

# Sea Surface Temperature Estimation using Visible and Infrared Scanner (VIRS)

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## *Abstract*

Sea Surface Temperature (SST) was estimated using the Visible and Infrared Scanner (VIRS) data for making a comparison between the SST estimations using infrared data of VIRS and microwave data of the Tropical Rainfall Measuring Mission (TRMM) Microwave Imager (TMI). The VIRS SST data are validated using the National Meteorological Center (NMC) global SST data (Reynolds and Smith, 1994) and Tropical Atmosphere Ocean (TAO) Array data. The comparison shows the estimated SST describes the global pattern of the SST reasonably, and its value is sufficiently accurate (the root mean square difference (RMSD) from TAO SST data is 0.68K) for comparison with TMI SST and other researches.

## 1. Introduction

Sea surface temperature is often estimated using infrared sensors such as the Advanced High-Resolution Radiometer (AVHRR) aboard the National Oceanic and Atmospheric Administration (NOAA) satellite (McMillin and Crosby, 1984). The accuracy, in terms of bias and root mean square difference (RMSD) from buoy data, is reported to be about 0.1 °C and 0.7 °C (May and Hoky, 1993). Because the satellites simultaneously observe SST over a wide area, their data are useful for analyzing the spatial distribution of SST and supplementing coverage of ground observation data (McMillin and Crosby, 1984). However, some researchers have reported that several problems arise because the satellites observe the Earth's surface through the atmosphere and infrared sensors observe a very thin layer (2μm to 3μm) in the ocean (McMillin and Crosby, 1984, Walton, 1988, Robinson and Ward, 1989).

Because TRMM carries both TMI and VIRS, we can estimate SST using microwave (Shibata et al., 1999) and infrared radiation simultaneously. Due to the difference of their wavelengths, responses to the atmospheric and ocean surface conditions and observed depths on the ocean surface (2mm to 3mm by TMI and 2μm to 3μm by VIRS) differ between the sensors. The difference may be useful not only for improving the atmospheric and sea surface correction in these methods but also for understanding the skin effect, in which the temperature of the very thin upper layer of the sea surface (skin layer) differs from the lower subsurface temperature (Kachi et al., 1999).

This document includes information on the format, methods of SST estimation and cloud screening, and accuracy of the VIRS SST for data usage.

## 2. Data Format

VIRS SST is calculated at each original pixel (about 2-km resolution) and averaged in time-space bins of 0.125 degrees equal Latitude-Longitude and 1-day, which covers the whole longitude and the latitude from 38 degree N to 38 degree S.

*Table 1 Format of VIRS SST Data set*

| <i>Data Type</i>                        | <i>1 byte unsigned integer (0 to 255)</i>                                                                                 |
|-----------------------------------------|---------------------------------------------------------------------------------------------------------------------------|
| Projection Type                         | equal latitude-longitude grid                                                                                             |
| Bin Unit (time/space)                   | 1day /0.125-degree                                                                                                        |
| Area Coverage                           | 0 to 359.875 degree E, 38 degree N to 38 degree S                                                                         |
| Pixel /Line number                      | 2880 Pixels /609 Lines                                                                                                    |
| Pixel number to Longitude of the center | Longitude [degree E]=0.125×(Pixel−1)                                                                                      |
| Line number to Latitude of the center   | Latitude [degree N]=38−0.125×(Line−1)                                                                                     |
| Missing Data                            | SST <10 °C: CountValue=0<br>Data missed due to Cloud Area: CountValue=254<br>Data missed due to Land Area: CountValue=255 |
| Conversion to SST value                 | SST[°C] =0.1×CountValue+10.0                                                                                              |

## 3. Algorithm Overview

We estimate SST from brightness temperatures (BTs) of channels 3, 4 and 5 using the multi-channel SST (MCSST) method (McMillin and Crosby, 1984). BTs are calculated from the thermal infrared radiation of Level 1B data using the reverse Plank formula at each center wavelength. Usually, MCSST coefficients are determined by making a regression of BTs to ground observation data (ex. drifting buoy data). However, to simplify the process, the coefficients in this study are determined by making a regression of VIRS BTs to NMC weekly global SST data set whose grid is 1-degree Latitude-Longitude (Reynolds and Smith, 1994). VIRS BTs are resampled at 0.25-degree Latitude-Longitude intervals (these are not same as VIRS SST resolution of 0.125-degree Latitude-Longitude) in the daytime and nighttime over a 24-hour period. NMC SST is spatially and temporally interpolated to a 0.25-degree and 1-day grid. The global BT data of seven days (5, 6, and 17 June and 11, 25, 27, and 31 July in 1998) are used in this regression, and we derive day and nighttime coefficients separately for the SST estimation formula. To avoid biasing SST ranges in the regression, we resampled an equal number of the pairs of BTs and NMC SST data from five bins of SST values (under 16 °C, 16 °C to 20 °C, 20 °C to 24 °C, 24 °C to 28 °C, above 28 °C), and finally the total data number in the five bins became 10229 and 10265 for day and nighttime. The coefficients for channel 3 minus channel 4 are set to zero in the daytime because channel 3 is influenced by the solar reflection. The formula for estimating SST and its coefficients in this study is shown below (Table 1).

$$SST[K]=a_0+a_1*BT_4+a_2*(BT_4-BT_5)+a_3*(BT_4-BT_5)*m+a_4*(BT_3-BT_4)+a_5*(BT_3-BT_4)*m \quad (1)$$

$$m=\sec(\theta)-1,$$

$\theta$ :satellite zenith angle

BT3, BT4, BT5: brightness temperatures of channel 3 (3.75  $\mu\text{m}$ ), 4 (10.8  $\mu\text{m}$ ), 5 (12.0  $\mu\text{m}$ )

*Coefficients for VIRS SST Estimation*

|           | $a0$    | $a1$   | $a2$   | $a3$   | $a4$   | $a5$   |
|-----------|---------|--------|--------|--------|--------|--------|
| Daytime   | 10.4585 | 0.9650 | 2.3996 | 0.7356 | 0      | 0      |
| Nighttime | 14.4559 | 0.9502 | 0.0936 | 0.3958 | 1.3712 | 0.2430 |

RMSD of above regression is 0.98K /0.72K in day /nighttime.

For cloud screening, we used BT4 minus BT5, estimated SST minus previous 9-day mean of VIRS SST data, reflectance of visible channel 1 (for daytime), BT3 minus BT4 (for nighttime), and linearity between BT3-BT4 and BT4-BT5 (for nighttime). A spatial uniformity test, which is defined as the difference in values of neighboring pixels, is also applied for the estimated SST values and reflectance of channel 1.

#### 4. Validation of the VIRS SST Data

*Global Pattern*

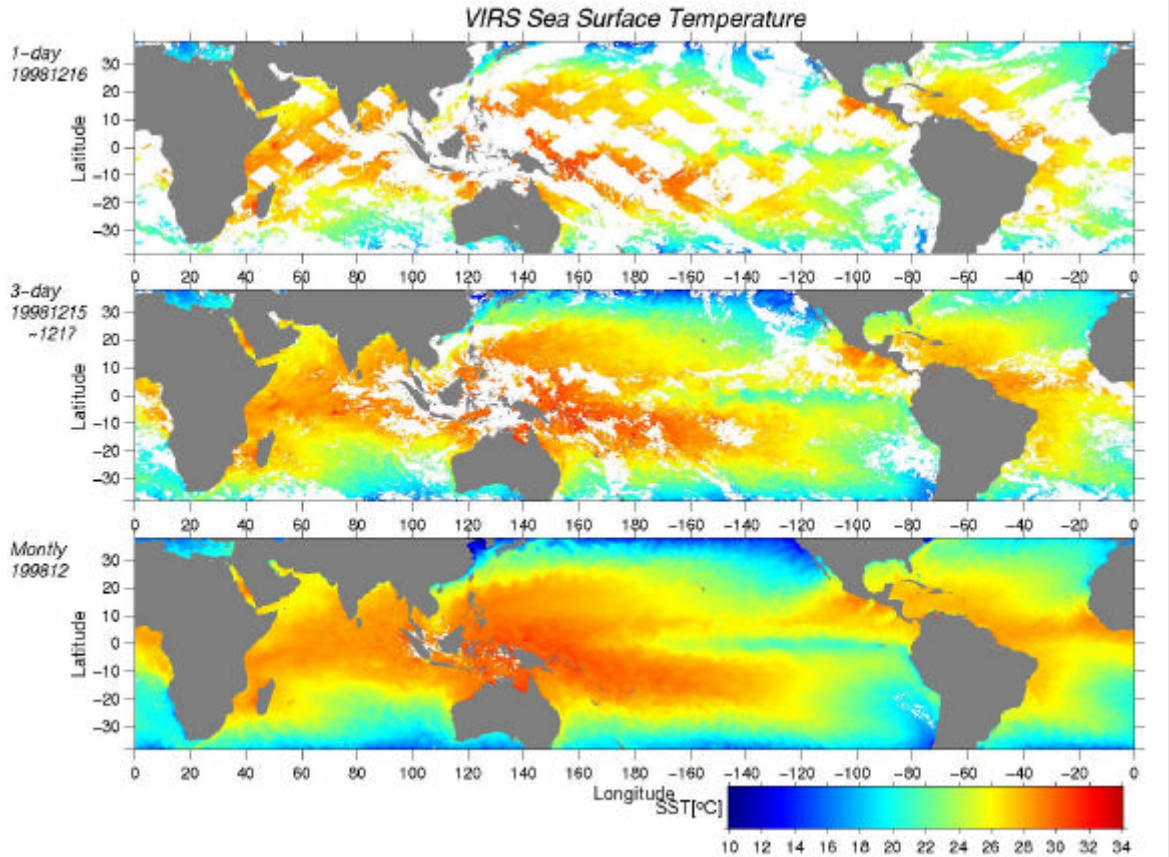


Fig. 1 1-day binned data for 16 December 1998 (upper image), 3-day mean data averaged from 15 to 17 December 1998 (middle image), and monthly mean data in December 1998 (lower image).

Figure 1 shows 1-day, 3-day and monthly mean VIRS SST data in December 1998. Cloud-masked areas decreased and small structures on the ocean surface are smoothed by increasing the number of days averaged. These VIRS SST data are compared with weekly (for daily and 3-day VIRS SST data) and monthly (for monthly VIRS SST) NMC SST data by adjusting the 0.25-degree Latitude-Longitude grid by spatial averaging and spatial interpolation. Although the MCSST coefficients of VIRS SST were derived using an NMC SST data set, the comparison is thought to be valid because those coefficients were derived in a period other than December 1998. The results show that the bias (defined as VIRS-NMC) is  $-0.04$ ,  $-0.08$  and  $-0.04$   $^{\circ}\text{C}$  and that the RMSD is 0.92, 0.87 and 0.53  $^{\circ}\text{C}$  for 1-day, 3-day and monthly data (Figure 2, 3, and 4). These biases are generally zeros over the entire observation area, and the RMSDs look small even though we disregard SST fluctuations due to temporally and spatially fine structures of the ocean surface within the grid size of NMC SST. These results demonstrate that the estimated SST has sufficient global accuracy and it generally describes the global pattern of SST.

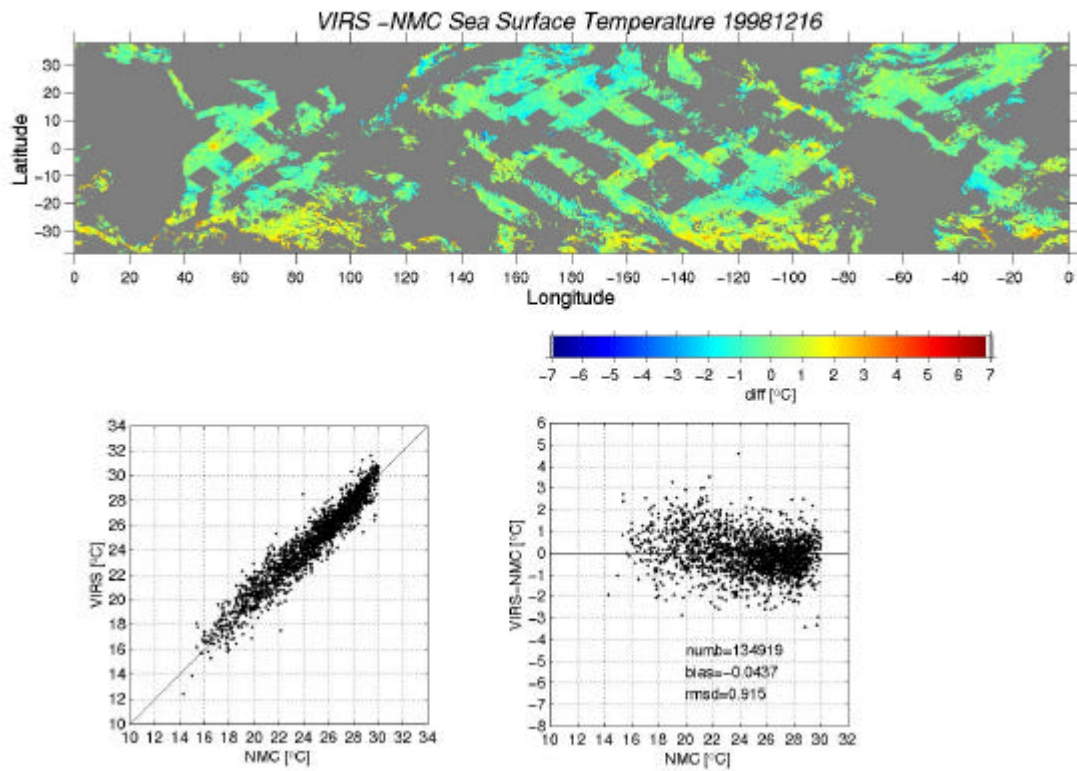


Fig. 2 VIRS-NMC SST comparison. VIRS SST data is 1-day binned data and NMC SST is weekly data.

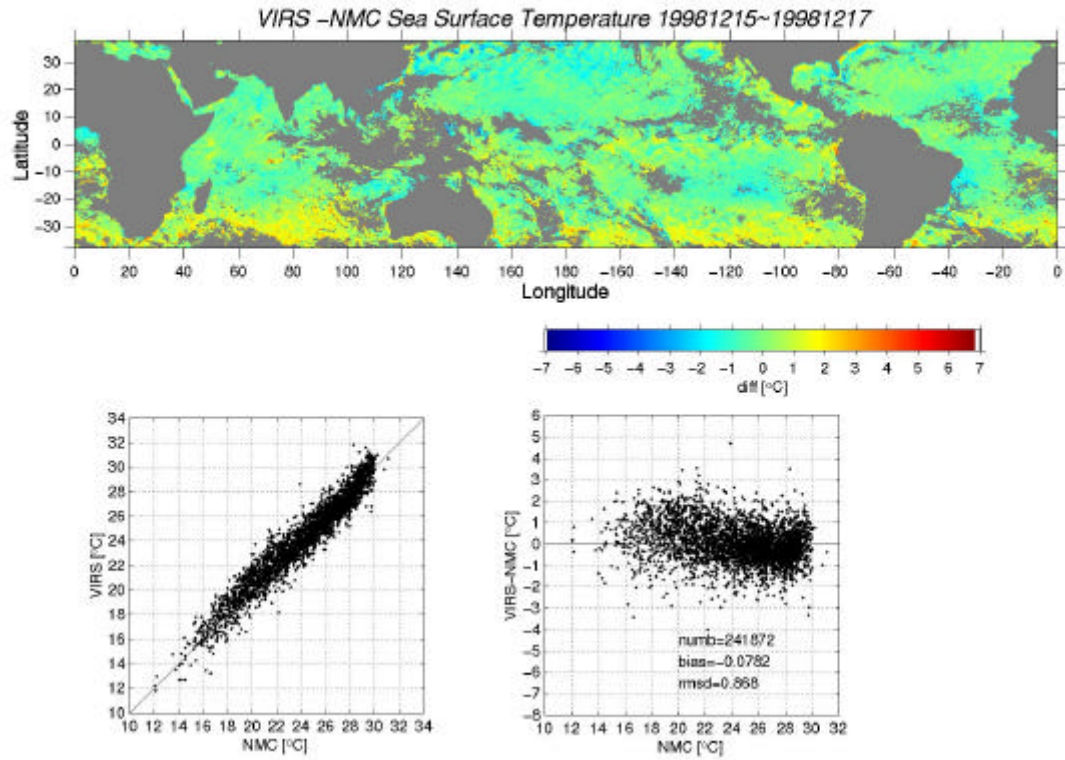


Fig. 3 VIRS-NMC SST comparison. VIRS SST data is 3-day binned data and NMC SST is weekly data.

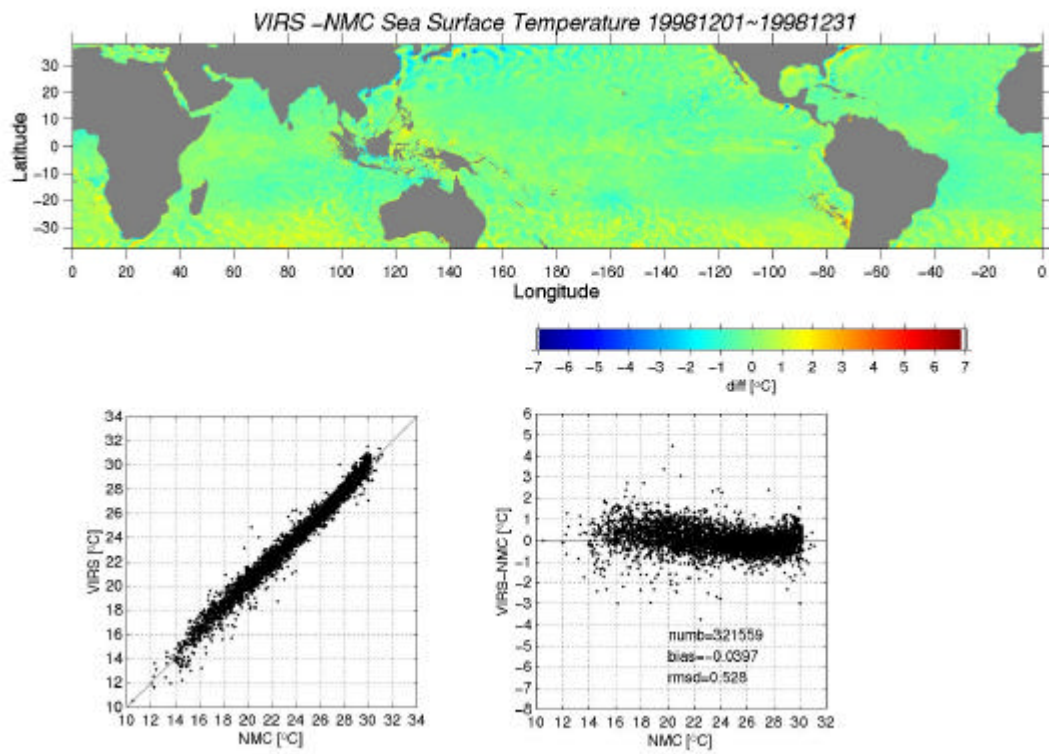


Fig. 4 VIRS-NMC SST comparison. VIRS SST data is monthly binned data and NMC SST is monthly data.

### *Accuracy of the values*

We also use 1-day mean SST data of the Tropical Atmosphere Ocean (TAO) Array for validating the VIRS SST. Buoy data tend to be limited in volume and value range (20 °C to 31 °C in the case of TAO buoy), but the error due to match up collocation can be limited to 1 pixel (0.125 degree in this study). The results show Bias is  $-0.13\text{K}$  and RMSD is  $0.68\text{K}$  for 3413 samples from November 1998 to March 1999 (Figure 5). This result's accuracy is as good as that of SST data sets derived by other satellites (May and Hoky, 1993, Sakaida et al., 1998), and it may indicate the VIRS SST has sufficient accuracy for comparison with TMI SST and other researches.

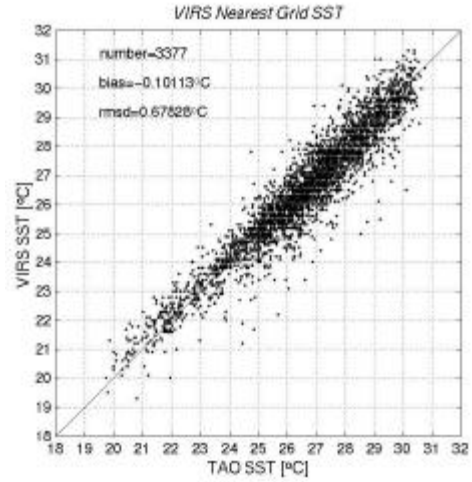
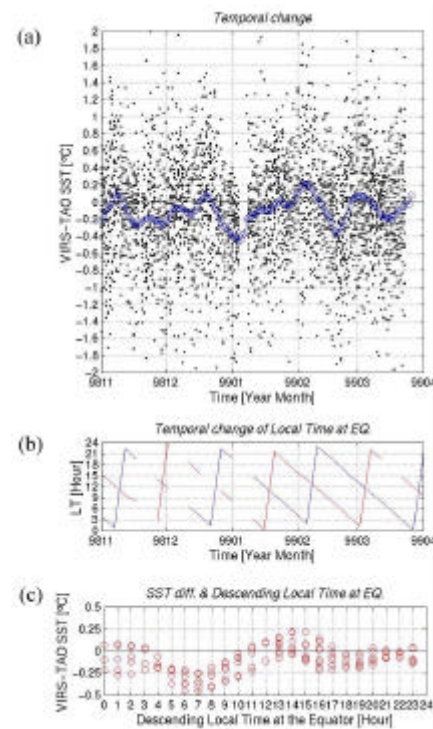


Fig. 5 VIRS–TAO buoy SST comparison. VIRS SST and TAO buoy data are daily data.

Figure 6a shows temporal change of the difference of VIRS-TAO SST. We found a periodic fluctuation (about 1.5 months) in the difference. Local time of the TRMM observation rotates in about 46-day in the low latitudes (Figure 6b) because the TRMM is not on sun-synchronous orbit. Daily cycle of SST may influence the difference of VIRS-TAO SST according to the local time change of observation. The change in Figure 6c may be reflected the local time influence, but we also have to take care of the difference of MCSST coefficients in day and nighttime.

Fig. 6 (a) Temporal change of VIRS–TAO buoy SST difference. Black plots show daily VIRS minus show TAO buoy SST data. Blue circle shows 5-day running average of the difference.  
(b) Temporal change of local time of the TRMM observation at the equator. Blue line indicates ascending path and red line shows descending path.  
(c) Scatter plot of descending local time to VIRS–TAO buoy SST difference. Ascending local time is about 12 hours different from descending time. SST peaks around local time of 2H and 14H.



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