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SEA SURFACE TEMPERATURE RETRIEVAL USING TRMM MICROWAVE IMAGER SATELLITE DATA IN THE SOUTH CHINA SEA

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ABSTRACT

The passive microwave TRMM Microwave Imager (TMI) sensor which is one of the payloads of the Tropical Rainfall Measurement Mission (TRMM) satellite was launched in 1997 by the National Aeronautics and Space Administration (NASA) and National Space Development Agency of Japan (NASDA). The TMI provides daily maps, 3 day average, weekly and monthly binary data via internet that can be used to retrieve geophysical parameters such as sea surface temperature (SST), 10 meter surface wind speed using 11 GHz channel, 10 meter surface wind speed using 37 GHz channel, atmospheric water vapour, liquid cloud water and precipitation rates. The SST study over the South China Sea was carried out using the 10.7 GHz channel of the TMI. The advantage of using this data is that the SST can be measured through clouds that are nearly transparent on this channel. This is a distinct advantage over the traditional infrared SST observations that require a cloud-free field of view. In this study, multitemporal TMI binary data were processed using FORTRAN Programming Language to evaluate the SST variations with time over the study area. The 3-day, weekly and monthly binary files are similar to the daily TMI binary files. All data consists of six maps with grid size of 0.25^{o} by 0.25^{o} and each file can be read as a 1440, 320, 6 array. For the data processing, the data values fall between 0 and 250 that need to be scaled to obtain meaningful geophysical data. The TMI scanning system causes striping that contains 0 or invalid data. In-situ temperature values were taken at locations where useful satellite data are available i.e. no striping. Regression analysis was carried out using the SST from TMI data and in-situ data obtained from the Meteorological Department of Malaysia. The two-dimensional scatter plot between TMI data and in-situ data gives a R^2 value of 0.92 and RMSE of 0.3^{o}C. The SST during the north east monsoon period was slightly lower than the SST during the south west monsoon. The study shows that TMI satellite data can be used to derive SST over large areas of the sea.

1. Introduction

Sea Surface Temperature (SST) is one of the geophysical parameters which are required by researchers for various applications. Conventional techniques can be used to retrieve SST values using ship, coastal stations and also drifting bouys (Emery and Yu 1997) within limited area coverage. Remote sensing from satellites has the advantage of obtaining global coverage more frequently. The major limitation of using the optical sensor is cloud cover problem especially in tropical areas (Chelton *et al*. 2000). In these areas, microwave sensor system has the additional advantage to provide its own illumination and capabilities to penetrate through cloud and operate in any climate conditions. This paper reports on the studies using TRMM Microwave Imager (TMI) which is one of the payloads of TRMM satellite to retrieve SST in South China Sea. The TMI data are suitable in tropical areas for obtaining SST values without cloud cover problems.

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2. Study area

The study was conducted in South China Sea located between 2° N to 7° N and 100° E to 107° E which includes Malaysia, Indonesia, Thailand, Taiwan and Philippines (Figure 1). This area undergoes climate changes during the monsoon and inter-monsoon periods. The SST values also vary during these periods.

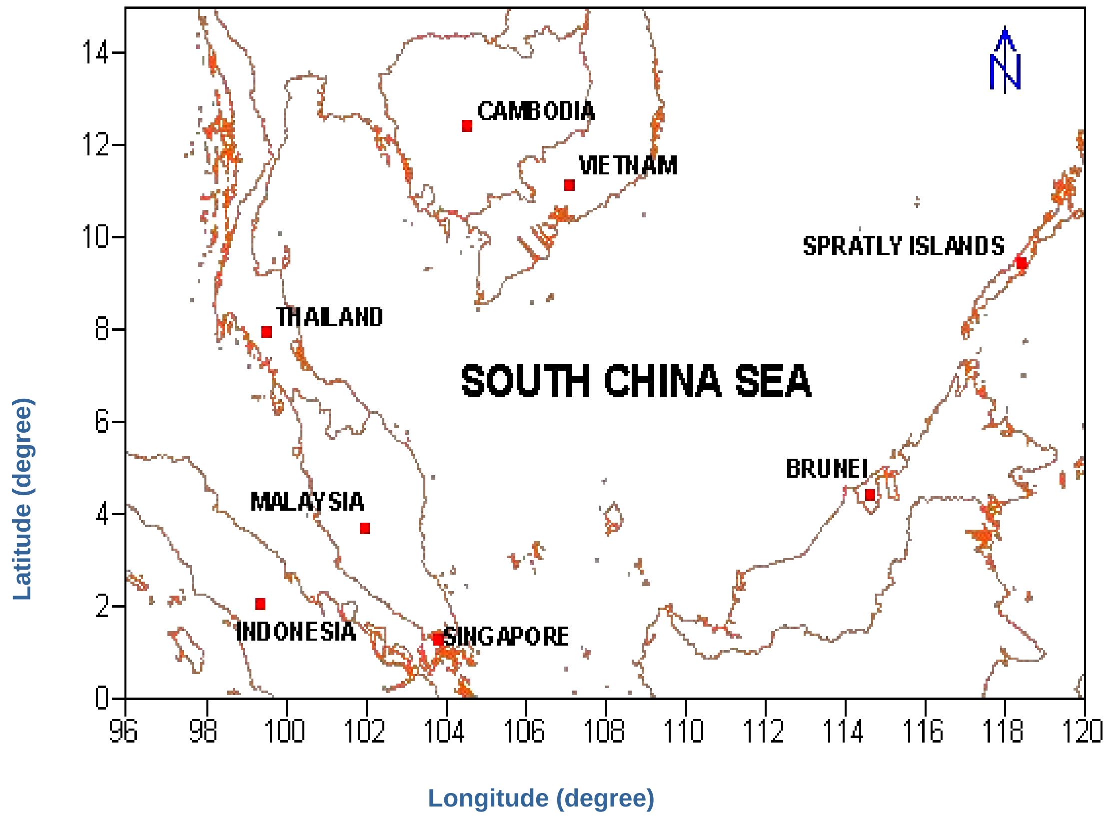

Figure 1. Study area.

3. Satellite data

3.1 TRMM microwave imager characteristics

TRMM is a joint mission between the National Aeronautics and Space Administration (NASA) of the United States and the National Space Development Agency (NASDA) of Japan (NASA Facts 1997). TMI is a nine-channel 10.7 GHz passive microwave radiometer with horizontal and vertical polarizations. TMI is 65 kg in weight and requires 50 W of main power to obtain data in 8.5 kbps (Kummerow and Barnes 1998). The characteristics of TMI are summarized in Table 1.

The instantaneous field of view (IFOV) is the footprint resulting from the intersection of antenna beamwidth and the earth's surface. Due to the shape of antenna and incident angle, the footprint can be described by an ellipse. The ellipse's major diameter is in the down-track direction called IFOV-DT and minor diameter in cross-track direction called IFOV-CT. The EFOV is the position of the antenna beam at the midpoint of the integration period. Figure 2 shows the IFOV and EFOV of TMI footprint characteristics.

Table 1. TMI characteristics of the 9 channels.

Channel Number	1	2	3	4	5	6	7	8	9
Center Frequency (GHz)	10.65	10.65	19.35	19.35	21.3	37.0	37.0	85.5	85.5
Polarization	V	H	V	H	V	V	H	V	H
Beam Width (degree)	3.68	3.75	1.90	1.88	1.70	1.00	1.00	0.42	0.43
IFOV-DT (km)	59.0	60.1	30.5	30.1	27.2	16.0	16.0	6.7	6.9
IFOV-CT (km)	35.7	36.4	18.4	18.2	16.5	9.7	9.7	4.1	4.2
Integrated time (ms)/sample	6.60	6.60	6.60	6.60	6.60	6.60	6.60	3.30	3.30
EFOV-CT (km)	9.1	9.1	9.1	9.1	9.1	9.1	9.1	4.6	4.6
EFOV-DT (km)	63.2	63.2	30.4	30.4	22.6	16.0	16.0	7.2	7.2
Number of EFOVs per scan	104	104	104	104	104	104	104	208	208
Number of Samples (N)/beam width	4	4	2	2	2	1	1	1	1
Beam EFOV (km x km)	63x37	63x37	30x18	30x18	23x18	16x9	16x9	7x5	7x5
Number of Beam EFOVs per scan	26	26	52	52	52	104	104	208	208

4. TMI data processing

Daily binary data file of TMI are available at ftp site, consisting of fourteen 0.25 x 0.25 degree grids of 1440 x 320 byte maps. Seven ascending maps include SST and six other geophysical parameters. The center of the first cell of the 1440 column and 320-row map is located at 0.125 E and –39.875 N latitude while the center of the second cell is at 0.375 E longitude, -39.875 N latitude. All the data values fall between 0 and 255. Specific values have been reserved as follows:

255	=	land mass
254	=	no TMI observations
253	=	TMI observations exist, but are bad
252	=	‘data set not used’
251	=	missing wind speed due to rain, or missing vapor due to heavy rain
0 to 250	=	valid geophysical data.

For the TMI data processing, the 3-day, weekly and monthly binary files are similar to the daily TMI binary files. All the data consists of six maps with grid size of 0.25^{o} by 0.25^{o} and each file can be read as a 1440, 320, 6 array. For the data processing, the data values between 0 and 250 need to be scaled to obtain meaningful geophysical data. In order to obtain the SST from the binary data, the data have to be multiplied by the scale factors as expressed below,

$$SST = (DATA * 0.15) – 3.0 \text{ to obtain SST between } –3^{o}C \text{ and } 34.5^{o}C. \quad (1)$$

This algorithm is based on a model for the brightness temperature (T_B) of the ocean and intervening atmosphere. The model and algorithm are precisely calibrated using a very large in-situ database containing SSMI observations. FORTRAN Programming Language is used to evaluate the SST values in each of the binary data starting from January 1998 until December 2002 during the north east and south west monsoon period.

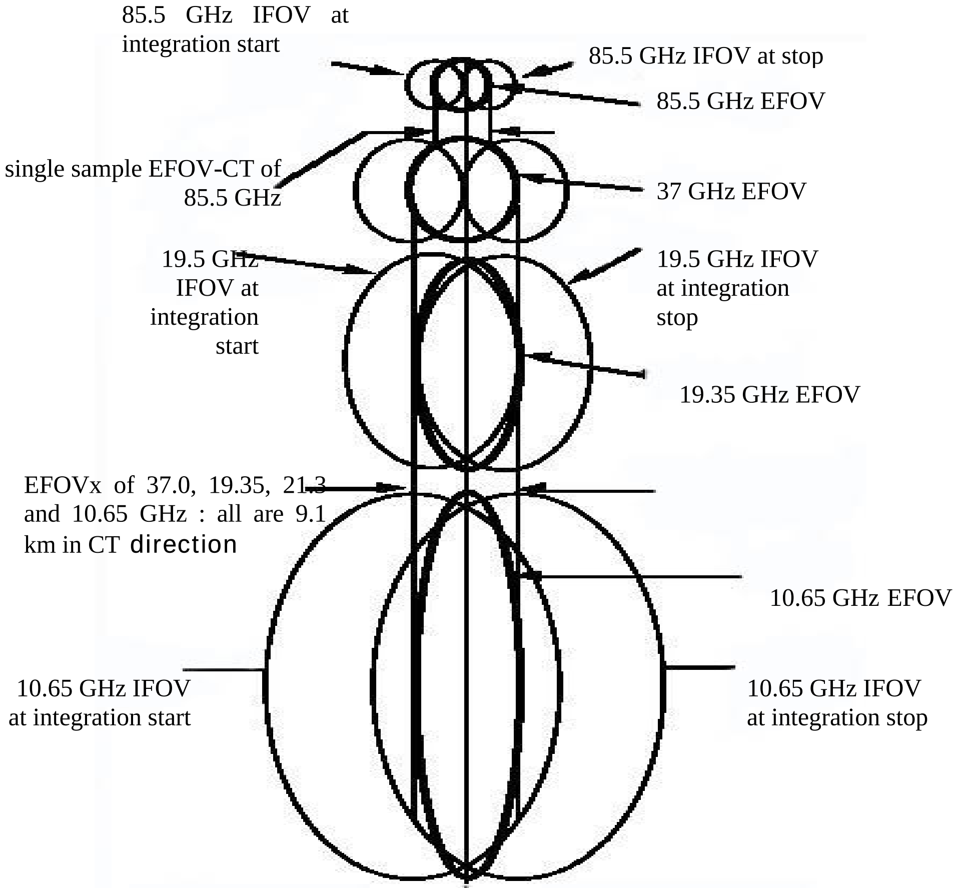

Figure 2. TRMM microwave imager footprint characteristics.
(Source: Kummerow and Barnes 1998)

5. Results

The SST values derived from TMI data using FORTRAN Programming Language for some dates during the north east and south west monsoon periods are tabulated in Table 2. The TMI scanning system causes striping that contains 0 or invalid data. Samples were taken at locations where data are available (no striping). Regression analysis was carried out using the SST from TMI data and in-situ data obtained from the Meteorological Department of Malaysia. Table 2 also shows the in-situ SST values during the north east and south west monsoon periods. SST values were derived from TMI data at 1031 points and compared with the corresponding in-situ SST values. The two-dimensional scatter plot between TMI data and in-situ data gives a R^2 value of 0.92 (Figure 3) and RMSE of 0.3^{o}C.

Regression analysis was also carried out during the north east (November to March) and south west (June to August) monsoon seasons for the year 1998, 1999, 2000, 2001 and 2002. The results are tabulated in Table 3.

Table 2. SST values derived from TMI data and corresponding in-situ SST values for a part of study area.

Date of data			Location (degrees)		SST Data (^oC)	
Year	Month	Day	Longitude	Latitude	TMI	In-situ
1998	1	15	4.6	106.1	27.675	28.0
1998	2	20	1.4	105.4	28.95	29
1998	3	19	5.4	106.8	28.875	29
1998	6	15	1.8	106.8	29.625	29.3
1998	7	9	4.0	105.8	30	30
1998	8	15	5.0	105.2	29.1	29.0
1998	11	25	4.3	105.8	28.8	28.4
1998	12	14	3.6	105.6	27.9	28.0
1999	1	28	5.1	106.5	27.45	27.0
1999	2	19	5.3	103.9	29.1	29.0
1999	3	11	3.9	105.9	29.7	30.0
1999	6	14	5.0	099.2	30.9	30.8
1999	7	14	5.6	103.6	30	30.0
1999	8	19	3.8	105.9	30.15	30.0
1999	11	15	2.0	104.8	28.8	29.0
1999	12	16	4.5	106.2	27.15	27.2
2000	1	14	2.3	104.9	28.05	27.6
2000	2	19	1.1	105.3	26.85	26.8
2000	3	24	5.9	105.9	25.8	25.7
2000	6	16	5.2	106.6	29.25	29.4
2000	7	16	5.2	106.9	28.95	28.8
2000	8	19	2.3	106.7	28.5	28.5
2000	11	25	5.1	106.6	28.05	28.0
2000	12	14	2.9	105.2	28.8	29.0
2001	1	10	4.0	106.0	27.45	27.0
2001	2	10	2.4	106.9	27.15	27.0
2001	3	15	4.5	106.3	27.45	27.4
2001	6	1	14.0	118.8	29.85	30.0
2001	7	7	13.6	110.7	27.75	28.0
2001	8	14	2.9	105.2	28.45	28.4
2001	11	18	14.0	118.8	29.85	29.7
2001	12	26	5.1	106.6	29.15	29.0
2002	1	3	3.8	105.9	28.95	29.0
2002	2	10	2.3	106.7	28.5	28.5
2002	3	15	1.7	105.4	27.85	27.9
2002	6	9	13.3	118.8	28.15	28.0
2002	7	8	5.2	106.6	29.25	29.3
2002	8	20	2.3	106.7	29.5	29.4
2002	11	10	3.8	105.9	29.5	29.8
2002	12	8	4.1	106.7	28.5	28.3

Key : ☐ north east monsoon period ☐ south west monsoon period

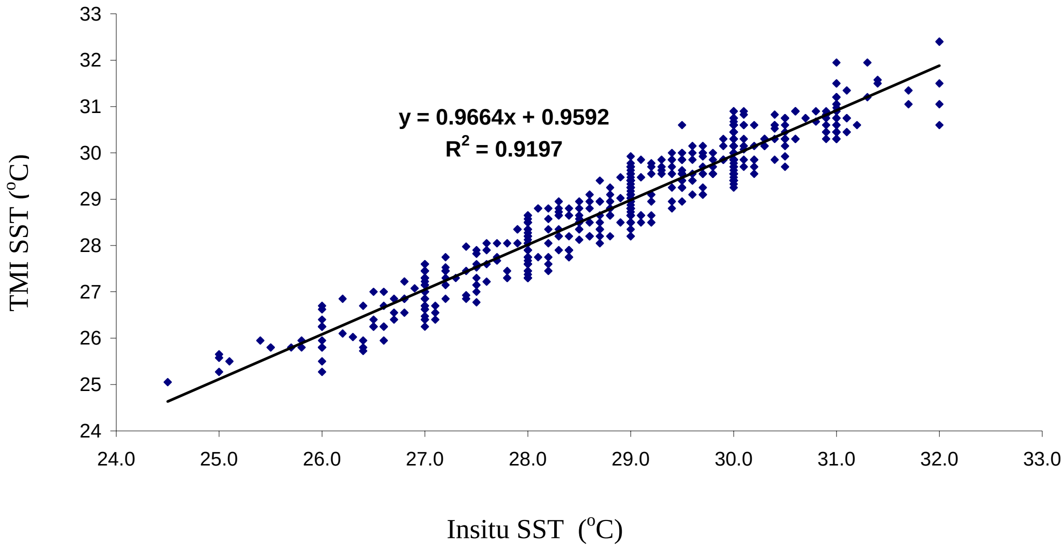

Figure 3. Regression of TMI SST versus in-situ SST from January 1998 to December 2002.

Table 3. Regression coefficient and RMSE of TMI SST and in-situ SST during monsoon period.

Year	North East Monsoon			South West Monsoon		
	No. of samples	R^2	RMSE	No. of samples	R^2	RMSE
1998	132	0.8748	0.5078	80	0.6120	0.5403
1999	142	0.8896	0.5002	72	0.5481	0.5982
2000	115	0.8989	0.421	64	0.5890	0.5816
2001	123	0.9015	0.382	105	0.7456	0.4982
2002	117	0.9198	0.398	81	0.8051	0.4150

In order to study the variations of SST, the TMI binary data were generated in image form. These generated images show the distribution of the SST during the two monsoon seasons. Figures 4(a) to 4(j) show the distribution of SST during the north east and south west monsoons from 1998 to 2002.

6. Conclusions

From the study, SST values can be derived accurately from TMI data. Comparisons with in-situ measurements indicate an accuracy of about ± 0.3°C. The R^2 value between in-situ and TMI SST is about 0.92. The SST during the north east monsoon period was slightly lower than the SST during the south west monsoon. This study shows that TMI data can be used to derive SST accurately over large areas of the sea.

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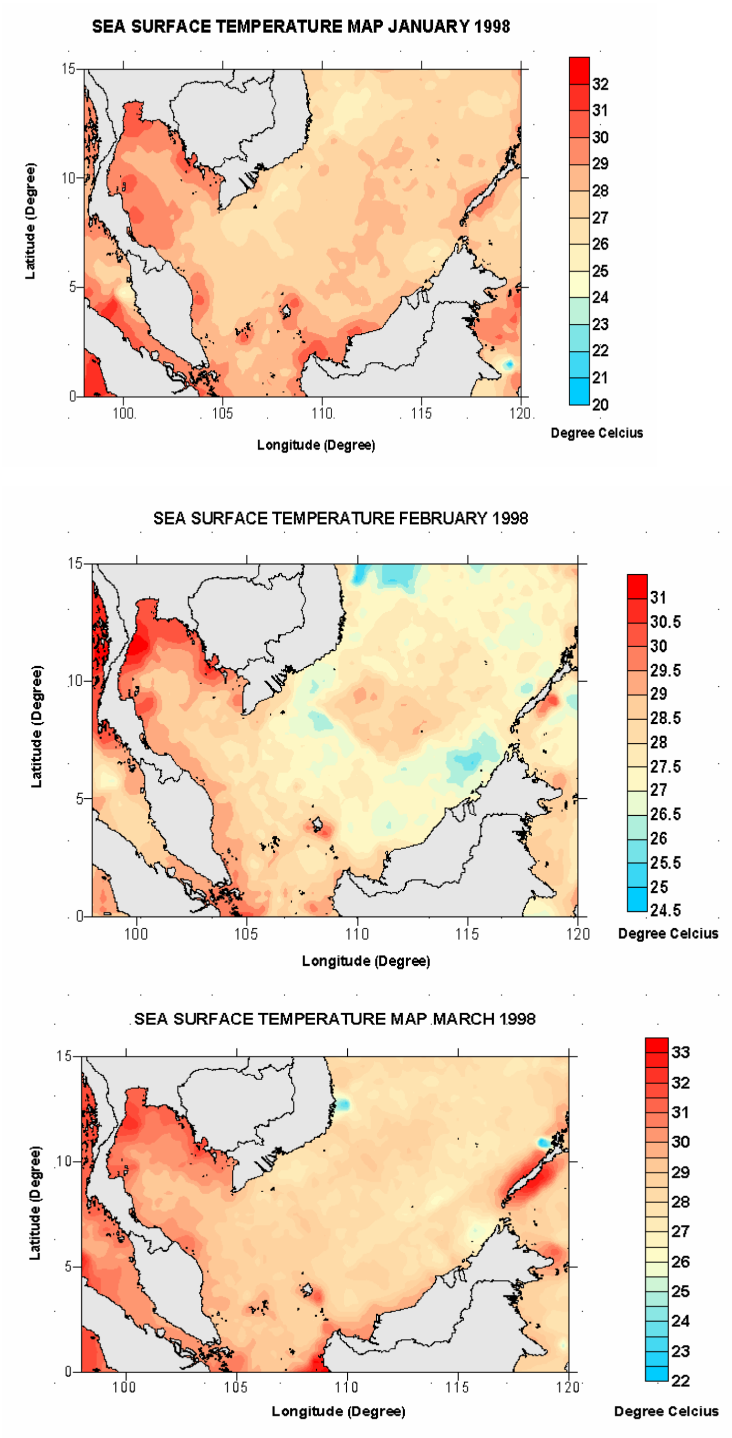

Figure 4(a). SST distribution during north east monsoon from Jan 1998 to Mar 1998.

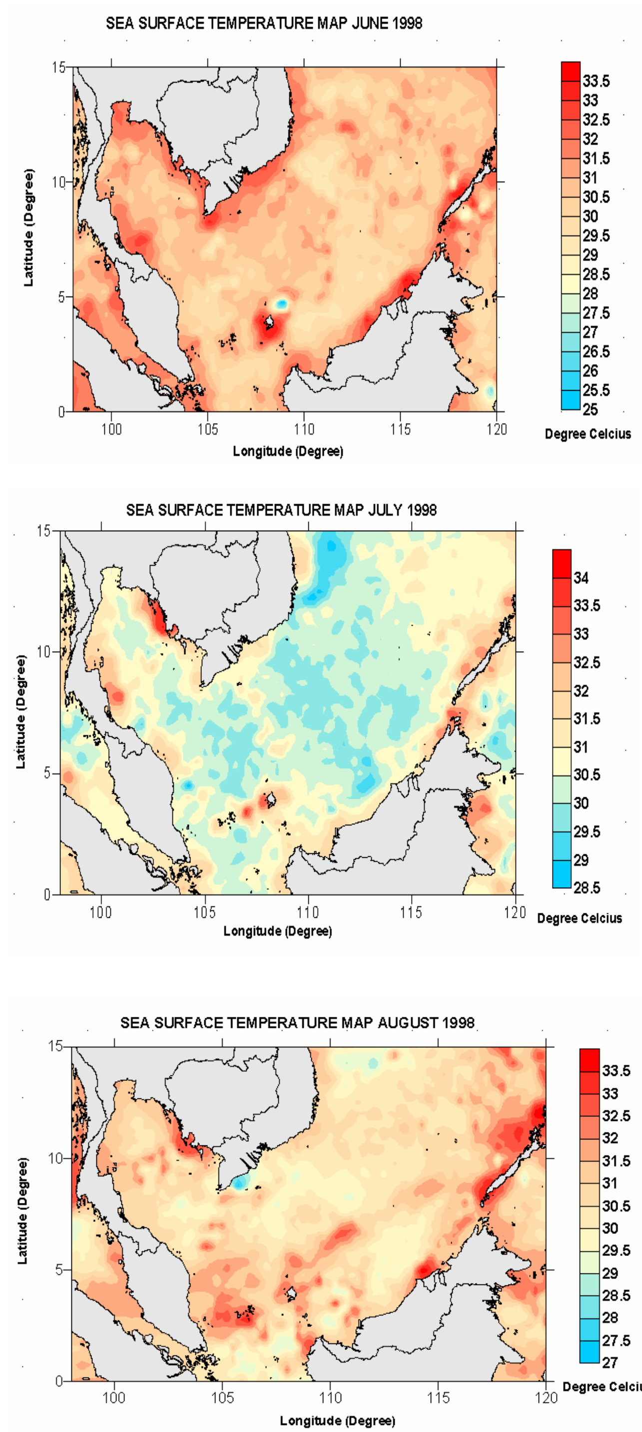

Figure 4(b). SST distribution during south west monsoon from June 1998 to Aug 1998.

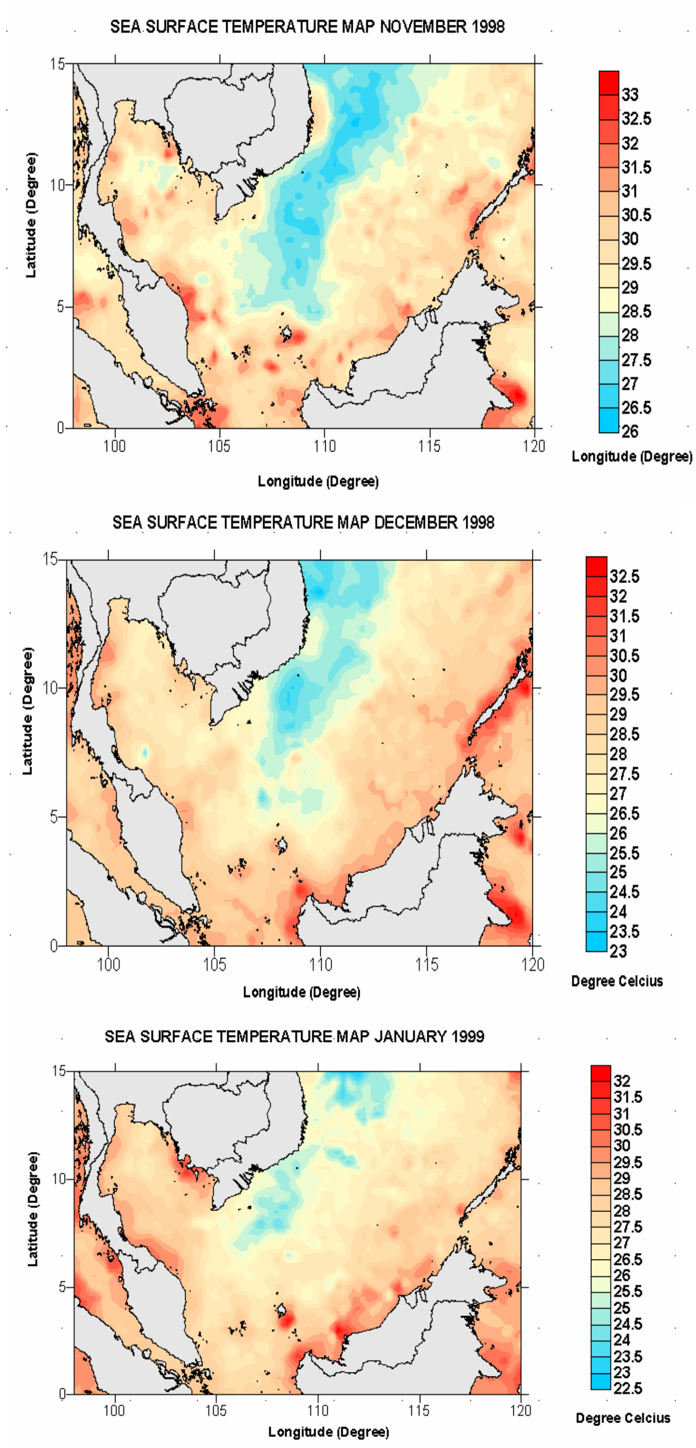

Figure 4(c). SST distribution during north east monsoon from Nov 1998 to Jan 1999.

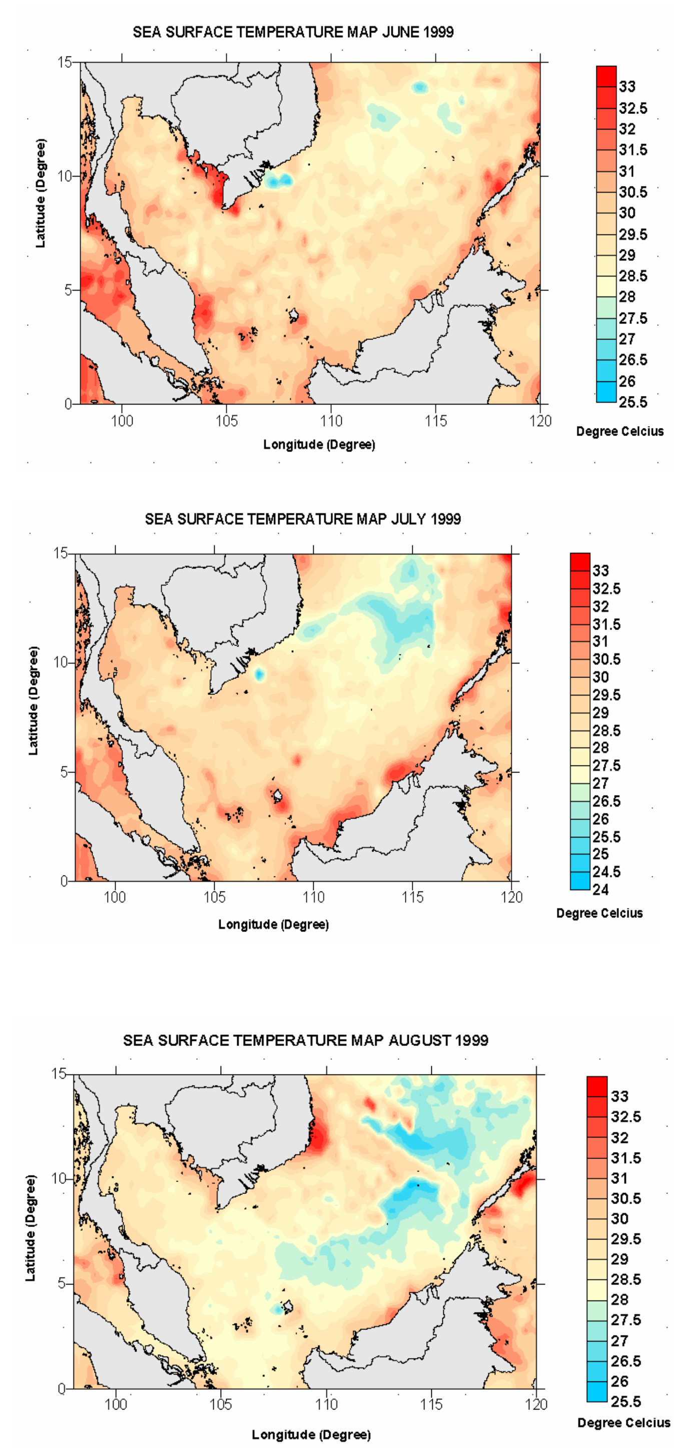

Figure 4(d). SST distribution during south west monsoon from June 1999 to Aug 1999.

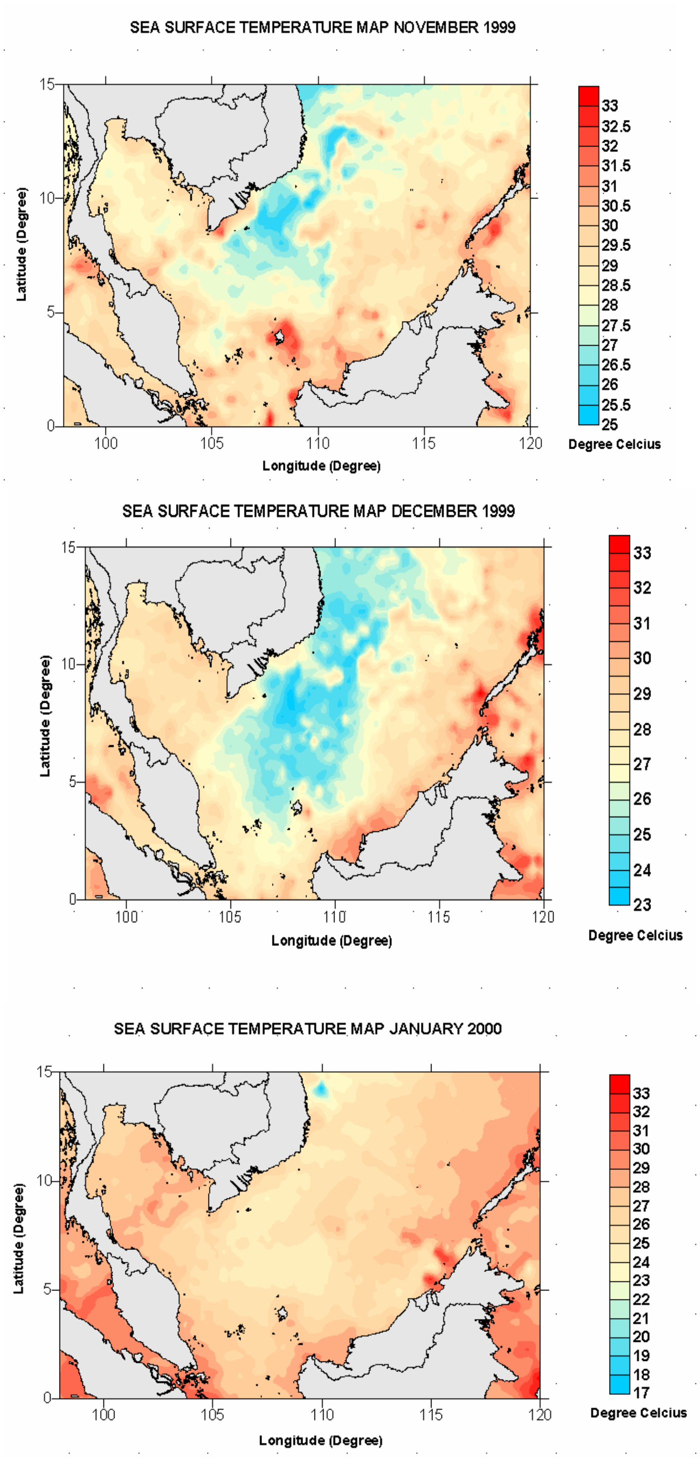

Figure 4(e). SST distribution during north east monsoon from Nov 19999 to Jan 2000.

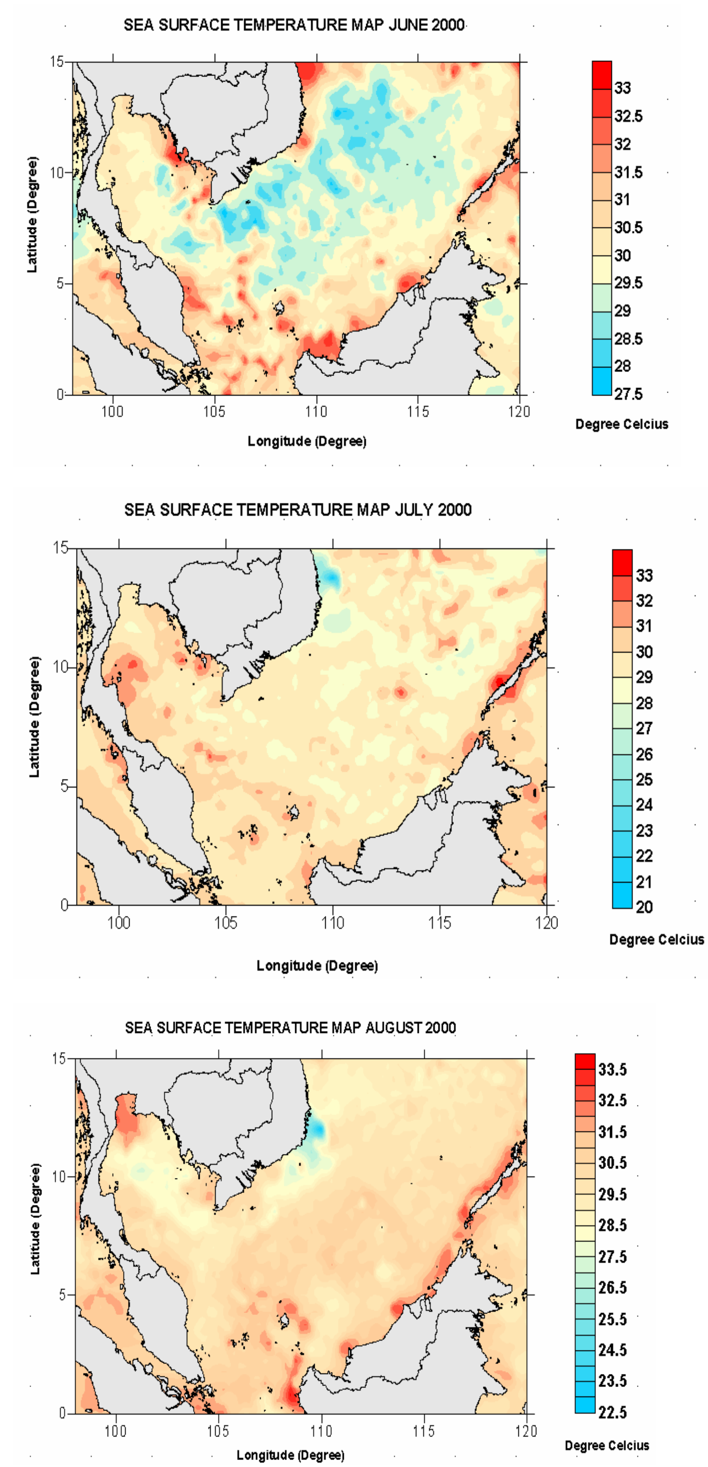

Figure 4(f). SST distribution during south west monsoon from June 2000 to Aug 2000.

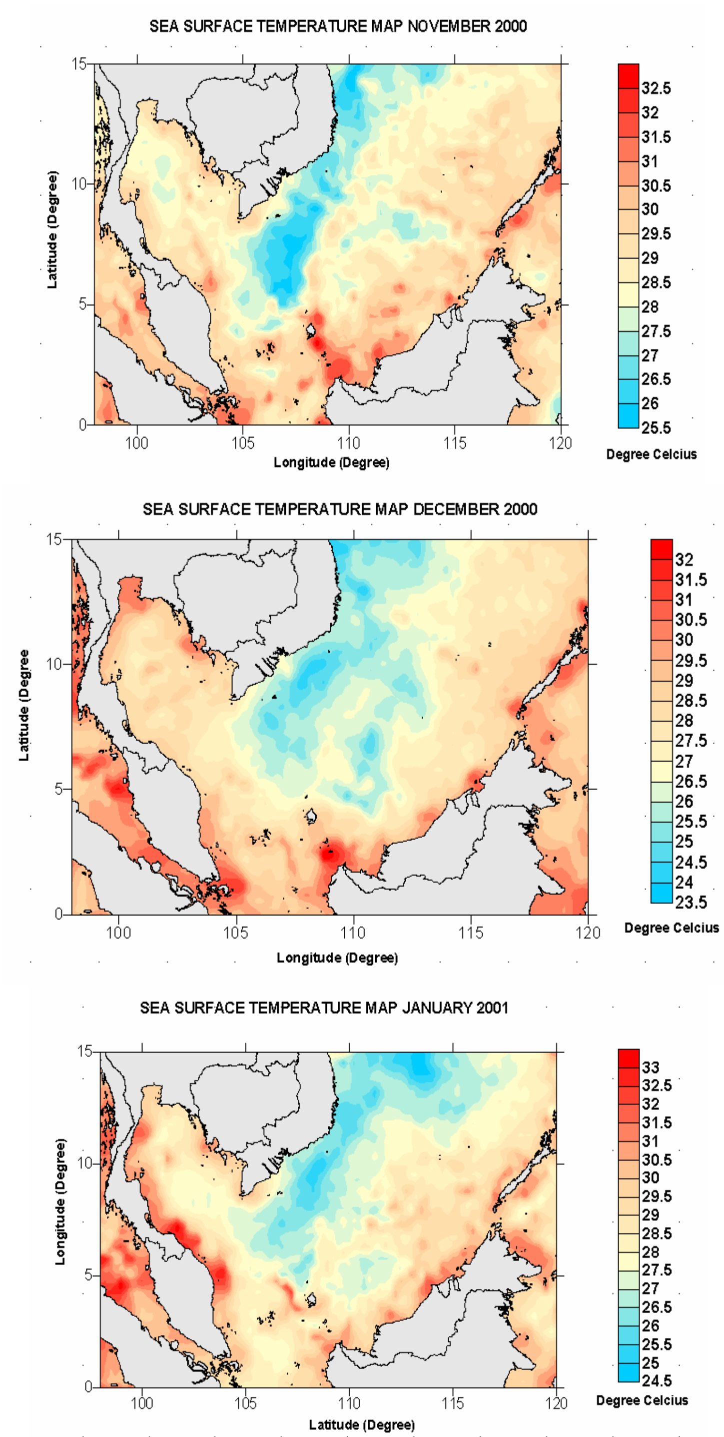

Figure 4(g). SST distribution during north east monsoon from Nov 2000 to Jan 2001.

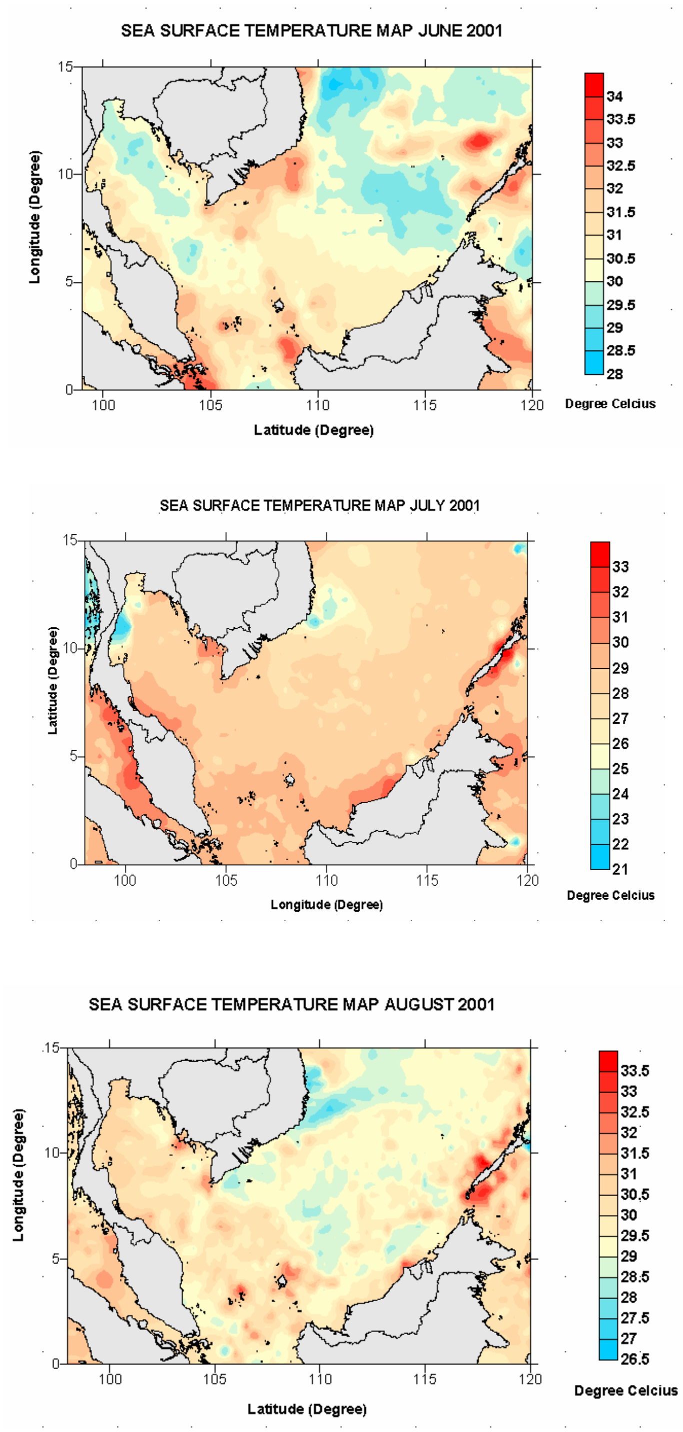

Figure 4(h). SST distribution during south west monsoon from June 2001 to Aug 2001.

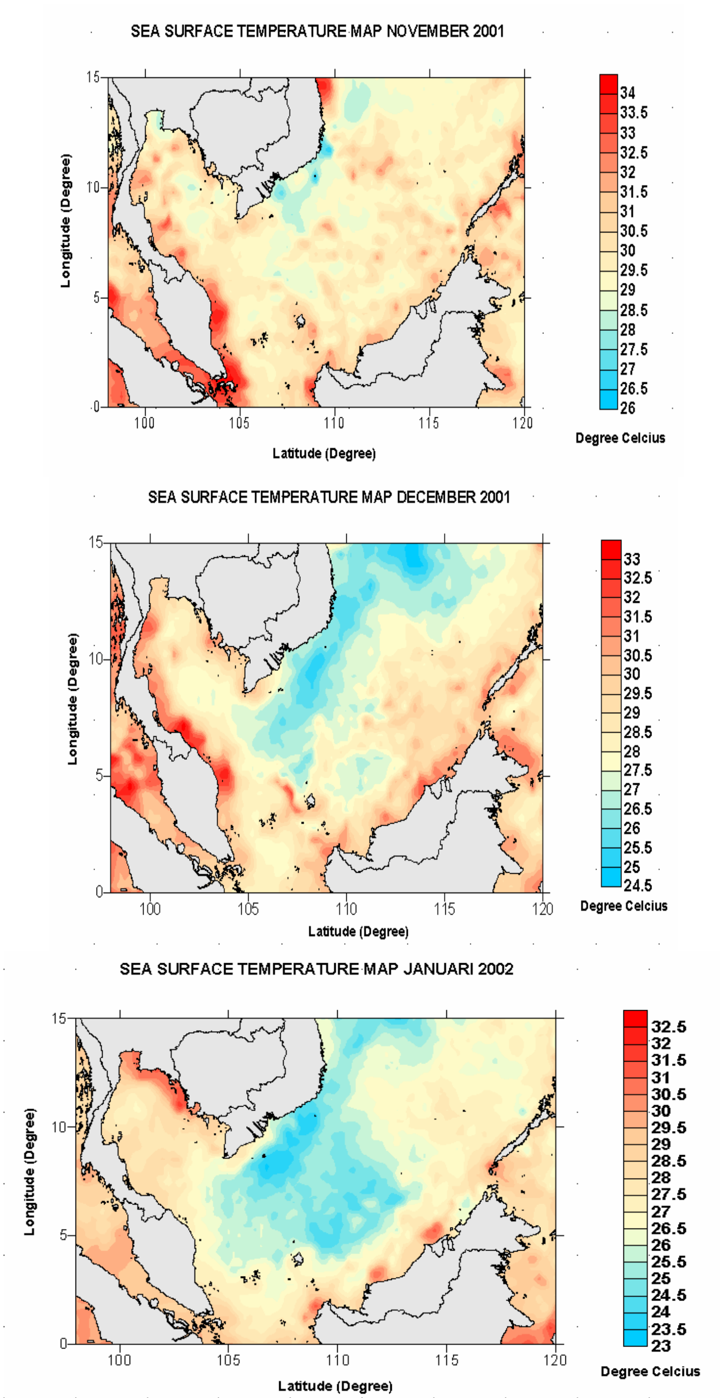

Figure 4(i). SST distribution during north east monsoon from Nov 2001 to Jan 2002.

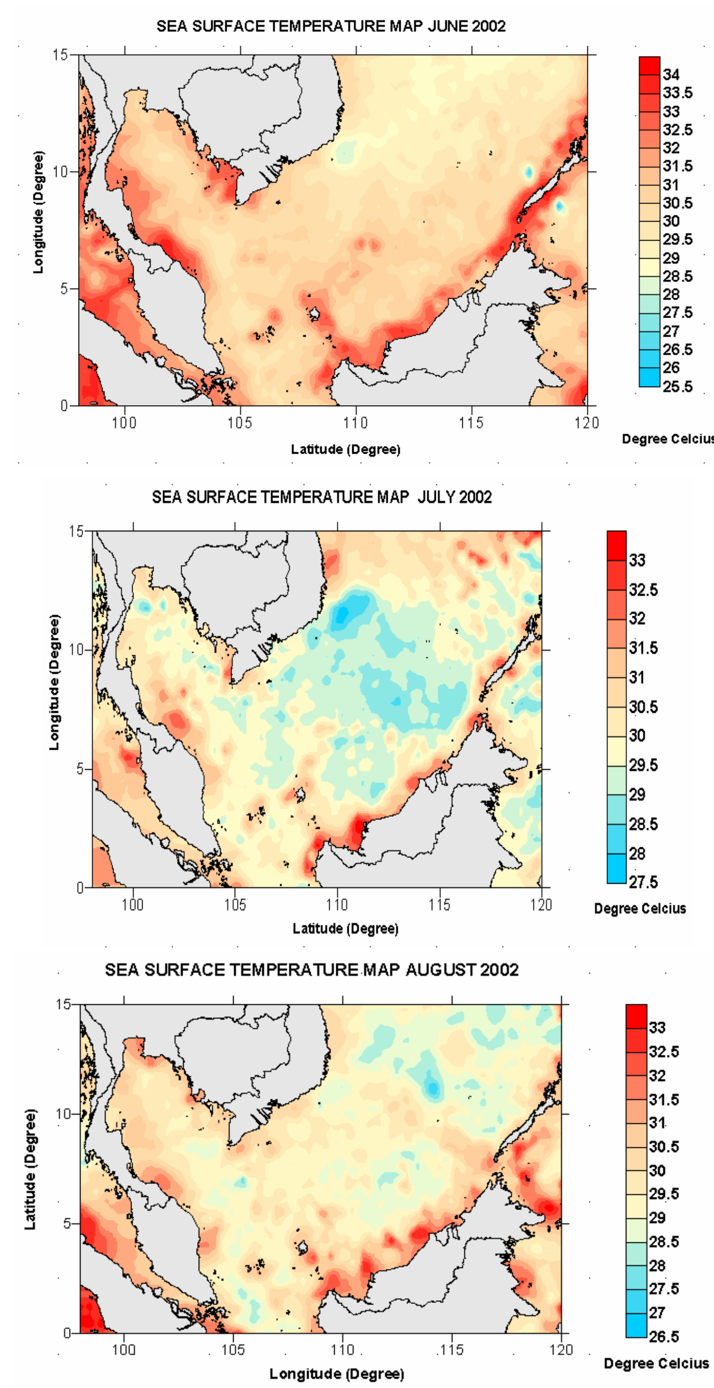

Figure 4(j). SST distribution during south west monsoon from June 2002 to Aug 2002.

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