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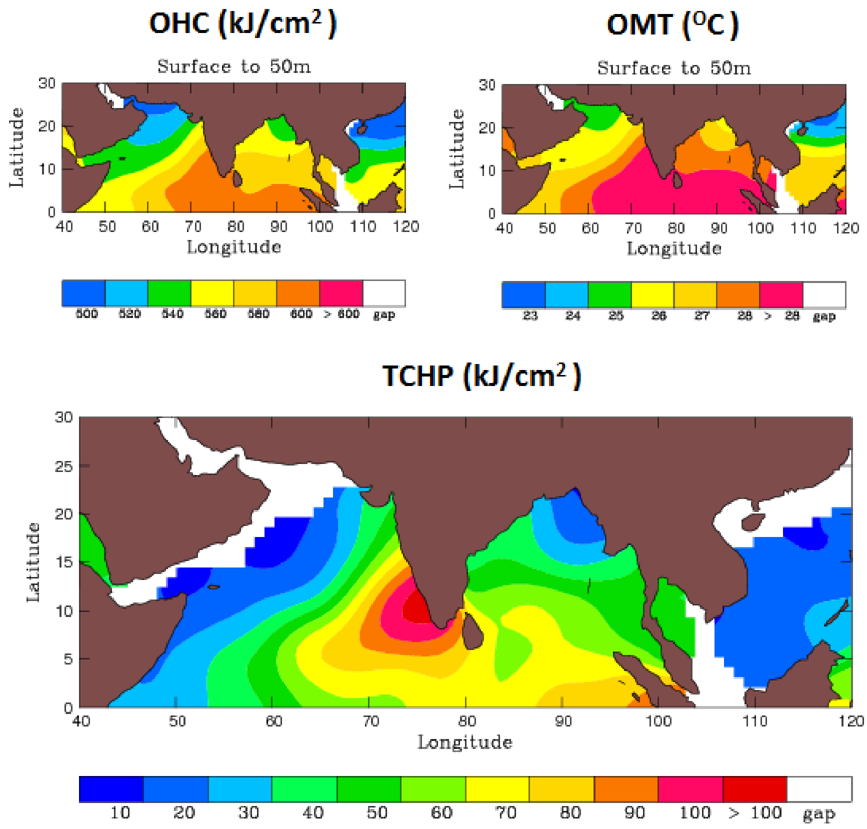
Computation of Ocean Heat Content, Ocean Mean Temperature of 7 layers on Operational basis



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15.	**Abstract:** Ocean heat content (OHC) and Ocean Mean Temperature (OMT) are important climatic parameters required for atmospheric and oceanic studies like cyclone and monsoon predictions and ocean heat transport estimations. The data used to estimate these parameters are (a) sea surface height anomaly (SSHA) from the available altimeters, (b) sea surface temperature (SST) from Tropical Rainfall Measuring Mission (TRMM) Microwave Imager (TMI) and the climatological values of OHC and OMT of various depths (50, 100, 150, 200, 300, 500, 700m and TCHP as an integral of OHC from surface to 26^{o}c isotherm and it's mean temperature). These parameters are estimated on a daily basis from 1998 to present with a delay of 3 days using artificial neural network techniques. The estimated OHC and OMT values are validated with independent data set and are found to be significantly correlated with the observed values. These products are made freely available and downloadable at http://bhuvan.nrsc.gov.in/data/download/index.php				

COMPUTATION OF OCEAN HEAT CONTENT, OCEAN MEAN TEMPERATURE OF 7 LAYERS ON OPERATIONAL BASIS

1. Abstract

Ocean heat content (OHC) and Ocean Mean Temperature (OMT) are important climatic parameters required for atmospheric and oceanic studies like cyclone and monsoon predictions and ocean heat transport estimations. The data used to estimate these parameters are (a) sea surface height anomaly (SSHA) from the available altimeters, (b) sea surface temperature (SST) from Tropical Rainfall Measuring Mission (TRMM) Microwave Imager (TMI) and the climatological values of OHC and OMT of various depths (50, 100, 150, 200, 300, 500, 700m and TCHP as an integral of OHC from surface to 26^{o}c isotherm and it's mean temperature). These parameters are estimated on a daily basis from 1998 to present with a delay of 3 days using artificial neural network techniques. The estimated OHC, OMT values are validated with independent data set and are found to be significantly correlated with the observed values. These products are made freely available and downloadable at http://bhuvan.nrsc.gov.in/data/download/index.php

2. Introduction

Ocean thermal energy is one of the key factors fueling the genesis and propagation of cyclones. Prediction of tropical cyclone intensity has been a challenging problem. Utilization of this thermal energy to improve the atmospheric models for cyclone and monsoon predictions has been realized in recent years [8].

Ocean Heat Content (OHC), an important ocean climatic parameter in determining the heat flux in the ocean-atmosphere system, can influence the weather systems like cyclones and monsoons. Hence, a precise estimate of OHC is essential for understanding the role of oceans in assessing the past and future climate change. Heat content of a slice of the ocean can be estimated as a product of integrated temperature, density of sea water and specific heat capacity from the surface down to a required depth. It is obtained by summing the heat content of the ocean column from the sea surface to a particular depth. OHC can be computed from *in situ* measurements from the equation (1).

$$OHC = C_p \int_{h2}^{h1} \rho T dZ \qquad \text{...(1)}$$

Where ρ is the density of the sea water, C_p is the specific heat capacity of the sea water at constant pressure, p; h1 is top depth, h2 is bottom depth and T is the temperature in ^{o}C.

The best approach for computing OHC is to use the *in situ* measurements, but due to the limited availability of *in situ* temperature profiles in space and time, remotely sensed sea surface temperature (SST) and sea surface height anomalies (SSHA) are employed in the computation of OHC in the Indian Ocean. OHC derived from *in situ* temperature profiles from ARGO floats along with collocated SST, SSHA and OHC climatology are generally used to estimate OHC values at various depths using an artificial neural network model [1]. Using this approach, these parameters are estimated daily on near real time basis.

An example temperature profile shown in below Fig [1]. As the depth increases the ocean temperature decreases. The Argo program measures the temperature and salinity of ocean surface waters around the world. It has deployed 3,000 free-drifting floats all over the ocean to measure the salinity and temperature throughout the surface layer of the ocean. Each float is programmed to sink to 2,000 meters down, drifting at that depth for about 10 days. The float then makes its way to the surface measuring temperature and salinity while popping up. Data is transmitted through the satellite communication once the float reaches the surface. Temperature profiles are also available from XBT (eXpendable Bathy Thermograph) and CTD (Conductivity, Temperature, Depth).

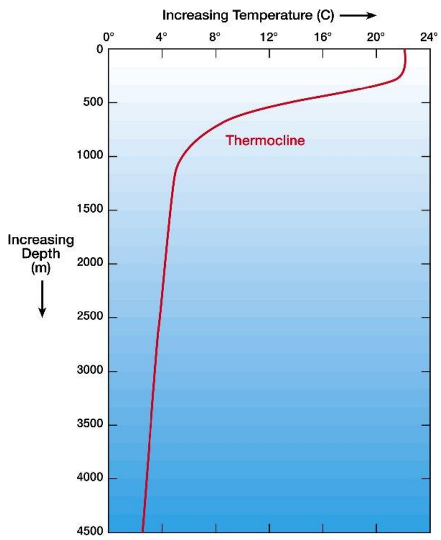

Fig. 1. Simple temperature-depth ocean water profile

The SST is the skin temperature of a very thin layer of about a few micrometres of the ocean. The SST has direct interaction with atmosphere. This has been the only oceanographic parameter used to represent the ocean heat energy. However, tropical cyclones and monsoons have long been known to interact with the deeper layers of the ocean than sea surface represented by the SST alone. The SSHA provides an integrated picture of ocean from bottom to surface. Typically, positive (negative) SSHAs correspond to more (less) upper OHC/OMT. Such information has been used to study tropical cyclones [5].

Since the SSHA is strongly correlated with the thermal structure of the upper ocean, the OHC can be estimated from this parameter over finer spatial and temporal scales on an operational basis. Ali et al. (2012) suggested a better method of estimating tropical cyclone heat potential from SSHA and sea surface temperature (SST) using a neural network approach [1]. Here, we use a similar approach. The only difference is (i) heat content, mean temperature values are made available up to various depths 50m, 100m, 150m, 200m, 300m, 500, 700m and surface to 26^{O}C isotherm instead of providing heat content values only up to 700m [3][1] . We have estimated at various depths because as of now we do not have a database information on which layer of the ocean interacts with different atmosphere process.

The ANN is a massive parallel-distributed computer model consisting of simple processing units called artificial neurons which are the basic functioning units. The ANN has been widely used in various meteorological, oceanographic, atmospheric studies and satellite remote sensing retrievals [6] [7]. In the present analysis, we used multilayer perceptions, which are feed-forward neural networks, with one input layer, three hidden layers and a one output layer. The input (independent) parameters are SSHA, SST and OHC_{clim} / OMT_{clim}. Dependent parameter is the $OHC_{\textit{in situ}}$ / $OMT_{\textit{in situ}}$

The data are available on near real time basis for a researcher to download from the NRSC Bhuvan website from 1998 onward over the north Indian Ocean spanning 0^{O} N - 30^{O} N and 40^{O}E - 120^{O}E.

3. Data and Methodology

Following data have been used in this ANN approach for estimating OHC, OMT:

- **SSHA**: Aviso (Archiving, Validation and Interpretation of Satellite Oceanographic data) distributes satellite altimetry data from Topex/Poseidon, Jason-1, ERS-1 and ERS-2, and EnviSat and Geosat Follow On (GFO) products worldwide since 1992. Since launches of new altimetric mission, series of products has been completing the *Aviso* catalogue. Ssalto/Duacs Gridded Sea level anomalies (1/3°x1/3° on a Mercator grid) is a gridded SSHA computed with respect to a 7-years mean [1993 to 1999] and are provided in near-real-time and in delayed time bases. Recently aviso(v15.0) updated the ssha files at the resolution of 0.25° as a reference mean of 20 years [1993 to 2012] period.(http://www.aviso.altimetry.fr/en/data/products/sea-surface-height-products/global/ssha.html)

Corrective steps are taken in SSHA data to ensure this consistency between the Map of Sea Level Anomaly (M*SLA)* and Mean Dynamic Topography (*MDT)* products. The obtained M*SLA* is equivalent to the former DUACS products by changing the M*SLA* reference period using Equation-2

$$SLA\_7y = SLA\_20y - ref20yto7y \quad \ldots\ldots (2)$$

Where SLA_7y is the seven years mean,
SLA_20y is the mean of 20 years and
ref20yto7y is the Change of reference from 20 years to 7 years.

- **SST**: The Tropical Rainfall Measuring Mission's (TRMM) Microwave Imager (TMI) is a multi-channel, dual polarized, conical scanning passive microwave radiometer designed to measure rain rates over a wide swath under the TRMM satellite. This radiometer is well-calibrated, and contains lower frequency channels (10.7 GHz channel) required for SST retrievals. SSTs from TMI are the first satellite microwave SSTs available and proved to be of great value to tropical cyclone intensity forecasting and research. The TMI data are provided as daily maps (separated into ascending and descending orbit segments). The data are available from December 1997 to the present, and covers a global region extending from 40^{o}S to 40^{o}N at a resolution of 0.25 deg (~25 km). The important feature of microwave retrievals is that SST can be measured through clouds, which are nearly transparent at 10.7 GHz. Ocean areas with persistent cloud coverage can now be viewed on a daily basis. Furthermore, microwave retrievals are insensitive to atmospheric water vapor.
- **OHC_{clim} up to 50, 100, 150, 200, 300, 500, 700m and up to 26^{o}c depths**: The climatological values of OHC are estimated from the temperature profiles of World Ocean Atlas 2009 [2].
- **$OHC_{in\ situ}$ up to 50, 100, 150, 200, 300, 500, 700m and up to 26^{o}c depths**: OHC values are estimated using the Argo *in situ* temperature profiles from 1998 to 2013.
- **Average $Temparature_{clim}$ at 50, 100, 150, 200, 300, 500, 700m and up to 26^{o}c depths**: The climatological values of average temperature are estimated from the temperature profiles of World Ocean Atlas 2009 [2].
- **Average $Temparature_{in\ situ}$ at 50, 100, 150, 200, 300, 500, 700m and up to 26^{o}c depths**: The climatological values of average temperature are estimated using the Argo *in situ* temperature profiles from 1998 to 2013.

SSHA data is of 0.25°x 0.25° resolution and SST is of 0.25° x 0.25° resolution. These SST and SSHA satellite observations are collocated with the *in situ* OHC, OMT estimations and a climatological value of OHC_{clim}, OMT_{clim} are assigned to this data set depending upon the grid and month of the observation. Following [1], an artificial neural network (ANN) model is developed between $OHC_{in\ situ}$,$OMT_{in\ situ}$ and SSHA, SST, OHC_{clim} and OMT_{clim} separately for OHC/TCHP and OMT . This relation is used to further compute the OHC, OMT from satellite observations on a day-to-day basis. In the present approach we used 6200 in situ observations during 2001-2006 to develop the model, 5200 observations during 2007-2010 for verification and 2600 independent observations during 2011-2013 to validate the model. This ANN model is used to estimate OHC and OMT on near time basis [4]. The output is stored as both ASCII data file and NetCDF format. For visualization PNG files are also generated for TCHP and OMT, OHC at few sample layers at 50m, 200m, 500m, and 700m.

4. Validation Results

Table 1: Statistical analysis of the validation dataset (independent data not used to develop the model) results. DM: Data mean of the *in situ* observations; MD: Mean difference; SDD: Standard deviation of the difference between *in situ* and estimated observations; AMD: Absolute mean difference; SI: Scatter index (SDD/DM).

Depth (m)	**DM kcal/cm² (°C)**	**MD kcal/cm² (°C)**	**SSD kcal/cm² (°C)**	**AMD kcal/cm² (°C)**	**SI**	**Corr. Coeff.**
50	551.8 (27.5)	-2.15 (0.09)	12.99 (0.63)	9.36 (0.45)	0.024 (0.023)	0.93 (0.93)
100	1068.6 (26.1)	-7.95 (0.18)	32.04 (0.78)	25.65 (0.63)	0.030 (0.030)	0.90 (0.90)
150	1481.6 (24.3)	-15.69 (0.00)	48.44 (0.82)	40.02 (0.63)	0.033 (0.033)	0.87 (0.87)
200	1823.7 (22.3)	-20.84 (0.25)	58.97 (0.71)	49.58 (0.46)	0.032 (0.032)	0.85 (0.86)

300	2375.5 (19.6)	-0.26 (0.16)	69.82 (0.56)	53.99 (0.46)	0.029 (0.023)	0.90 (0.89)
500	3383.4 (16.5)	-10.25 (0.05)	81.35 (0.39)	64.59 (0.31)	0.024 (0.024)	0.95 (0.95)
700	4226.6 (14.7)	-1.32 (0.01)	89.47 (0.31)	69.55 (0.24)	0.021 (0.021)	0.97 (0.97)
TCHP	61.1 (28.1)	-0.54 (0.01)	15.8 (0.34)	12.39 (0.26)	0.26 (0.012)	0.88 (0.90)

Out of the 14,000 observations, we used about 44% of the data set (nearly 6200 observations) during 2001-2006 for training the ANN model, about 38% (5200 observations) during 2007-2010 for verification, and 18% (2600 sets) during 2011-2013 for validation of the predicted results. [4]

Summary and Conclusions

OHC is one of the critical parameters for climate studies. In view of the limited *in situ* observations, satellite observations of SSHA, SST along with climatological values are being used to estimate these parameters. Since we do not have a clear understanding of which layers of the ocean interacts with which atmosphere process, we estimate OHC and OMT of various layers of the ocean. The estimations are validated with independent in situ measurements.

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1. SST data - US NOAA (National Oceanographic and Atmospheric Administration) for providing the ocean depth-temperature profiles.
2. SSHA - CNES/AVISO team for providing the altimeter product via http://www.aviso.oceanobs.com/duacs/
3. Argo data from many international partners in the International Argo Program

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References

[1] M M Ali, P S V Jagadeesh, I-I Lin, and Je-Yuan Hsu,2012, "A Neural Network Approach to Estimate Tropical Cyclone Heat Potential in the Indian Ocean", IEEE Geoscience and Remote Sensing Letters, DOI No: 10.1109/LGRS.2012.2191763 (IF: 1.8).

[2] R. A. Locarnini, A. V. Mishonov, J. I. Antonov, T. P. Boyer, H. E. Garcia, O. K. Baranova, M. M. Zweng, and D. R. Johnson, "World Ocean Atlas 2009, Volume 1: Temperature*".*

[3] Neethu Chacko, D Dutta, M M Ali, J R Sharma, and V K Dadhwal. "Near real time availability of Ocean heat content over north Indian Ocean", IEEE Geoscience and Remote Sensing Letters (in press)

[4] P S V Jagadeesh, M M Ali, and M Suresh Kumar. "Estimation of OHC and OMT of different ocean layers" (in prepation)

[5] N. Sharma, M M Ali, J. A. Knaff, and P. Chand, 2013, "A soft-computing cyclone intensity prediction scheme for the Western North Pacific Ocean". *Atmospheric Science Letters*, *14*(3), 187-192.

[6] M M Ali, D. Swain, and R. A. Weller, 2004, "Estimation of ocean subsurface thermal structure from surface parameters: A neural network approach". *Geophys. Res. Lett*., 31, L20308.

[7] I. I. Lin, G. J. Goni, J. A. Knaff, C. Forbes, M M Ali, 2013, "Ocean heat content for tropical cyclone intensity forecasting and its impact on storm surge." *Natural hazards* 66.3: 1481-1500.

[8] P. V. Nagamani, T. Venugopal, M M Ali, G. J. Goni, V. G. Krishna, T. U. Bhaskar, and V. Bhanu, 2012, "An Atlas of the Tropical Cyclone Heat Potential of the North Indian Ocean".