AN APPROACH TO PREDICT TEMPERATURE VERTICAL PROFILE OF THE OCEAN USING SATELLITE DATA

Jagath Rajapaksha,
National Aquatic Resources Research and Development Agency (NARA),
Crow Island, Colombo 15, Sri Lanka
Tel: +94 112520367 Fax: +94 112520367
Email: Jagath_r@hotmail.com

Satsuki Matsumura
Fisheries Research Agency
15F Queen's Tower B, 2-3-3 Minato Mirai, Nishi-ku, Yokohama, Kanagawa, JAPAN 220-6115
Tel: +81-45-227-2600 FAX : +81-45-227-2700
Email: smatsu@affrc.go.jp

Lal Samarakoon
Geoinformatics Center, Asian Institute of Technology, PO. Box4, Klong Luang,
Pathum Thani 12120, Thailand
Tel: +66 25246487 Fax: +66 25246147
Email: lal@ait.ac.th

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Abstract: Remote sensing techniques have been heavily used for monitoring surface properties of the ocean such as temperature, chlorophyll, ocean currents as the satellite being measured the uppermost layer of the ocean. However, a methodology has been developed to predict the temperature vertical profile of the ocean in space and time. Temperature profiles form Argo floats during a 3-year period from 2007-2009 were analyzed and modeled to a simple 5 parameter equation combining sigmoid curve which represent the mixed layer and thermocline and a linear term to account for deep water cooling.

Temperature vertical profiles (1400) were fitted into the model and a set of parameters were obtained. The parameters were matched with sea surface dynamic heights obtained from TOPEX/Poseidon in 1x1 degree grids. Sea surface height has shown a linear relationship with the depth of thermicline based on the latitudes. Significant linear relationships were found among other model parameters. Temperature maximum of the sea surface were obtained from the (AMSRE-AVHRR) merged products from National Climatic Data Center (NCDC) for the predictive model.

Prediction of the vertical temperature of the ocean using satellite observations is discussed. Thermal structure of the ocean has wider applications in oceanography and fisheries. This study was supported by Space Application for Environment (SAFE) an initiative of Asia Pacific Space Agency Forum (APRSAF).

Introduction

Indian Ocean is greatly influenced by two monsoon winds; southwest and northeast causing characteristic seasonality of temperature, phytoplankton concentration, circulation and mixed layer properties. Over half of the solar radiation is absorbed by the top 100 m of the ocean and regulate global climate system. Ocean is a huge heat sink and the turbulent mixing in the surface layer is promoted by the interaction of wind waves creating a mixed layer. In the mixed layer, convection and turbulence mixing are so effective that the temperature and salinity are almost uniform with depth. The deep ocean comprises about 80% of the total volume of the oceans been cold and driven by density gradients slow circulations and estimated the time required for complete overturning is on the order of 1000 years.

It has been repeatedly claimed that sea level, isotherm depth, heat content and dynamic height of the upper layer of the ocean are related. Shoji (1972) related sea level and dynamic height in the Kuroshio and found an excellent linear relation over a wide range of 1m. Saur (1992) invested the sea level differences between Honolulu and San Francesco and obtained the correlation coefficients of 0.65 and 0.54 respectively between sea level and dynamic height at the two locations. Wunsch (1972) found that low-frequency variations of sea level at Bermuda are reflected in the density structure and dynamic height. Chaen and Wyrki (1981) related sea level and isotherm depth at Truk and found a correlation of 0.92 for monthly mean values.

This study reveals an approach made to find relationships of the dynamic SSH and thermal structure by modeling temperature profiles obtained from Argo floats in the North East Indian Ocean.

OBJECTIVES

The aim of this study is to develop a predictive model for thermal structure of the ocean using satellite derived oceanographic parameters such as sea surface temperature (SST) and sea surface height (SSH).

MATERIALS AND METHODS

Temperature and depth profiles

Argo is an array of approximately 3000 profiling floats that observe the upper 2000 m of the ocean in near real-time. The floats capture important oceanographic parameters such as salinity and temperature and upload data to ground stations via satellites in 10-day cycles. Argo temperature and depth profiles were obtained from the Global Ocean Data Assimilation Experiment (GODAE), a near real-time global ocean data support for climate forecasts and oceanographic research. In this study, the data were obtained between latitude from 00-20N and longitude between 070-095E during a 3-year period from 2007 to 2009.

Sea surface height

Sea surface height data were obtained from the information collected by TOPEX/Poseidon and ERS satellite altimeter data. The data were available at archiving, validation and interpolation of satellite oceanographic data (ftp://ftp.cls.fr/pub/oceano/AVISO/) in netCDF format. These data (gridded 1/3 latitude x longitude) were obtained in merged delayed time products of sea surface dynamic heights (SSH)

Sea surface temperature

Sea surface temperature (SST) merged data product from two satellite sensors AMSRE and AVHRR were obtained from the NOAA optimum interpolation 1/4 degree daily sea surface temperature analyses. The SST data are distributed by National Climate Data Center of NOAA (ftp://eclipse.ncdc.noaa.gov) in netCDF format.

DATA TREATMENTS

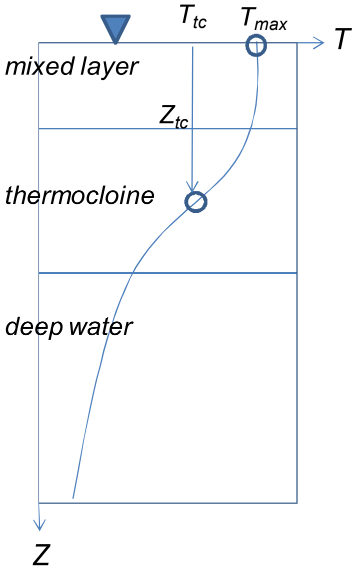

Figure 1 Sketch diagram showing temperature vertical profile of the ocean, illustrating upper mixed surface waters and non-mixed deep waters and in between the thermocline layer

A simple 5-parameter equation combining a sigmoid curve (Maury 2004) which represents the mixed layer and thermocline, and a linear term to account for deep water cooling with depth can be represented as,

$$T_a(z) = T_{max} + (\rho z - A)\left(\frac{z^\lambda}{z_{tc}^\lambda + z^\lambda}\right) \quad \text{Equation 1}$$

where z being the depth, T_a the ambient temperature, z_{tc} the depth of thermoline (depth of maximum temperature gradient) and ρ, A and λ being parameters.

SSH datasets were gridded into 1 degree (lat x lon) grids during the 3-year period and matched with model parameters of corresponding profiles. Statistical analyses were performed to obtained relationships between model parameters and sea surface heights.

RESULTS AND DISCUSSION

Argo observation of temperature profiles are not an *in-situ* but measure temperature and pressure in the water column with self controlled buoyancy to move from surface down to 1000-2000 m. at the same time the floats are moving with the prevailing horizontal currents. The average equatorial surface current is around 0.5 m s^{-1} but it is low towards the mid latitudes. However, Argo floats spent their time below the very surface layer during its 10-day cycle. Therefore, we assumed that the average horizontal speeds of floats are around 0.125 ms^{-1}, so that the spatial extent of 10-day cycle can be taken as 1 degree. Hence data matching were performed in 1 degree grids of sea surface heights.

Figure 2 shows the temperature profiles in the study area during the 3-year period. Total of 1391 profiles were used in this analyses. Temperature of the upper 40 m varies from 24-31^{o}C while the temperature at 500 m fluctuate between 9-11^{o}C.

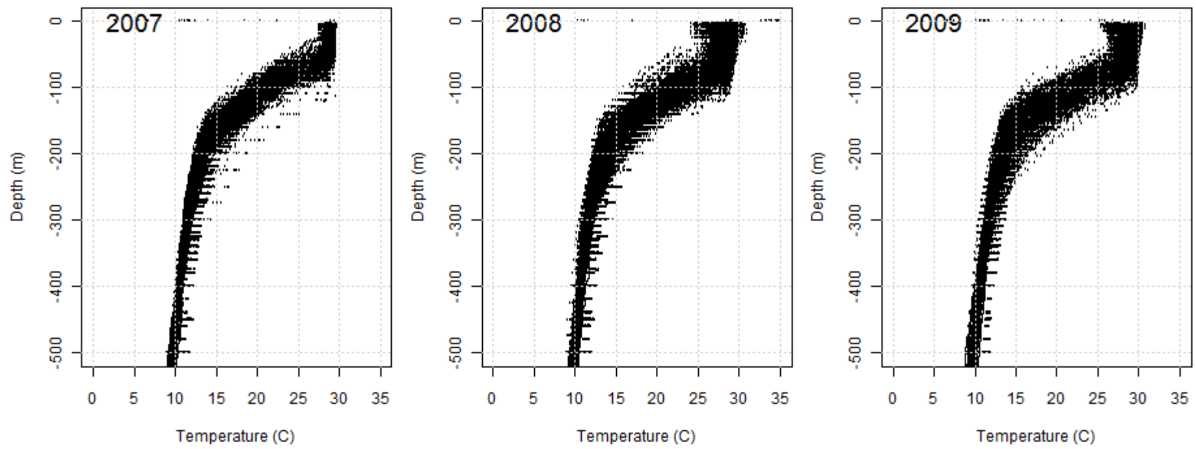

Figure 2: Temperature vertical profiles in the surface 500m obtained from Argo floats in the study area during the period from 2007-2009.

The 5-parameter model (Eq.1) is fitted to the observed temperature profiles and given that the R^2 over 0.9 implying the goodness of model fits. Figure 3 shows the measured argo temperature profile (dots) and model fit (solid line) to the profile on Jan. 25th 2008 at latitude 12.66N and longitude 70.33E. Similarly all the profiles were fited in to the model to obtain the series of parameters including temperature at thermocline. The dashed horizontal line indicates the thermocline depth (127.26 m) and dashed vertical line indicates the corresponding thermocline temperature (27.8^{o}C).

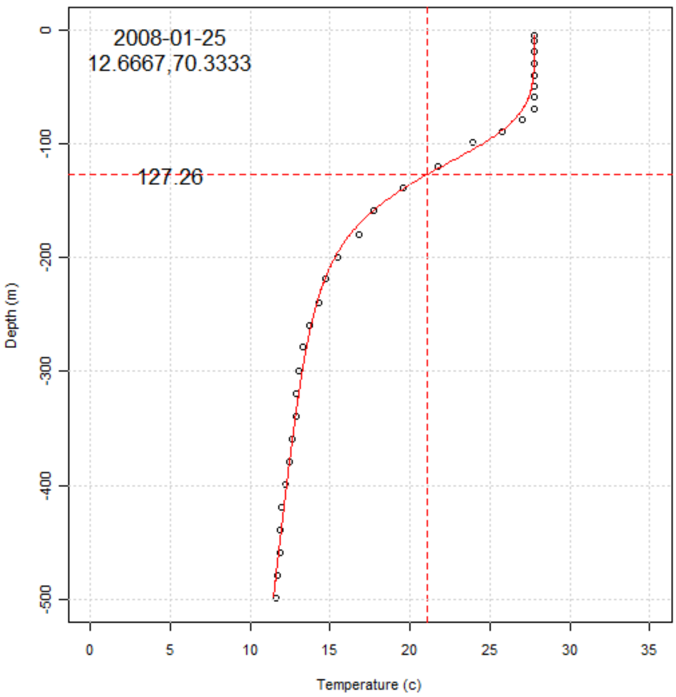

Figure 3: Model fit (solid line) to the temperature profile measured by Argo float (dots) on 25.01.2008 at location 12.66N and 70.33E.

Thermocline depth varied from about 75 m to 150 m occurring highest frequency around 110 m. Temperature at thermocline varied from 19.0-23.0^{o}C while its mean around 21^{o}C. Average temperature of the surface 40 m layer varied from 27-30^{o}C and the mean is around 29^{o}C (Figure 4).

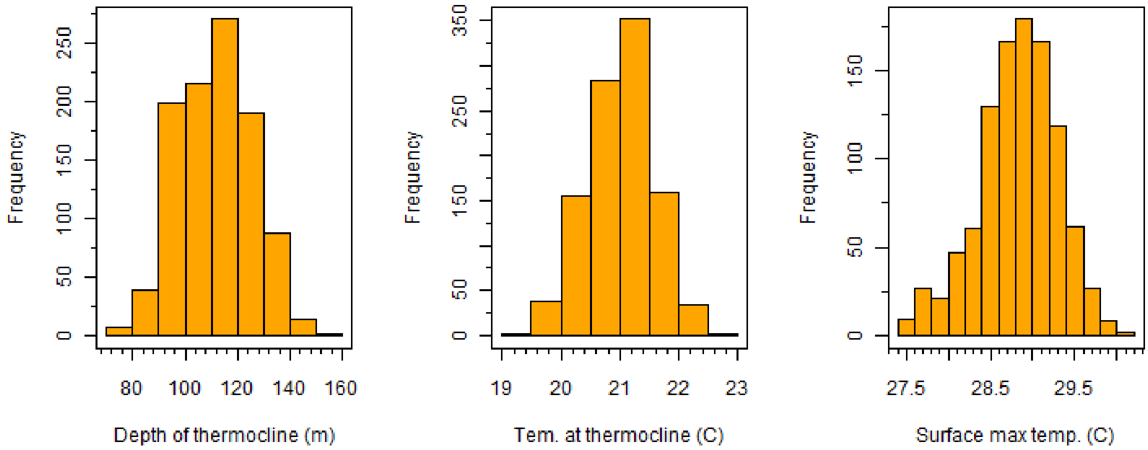

Figure 4: Histograms of thermocline depth, thermocline temperature and surface maximum temperature from model fits to the Argo data obtained during the 3-year period.

Satellites measure the skin temperature of the sea surface which is highly influenced by the prevailing wind field over the ocean. However, the temperature of the mixed surface layer is constant and accurate temperature of the mixed layer represented by float measurements. Since the mixed layer of the study area is always greater than 40 m, the Argo temperature of the top 40 m was averaged. In order to predict the temperature profile, SST measured by satellites is inappropriate. Hence, the satellite SST can be converted to mixed layer temperature by using the following relationship (Fig.5).

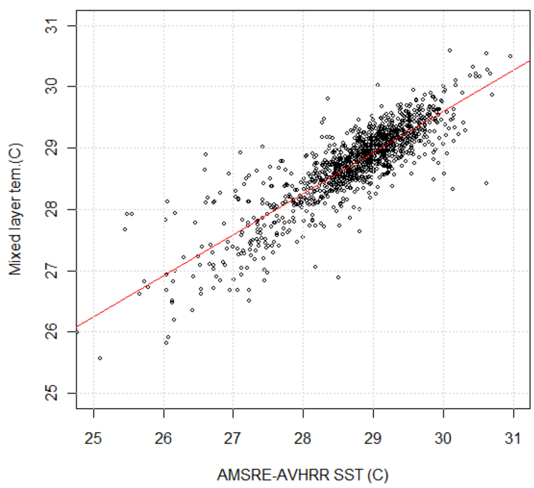

Figure 5 Showing relationship between SST obtained from TOPEX/Poseidon and Mixed layer temperature obtained from Argo averaged over top 40 m.

Matching the profile parameters to satellite sea surface heights, the depth of thermocline has shown linear relationships based on latitudes. Figure 6 shows the linear relationships between SSH and thermocline depth (Z_{tc}) between latitudes in 1 degree interval.

Hence the sea surface heights measured by satellites can be used to predict thermocline depth in space and time using the relationships shown in figure 6. The linearity of thermocline depth against sea surface height may influenced by the other oceanographic parameters such as tides, currents, local winds etc. This relation may also be influenced by the corresponding sea surface height variation over the float 10-day cycle.

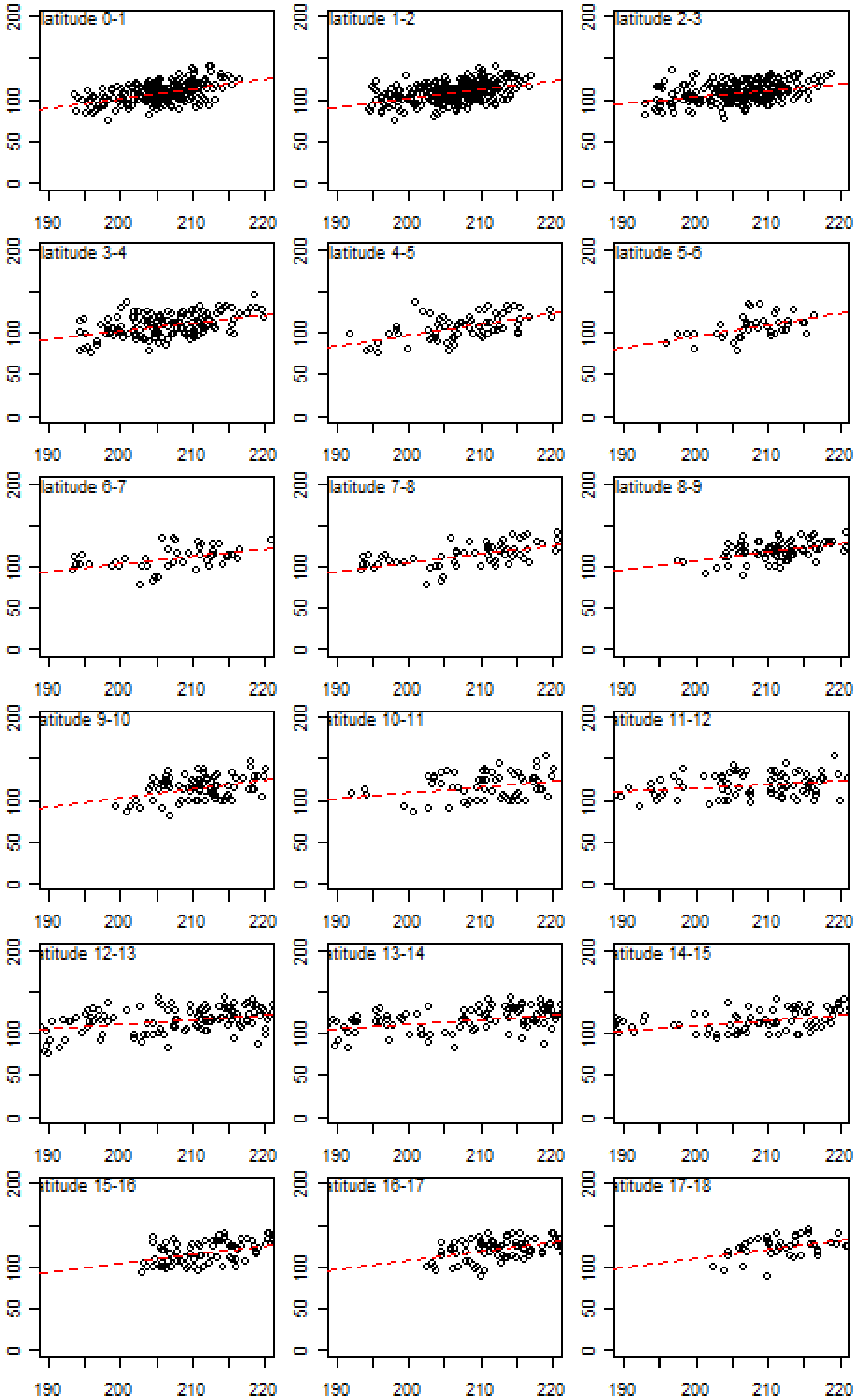

Figure 6 Latitudinal (00-18N) plots of thermocline depths against sea surface height obtained from TOPEX/Poseidon showing a linear relationship

Estimation of other parameters required for prediction of vertical temperature profiles were obtained by fitting linear models as shown in the Figure 7 for latitude between 12-13N. Similar relationships have been obtained for other latitudes from 00-18N in 1 degree intervals. Mixed layer temperature can be obtained from relationship shown in Figure 5. Parameter A is determined using mixed layer depths, ρ and λ are determined using A as relations shown in figure 7.

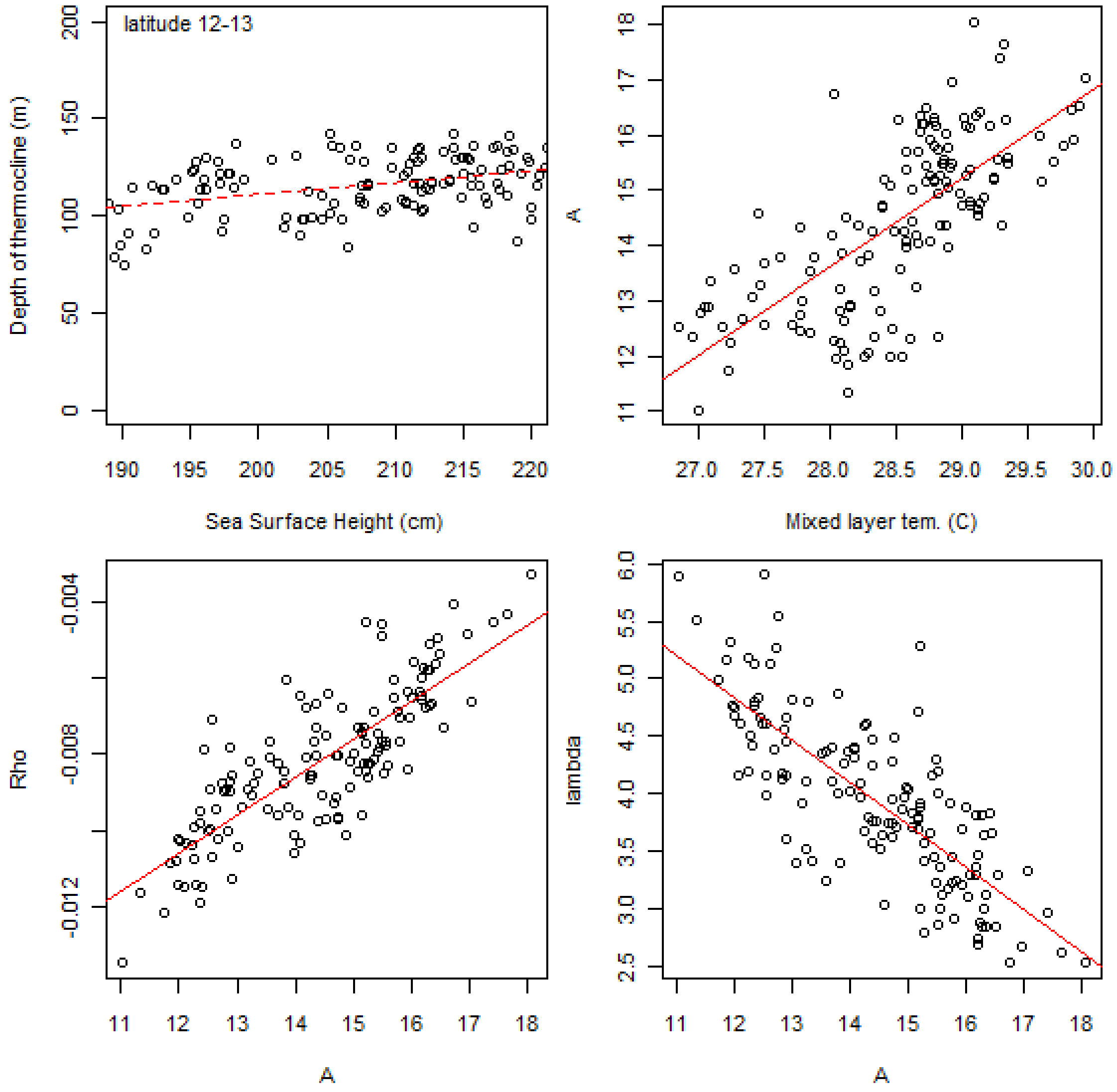

Figure 7: Linear model fits to the model coefficients, upper left Z_{tc}, vs SSH, upper right A vs T_{max}, lower left ρ vs A and lower right λ vs A

Test predictions have been made using SSH and SST data obtained from the two satellites and the Figure 8 shows the model predictions compared with Argo observations on 16th Sep. 2007. Predicted profiles are reasonably close to the observations and therefore, spatial prediction of temperature profiles can be made using TOPEX/Poseidon SSH and AMSRE-AVHRR SST data products.

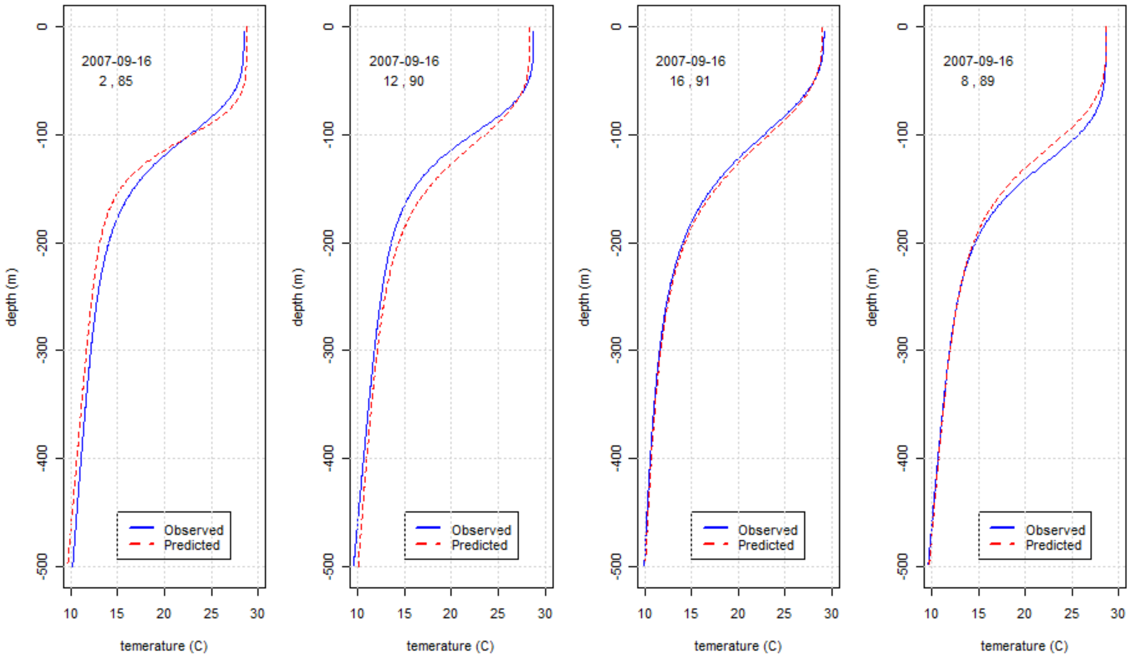

Figure 8: Comparison of model predicted temperature profiles (dashed line) and Argo profiles (solid line) in four locations (02N, 085E), (12N, 090E), (16N, 091E) and (08N, 089E) on 2007.09.16

CONCLUSION

Satellite derived surface information such as SSH and SST can be used to predict subsurface thermal structure of the ocean. However, the relationships between surface information and subsurface structure may be improved by further analyses and validation. Sea level variability on top of dynamic sea surface height may have an influence for the relationships obtained in this study. As the Argo floats provide the profile data in 10-day cycles, SSH variability during this period may have influences on the results. Horizontal movements of float in 3-dimensional oceans are variable and depend on the prevailing ocean currents. Therefore, the averaging grid size for SSH to match with the temperature profiles are uncertain as individual float movements are vary with the prevailing ocean currents.

Although satellites provide bulk surface information, this study is an approach to use satellite surface information to predict subsurface thermal structure of the ocean. The prediction methodology can also be incorporated with near real-time observation of Argo floats. This study reveals that the methodology developed in this study can be used to predict any depth of interested temperature, for instant fish aggregating depth knowing their swimming temperature.

ACKNOWLEDGEMENTS

The Argo data were obtained from Global Ocean Data Assimilation Experiment (GODAE) at ftp://usgodae.org/. Sea surface height obtained from TOPEX/Poseidon and blended sea surface temperature products obtained AMSRE and AVHRR distributed by NCDC, National Climate Data Center (ftp://eclipse.ncdc.noaa.gov/) of NOAA. This study was supported by the Space Application for Environment (SAFE) which is an initiative of Asia Pacific Space Agency Forum (APRSAF).

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