tropics). At high latitudes, where the total water vapour content is low, the impact is smaller and the 3.7  $\mu\text{m}$  channel do not seem to contribute to improve the SST retrieval. The problem with this algorithm is that it can only be used during night-time because of solar contamination of the 3.7  $\mu\text{m}$  channel during daytime. But using the TRI-algorithm gives promising results at low/mid latitudes during night-time.

The developed algorithms were tested with a subset of the Pathfinder MDB including all matchups poleward of 40°. This was to study the transition zone between low/mid

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**Table 1 : Bias and standard deviation for the developed low/mid latitudes (lml) and high latitudes (hl) SST algorithms. The formalism of the algorithms is given previously. TIGR and CADR are the radiosounding databases used for the radiative simulations, so these columns shows the performance on the simulated radiances. The Pathfinder columns are different subsets of the Pathfinder Ocean matchup database (d/n - day and night cases).**

Validation files	TIGR global maritime		CADR high lat. maritime		Pathfinder global d/n		Pathfinder poleward 40° d/n		Pathfinder poleward 40° night	
	no. cases									
	bias	st.dev.	bias	st.dev.	bias	st.dev.	bias	st.dev.	bias	st.dev.
WV-lml	-0.03	0.36	-0.07	0.17	0.27	0.71	0.33	0.58	0.34	0.63
WV-hl			0.00	0.14	-0.13	0.81	0.22	0.57	0.22	0.63
NL-lml	0.00	0.51	-0.07	0.25	0.22	0.67	0.14	0.57	0.16	0.61
NL-hl			0.00	0.18	-0.16	0.68	0.15	0.54	0.17	0.59
TRI-lml	0.00	0.17	-0.04	0.19					0.25	0.60
TRI-hl			0.00	0.17					0.29	0.62

latitudes and high latitudes. The low/mid latitudes algorithms had been developed using radiosoundings up to 70° and the high latitude algorithms using radiosoundings poleward of 50°. The high latitudes algorithms performed a bit better than the low/mid latitudes algorithms on the whole subset, but they differed only 5% in standard deviation for the NL-algorithms and less than 2% for the WV-algorithms (see Table 1). When the algorithms were tested on a global MDB (Pathfinder global d/n in Table 1) the NL-algorithms did still perform equally, but the standard deviation for the low/mid latitudes WV-algorithm was clearly lower than for the high latitudes WV-algorithm (by 12%, see Table 1). The biases for the high latitudes algorithms are generally lower or equal to the low/mid latitudes biases. The validation files indicates that the NL-algorithm might be the best algorithm type for global SST retrieval.

The difference in standard deviation between the low/mid latitudes algorithm and high latitudes algorithm as a function of latitude was studied. No distinct pattern was found that could indicate that the high latitudes algorithms performed best at high latitudes and the low/mid latitudes algorithms performed best at mid latitudes. The reason for the similar performance independent of latitude might be found in the radiosonde databases used for the algorithm development. As pointed out earlier in this report the two radiosounding databases used are both biased against mid latitude conditions. This might have caused the developed algorithms to be biased against mid latitude conditions and giving similar performance. This will be further discussed later.

## *2.2 Study of the differences between conditions for SST retrieval at low/mid latitudes and high latitudes*

The high latitudes algorithms were further compared with the low/mid latitudes algorithms. Especially the WV-algorithm was investigated to study the effect of including total water vapour content (WVC) in the coefficients. The coefficients B and C in Equation (1) were plotted against WVC directly in the regression analysis for different values of zenith angle ( $z = \sec(\text{zenith angle})$ ) and coefficient A. These plots are shown in Figure 6, Figure 7 and Figure 8. These figures shows that the coefficient B depends quite line-

arly on WVC for  $WVC > 0.5 \text{ g/cm}^2$ . The coefficient B increases both with WVC and  $z$ . The coefficient C seems to have a more quadratic dependency in WVC, decreasing with increasing WVC. C increases with  $z$ . The conditions at low/mid latitudes are characterized by higher WVC and higher sea surface temperatures. But even though the preferred WV-algorithm at low/mid latitudes has the same formalism as at high latitudes with the coefficient B depending linearly on WVC and  $z$  and the coefficient C depending quadratically on WVC and linearly on  $z$ .

For  $WVC < 0.5 \text{ g/cm}^2$  the coefficient B seems to increase a bit with decreasing WVC (for low values of coefficient A). Other studies (i.e. Coll and Caselles, 1994) have shown a quite similar linear behaviour for the coefficient  $B > 0.75 \text{ g/cm}^2$  and increasing B for  $WVC < 0.75 \text{ g/cm}^2$ . But this increase is more distinct in that study. The radiosonde database used for simulations at high latitudes contains too few cases with low WVC to study this further. High values of B might give a problem because of noise amplification. We agreed that a constant value for B for  $WVC < 0.5 \text{ g/cm}^2$ . This will not affect the accuracy of the algorithm much since the atmospheric correction is small at these WVC values. Varying the coefficient A also have an effect on coefficient B, but only for low values of WVC. This emphasizes that coefficient B is very sensitive at low WVC.

The formalism of the non linear algorithm was also investigated to see how the performance of this algorithm varied when different parameters were included in the coefficients. In Equation (2) coefficient A, B and C were changed and new versions of the algorithms defined. The performance was tested on the simulated radiances and the Pathfinder MDB. The results are shown in Table 2.

**Table 2 : Standard deviation for different high latitude NL-algorithms. The standard deviations are for the simulated radiances (sim. rad.) and a high latitude version of Pathfinder (poleward of  $50^\circ$ , day and night).**

	Coefficients (from Equation (2))			std.dev.	
	A	B	C	sim. rad.	Pathfinder
1	$A_0$	$B_0S+B_1T_{\text{guess}}$	$C_0$	0.239	0.494
2	$A_0$	$B_0+B_1S+B_2T_{\text{guess}}$	$C_0$	0.201	0.494
3	$A_0+A_1S$	$B_0+B_1S+B_2T_{\text{guess}}$	$C_0+C_1S$	0.179	0.478
4	$A_0+A_1S$	$B_0+B_1S+T_g(B_2+B_3S)$	$C_0+C_1S$	0.178	0.480
5	$A_0+A_1S$	$B_0+B_1S+B_2T_g+B_3wvc$	$C_0+C_1S$	0.171	0.487
6	$A_0+A_1S$	$B_0+B_1S+B_2T_g+B_3wvc$	$C_0+C_1S+C_2wvc$	0.155	0.503

From Table 2 it is clear that the more parameters that are included in the coefficients A, B and C, the better the algorithm performs on the simulated radiances. But on real in situ data from the matchup database algorithm 3 performed best. Including the total water vapour content only worsen the results. The best formalism for the non-linear algorithm is therefore with coefficients without dependency in total water vapour, but all dependent on the satellite zenith angle.

### 2.3 Mid to high latitude transition

The SST Merged Atlantic Product (MAP) will be a merging of two products; the low/mid latitudes SST product based on data from GOES-8 and MSG, and the high latitudes SST product based on AVHRR data from polar NOAA satellites and METOP. The merging of

these two subproducts must be done in a consistent way so that no degradation of the quality of the SST fields are introduced. An averaging on a grid point basis will be used on the final grid. This averaging will be a weighted averaging in a transition zone. The original suggestion was to define this transition zone using a latitude band (i.e. between 50° and 60°). But it was also suggested to use the climatological SST or WVC to define the transition limits. In this approach the high latitude algorithm will be used when the SST or WVC is below a certain limit and the low/mid latitudes algorithm above a certain limit, with a transition zone between these two limits.

The errors in the low/mid latitudes algorithms and high latitudes algorithms were investigated. This was to study the possibility of using latitude, SST and WVC to define the transition zone. The latitude zone between 40° and 65° was considered to be the potential transition zone. As discussed in Chapter 2.1 and shown in Table 1 there are only small differences between the developed algorithms in this zone, also when the variation of the error against latitude, SST and WVC is studied. These results might indicate that there is no need for two algorithms and that just one global algorithm might be sufficient. However, as discussed in Chapter 2.1, these must be considered temporary results since the radiosonde databases used are both biased against mid latitudes.

This conclusion made it necessary to study more thoroughly the effect of regional optimizing of SST algorithms. The Pathfinder Ocean MDB for 1995 and 1996 (for NOAA 14) was used for this purpose. The matchups were used to define regional optimized and global WV-algorithms and NL-algorithms by regression analysis. Characteristics of latitude, SST and WVC for these matchups are shown in Figure 9 and Figure 10. The algorithms were optimized in three ways, using the latitude, SST and WVC of the matchups to divide into regions. From the latitude the matchups were divided into three intervals: 0-30°, 30-60° and 60-90°. For each of these intervals an algorithm was defined. These three algorithms was then used together to define a composite regional optimized global algorithm, using a linear weighting function in a transition zone between the three intervals. The same method was used to define SST-optimized and WVC-optimized algorithms using the observed SST and climatological WVC from the matchups. The intervals used for this optimizing are shown in Table 3. There is a certain correlation between these intervals which can be seen in Figure 9 and Figure 10. The formalism used for the algorithms are shown in Equation (4) and Equation (5).

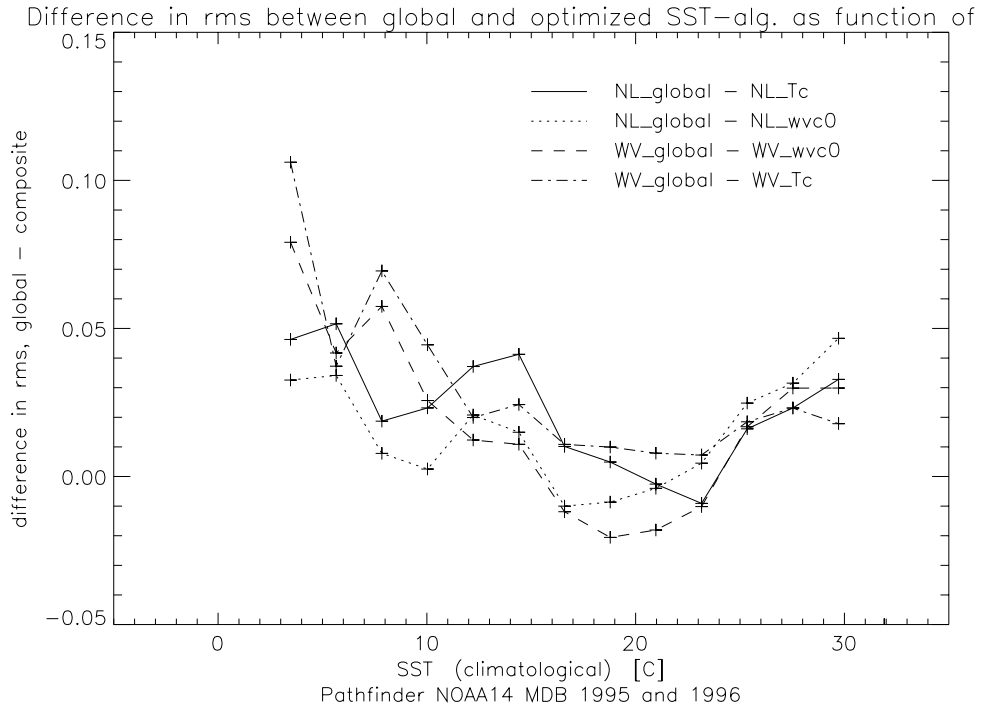
$$WV\_SST = T_{11} + (B_0 + B_1 wvc)(T_{11} - T_{12}) + C_0 + C_1 S + C_2 wvc \quad (4)$$

$$NL\_SST = A_0 T_{11} + (B_0 S + B_1 T_{guess})(T_{11} - T_{12}) + C_0 \quad (5)$$

As shown in Table 2 the best formalism for the NL-algorithms is not the same as the one chosen in Equation (5). The formalism in Equation (5) is the one used operationally by NOAA and it was used here to study the effect of regional optimizing. These studies showed that the algorithms developed using SST-optimizing and WVC-optimizing

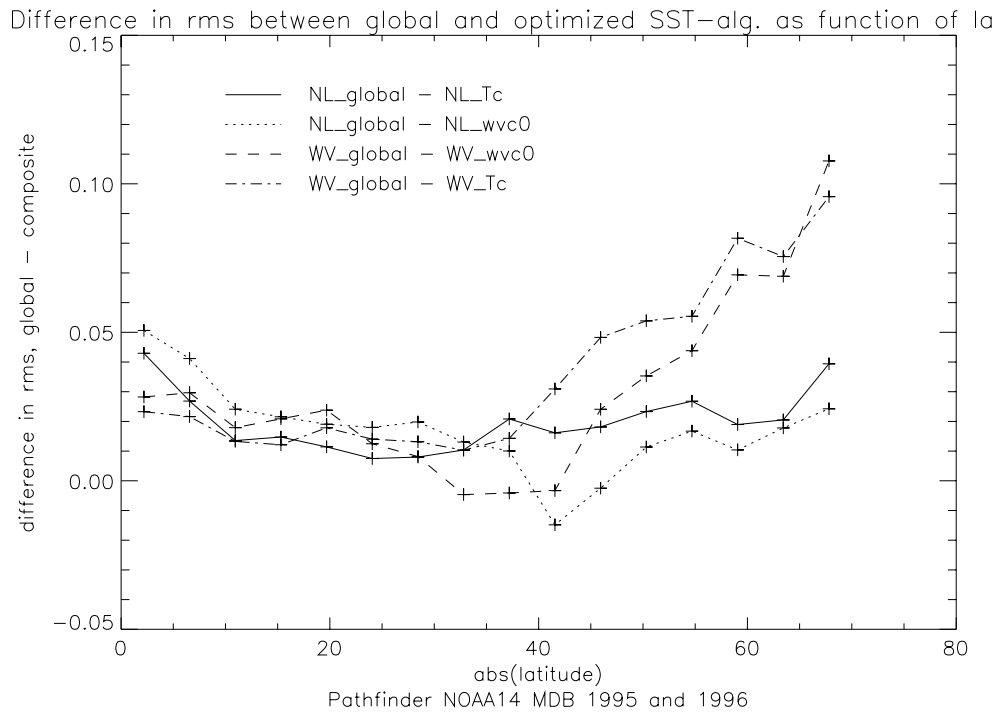
**Table 3 : The intervals used in latitude, SST and climatological WVC for regional optimizing of SST algorithms.**

interval	latitude	SST	WVC
1	0 - 30°	22°C ->	3.0g/cm2 ->
2	30 - 60°	12 - 22°C	1.5 - 3.0g/cm2
3	60 - 90°	-> 12°C	-> 1.5g/cm2



**Figure 1**

The difference in rms between global and composite regional optimized global NL and WV-algorithms as a function of SST. The rms has been calculated in SST intervals (the + sign marks the middle of these intervals). Tc indicates SST-optimized algorithms and wvc0 indicates WVC-optimized algorithms.



**Figure 2**

As Figure 1, but showing differences in rms as function of latitude.

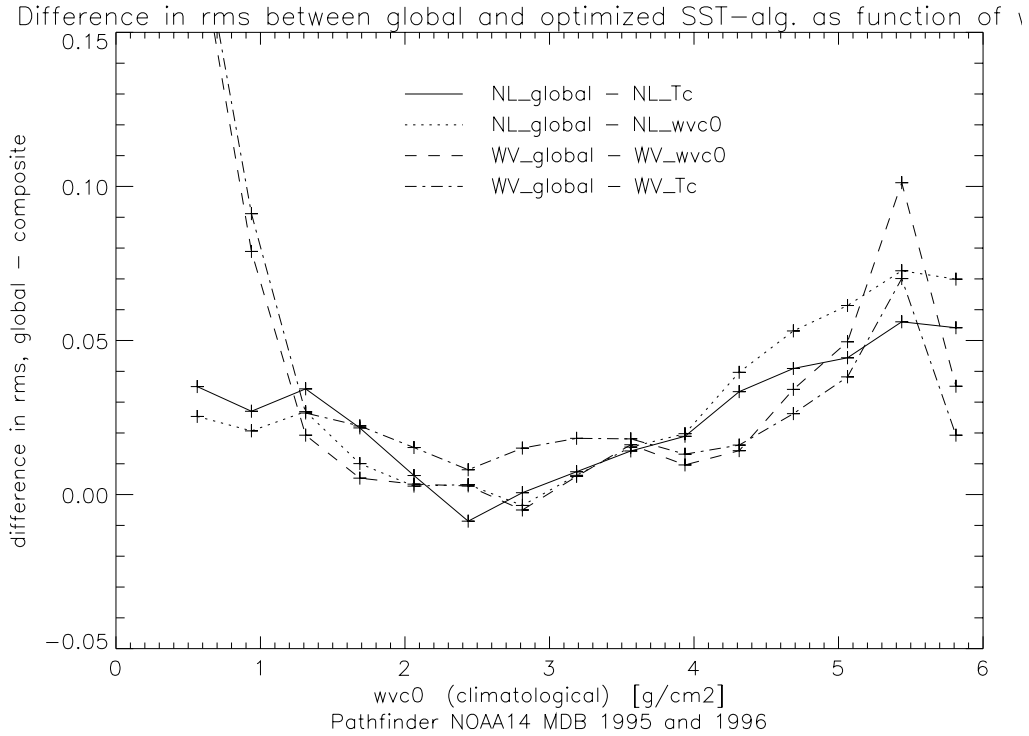


Figure 3

As Figure 1, but showing differences in rms as function of climatological WVC.

performed better than the algorithms developed using latitude-optimizing. All three composite regional optimized global algorithms performed better than the all global algorithms. In Figure 1, Figure 2 and Figure 3 the difference in rms between the global and composite WV and NL-algorithms are plotted (only SST and WVC-optimized). From these figures it is clear that regional optimizing gives the largest improvement at low and high values for SST and WVC and at low and high latitudes. The largest improvements is for the WV-algorithms at high latitudes. At mid latitudes, with SST between 15 and 23°C and WVC between 2 and 4g/cm2 there is little or no difference between the global and composite algorithms. The optimized algorithms performs better than the global algorithms on all the 9 subsets on which the optimized algorithms were defined. In Figure 1, Figure 2 and Figure 3 there are a few intervals were the global algorithms performs slightly better than the composite algorithms. This is because the global and optimized algorithms perform quite similar on mid latitude conditions. The linear weighting function which is used in the composite algorithms also smooths the advantage of the composite algorithms a bit in the transition zone.

The global algorithm seems to be averaged against mid latitude conditions. Therefore it appears to be potential for an increase in accuracy of the SST algorithms using regional optimizing at low and high latitudes. The best way to do this seems to be by using a SST-optimized algorithm. SST-optimized algorithms gave better results than latitude-optimized algorithms and SST appears to be a more reliable parameter than WVC. The potential for increase in accuracy appears to be best at low (<10-15°C) and high (>25°C) SST. Further conclusions concerning the actual value of this increase will be made when the algorithms are verified on an independent dataset. The Pathfinder NOAA14 MDB 1997 will be used for this when it is available in October 1998 (G.P. Podesta, personal communication).

Comparison between the NL and WV-algorithms in Figure 1, Figure 2 and Figure 3 also

showed that the NL-algorithms perform better than the WV-algorithms.

## 2.4 The effect of noise in T11 and T12 and error in WVC

Some studies were also done on the performance of the algorithms concerning the effect of noise in T11 and T12 and the errors in WVC. This is important because the regression analysis assume that the data used are free of errors. It might be possible to use a statistical regression model which accounts for the errors in the regression parameters, but the easiest method is to introduce a normal distributed error to the input data. It is then necessary to have knowledge about the magnitude of the error.

The effect of noise in T11 and T12 brightness temperatures was studied by adding a normal distributed error with a standard deviation of 0.12K to the simulated radiances on the high latitude data. This should represent the radiometric noise in the AVHRR IR channels (Planet, 1988). Smoothing of the brightness temperatures over several pixels will reduce this level of noise. This will especially affect the atmospheric correction term containing T11-T12 (see Equation (4) and Equation (5)). In the final 10 km resolution SST product some averaging will also be done. It is therefore difficult to know the actual level of noise caused by the radiometric noise.

A new WV-algorithm was defined using these noisy data (hereafter called the noisy WV-algorithm). This algorithm was validated using central pixel value matchups (from the CMS Berta MDB) as well as noise free and noisy simulated radiances. The results are given in Table 4. From this table it is clear that the noisy WV-algorithm perform better than the noise free WV-algorithm when the same amount of noise is added to the simulated radiances. Validation with matchup data gave the same result, but not the same magnitude of difference. The noisy WV-algorithm gave a lower standard deviation by 1.7% compared to the noise free algorithm. The bias is also reduced when using the noisy algorithm. This indicates that there might be an improvement in taking into account the effect of noise in the algorithm definition. This should however be further studied. More matchup data with single pixel values are needed. The Pathfinder MDB contains GAC data which are averaged over several pixels. This averaging reduces the effect of radiometric noise, and these data are therefore not suited for validation.

The effect of error in the total water vapour content was also studied. The NL-algorithms are not affected by this, and this is one of the reasons why the WV-algorithms perform worse than the NL-algorithms on matchup data. In our validation with the MDBs a climatological value for WVC have been used. This will reduce the performance of the WV-algorithms. Studies will be done using climatological values for WVC, instead of the

**Table 4 : Standard deviation for algorithms developed on noise free and noisy simulated radiances. The algorithms are validated against the same noise free and noisy simulated radiances and the CMS Berta MDB with central pixel values.**

Algorithm	Noise free sim. rad.	Simulated rad. with noise	CMS MDB central pixel
No. of cases	1729	1729	299
Noise free WV-alg.	0.155	0.405	0.451
Noisy WV-alg.	0.210	0.368	0.443
Noise free NL-alg.	0.203	0.430	0.430

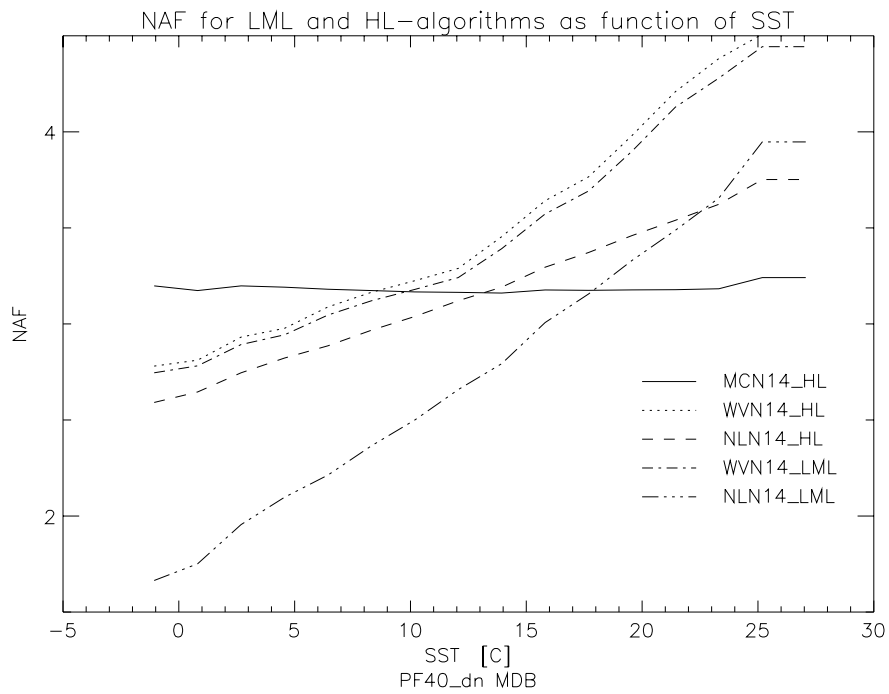
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accurate measures, with the simulated radiances to see how the WV-algorithms perform. In this way the effect of the accuracy in WVC can be isolated.

In the Pathfinder MDB some of the matchups have WVC values extracted from SSM/I data (see Podesta et al., 1997), and in the CMS Berta MDB some of the matchups have WVC values extracted from the Arpege NWP model (see Brisson et al., 1997). These WVC values were compared with the climatological WVC values. The difference varies from 15% to over 30%, with largest variation for low WVC (these studies were done for mid and high latitudes). These SSM/I and NWP WVC values were then used instead of the climatological WVC values to validate the WV-algorithm. The SSM/I extracted WVC gave about 2% lower standard deviation than when using climatological WVC and the Arpege NWP extracted WVC gave about 1% higher standard deviation. The tests were performed on a WV-algorithm with coefficients with linear dependency in WVC. The simulated radiances with radiosonde WVC values was also used to study the effect of error in WVC. A normal distributed error of 25% was added to the WVC. This gave a 13% higher standard deviation in the same linear WV-algorithm and up to 30% higher standard deviation for quadratic WV-algorithms. This shows that the WV-algorithms containing quadratic WVC-terms are more sensitive to errors in the WVC than WV-algorithms with only linear WVC-terms.

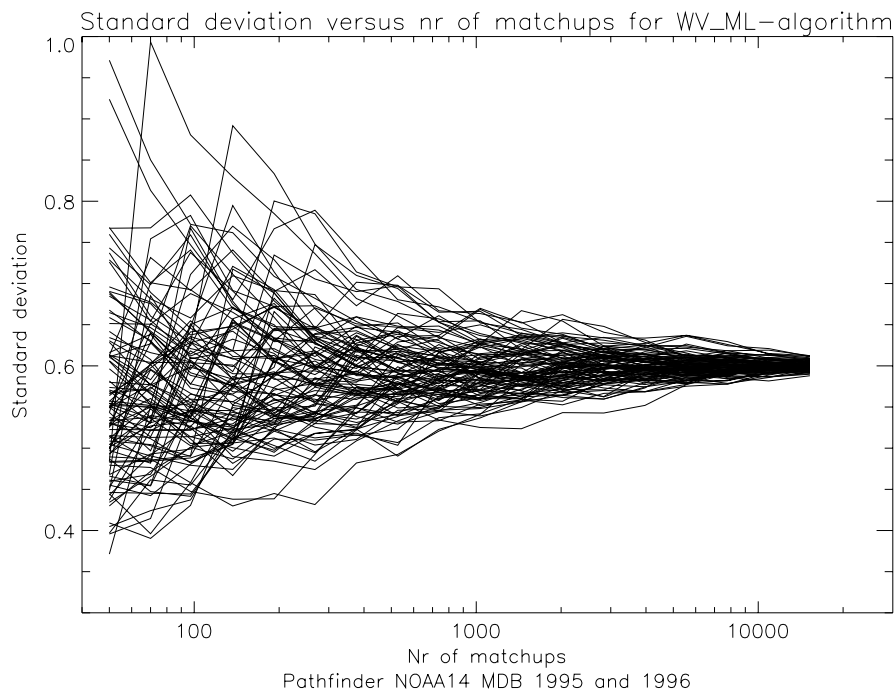
This error in the WVC can only partly explain why the WV-algorithms perform better than NL-algorithms on simulated data and not on MDB data. When an error of 25% was added to the WVC on the simulated data, the linear WV-algorithms still performed better or as good as the NL-algorithm. Another reason is probably the noise amplification factor (NAF). This has to do with the coefficients in the algorithm and the fact that they enlarge the noise in T11 and T12 (see Brisson et al., 1998). In Figure 4 the NAF for the developed low/mid and high latitudes algorithms are plotted. From this figure it is clear that the NAF is lower for NL-algorithms than for WV-algorithms, both for low/mid latitudes algorithms and high latitudes algorithms. Figure 4 also shows that the NAF is higher for the high latitudes NL-algorithm than the low/mid latitude NL-algorithm. This is because the high latitudes NL-algorithm uses formalism 3 in Table 2 and the low/mid latitudes NL-algorithm uses formalism 1. Because of this the coefficient B is higher for the high latitudes algorithm than for the low/mid latitudes (up to 23°C). The NAF increases more slowly with SST for the high latitudes algorithm than the low/mid latitudes algorithm. This is because the high latitudes algorithm has a smaller coefficient for the  $T_{\text{guess}}$  than the low/mid latitudes algorithm.

Table 4 shows that even when noise is added to the simulated radiances, the WV-algorithms perform better on simulated radiances than on the matchup data. This is not the case for the NL-algorithm. This has probably to do with the error in the WVC used in the MDB. But it might also be because different number of cases was used in the validation. Figure 5 shows the effect of using different number of matchups when validating an algorithm. A random subset of the Pathfinder Ocean MDB was selected and the standard deviation for a linear WV-algorithm was calculated. First all the matchups were randomly sorted. From this set a subset with an increasing number of matchups was selected and the standard deviation calculated. Each line in Figure 5 represent such a sorted set. This figure shows that there is a large variation in standard deviation depending on which matchups are used. This variation decreases when the number of matchups increases. The standard deviation converges to the standard deviation for the algorithm using all the matchups.



**Figure 4**

The Noise Amplification Factor (NAF) for the developed low/mid and high latitudes SST algorithms at mid/high latitudes. The Pathfinder Ocean MDB for 1995 and 1996 poleward of 40° has been used.



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**Figure 5**

The variation in standard deviation when using a random sorted subset with increasing number of matchups for validation. See text for further explanation.

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The WV-algorithm defined both for low/mid and high latitudes gives the best results on the simulated radiances (except for the TRI-algorithms). When validated with matchup databases the NL-algorithms perform better than the WV-algorithm. The reasons for this is probably that the total water vapour content values given in the MDBs are inaccurate and that the WV-algorithms have a larger NAF than the NL-algorithms.

The TRI-algorithms perform better than the WV and NL-algorithms at low/mid latitudes, but not at high latitudes. This is probably because the use of 3.7/3.9 $\mu$ m radiances have the largest impact in regions with high WVC. The disadvantage with this algorithm is that it only can be used during night-time because of solar contamination during daytime.

The preliminary algorithms developed at CMS for low/mid latitudes and at DNMI for high latitudes do not differ much. The reason for this might be that the simulation data at CMS and DNMI are both dominated by data from mid latitudes. From these simulations a global NL seems to be the best solutions, but there is a potential in increase of accuracy using regional optimizing. The best to do this regional optimizing seems to be by defining regions using the climatological SST and not simple latitude bands.

Studies of the effect of radiometric noise shows that the performance of the algorithms might improve by including the radiometric noise in the regression analysis when defining the algorithms.

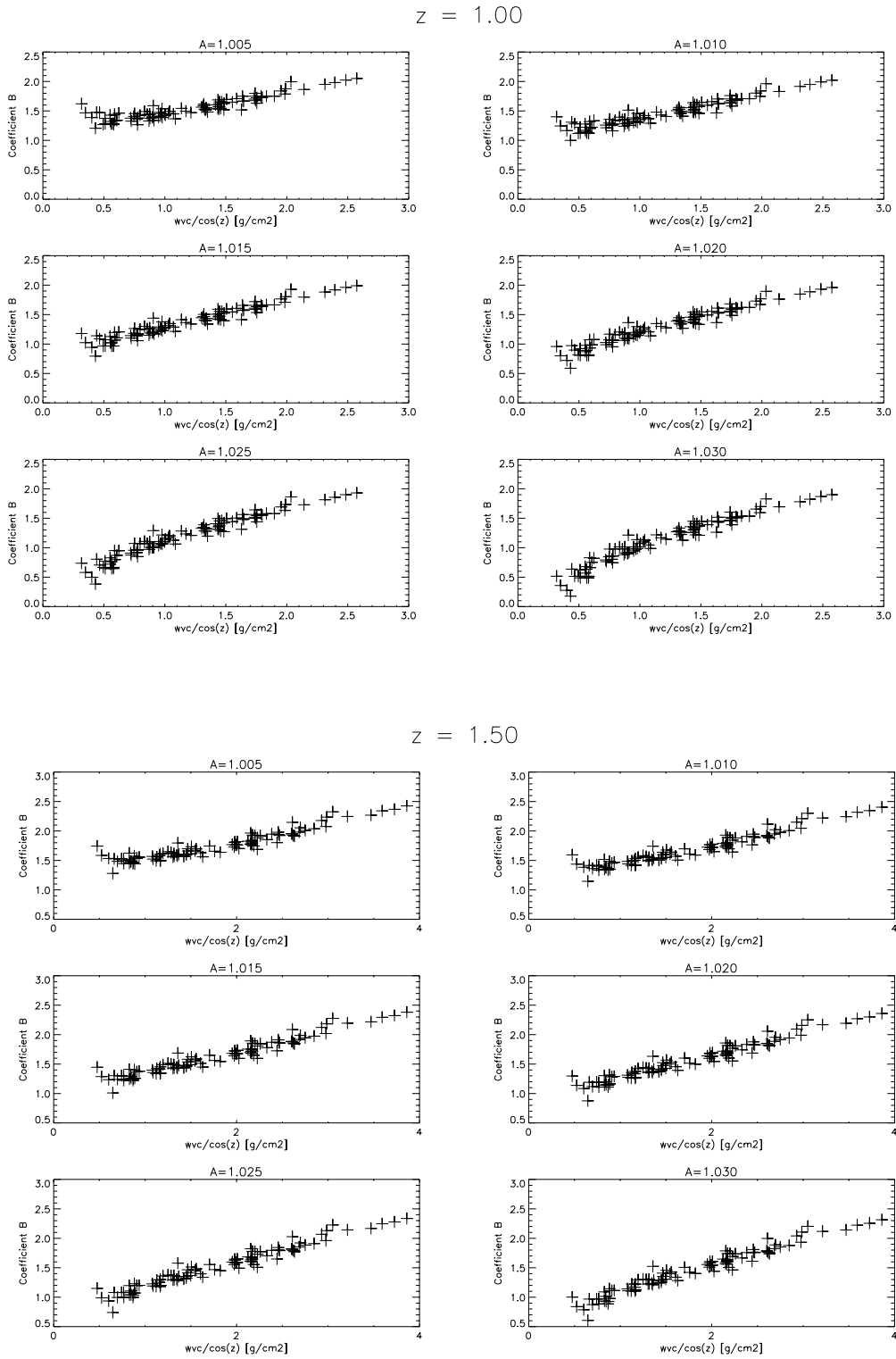
#### **Further studies to be made:**

Further studies have to be made before the final SST algorithm for the Merged Atlantic product can be selected. These will be done at CMS and DNMI in 1998 and 1999. In this context it would be fruitful for Steinar Eastwood to come to CMS. We hope that the remaining fundings for this visiting scientist stay can be used for such a stay.

Here is a list of further studies to be made:

- Conclude on the WV versus NL-algorithm difference, in particular by using climatological WVC when applying the algorithms on the simulated radiances.
- Collect more radiosoundings at low and high latitudes to balance the radiosounding databases. The radiosounding databases must be geographically and seasonally balanced.
- Make new simulations of the IR radiances with MODTRAN 3.5 using the new balanced radiosounding databases. This should be done both for low/mid and high latitudes.
- Define new algorithms (using the formalism agreed upon in this report) with the new simulated radiances. Define algorithms optimized in both SST and latitude.
- Study more thoroughly the difference between the algorithms optimized in SST and latitude and the practical aspects of using SST instead of latitude when defining a transition zone.
- More noise studies. Noise in T11, T12 and error in WVC and the effect of this on the algorithm performance. What is the actual noise/error in these parameters?

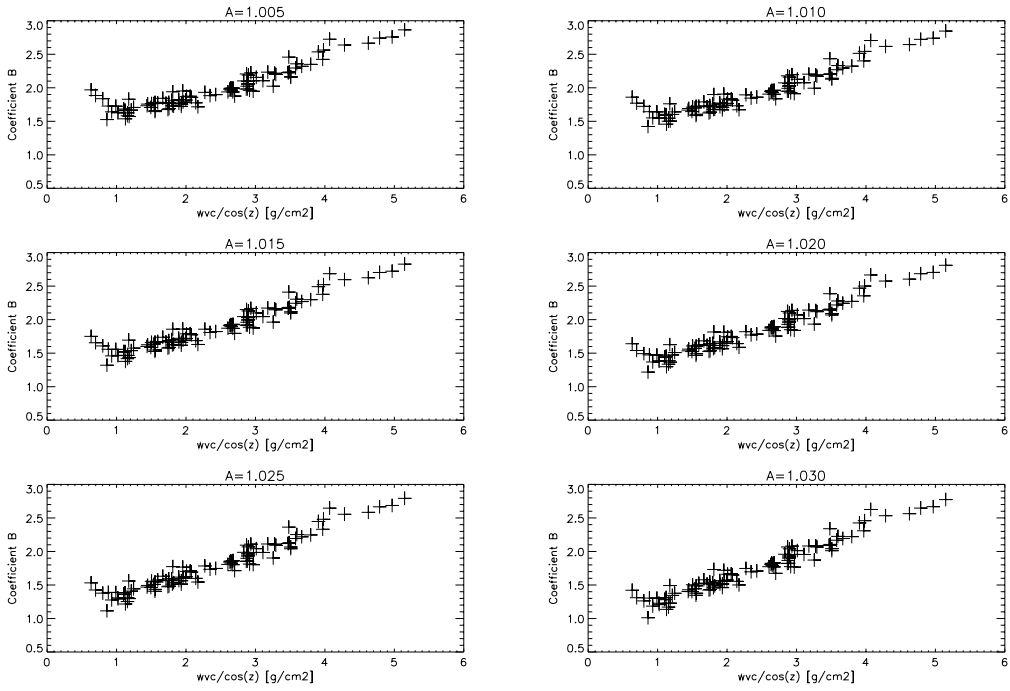
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**Figure 6**

Coefficient B as function of total water vapour content for high latitudes WV-algorithm with varying values for coefficient A and  $z = 1.00$  and  $1.50$  ( $z = \sec(\text{zenith angle})$ ).

$z = 2.00$



$z = 1.00$

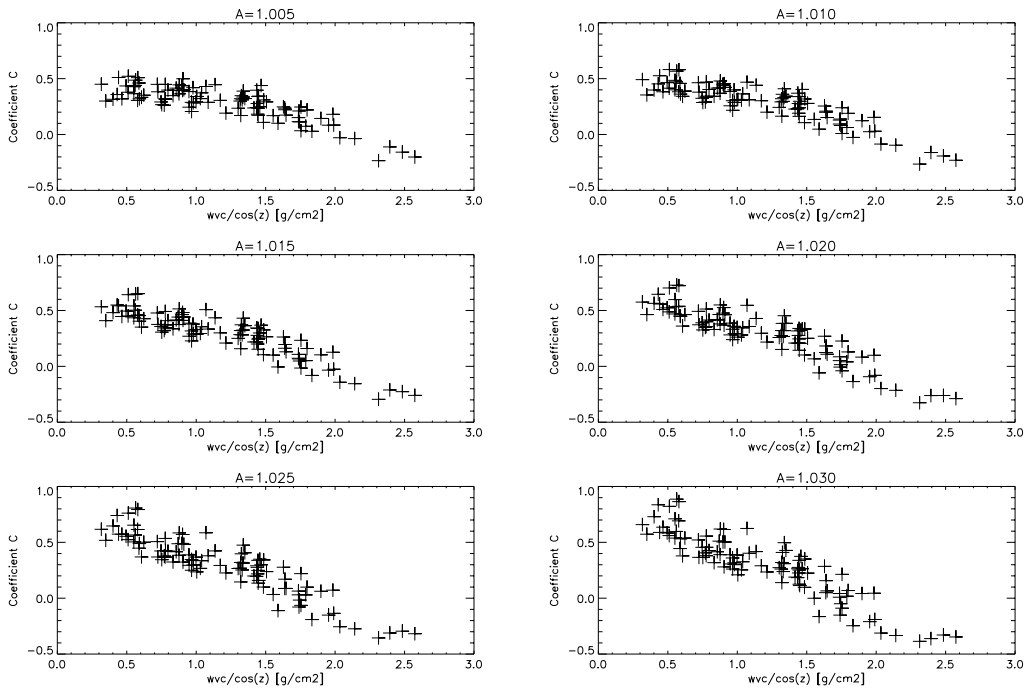
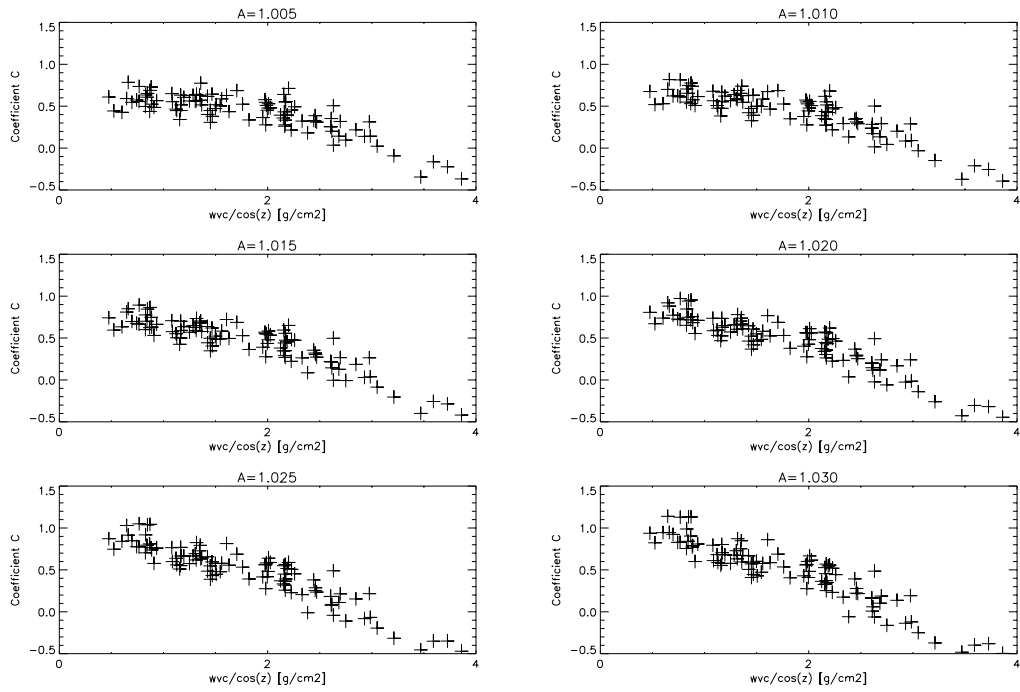


Figure 7

As Figure 6, but coefficient B for  $z=2.00$  and coefficient C for  $z=1.00$ .

$z = 1.50$



$z = 2.00$

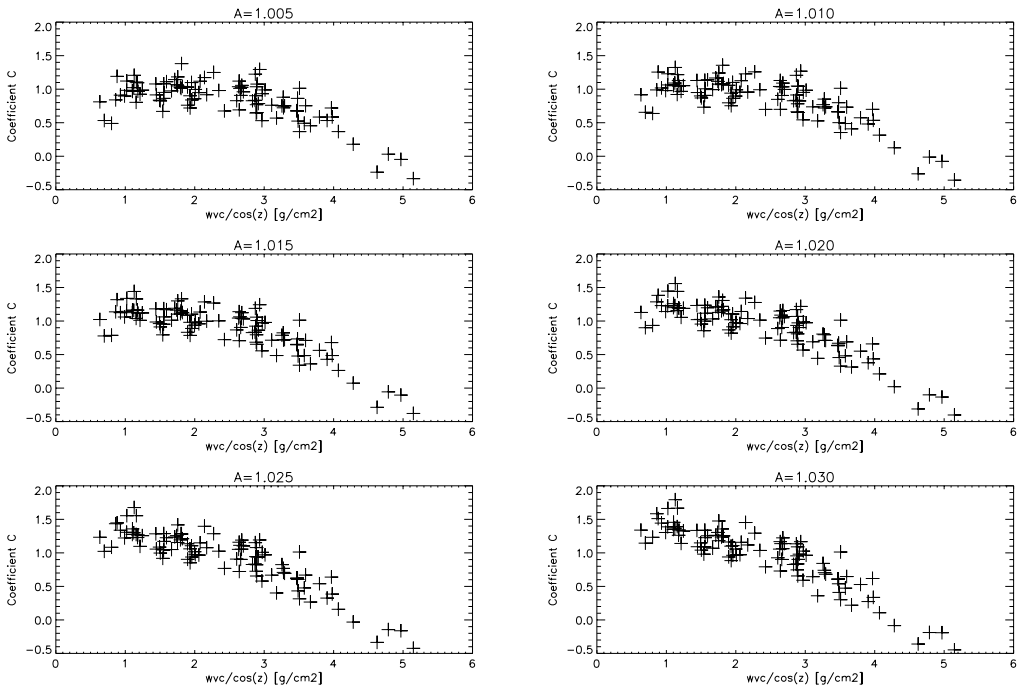
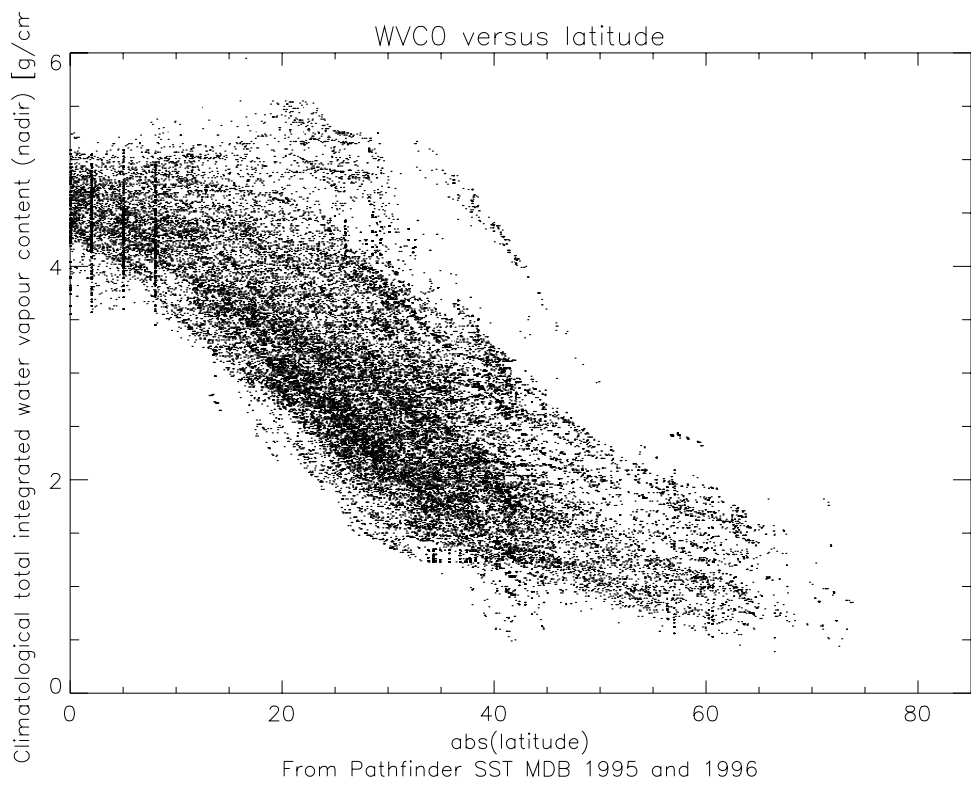
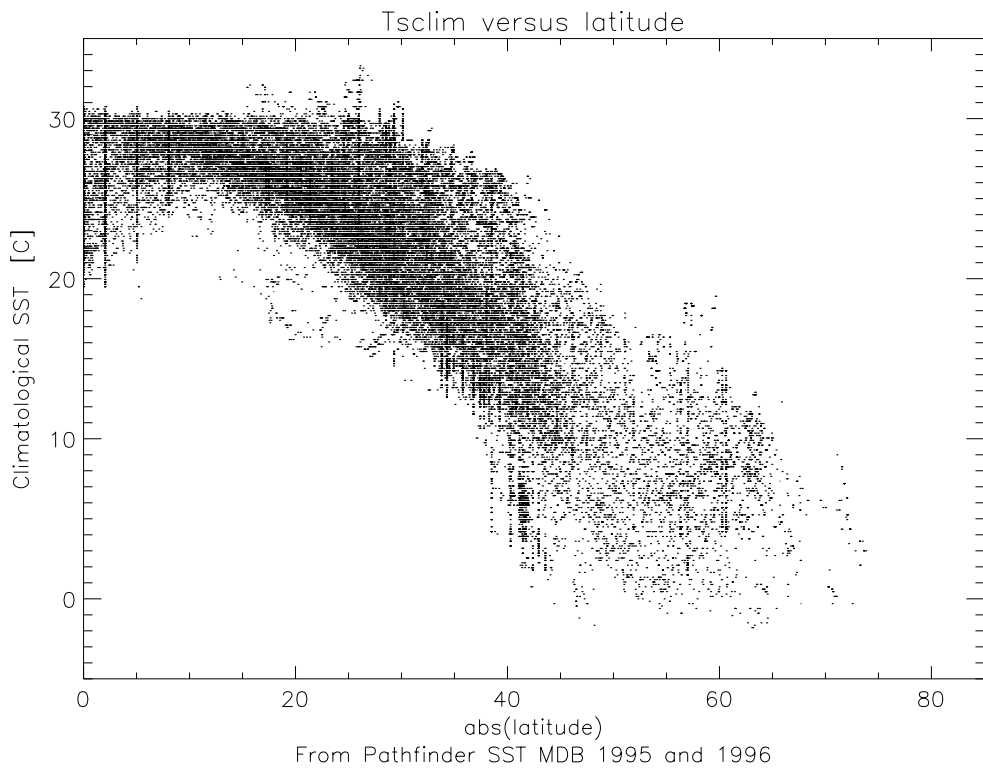


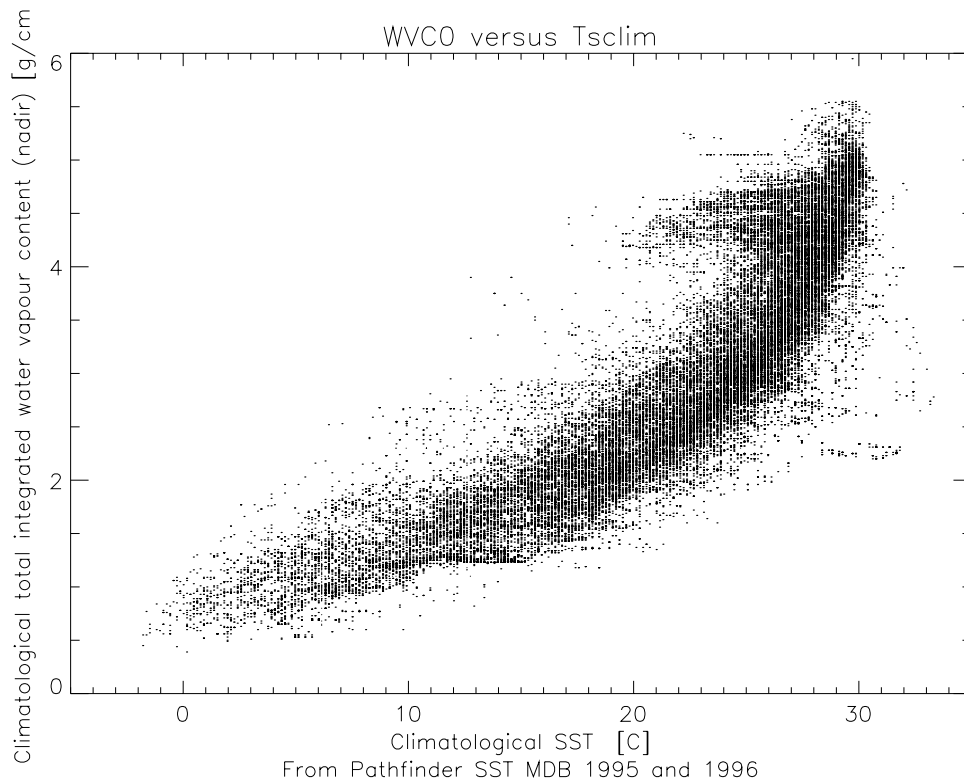
Figure 8

As Figure 6, but coefficient C for  $z=1.50$  and  $z=2.00$ .



**Figure 9**

Characteristics of the matchups in Pathfinder MDB from 1995 and 1996 (NOAA-14).



**Figure 10**

Characteristics of the matchups in Pathfinder MDB from 1995 and 1996 (NOAA-14).

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