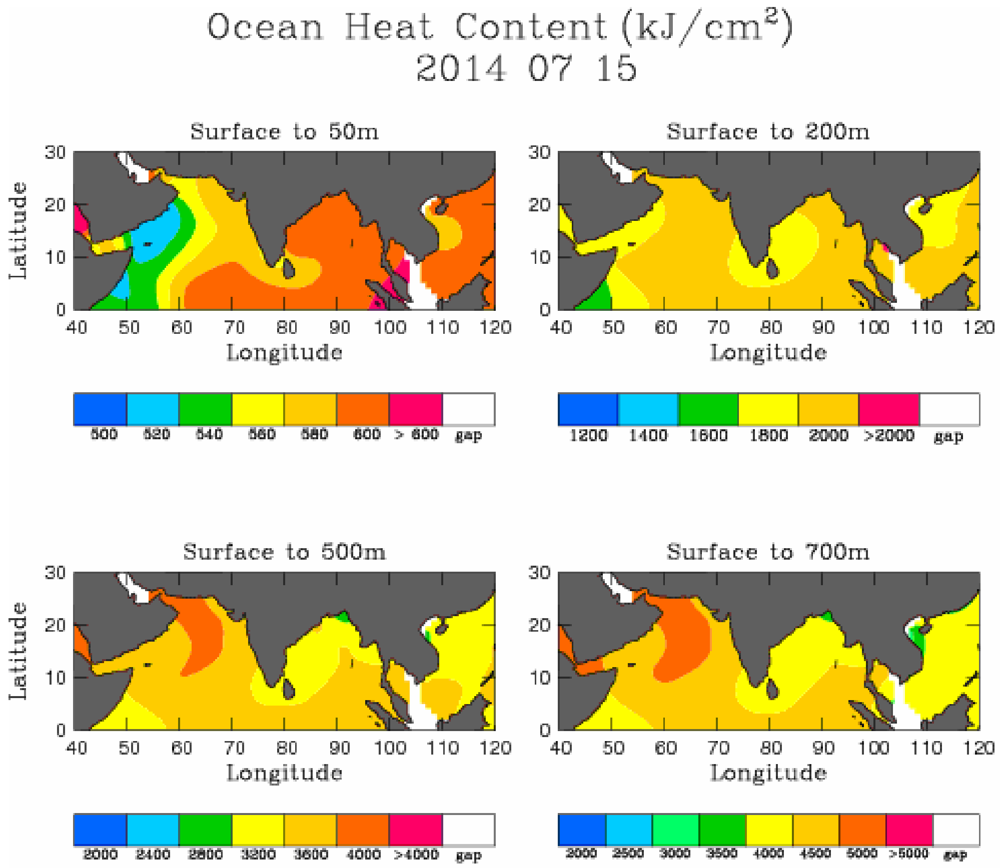
OHC and OMT at seven different ocean depths along with TCHP Products using AMSR2 SST



OHC estimated based on AMSR2 SST

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15 **Abstract**: The Ocean Heat Content (OHC) and Ocean Mean temperature (OMT) at seven different depths up to 700 m along with Tropical Cyclone Heat Potential (TCHP) are provided through the National Centre for Climate and Environmental Science (NICES) activity of the National remote Sensing Center (NRSC). The products are generated using Sea Surface Temperature (SST), Sea Surface Height Anomaly (SSHA) from satellite data and temperature profiles of World Ocean Atlas, 2009 in the north Indian Ocean (40-120^{o}E and 0 - 30^{o}N). The SST data are used form Tropical Rainfall Measuring Mission Microwave Imager (TMI) SST. Since TMI SST is no longer available beyond April 2015, we use AMSR2 derived SST. Towards this, TMI and AMSR2 SST data sets and the derived OHC, OMT and TCHP products are compared for their overlapping phase in 2014 on selective days of all the months. The comparisons have shown good co-relationship between the similar products (r>.99). Now, the AMSR2 derived OHC, TCHP and OMT products are provided through Bhuban website of NICES in near real-time mode for their further utility.

Key Words: OHC, TCHP, OMT, Indian Ocean, SST, SSHA, TMI, AMSR2

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Summary

The Ocean Heat Content (OHC) at seven different depths up to 700 m and related products such as, Tropical Cyclone Heat Potential (TCHP) and Ocean Mean temperature (OMT) are provided by the National Information System for Climate and Environment Studies (NICES) activity of NRSC. These products are generated using satellite derived Sea Surface Temperature (SST) and Sea Surface Height Anomaly (SSHA) altimeter data of the North Indian Ocean (40 - 120^{o}E and 0 - 30^{o}N). The products are generated using Artificial Neural Network (ANN) with a feed forward multi-layer perception in neural network where there are one input layer, three hidden layer and one output layer. The products are generated up to April 2015 till its availability. TMI has completed its tenure and the products are stopped lead to a discontinuity in OHC activities at NRSC. To continue the generation of OHC and related products, AMSR2 derived SST is considered due to its proximity in its sensing ability, algorithms and format available to TMI SST. The SSTs of AMSR2 are compared well with TMI (R^2 >0.9). The OHC at seven different depths along with TCHP and OMT are estimated and compared with those of TMI products during overlapping period in 2014. The monthly comparisons has shown good relationship (R^2 >0.9) through out the year. The variation of OHC estimations has remained high in the surface layer (-21.3 to 22.54 kJ/cm2) for the mean values ranging from 571 to 4085 kJ/cm^2 for depth levels of 50 to 700 m. These products have been used in cyclone tracking and their intensity prediction (Jagadeesh *et al*, 2015). These products have a scope to study of climate change, global warming, ocean productivity, monsoon rainfall. The Bhuvan website of NRSC is providing these products to users.

List of Figures

List of Tables

Contents

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1. **Introduction**

The National Remote Sensing Center (NRSC) is generating the Ocean Heat Content (OHC) at seven different depths (50 to 700m) of the North Indian Ocean along with Tropical Cyclone Heat Potential (TCHP) and Ocean Mean Temperature (OMT) using satellite derived Sea Surface Temperature (SST) and Sea Surface Height Anomaly (SSHA). The estimations are made with models developed using Artificial Neural Network approach (Ali et al, 2012). World Ocean Atlas (2009) thermal profiles and Argo profiles are used to validate the results. The products find their utility in the study of warming and cooling in the Indian Ocean. Their response to cyclone tracking and intensification has been established (Ali *et al*, 2010). The ocean heat are also found related to monsoon rainfall (Ali *et al*, 2015). The products also find its scope to study ocean surface productivity, surface dynamics, eddies and boundary flows, air-sea fluxes, energy and gas exchange. Since April, 2015, the OHC products are discontinued due to non-availability of one of the input parameters, SST from TMI. In order to continue the products, an alternative SST product from AMSR2 is considered. The SST and OHC are generated with AMSR2 data. The products are compared with TMI data during overlapping period of 2014. This document highlights some of the comparisons made between SSTs and OHCs. The TCHP and OMT products have also shown good relationship (R^2 > .9). All these products are provided through the Bhuvan website of NRSC on daily basis.

2. Data and Methods

The satellite derived SST and SSHA are two major input required daily in generation of OHC products. Methods developed earlier are used in generation of products. While Argo profiles of temperature and WOA 2009 thermal data are available to validate the results. The satellite derived products are as follows,

SSHA Data

Daily Sea Level Anomalies (SLA) from multi-mission altimeter data products in 1/3-degree. They are produced by Ssalto/Duacs and distributed through www.aviso.oceanobs.com of AVISO (Archiving Validation and Interpretation of Satellite Data in Oceanography). The products are generated from an active microwave sensor, the altimeter. The Ku and C band microwave signals collected from its nadir view of the polar orbiting satellites operated in different orbital modes depending on the requirement of experimental design. They provide along track data on satellite range information, which is converted to SSHA adopting several complex correction associated with waves, tide, water vapor, rainfall, Total Electron Concentration in upper atmosphere, and precisely locating the signal by Doppler Reflectrometry (DIRIS) and Lidar Ranging (LRA) on the Earth’s surface. These data sets are available in different modes for their along the track observation. AVISO maps these products and blend with other contemporary missions providing similar products. Even ISRO provide SSHA products from its SARAL mission with high accuracy with many improvements in the coast waters. However, the data remain inadequate to build up smooth maps of SSHA on daily basis in high spatial resolutions at the sea. Hence, merged databases with AVISO are used provide better results. Hence, daily grided SSHA database are selected for the present exercise between 40 -120 E and 0-30N of the north Indian Ocean.

SST Data

The microwave SST data has been used in the present study. Earlier SSTs are used from TMI and now from AMSR2. The AMSR2 is launched on 18 May 2012 flown by JAXA's GCOM-W1 spacecraft providing full global coverage over the oceans. The satellite in near-polar orbit collects data twice daily for a given Earth location. The instruments are dual-polarized passive microwave radiometers. As a microwave instrument, it can "see" though clouds. The only obstacle is heavy precipitation. The geophysical products are SST, surface wind speed, vertical column vapor and cloud water, and rain rate. The instrument is a successor of JAXA's AMSR of EOS (AMSR-E) on the NASA's Aqua satellite, which was launched in May 2002. AMSR2 SSTs are having the advantages of better coverage than TMI towards the polar region. The sensitivity of the instrument is better due to presence of additional low frequency bands. Hence replacing SST of AMSR2 in place of TMI is a good alternative, since the products available from the site over the net have similar format. This helps OHC product generation simpler.

The OHC products are estimated based on SST and SSHA with reference to the methods developed by Ali et al (2012). The OHC is estimated at 50, 100, 150, 200, 300, 500, and 700 m depth levels and TCHP with reference to 26^{o}C isotherms. The OMT is estimated as a supplementary product. The products are mapped to quarter degree and data sets made available to user as one degree grid scales through the NRSC web site.

3. Methodology

Daily OHC products are estimated at seven different depths of water column along with TCHP and OMT. The SST and SSHA are acquired from Remote Sensing Systems (RSS) and AVISO web site, respectively over the net. Artificial Neural Network algorithms with a feed forward neural network method of multi-layer perception where one input layer, three hidden layer and one output layer are used to compute OHC products (pl see for details on the previous version of this technical report). They are broadly described as follows,

1. Download Global SSHA, SST datasets
2. Sub-set to Indian region (40-120 E; 0-30 N)
3. Re-grid SSHA onto SST database
4. Calculation of OHC, OMT at seven different depth and TCHP with reference to 26^{o}C isotherm from climatology values
5. The estimation used Artificial Neural Network Model
6. Output products stored as NetCDF files
7. Generation of visuals for Bhuban display and text products for user

The computation of OHC and their visualisation has shown in following flow diagram (Figure 1). The programs are interlinked through different modules of software and automated to visualize daily thorough Bhuban web site of NRSC.

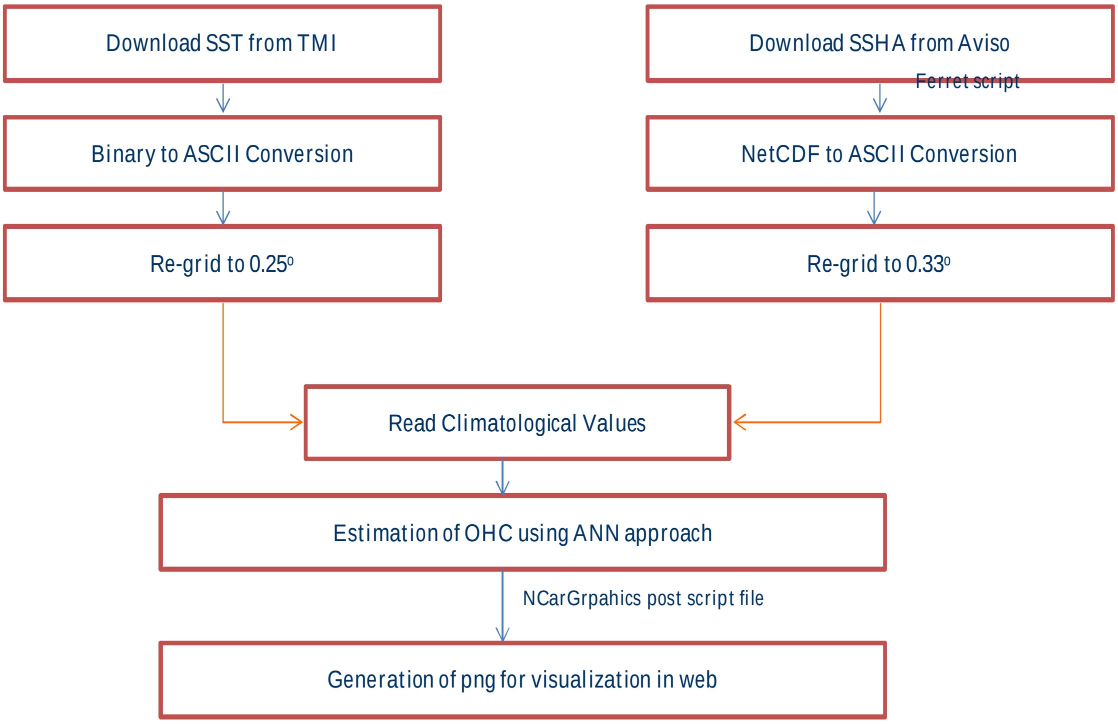


Figure 1: Flow diagram show generation of OHC at different depth and related products.

4. Results and Discussion

SST comparisons

The OHC estimations at NRSC have used TMI SST and being replaced by AMSR2 SST for future product generation. The SSTs of AMSR2 and TMI are compared for overlapping days of January 15 and July 15 of 2014. This has shown good relationship (R2> 0.94; Figure 2a). Figure 2b shows the spatial distribution of SST on 15 January 2014. Their deviations have shown changes in a narrow range of +/- 0.5°C. This can be attributed to change in sensors and algorithms adopted for SST estimations. AMSR2 SST algorithms are using 6.93 and 7.3 GHz frequencies sensitive to ocean surface temperature than 10.65 GHz used in TMI (Table 1a and b). Besides improvements in water vapor and rainfall filters expect better SST with AMSR2 algorithms. Hence, OHC and related products are also expected to improve in future estimations.

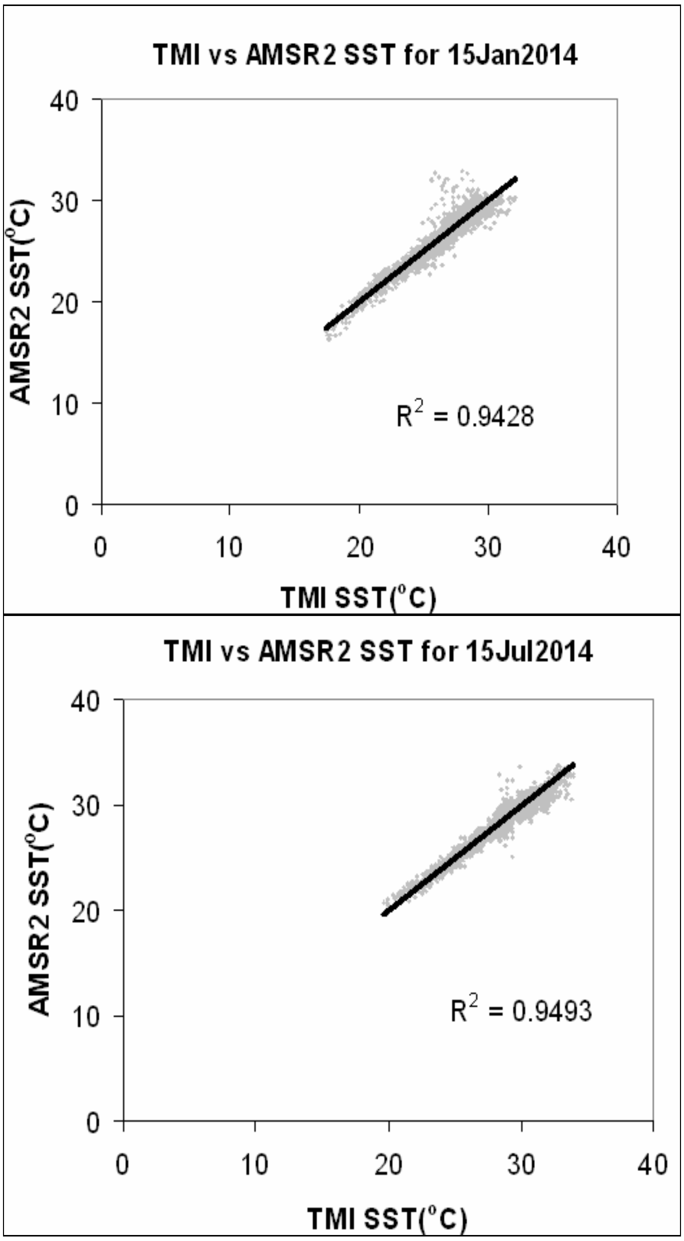


Figure-2a: SST comparisons are made between TMI and AMSR2 SST (°C) for 15 January 2014 (left) and 15 July 2014 (right).

Table 1a: AMSR SST product details.

Acronym	Product Name	Product Description	Scale	Offset	Valid Data Range	Reason for No Data
SST	Sea surface temperature	Temperature of top layer (skin) of water ~1 mm thick	0.15	-3.0	-3 to 34.5 deg	high winds (<20 m/s), sun glint, rain, RFI, near sea ice or land (~75 km)
TIME	Time	Minutes since midnight GMT Fractional hour of day GMT	6.0 0.1	0. 0.	0 to 1440 0.0 to 24.0	no data

Table 1b: AMSR2 and TMI Sensor specifications

AMSR2 Band [GHz]	Polarization	Spatial Resolution (3-dB footprint size) [km x km]	TMI Band [GHz]	Polarization	Spatial Resolution (3-dB footprint size) [km x km]
6.93	V,H	62 x 35			
7.3	V,H	62 x 35			
10.65	V,H	42 x 24	10.65	V,H	63 x 37 / 72 x 43
18.7	V,H	22 x 14	19.35	V,H	30 x 18 / 35 x 21
23.8	V,H	19 x 11	21.3	V	23 x 18 / 26 x 21
36.5	V,H	12 x 7	37.0	V,H	16 x 9 / 18 x 10
89.0	V,H	5 x 3	85.5	V,H	7 x 5 / 8 x 6

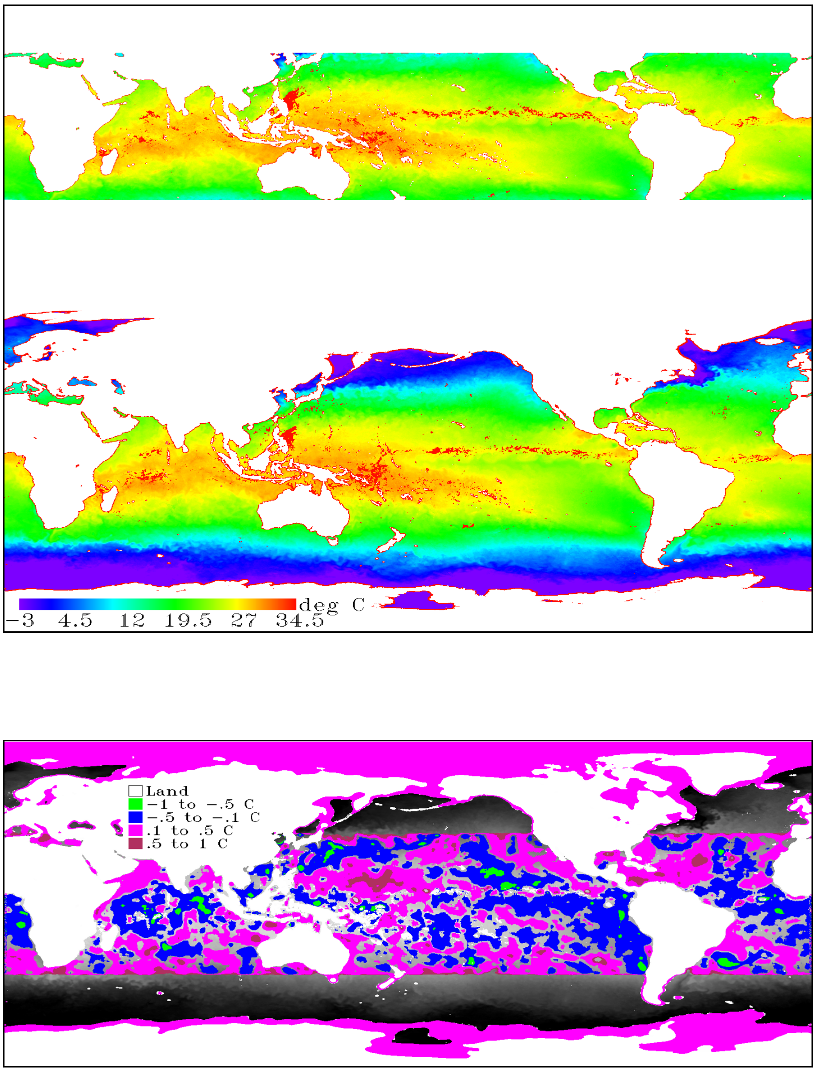


Figure-2b: Global distribution of TMI (upper) and AMSR2 (middle) SST and their differences (lower) on 15 January 2014.

OHC comparisons

The OHC from AMSR2 SST for water columns between 50 m and 700 m are compared with estimations made with TMI data on monthly basis for overlapping phase on both the data sets in 2014. Table 2a provides overall statistics of OHC estimations. They are as follows,

Table 2a: Statistics of OHC of AMSR2 and TMI based observations.

OHC	50m	100m	150m	200m	300m	500m	700m
RMSE	3.08	2.37	2.89	4.51	7.16	6.95	7.9
r	0.999	0.994	0.999	0.993	0.999	1	1
Mean	571	1083	1491	1819	2369	3289	4085

Table -2b: Monthly relationship (R^2 values) of OHC estimated at 50 to 700 m using TMI and AMSR2 based SST.

Month/Depth	50	100	150	200	300	500	700
JAN	0.985	0.997	0.998	0.998	0.998	0.999	0.999
FEB	0.985	0.997	0.998	0.997	0.997	0.999	0.999
MAR	0.987	0.998	0.999	0.998	0.998	0.999	0.999
APR	0.992	0.998	0.998	0.997	0.997	0.999	0.999
MAY	0.985	0.998	0.997	0.995	0.996	0.999	0.999
JUN	0.999	0.996	0.998	0.997	0.996	0.999	0.999
JUL	0.99	0.998	0.999	0.999	0.997	0.999	0.999
AUG	0.993	0.998	0.999	0.999	0.997	0.999	0.999
SEP	0.986	0.998	0.999	0.999	0.998	0.999	0.999
OCT	0.98	0.999	0.999	0.998	0.997	0.999	0.999
NOV	0.983	0.999	0.999	0.998	0.997	0.999	0.999
DEC	0.973	0.998	0.999	0.998	0.997	0.999	0.999

The good relationship ($R^2 > .98$) between the OHC data products derived from TMI and AMSR2 is seen through all the months and depths of their estimation (Table-2b). The reduction in relationship of upper layer is due to higher level of variation in the geophysical parameters.

Figure 3 show OHC comparison between at 50 m and 700 m depth. They are found well related to each other (R^2 >0.973). The mean values at estimated depths ranged from 571 at 50 m to 4085 kJ/cm^2 at 700 m depth (Table 2a). The OHC at 50 m depth ranged between 450 and 650 kJ/cm^2 (RMSE 3 kJ/cm^2). With increasing depth, mean value have increased and RMSE. The range of their variation has also changed. The range of OHC has remained low at around 200 and 300 m depth. The low levels of change in heat content in middle region indicate lateral flux of heat, which need further investigation. At 700 m depth, the variations are in the range of -21.14 to 22.13 kJ/cm^2, which has changed from -19.68 to 11.71 kJ/cm^2 at 500 m depth. The low range of their variation provides confidence in utilization of data sets.

Figure 4 establishes through a cumulative figure of all these changes under a single scale. The relationships in linear mode between AMSR2 and TMI observations has shown R^2 >0.96 with slope of the trend remained at .98. The bias for all these relationships has changed from -14.75 (for TCHP) to 13.56 at 700 m depth. The negative bias in surface layer indicates warming in surface layer and cooling in deeper layer with reference to AMSR2 SST. TCHP has shown warming up of ~14 kJ/cm^2 with new estimation which has varied to a maximum value of 140 kJ/cm^2 (Figure 6). The range of variation has remained insignificant and allows using OHCs and related products estimated with TMI

SST fields in the past. However, reprocessing of past OHC with new algorithm is required.

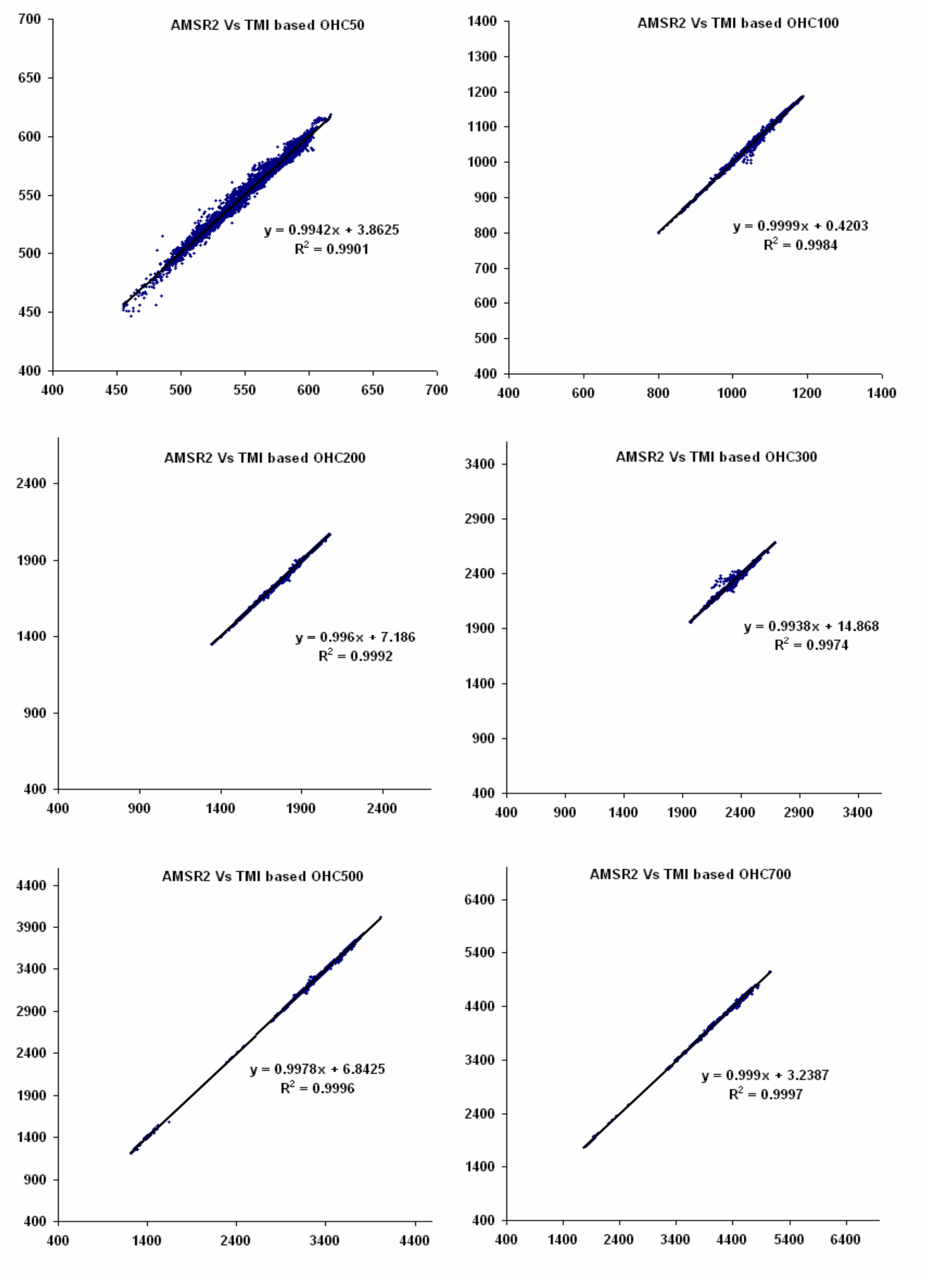


Figure-3: Comparison of OHC (kJ/cm^2) between AMSR2 and TMI (^{o}C) based SST.

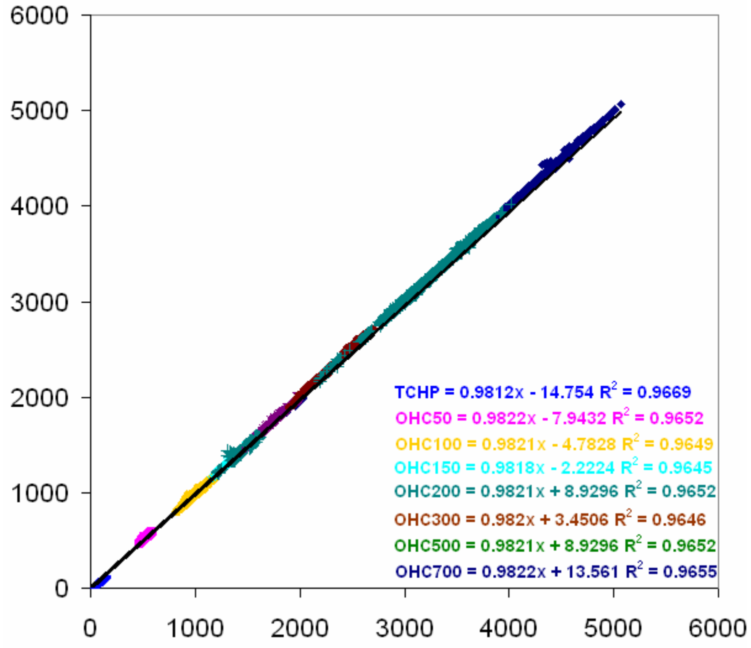


Figure 4: A cumulative relationship of all the layers of OHC between 50 to 700 m and TCHP in kJ/cm^2 (X-axis is with AMSR2 SST and Y-axis is with TMI SST)

The changes are hardly visible in the classified maps as those have been grouped in the scales much larger than their variance level. Figure 5a and 5b shows OHC at four different levels of 50, 200, 500 and 700 m as estimated using TMI and AMSR2 based SSTs. A marginal variation is observed at the boundary zones and in the coastal waters. The OHC maps on 15 January and July in 2014 representing two contrasting sessions in the Indian Ocean region could hardly show any significant variations in the OHC estimation. Similarly, TCHP, the ocean heat estimated with reference to 26^{o}C isotherm, and OMT derived from TCHP have followed a good co relationship in their comparisons.

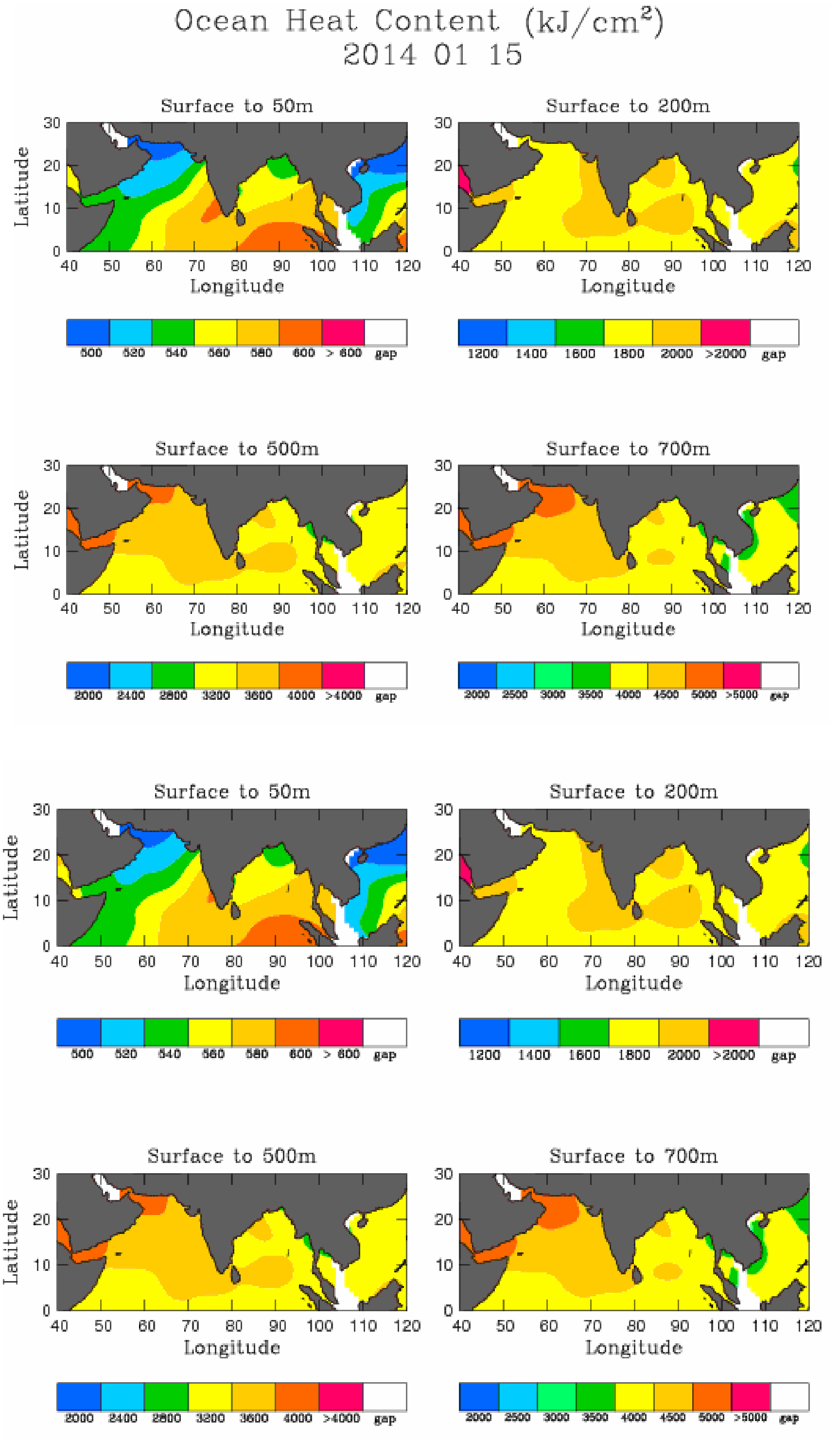


Figure-5a: OHC of 15 January 2014 for 50, 200, 500 and 700 m as computed wrt SST of AMSR2 (top) TMI (bottom).

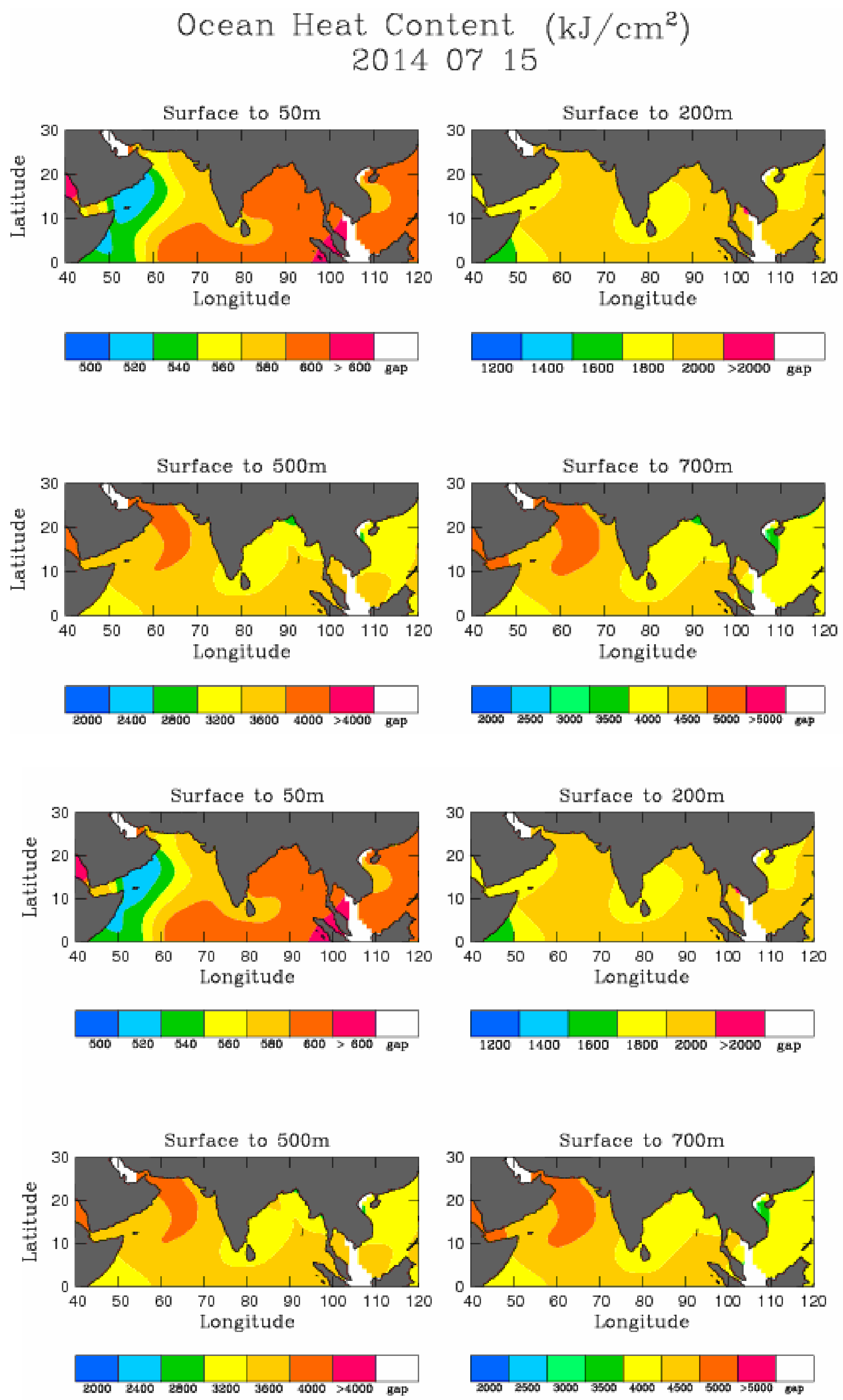


Figure-5b: OHC of 15 July 2014 for 50, 200, 500 and 700 m as computed with reference to SST of AMSR2 (top) TMI (bottom).

TCHP comparisons

TCHP from AMSR2 has been compared with TCHP of TMI data. A positive bias of -0.2258 kJ/cm^2 is observed with in a range of 0 and 140 kJ/cm^2 with very good co-relation coefficient, R^2 of 0.9868 (Figure 6). AMSR2 SSTs provide a marginally higher TCHP than earlier estimations. Figures 7a and 7b are the spatial distribution on 15 January and 15 July of 2014. They could show hardly any difference in AMSR based TCHP and TMI distribution pattern. The differences are low in January and July 2014. A minor change is observed in the equatorial region around southern India.

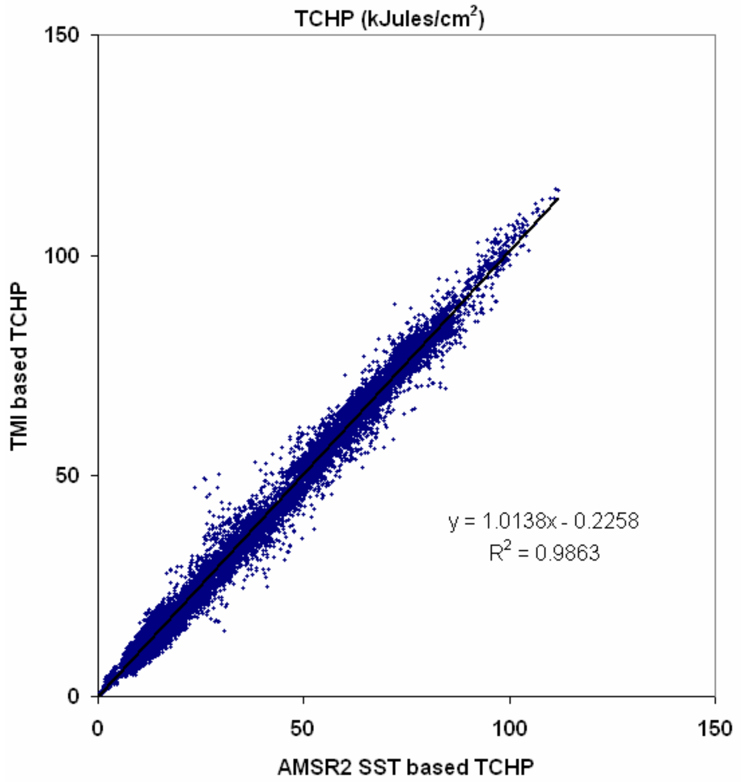
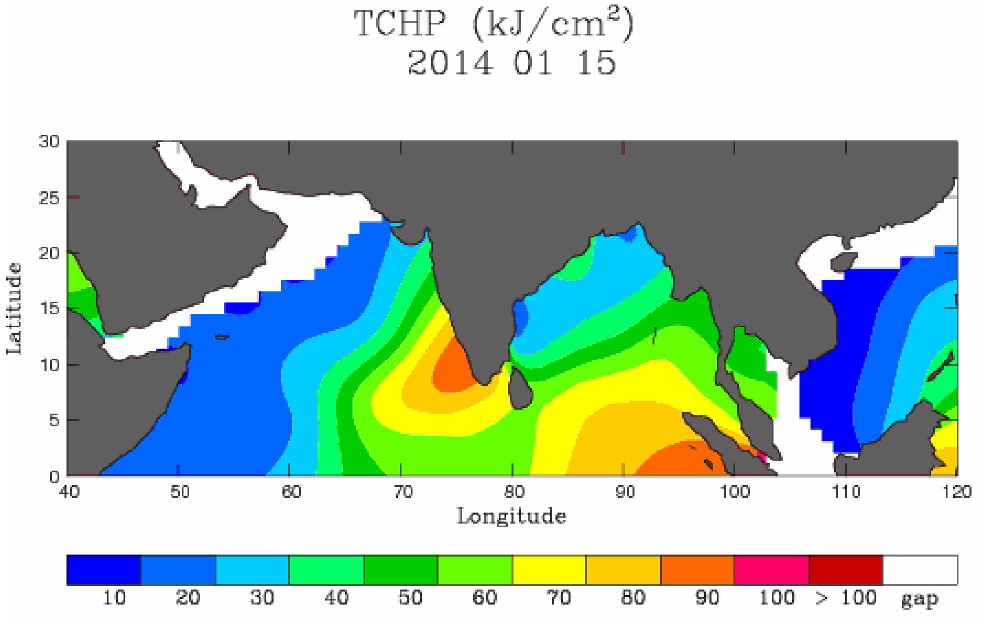


Figure-6: TCHP is compared between TMI and AMSR2 SST (^oC).



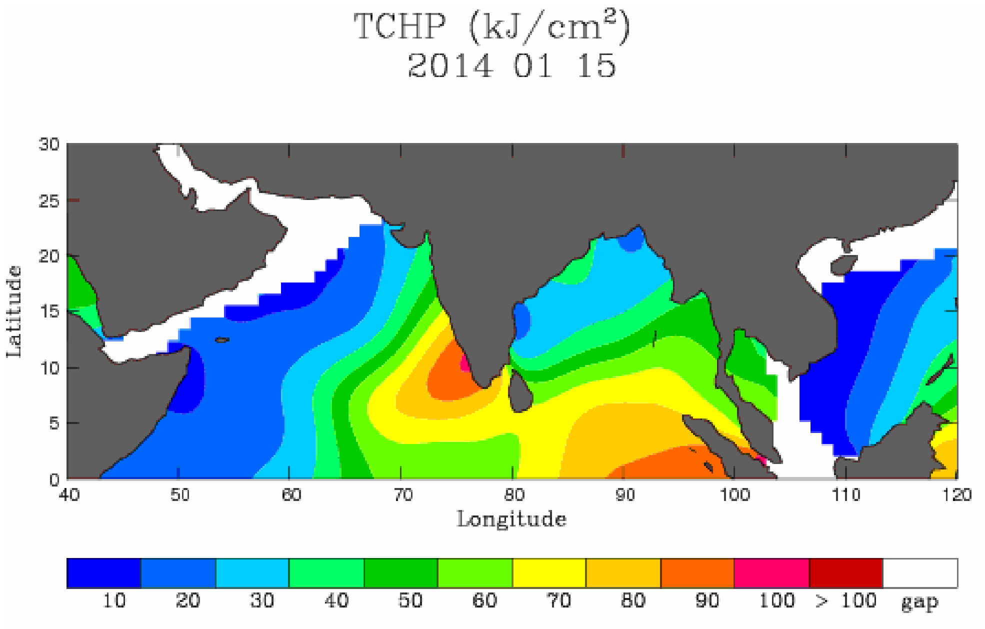


Figure-7a: TCHP of 15 January 2014 for 50, 200, 500 and 700 m as computed wrt SST of AMSR2 (top) TMI (bottom).

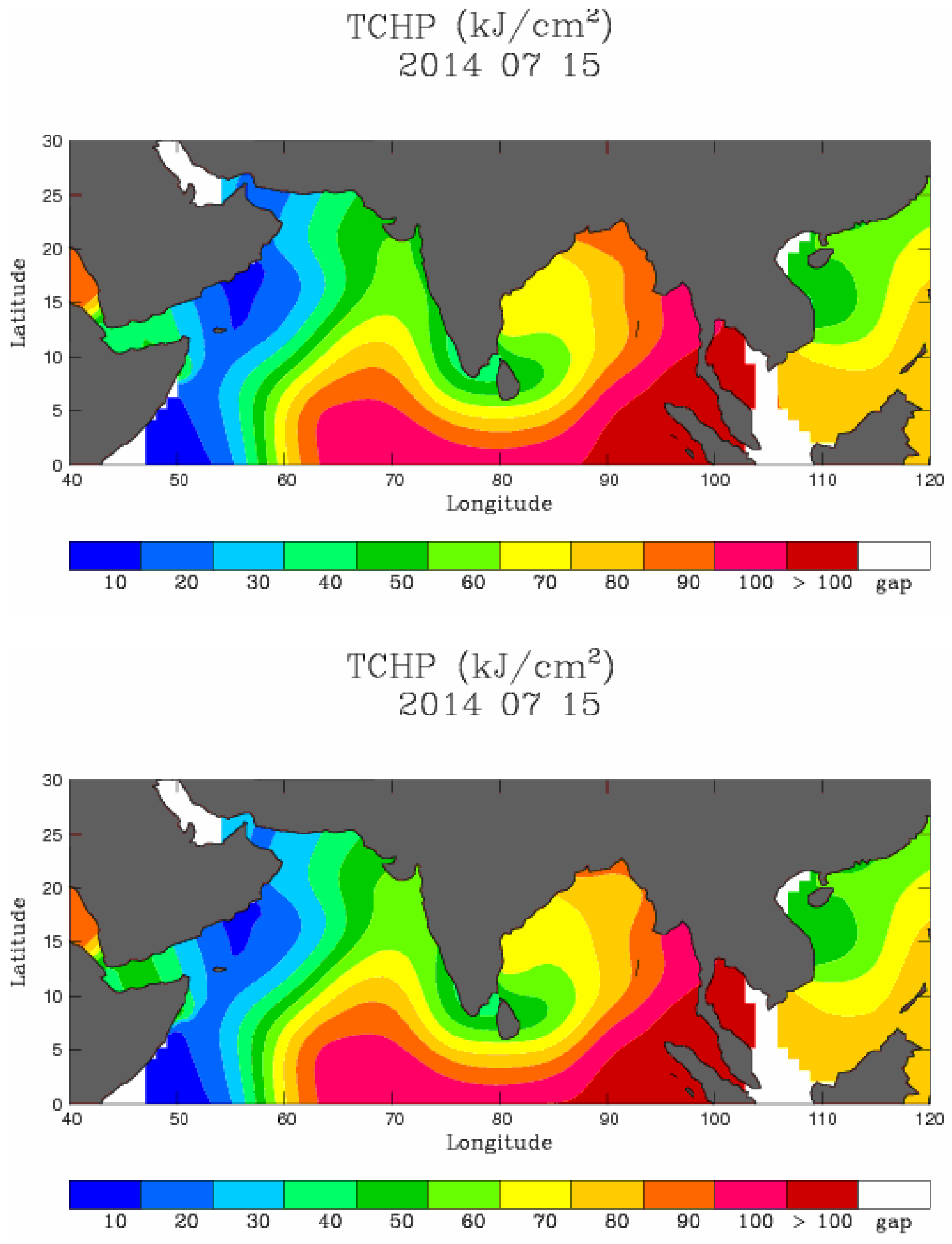


Figure-7b: TCHP of 15 July 2014 for 50, 200, 500 and 700 m as computed with reference to SST of AMSR2 (top) TMI (bottom).

OMT comparisons

The OMT estimation with AMSR2 is similar to that of TMI in both the seasons as seen with reference to observations compared for January and July data. AMSR2 SSTs are cooler by 0.65°C for the seas warmer than 26°C (Figure 8). Figures 9a and 9b show spatial distribution of OMT values for January and July 15 of 2014. They are found well related to each other.

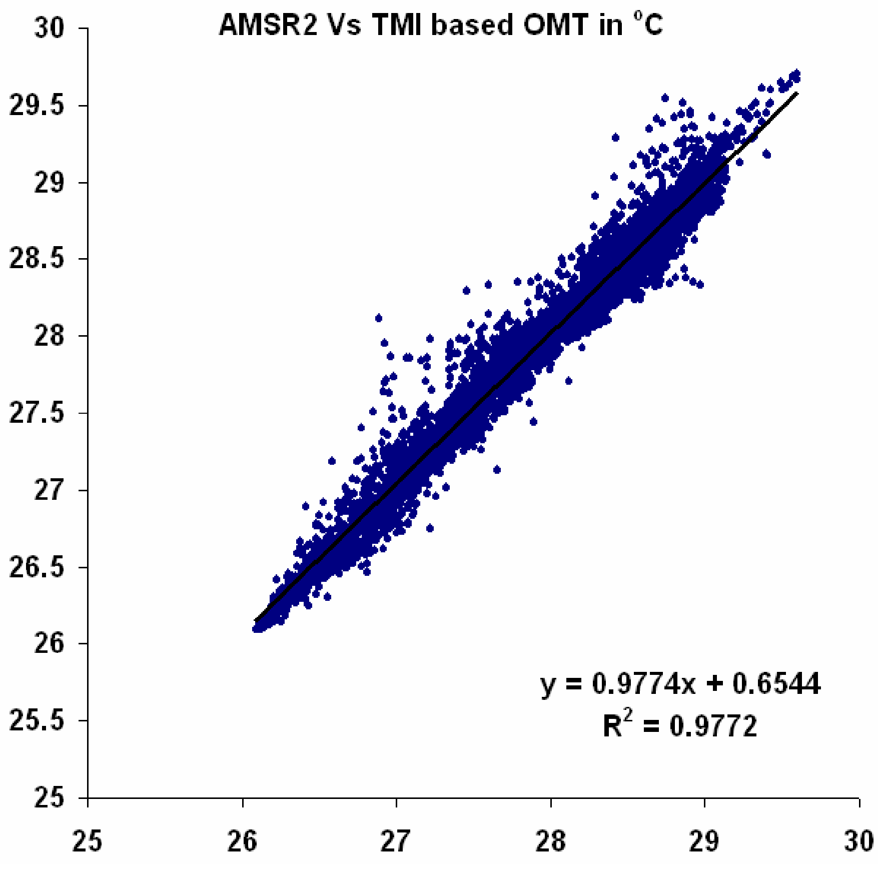


Figure-8: OMT with reference to SST of AMSR2 and TMI.

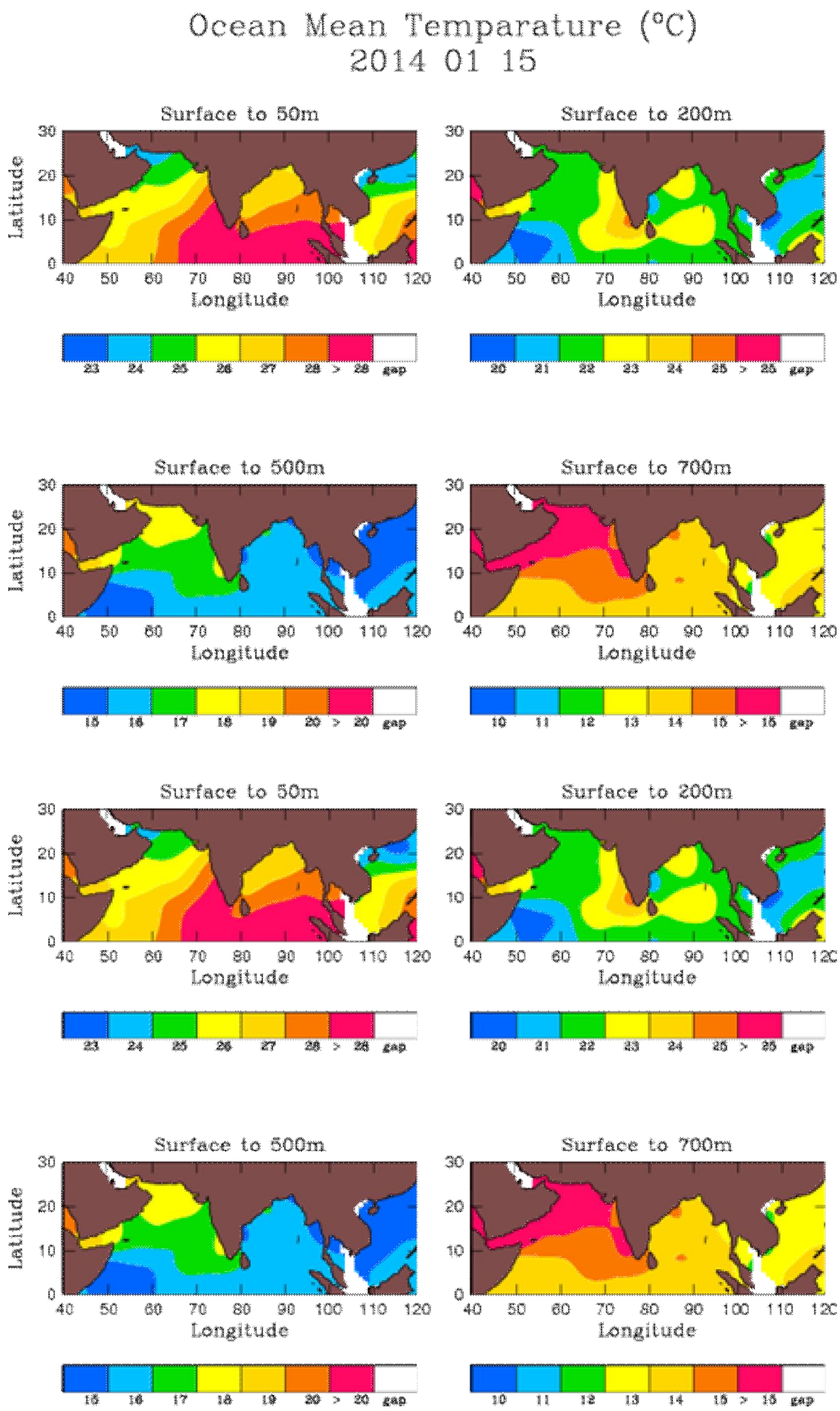


Figure-9a: OMT of 15 January 2014 for 50, 200, 500 and 700 m as computed with reference to SST of AMSR2 (top) and TMI (bottom).

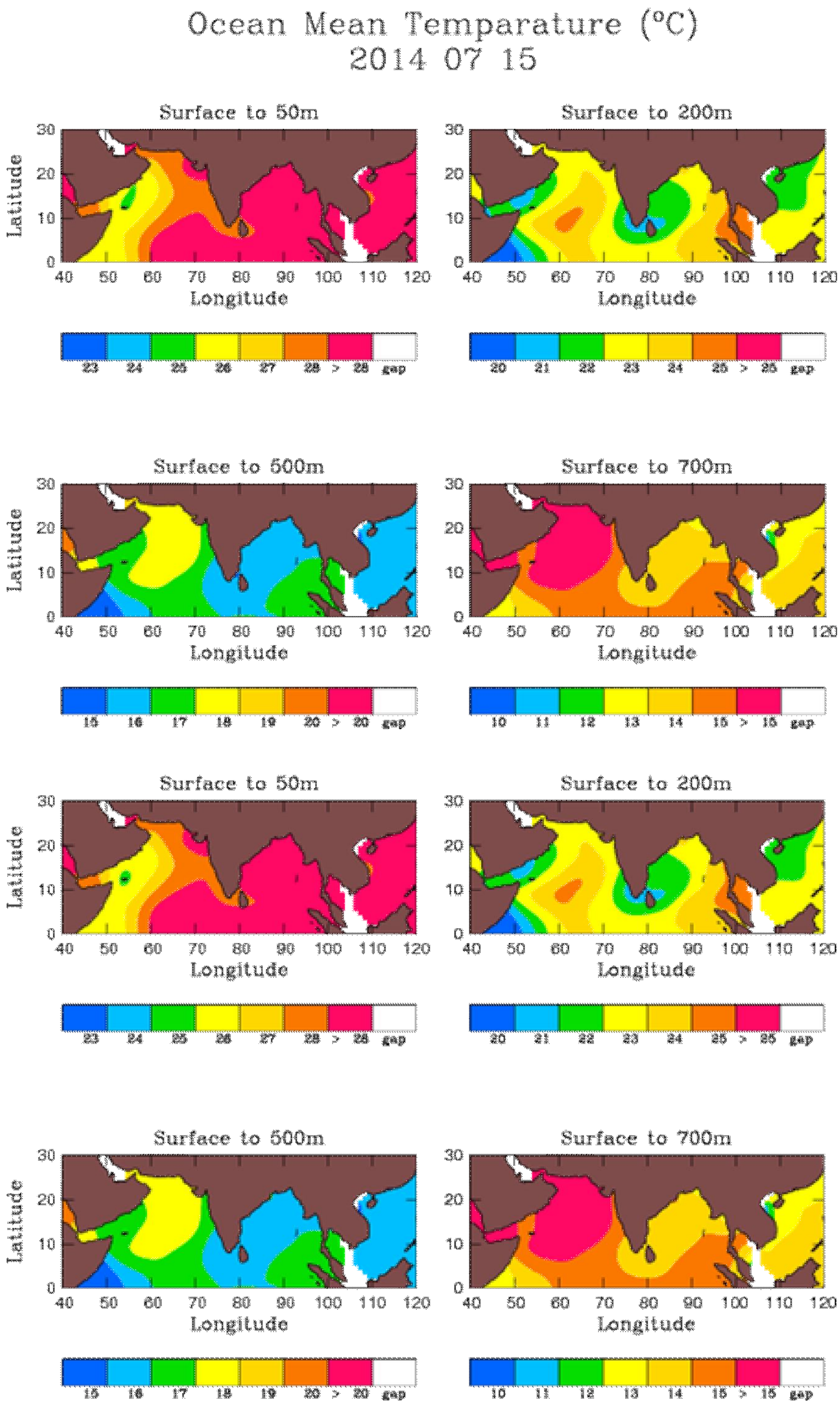


Figure-9b: OMT of 15 July 2014 for 50, 200, 500 and 700 m as computed with reference to SST of AMSR2 (top) and TMI (bottom).

The OHC estimations are strongly correlated to each other in all levels of their estimation ranging from 50 m to 700 m. TCHP estimated with reference to 26^{o}C isotherm and OMT too have also shown a good relationship in the months of contrasting season prevails in the area. The observations in contrasting seasons provide are expected a wide range of observation.

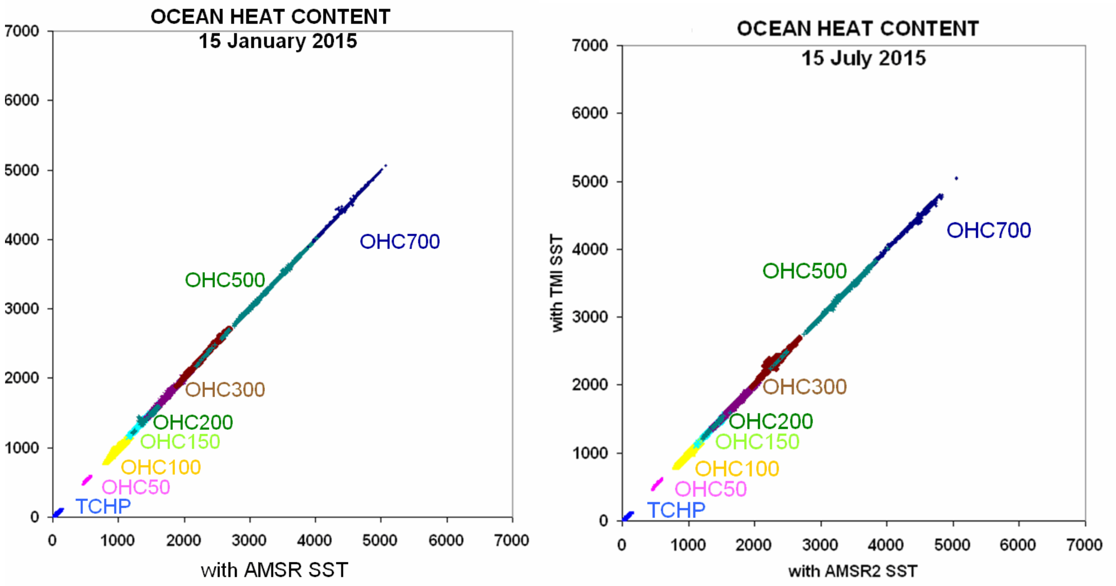


Figure-10: Comparison of TCHP, OHC for 50 to 700 m depth, OMT of January and July 15, 2015 as computed with reference to SST of AMSR2.

4. Conclusions

The continuity of generating of OHC at seven different depths along with TCHP and OMT is maintained with the use of AMSR2 SST in place of TMI SST. The products are found well related to TMI based OHC products estimated earlier. The marginal deviations observed is planned to improve further in its accuracy with suitable modification to OHC algorithms and reprocessing of old database.

Acknowledgements

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