DETERMINATION OF SEA SURFACE TEMPERATURE FROM SYNERGY OF TOVS AND AVHRR DATA.

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1. INTRODUCTION

At present, the most useful multichannel algorithms are the split-window algorithms, which employ channels 4 and 5 of AVHRR (Advanced Very High Resolution Radiometer) and can be applied to both day time and night time images. Commonly, these algorithms express the sea surface temperature (SST) as a linear combination of the satellites brightness temperatures in both channels, T_4 and T_5, with constant coefficients, obtained empirically by means of statistical regressions of "in situ" and satellite measured surface temperatures. When a world-wide data set of SST is used, global linear split-window algorithms have been derived (McClain et al., 1985). However it has been pointed out the atmospheric dependence of the split-window coefficients (Coll et al., 1994), which prevents from using linear algorithms with constant coefficients in areas of particular climatic conditions. In such way, Llewellyn-Jones et al. (1984) found deviations of 0.4K when a global algorithm was applied to a midlatitude data set. Then, it is not recommendable the use of global linear algorithms in regional studies, because certain degradation of the results is expected in areas such as the Canary Islands, where the coefficients may be inadequate and inaccurate.

In the same way, the algorithms that use radiative transfer models and radiosondes data, create doubts about the validity of atmospheric profiles used to make corrections to the SST, because they are launched from land surface and it exists, principally over the oceans, a great variability of water vapor that the radiosondes do not measure. There is another problem that we can not obviate if we wish obtaining the true surface temperature, that is, the difference in time between satellite pass and the radiosonde launching. Besides, they exist global models which consider the different environments (water vapor contents); but they work with elevate errors (~ 1K) and do not produce accurate values for the Canary Islands region.

In this work, an alternative to the algorithms using directly or indirectly traditional radiosoundings is established, and a new method is proposed combining the obtained water vapor data from TOVS (Tiros Observer Vertical Sounder) with the information of thermal-infrared channels of AVHRR to improve split-window equation.

2. METHODOLOGY

2.1. Split-window technique

The method employed for the determination of SST is the split-window. This algorithm make use of radiances measured by 4 and 5 channels of AVHRR.

If T_4 and T_5 are the registered brightness temperatures by each channel, the true surface temperature, T, could be calculated by means of the equation:

$$T = T_4 + A(T_4 - T_5) + B \qquad (1)$$

The expressions of A and B coefficients, for sea surface temperature, can be found in Maul (1983).

2.2. Water vapor from TOVS sensors

The water vapor, W, is an atmospheric component which is not evenly distributed on the global scale, that makes impossible to know its distribution with only radiosounding data, because their validity is restricted to a few km^2. Then, obtaining data over the oceans for correctly characterizing the water vapor content is an interesting task.

TOVS system on board NOAA (National Oceanic and Atmospheric Administration) satellites make possible the study of total atmospheric water vapor. To do it, the International TOVS Processing Package from University of Wisconsin is employed (Smith et al., 1985).

In order to get the same spatial resolution between AVHRR and the water vapor obtained from TOVS, we have made an interpolation based on inverse square distance. Then, we have a value of water vapor for each AVHRR pixel.

2.3. Synergy of TOVS and AVHRR

Our algorithm propose the synergy of the water vapor calculated from TOVS channels radiances with the AVHRR temperatures using the split-window technique. The split-window coefficients are expressed as a function of the water vapor obtained from TOVS sensors.

The coefficients A and B of split-window have been calculated from results obtained by Coll and Caselles (1994). They show in figures 1 and 2 the coefficients A and B as a function of the water vapor content, W, which ranges from 0.3 to 3.3 g/cm^2. Two cases were studied: *(a)* only water vapor was considered, and *(b)* all atmospheric gases was accounted for. When only water vapor is considered, the coefficient A shows a linear dependence on W. However, in case *(b)*, A takes large values for dry atmospheres ($W \leq 0.5$ g/cm^2) because in this case the channel 4 and 5 transmitances become roughly equal. Then, avoiding this mathematical problem, we can adjust A versus W, using the values of the figure 1 by Coll and Caselles (1994), and to obtain a linear relationship between the coefficient A and the water vapor, W (see figure 1a):

$$A = 1.95 + 0.33W \tag{2}$$

with a correlation coefficient of 0.962 and a standard error of estimate of 0.08. Equation (2) will be valid for $W \geq 1.0$ g/cm^2. Using now the values given in figure 2 for the case *(b)*, an analysis of coefficient B has been performed. Unlike coefficient A, we have found a quadratic relationship between the coefficient B and W. Moreover, the coefficients of this relationship are not constants but depend on the satellite zenith observation angle, θ (see figure 1b). Then we have obtained the following relationship:

$$B = B_0 + B_1 W + B_2 W^2 \tag{3}$$

where

$$B_0 = -0.21 + 0.4091 \sec\theta \tag{3a}$$

$$B_1 = -0.0364 + 0.0888 \sec\theta \tag{3b}$$

$$B_2 = -0.2219 + 0.0748 \sec\theta \tag{3c}$$

with a correlation coefficient of 0.955 and a standard error of estimate of 0.16K. Equations (2) and (3) are valid for $1 \leq W \leq 5$ g/cm^2; the observation angle was included in order to increase the validity range of equations (2) and (3), because only nadir observations were assumed in figures 1 and 2 of Coll and Caselles (1994).

Using equations (2) and (3) in equation (1) it will be possible to obtain the sea surface temperature from the AVHRR channels 4 and 5 temperatures and the water vapor content obtained from TOVS data. This is the basic idea of this paper, which has been outlined in figure 2.

3. RESULTS

3.1 Simulated data

A data set of simulated NOAA-AVHRR brightness temperatures have been used for testing the ability of equation (2) and (3) to provide the appropriate split-window coefficients for retrieving the sea surface temperature in different atmospheric conditions. A number of midlatitude atmospheric profiles of water vapor were used as inputs of the LOWTRAN 7 computer code, and all the atmospheric gases have been considered.

For each profile, three sea surface temperatures and four observation angles of 40° or below (Coll and Caselles, 1994). Then, a set of 156 simulated points (T, T_4 and T_5) has been obtained.

For each of these points, the atmospheric water vapor content and the observation angle are known. Then we can calculate the line-of-sight water vapor content, W, which can be used in equations (2) and (3) to retrieve the split -window coefficients A and B. Using the calculated coefficients and the brightness temperatures T_4 and T_5, the sea surface temperature, T, has been calculated and compared to the prescribed T. Figure 3 shows the difference between the prescribed and calculated temperatures, δT, versus the brightness temperature difference T_4-T_5. The error δT gives a mean value of -0.04K and a standard deviation of 0.28K. The algorithm produces a negligible overestimation in the surface temperature, and the standard deviation is sufficiently small to give confidence to the method proposed.

3.2 Algorithm comparisons

The results obtained with our algorithm are compared with those obtained by application of other methods. Table 1 shows the results, for 25 points of an image corresponding to the NOAA-12 overpass at 20:31 hours GMT on 17 December 1994, after application of different algorithms. In all cases the same mask for eliminating clouds and land zones was used. So, calculation of SST has only been made for clear pixels.

The MCSST algorithm is a linear algorithm applicable at global scale, then it may produce some errors in a particular area such as the Canary Islands region. In fact, a slight underestimation of the SST comparable to that reported by Llewellyn-Jones et al. (1984) is observed for the MCSST algorithm.

Sobrino et al.'s model requires the knowledge of the total water vapor amount, which must be obtained from a radiosounding. We have used the atmospheric vertical profile of air humidity obtained at 00:00 hours GMT by the Spanish Institute Meteorology in Santa Cruz de Tenerife. Thus a value of 1.76 g/cm^2 was calculated for the total water vapor amount (W). Using now the results given by Sobrino et al. (1991) in their figure 5, the sea surface temperature was obtained. The average difference with the algorithm proposed in this paper (-1.2K) can be easily explained: the atmospheric water vapor amount on the sea is larger than over the land. A value of 2.6 g/cm^2 was obtained over the sea for 25 studied points. The difference with the land value (1.76 g/cm^2) is also due to the time difference (3.5 hours between the meteorological sounding and the satellite overpass). Then, the main difficulty of the Sobrino et al.'s method is the validity of radiosounding launched over land to obtain SST, and the difference in time between that and the satellite overpass. Three and half hours can be too much time in hot months with high evaporation.

Coll et al.'s method has also a global character, but in this case a quadratic split-window equation is used in order to implicitly consider the world-wide atmospheric variability. then, the coefficient A is not regarded as a constant but is assumed to depend linearly on the brightness temperature difference itself, i.e.,

$A=a_0+a_1(T_4-T_5)$, whereas coefficient B can be taken as a constant. The numerical coefficients of the algorithm were

derived empirically using "in situ" sea surface temperatures with coincident AVHRR data. The algorithm has been applied to a data set of sea surface temperatures provided by the CMS Lannion, France, composed of 348 points. The comparison between the measured and retrieved surface temperatures yielded a root mean square difference (rmsd) of 0.56K around a bias of 0.17K. In the comparison of the present paper, it is worth noting the good agreement of the quadratic algorithm of Coll et al. (1994) with the algorithm proposed in this paper.

4. CONCLUSION

A new method for determining SST is proposed, which combines the information supplied by TOVS and AVHRR sensors. Coefficients A and B being determined as a function of the water vapor content, which is calculated using the TOVS sensors. Thus, the problems of extrapolating land meteorological radiosoundings, taken at different time of the satellite overpass, are avoided.

The model suggested here was the most appropriate for determining SST in the Canary Islands region. However, the comparison with in situ measurements will be the next step in our investigation. Therefore, we are organizing a joint campaign with the Marine Sciences Canary Institute in order to obtain ship measurements and to validate the proposed methodology.

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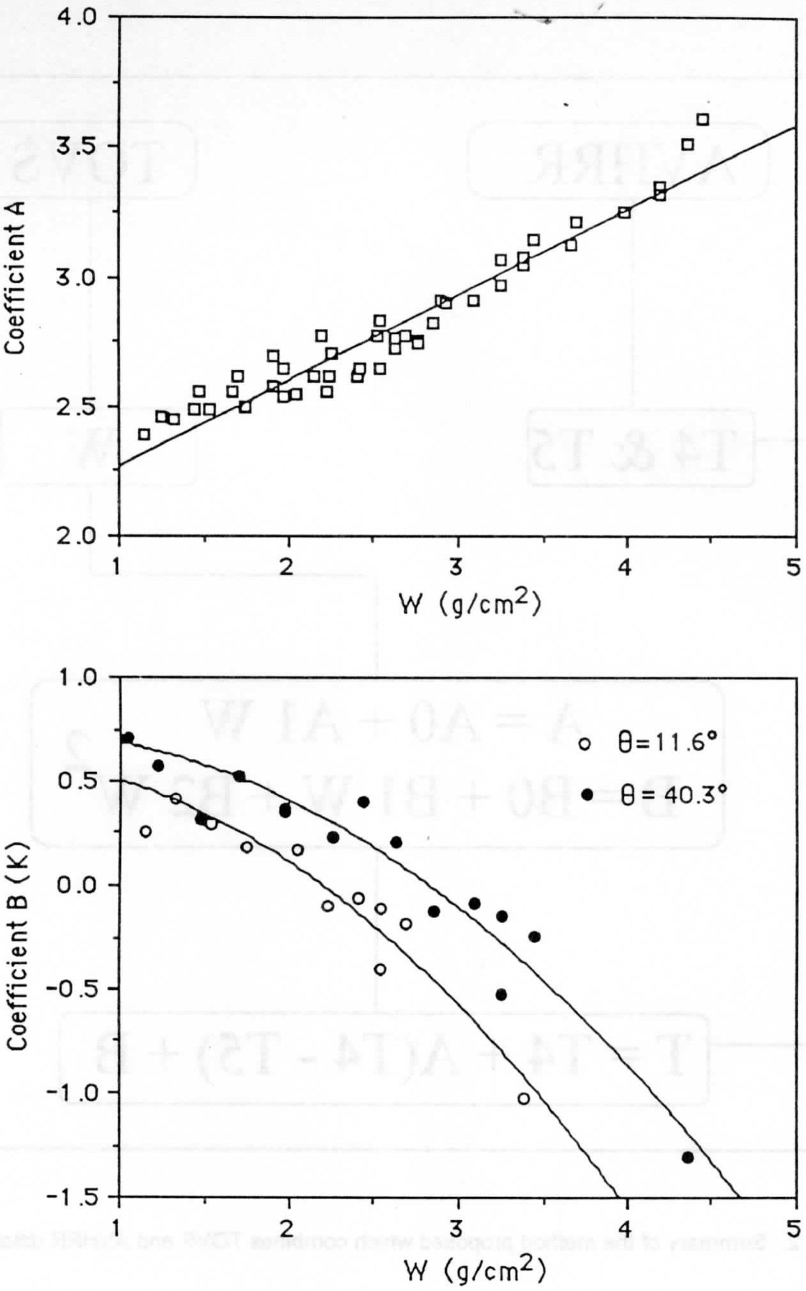

Figure 1.- Coefficients A and B as a function of the water vapor content, W, for a set of radiosonde data. All atmospheric gases were taken into account. this figure is a modification of figures 1 and 2 of Coll and Caselles (1994), where nadir observation was assumed.

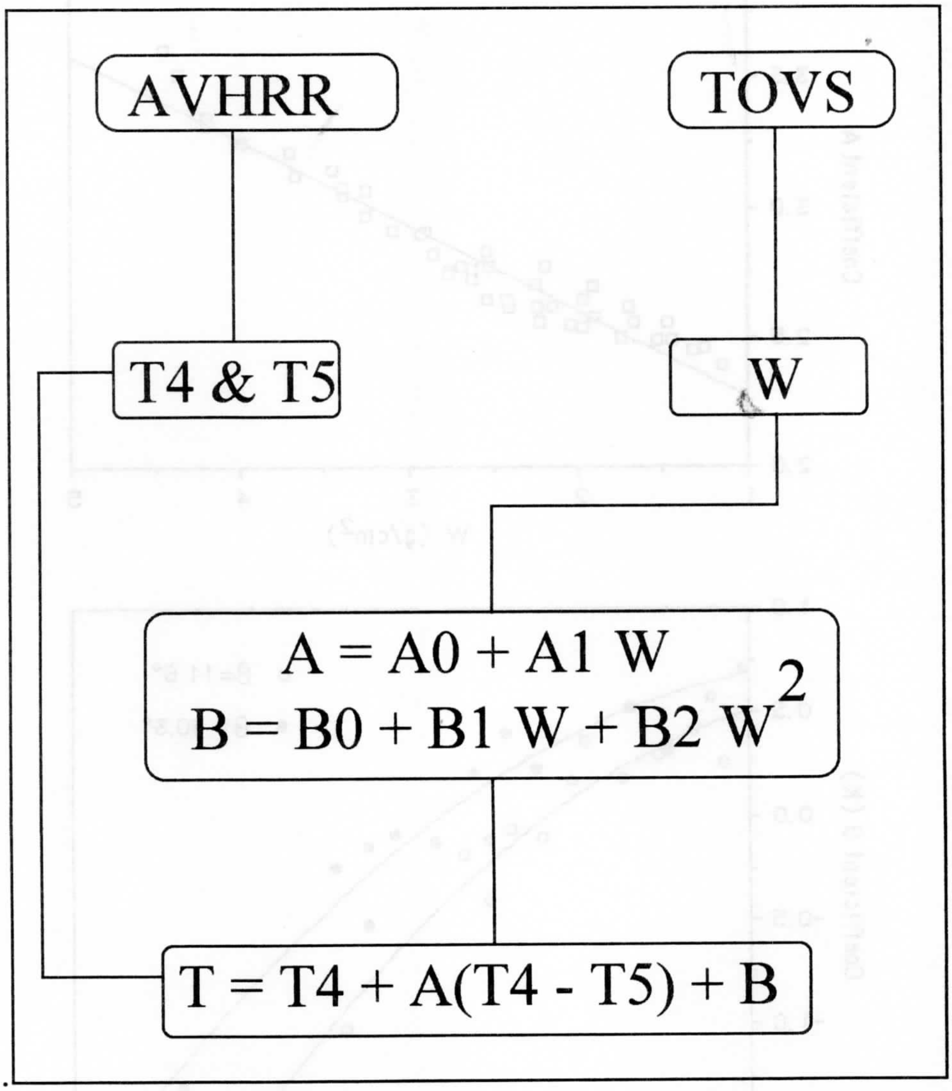

Figure 2.- Summary of the method proposed which combines TOVS and AVHRR data.

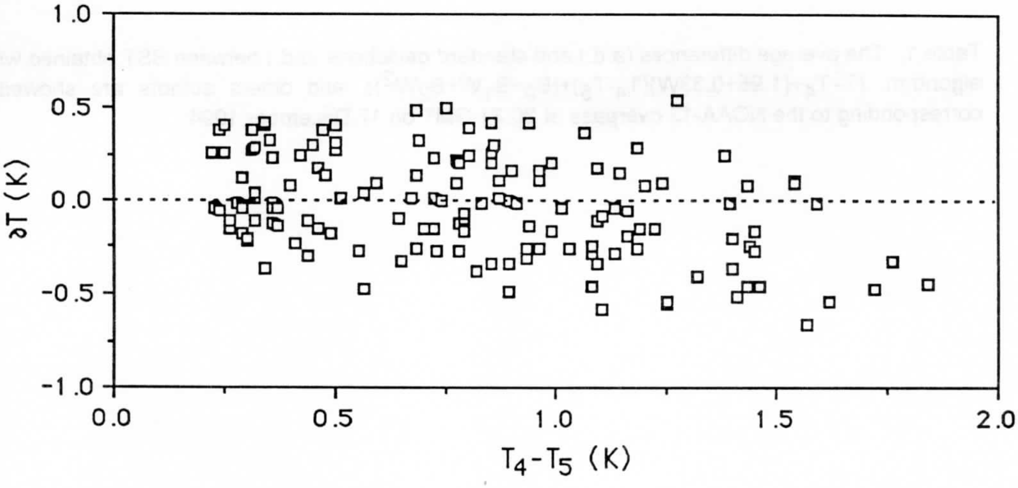

Figure 3.- Comparison of the method proposed with simulated brightness temperatures. δT is the difference between the prescribed and the calculated sea surface temperatures.

Algorithm	Split-window Equation	(a.d.)	(s.d.)
MCSTT	$T=1.0561T_4+2.542(T_4-T_5)+0.888(T_4-T_5)(\sec\theta-1)-16.98$	0.62	0.03
Sobrino et al. (1991)	$T=T_4+1.9257(T_4-T_5)$	1.15	0.09
Coll et al. (1994)	$T=T_4+(1.0+0.58(T_4-T_5))(T_4-T_5)+0.51$	0.09	0.06

Table 1.- The average differences (a.d.) and standard deviations (s.d.) between SST obtained with the proposed algorithm, $(T=T_4+(1.95+0.33W)(T_4-T_5)+(B_0+B_1W+B_2W^2))$, and others authors are showed for an image corresponding to the NOAA-12 overpass at 20:31 GMT on 17 December 1994.

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