Egyptian Journal of Aquatic Biology & Fisheries
Zoology Department, Faculty of Science,
Ain Shams University, Cairo, Egypt.
ISSN 1110 – 6131
Vol. 28(2): 1169 – 1182 (2024)
www.ejabf.journals.ekb.eg

Red Sea Salinity Profiles Estimation

Hussein, Maged M., Kamel, Mohamed S. Radwan, Ahmed A.*
National Institute of Oceanography and Fisheries (NIOF), Egypt, Physical Oceanography Lab

***Corresponding Author**: **aa_radwan@yahoo.com**

ARTICLE INFO

Article History:
Received: April 14, 2023
Accepted: March 29, 2024
Online: April 29, 2024

Keywords:
Seawater surface salinity,
Seawater temperature profile,
Regression,
Red Sea,
Seawater salinity profile

ABSTRACT

The salinity data in the ocean are non-uniform and irregular, therefore methods for salinity estimation using available predictors (i.e. temperature data or others) are mandatory. A set of regression models were presented for estimating salinity profiles in the upper 500m of the Red Sea from the measurements of temperature profiles, surface salinity, and some other predictors. Both temperature and surface salinity were used to capture the curvature seen in temperature salinity plots, latitude and longitude were used to capture systematic spatial variations over the fitting regions and Julian day was used to capture seasonal variability in the region. Hence, the best-fit regression curve and the minimal errors of the salinity estimates were found for the study area. This regression model over all for the entire region at all depths was quadratic in temperature and linear in surface salinity, longitude, latitude and day of the year. Even without the surface salinity measurement we could estimate the salinity with good reduction of RMS errors for all depths below 150m.

INTRODUCTION

The Red Sea is a semi-enclosed, narrow basin that extends between latitudes 12.5 and 30°N, with an average width of 220km, a mean depth of 524m, and maximum recorded depths of about 3000m (Fig. 1). The only opening to the Indian Ocean is at its southern end through the shallow and narrow Bab el Mandeb Strait (a sill depth of 160m and a minimum width of about 25km) where it communicates with the Gulf of Aden **(Radwan, 2008)**.

The World Ocean Database of the temperature (T) and salinity (S) measurements isavailable, but unfortunately its coverage of the Red Sea is almost non-uniform. Due to this irregularity, two methods can be used to apply these data in different applications. The first method is the traditional application of climatic mean values of T and S obtained from this database interpolated over a one-degree grid. The second method is developing methods that make it possible to estimate the salinity at any point of the ocean on the basis of the temperature measurements and the statistical relation between *S* and *T*. The second method seems very promising since it can result in more precise and uniform distribution of the T–S data over the study region of the World Ocean, which is extremely important for initializing numerical models and data assimilation **(Korotenko, 2007; Thacker *et al.*, 2007)**.

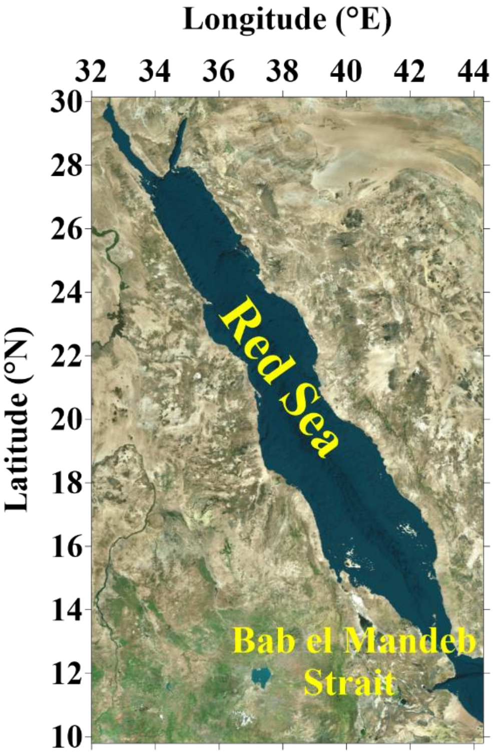

Fig. 1. Area of the Study; Red Sea

The application of the statistical correlation between the salinity and temperature in the ocean for estimating the salinity has also been known along time ago. The method for calculating the salinity is conducted on the basis of the relation Ŝ(z)=Ś[T(z)] suggested by **Stommel (1947)**, where Ŝ (z) is the estimate of the salinity variation with depth z, and Ś[T(z)] represents the average salinity value at a given temperature. In some regions, a more reliable salinity estimate can be obtained using the so-called method of average salinity Ŝ(z)=<S(z)>, where <S(z)> represents the climatic mean salinity value **(Emery & Brien, 1978)**. **Stommel**'s method **(1947)** was modified by **Donguy *et al.* (1986)**, where the salinity was estimated on the basis of temperature profiles and salinity measurements at the ocean surface.

The main disadvantage of **Stommel**’s method **(1947)** and all its modifications is the fact that they can repeat (restore) salinity anomalies that correlate with the temperature anomalies, while all the methods are absolutely useless in the layers where both T and S have different functional dependences on the depth **(Korotenko, 2007)**. These are the so called barrier layers.

A regression method for salinity estimates from the temperature measurements was suggested by **Hansen and Thacker (1999)** and applied by **Hussein (2016)**, where a salinity dependence on the latitude, longitude and day of the year was introduced along with the dependence of the salinity on the temperature, geographic location and season, respectively. The general regression Eq. (relation) was written as

$$\hat{S}(z) = <S(z)> + \sum_i a_i(z)\ (P_i - <P_i>) \tag{1}$$

Where, angle brackets represent climatologically averages, P_i denotes the variables that are used as predictors, and the values of the coefficients a_i are derived from regressions for each depth z. Estimates are modifications of the climatologically salinity profile by deviations of the observed predictors from their climatologically means.

Hussein *et al.* (2011) compared the salinity estimates for different versions of the predictors in (Eq. 1) for the upper 500-m layer in the southeastern Mediterranean Sea. The introduction of the surface salinity allowed the authors to decrease the error of the estimate only in the upper 50-m layer, while the account for the longitude makes it possible to decrease the salinity estimate error in the 50– 500m layer.

The next step in the development of regression methods for estimating the salinity in the ocean was the application of regression relations with high-degree polynomials for predictors P_i. Thus, the following regression was used instead of (1):

$$\hat{S}(z) = \sum a_{i,l}\ (z)\ P^{l}_{i} + \varepsilon \tag{2}$$

This relation, for example, in the case of n degree polynomials for the temperature is written as:

$$\hat{S}(z) = a_o + a_{T,1}\ T + a_{T,2}\ T^2 + a_{T,n}\ T^n \tag{3}$$

Thacker (2007) and **Thacker and Sindlinger (2007)** made attempts to find suitable regression Eqs. for estimating the salinity in the Gulf of Mexico and in the region of the Northwest Atlantic (25°–45°N×65°–35°W) on the basis of the NODC WOD-2001 data. In the region of the Gulf of Mexico, a polynomial of the second degree in Eq. 3 was sufficient to approximate the salinity profile.

Hussein (2016), applied different forms of the predictors in Eq. 3 to estimates salinity for the upper 500-m layer in the region of the southeastern Mediterranean Sea. In this region, the surface salinity added to polynomial of fourth degree in Eq. 3 were better for upper 130m, while when longitude (X), latitude (Y) and day (d) of the year were added to polynomial of third degree, Eq. (4) was the best for the remaining depths.

$$\hat{S}(z) = a_o + a_{T,1}\ T + a_{T,2}\ T^2 + a_{T,3}\ T^3 + a_{lon}\ X + a_{lat}\ Y + a_{day}\ d \tag{4}$$

The use of the date (d) of the measurements, along with the temperature, surface salinity S(0), longitude (X), and latitude (Y), reflected the dependence of the observations on the seasons, giving a chance to improve the salinity estimates.

The main objective of the present work was to estimate the Red Sea salinity profile (in the upper 500m) from measurements of (1) only temperature profiles, (2) temperature profiles, and sea surface salinity. These profiles could be used to estimate salinity profiles for assimilation into numerical circulation models or for such applications as they may be needed.

MATERIALS AND METHODS

The NODC WOD-2001 databasewas used in this study, and the locations of the 111 CTD profiles selected to be used in this study to establish empirical relationships between salinity and temperature for the region from 33.5 to 38.5°E and from 22 to 28°N, 5×6° are shown as dots in Fig. (2). These profiles were occupied during years 1962 to 2011. The profiles had data listed in different intervals (0, 10, 20, 30, 50, 75, 100, 150, 200, 300, 400, and 500m). Only the data for the upper 500m were used since that range is the most available profiles.

The 111 temperature and salinity profiles were separated into two sets, 74 profiles comprising the training data to be used for model fitting (Fig. 2) and 37 profiles for independent verification (Fig. 2). Fig. (3) represents scatter plots of T-S at different depths for the study area.

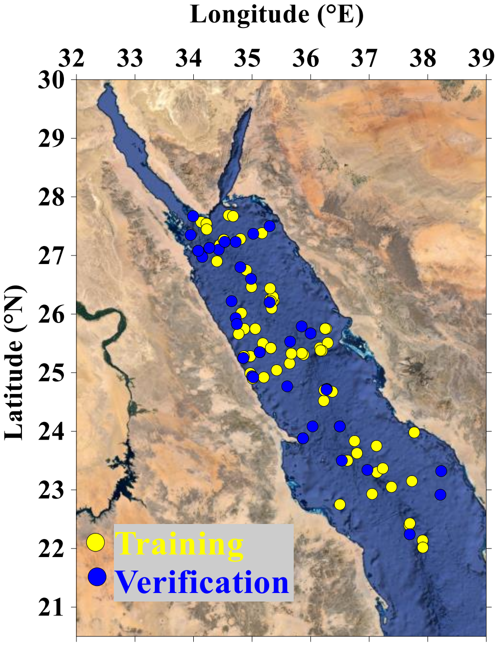

Fig. 2. Selected data profiles locations of the 111 CTD stations in study area as training and verification sampling stations

The mean profiles of salinity <S(z)> and temperature <T(z)> are shown in Fig. (4) together with their standard deviations. Correlation coefficients between S(z) and T(z), surface salinity S(0) and S(z) at different depth interval are shown in Fig. (5).

Correlation between salinity and temperature is small and negative in the upper 150m, nearly zero in 300m, also small and positive between 300 and 500m depth. Correlation with surface salinity is strong in the above 75m, moderate between 100 and 150m and negligible elsewhere. The complementary nature of these correlations suggests that their joint use should be advantageous.

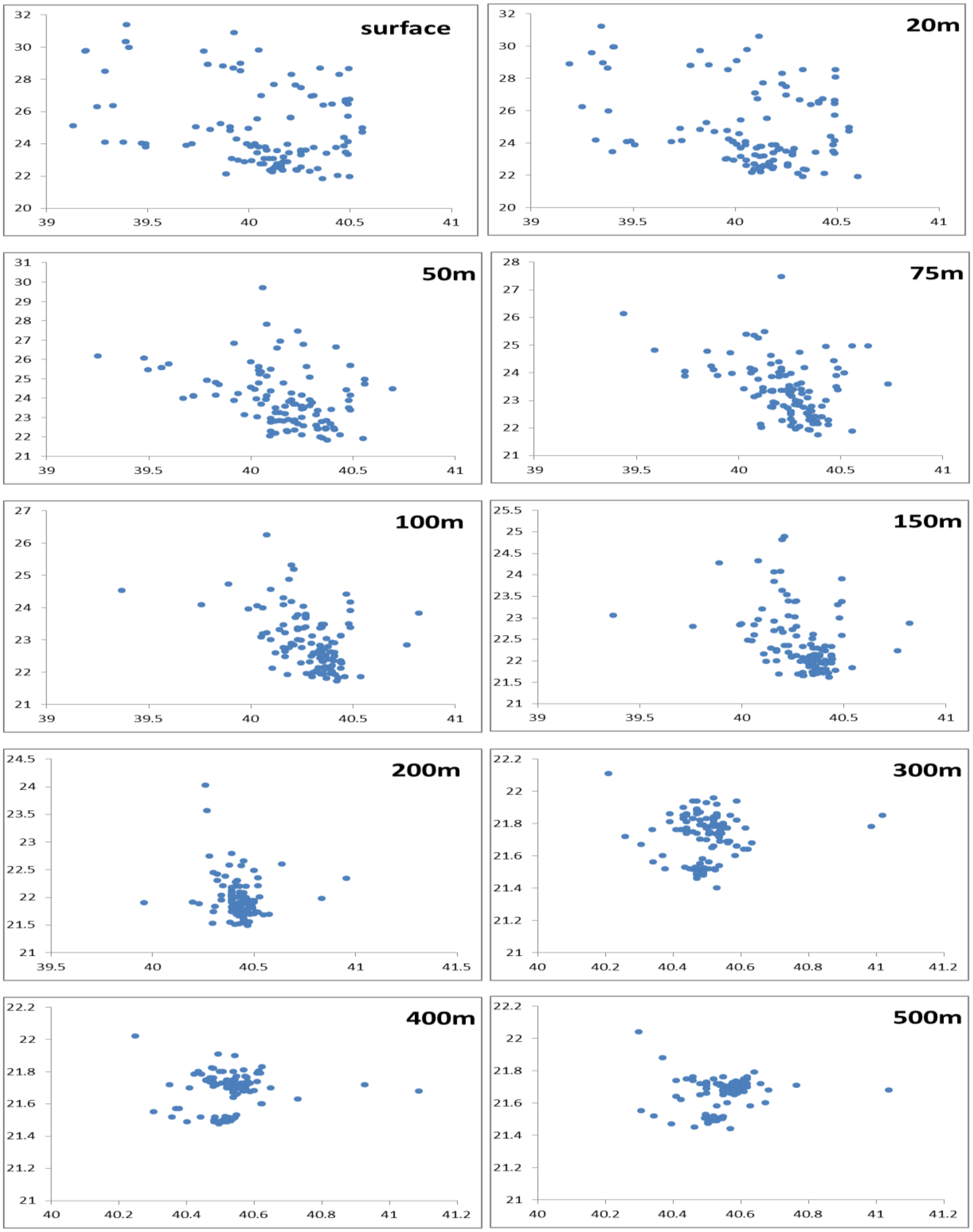

Fig. 3. Scatter plot of temperature and salinity CTD data
at different depths in the study area

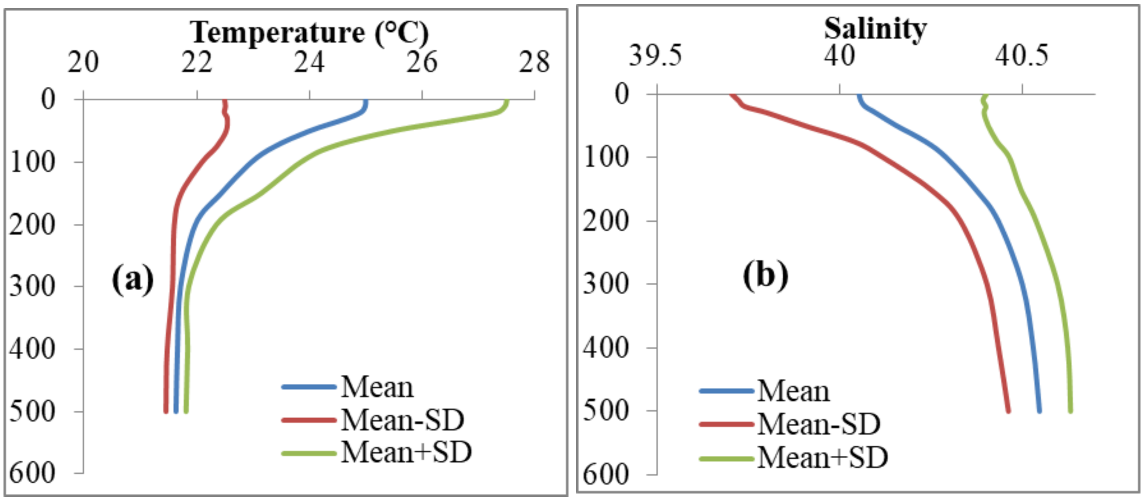

Fig. 4. Mean values of **(a)** temperature and **(b)** salinity shown by blue curve for 111 data sets in this study, and standard deviations from mean by other curves

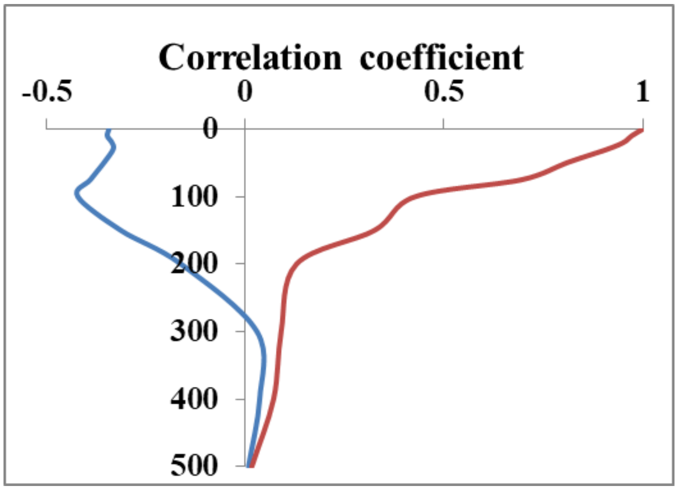

Fig. 5. Blue curve representing correlation coefficient between salinity S(z) and temperature T(z) and red curve between S(0) and S(Z) at different depth intervals

The salinity and temperature profiles in addition to T-S curves for these data are shown in Fig. (6). The salinity profiles reveal some variability in the surface mixed layer commonly reaches nearly 1.7. The haline mixed layer commonly reaches 30 meter or more, indicating that surface salinity is a useful indicator of the upper salinity in this region. Below a depth of 200,m the scatter among the profiles becomes small. The temperature profiles exhibits much variability in the surface mixed layer and relatively little scatter below the thermocline. The T-S relationship is well defined for temperatures less than 23°C, but becomes increasingly less defined from the bottom of the thermocline to the surface.

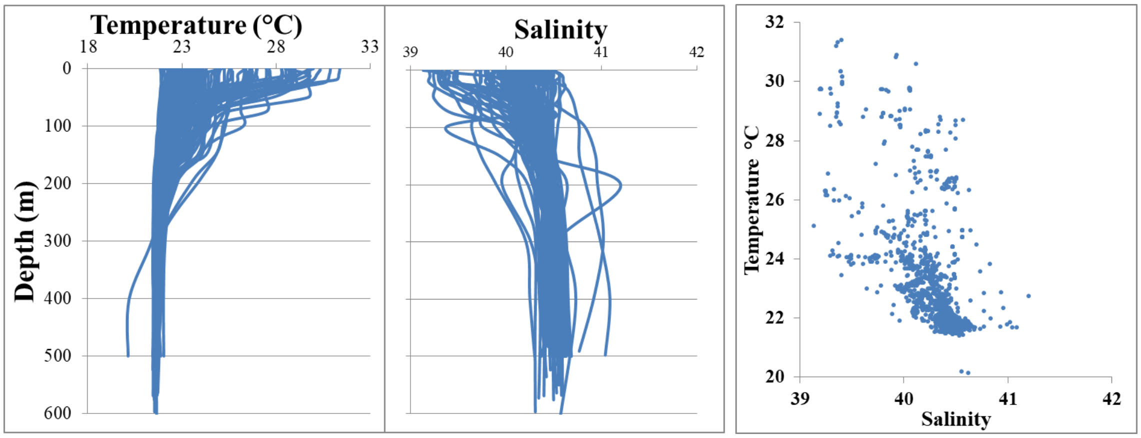

Fig. 6. Profiles of temperature and salinity and temperature-salinity scatter plot for the 111 data sets used in this study

The analysis methods

The procedure for estimating salinity is to identify regression models for each pressure level that explain the data in Fig. (3). The skill of these models is to be assessed against the independent verification data for the corresponding levels. The scatter plot in Fig. (3) suggests that salinity might be modeled by polynomial of temperature of first degree (linear) or higher degrees and that proved to be the case. Polynomial of temperature of different degree was fitted to the training data at each pressure level. The following Eqs. (from Eq. 5 to Eq. 16 about 12 types of regression models) were used at each depth level.

$$S = P1(T) = a_o + a_1T \qquad (5)$$

$$S = P2(T) = a_o + a_1T + a_2T^2 \qquad (6)$$

$$S = P3(T) = a_o + a_1T + a_2T^2 + a_3T^3 \qquad (7)$$

$$S = P4(T) = a_o + a_1T + a_2T^2 + a_3T^3 + a_4T^4 \qquad (8)$$

$$S = P3(T)+day+lat+long=a_o+a_1T+a_2T^2+a_3T^3+a_4d+a_5x+a_6y \qquad (9)$$

The next regression models were used at each depth level corresponding to the combinations between $P_2(T)$, $P_3(T)$, $P_4(T)$ and surface salinity in addition to day, latitude, and longitude.

$$S=P_2(T)+S(0)=a_o+a_1T+a_2T^2+a_3S(0) \qquad (10)$$

$$S=P_3(T)+S(0)=a_o+a_1T+a_2T^2+a_3T^3+a_4S(0) \qquad (11)$$

$$S=P_4(T)+S(0)=a_o+a_1T+a_2T^2+a_3T^3+a_4T^4+a_5S(0) \qquad (12)$$

$$S=P_3(T)+S(0)+long=a_o+a_1T+a_2T^2+a_3T^3+a_4S(0)+a_5\,long \qquad (13)$$

$$S=P_3(T)+S(0)+lat=a_o+a_1T+a_2T^2+a_3T^3+a_4S(0)+a_5\,lat \qquad (14)$$

$$S=P_3(T)+S(0)+day=a_o+a_1T+a_2T^2+a_3T^3+a_4S(0)+a_5\,day \qquad (15)$$

$$S=a_o+a_1T+a_2T^2+a_3T^3+a_4S(0)+a_5d+a_6x+a_7y \qquad (16)$$

Where, S denotes the estimate for salinity; T, S(0), d, x, y denote observed temperature, surface salinity, day of the year (Julian day), longitude and latitude respectively; and where the coefficients a_0, a_1, a_2, a_3, a_4, a_5, a_6 and a_7 were determined for each model by fitting to the local training data.

RESULTS AND DISCUSSION

I. A regression method without mean salinity (<S(z)>)

Salinity profiles were estimated for the upper 500m using different polynomial degrees of temperature profile. 12 variants of the regression procedure (Eqs 5-16) for the 37 profiles of the verification data set. The root mean square (RMS) differences between the estimated and measured salinities for the verification profiles were computed and are shown in Figs. (7, 8).

I.1. The temperature polynomial (TP) models

For the first five types of models (Eqs 5- 9, the RMS error decreased with depth. The first four models (5- 8) are nearly indistinguishable. The third (Eq. 7) and fourth (Eq. 8) models enhanced RMS error than the first (Eq. 5) and second (Eq. 6) models, as shown in Fig. (7a). For depths between 200 and 400m, i.e., below the thermocline, the positive tight relationship between temperature and salinity allows a third and fourth degree polynomial of temperature to estimate salinity with RMS errors smaller than 0.06 (Fig. 7a). By adding day, latitude and longitude to a third degree of polynomial (Eq. 9), RMS errors were enhanced more than the previous Eqs. (5- 8) between surface and depths less than 200m. Below 200 to 400m in depth, it coincided with the Eqs. (5-8) models. Below a depth of 400m, RMS reached 0.045 (Fig. 7a).

I.2. TP and surface salinity (TPS) models

The next three models Eqs. (10, 11 & 12) suggested getting a benefit of the high correlation between S(0) and the S(Z) for the upper 75m depth (0.69 to 1). The correlation between S(0) and S(Z) are dramatically decreased below 200m depth. The issue of using measurements of surface salinity is to capture some of variability that characterizes the upper several tens of meters. The RMS values for the upper 250m depth was between 0.05 and 0.08, which was illustrated better than the output from TP models. Between 50- 100m, it increased to 0.12; between 100– 200m the RMS values changed from 0.06 to 0.08, and below 200m, it fluctuated between 0.04 and 0.07 (Fig. 7b). The RMS range values of the three models (Eqs. 10 to 12) at all depths between surface and 100m were represented nearly indistinguishable. The RMS values of the regression model (Eq. 11) were lower than the other two models (Eqs. 10 & 12) for the depths between 100 and 400m, and coincide with model (Eq. 12) at a 500m depth. In general, the RMS range values of these three models were better than the TP regression models previously.

For reliable statistics, data must be drawn from a sizable region, e.g., our 5×6° region, over which horizontal gradients of water properties may contribute significantly to the variances about the mean profiles. To test the possibility of capturing a part of this variability as those discussed below, the latitude (y) and longitude (x) would be added to the other predictors since the climatological structure in the Red Sea may be primarily zonal. The longitude, latitude and the day of the year in addition to S (0) were added to P_3 (T) individually, as shown in Eqs. (13, 14 and 15), and given by Eq. (16).

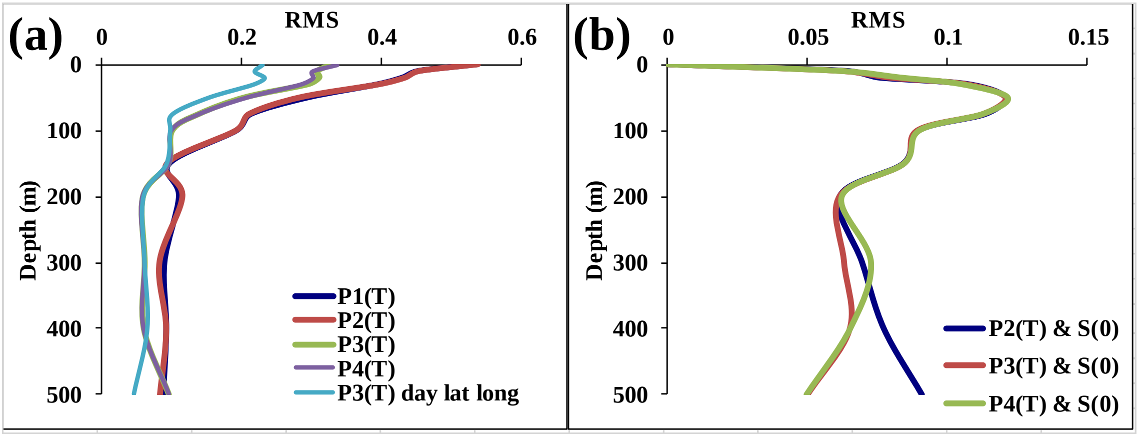

Fig. 7. RMS errors for **(a)** models (Eqs 5- 9), RMS errors for **(b)** models (Eqs 10- 12)

I.3. TPS, longitude, latitude and day of the year

There is no RMS error valuable difference between models (Eq. 13, 14, 15 & 16), as shown in Fig. (8a); RMS values of these models nearly coincide with each other.

In comparison between the RMS values of Eqs. 12 and 16 (Fig. 8b), the output of the model (Eq.16) illustrates that RMS errors enhanced the salinity estimation until 150m depth than model (Eq.12), coinciding with each other downward to a 500m depth.

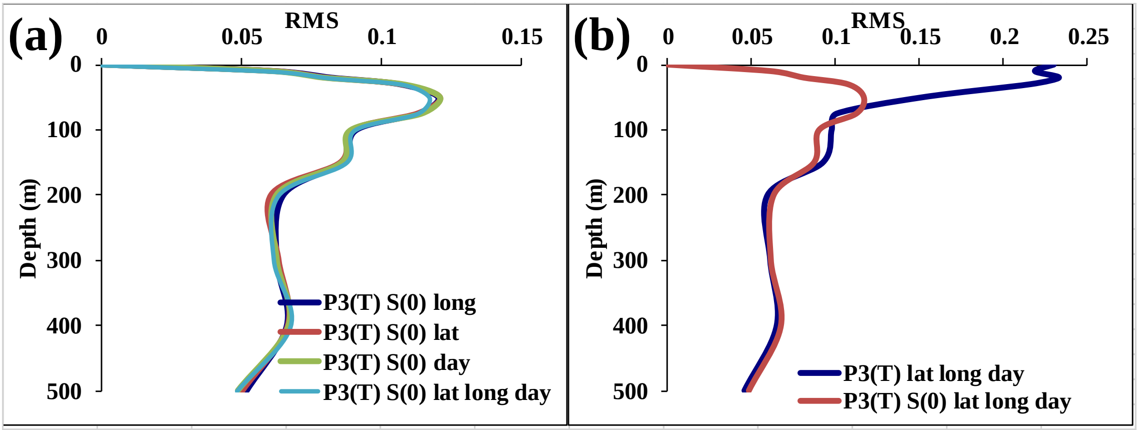

Fig. 8. RMS errors for **(a)** models (Eqs 13- 16); a comparison among RMS errors for **(b)** models (Eqs 12 and 16)

II. A regression method with mean salinity <S(z)>

Salinity profiles were estimated for the upper 500m using the mean salinity profile, and six variants of the regression procedure for the 37 profiles of the verification data set. The root mean square (RMS) differences between the estimated and measured salinities for the verification profiles were computed and are shown in Fig. (9a, b).

II.1. The mean salinity method

This method examines the estimation of salinity by its climatologically mean:

$$\hat{S}(z) = \langle S(z) \rangle \qquad (17)$$

The RMS errors for this method was labeled “mean salinity; as shown in Fig. (9a). Near the surface, errors slightly exceed the variability because of the difference between the training and verification data. This method captures more variability at 200m depth and small variability at 500m.

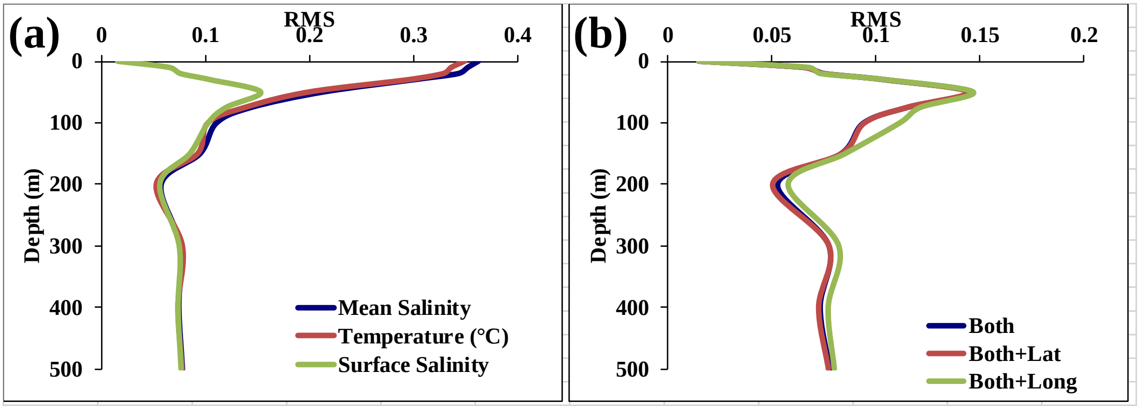

Fig. 9. Root mean square errors for various methods of estimating salinity profiles of verification data. RMS errors for **(a)** mean salinity profile, regression on temperature and regression on surface salinity. RMS errors for **(b)** regression on surface salinity and temperature (Both), both and latitude and both and longitude

II.2. The temperature (T) method

The complementarily of depths at which the T-S and climatologically mean methods perform best suggests merger of these methods, using observed temperature to improve upon the climatological mean salinity in a regression model **(Hansen & Thacker 1999, Hussein, 2011)**:

$$\hat{S}(z) = \langle S(z)\rangle + a_T(z)\,[T(z) - \langle T(z)\rangle] \qquad (18)$$

This method and those discussed below were fitted to the training data. Although the model was fitted independently at each level of the selected interval, the coefficients varied with depth. The RMS errors, labeled "Temperature" in Fig. (9a) show that this approach realizes better than the mean salinity method in the upper 30m; in the depth intervals of 50 to 100m and 200 to 500m, the two methods are equivalents; in the depth interval between 100 and 150m, the RMS value decreased. These results are supported by the correlation theme in Fig. (5), which represents the existence of negative moderate correlation between salinity and temperature for the upper 30m layer, and the correlation increased between the intervals of 100 and 150m depth, and a change to positive was detected with a low correlation value in the depth interval below 250 to 500m.

II.3. The surface salinity (SS) method

We turn now to the issue of using measurements of surface salinity to capture some of the variability that characterizes the upper several tens of meters. First, we consider their use in the absence of an observed temperature profile. At each depth z, a regression Eq. establishes how deviations of the observed surface salinity from its mean modify the estimates based on the mean salinity profile:

$$\hat{S}(z) = \langle S(z)\rangle + a_s(z)\,[S(0) - \langle S(0)\rangle] \qquad (19)$$

Owing to the strong correlation of S(z) with S(0) in the upper 100m of the water column, the RMS estimation error, labeled "Surface salinity" in Fig. (9a), is reduced to 0.15 in the upper 50m, and reduced to 0.1 in the interval between 75 to 150m depth. Deeper than 200m, surface salinity provides no information, the regression coefficient

$a_s(z)$ is essentially zero, and the “surface salinity” curve of Fig. (9a), becomes coincident with the "mean salinity" and "Temperature" curves.

II.4. The SS and T (Both) method

It is straight forward to include deviations of both temperature and surface salinity profile from their means to estimate deviations of salinity:

$$\hat{S}(z) = \langle S(z)\rangle + a_T(z)\,[T(z) - \langle T(z)\rangle] + a_s(z)\,[S(0) - \langle S(0)\rangle] \qquad (20)$$

The values of the coefficients a_T and a_s are not the same as those for Eqs. (18) and (19); they must be determined by fitting Eq. (20) to the experimental data. However, at depths where surface salinity carries no information about the subsurface salinity, it turns out that, a_s (z) decrease with depth to nearly zero and a_T (z) is almost the same as that found for Eq. (18). The curve labeled "Both" in Fig. (9b), indicates that near the surface this extension yields no improvement over use of surface salinity, but it further slightly reduces errors in all depths deeper than 75m.

II.5. The SS and T (Both) plus latitude

In this method, the latitude was added to the set of predictor, as shown in Eq. (21). The results were indistinguishable from those obtained using both surface salinity and temperature method, as shown in Fig. (9b).

$$\hat{S}(z)=\langle S(z)\rangle+a_T(z)[T(z)-\langle T(z)\rangle]+a_s(z)[S(0)-\langle S(0)\rangle]+a_y[y-\langle y\rangle] \qquad (21)$$

II.6. The SS and T (Both) plus longitude

In this method, the longitude was added to the set of predictor, as shown in Eq. (22). The results also like previous method were indistinguishable from those obtained using both, surface salinity and temperature method or surface salinity and temperature plus latitude, as shown in Fig. (9b).

$$\hat{S}(z)=\langle S(z)\rangle+a_T(z)[T(z)-\langle T(z)\rangle]+a_s(z)[S(0)-\langle S(0)\rangle]+a_x[x-\langle x\rangle] \qquad (22)$$

II.7. The SS and T (Both) plus day, latitude and longitude

In this method, the day (d) was added to the set of predictor, as shown in (Eq. 23). The results also like previous method were slightly distinguishable in some depths from those obtained using both surface salinity and temperature method and both surface salinity and temperature plus latitude (Fig. 10).

$$\hat{S}(z)=\langle S(z)\rangle+a_T(z)[T(z)-\langle T(z)\rangle]+a_s(z)[S(0)-\langle S(0)\rangle]+a_d–[d-\langle d\rangle]+a_y[y-\langle y\rangle]+a_x[x-\langle x\rangle] \qquad (23)$$

Results from previous seven methods (Eq. 17 to Eq. 23) of estimating salinity profiles have been presented in the present work, including one conventional procedure using mean salinity. The curves shown in Figs. (9, 10) sort themselves into three classes in the near surface and three different classes in deep waters. The seven methods are nearly indistinguishable near 300m depth. Near surface, the largest errors are associated with mean salinity method. However, the mean salinity with the addition of temperature data are slightly better. The use of salinity only as predictors substantially reduces the RMS estimation error. Additional of surface salinity information to the climatologically profiles reduces the estimation errors to 0.15 in the upper 50m.

At depths between 50 and 200m, inclusion of temperature information by regression is more beneficial than mean salinity. At depths greater than 200m, all methods of using temperature provide equivalent results, reducing the errors to 0.08 or less. Surface salinity provides no improvement at depths of 100m. Latitude or longitude provides no improvement than both of surface salinity and temperature. Inclusion of day, latitude and longitude give further improvement in lower than 50m, yielding the nearly smallest errors at nearly all depths. The model of Eq. 23 is nearly the best in all depth ranges.

Finally, from the above results (Fig. 11a), model (Eq. 16) enhances the salinity estimate value than model (Eq. 23) between 50 and 75m depth, and also below 200m depth. Model (Eq. 23) gives some enhancement in salinity estimate from 150 to 250m depth than model (Eq. 16).

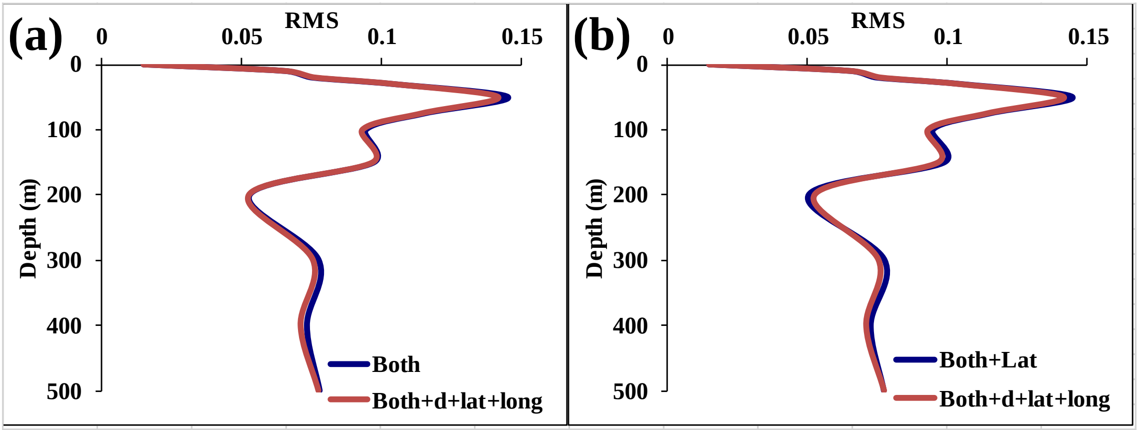

Fig. 10. RMS errors for models **(a)** Eq. 20 and Eq. 23, RMS errors for **(b)** models Eq. 21 and Eq. 23

In case the surface salinity is available, the regression model represents by Eq. (16) is best one to estimate salinity in the study area. While, in case that the surface salinity is not available, one can use the regression model represented by Eq. (9), which nearly coincides with the results of Eq. 16 for the depth below 75m (Fig. 11b).

The regression model represented by Eq. (16) performs the best model in case of the availability of surface salinity. To illustrate the ability of the regression model of Eq. (16) to replicate individual salinity profiles, all 37 observed and estimated salinity profiles at each selected interval of the verification data set are displayed in Fig. (12). In addition, the associated temperature profiles of these samples are shown in Fig. (13).

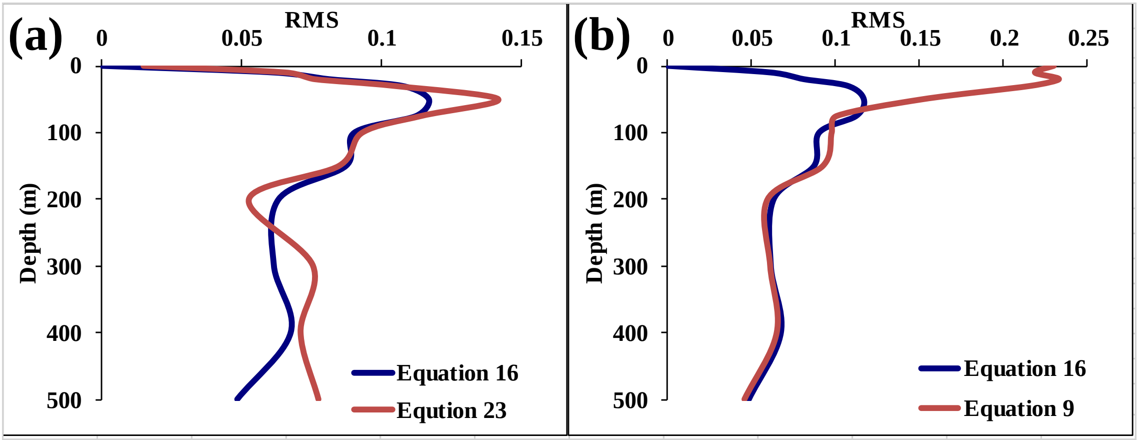

Fig. 11. Comparison between RMS errors for **(a)** models Eq. 16 & Eq. 23 andRMS errors for **(b)** models Eq. 9 & Eq. 16

Case Study

We conducted another experiment for the same study area (Red Sea) on more recent data than we used before. These data were taken from WOD for period 2000 to 2018. Hence, the number of experimental data was 73 profiles and the number of verification data was 34 profiles, as shown in Fig. (12). Models 9, 12 and 16 were applied to the profiles data to obtain the regression coefficients, and then we used the verification profiles data to estimate the salinity profiles based on the used model Eqs. (9, 12 and 16). The RMS errors results are shown in Fig. (13a, b).

Through the results obtained from the two mentioned case studies, we can confirm that the estimation of the salinity values given by Eq. 16 is the best of all, in case the surface salinity data are available. If the surface salinity data are not available, we can use Eq. 9 as it corresponds to the results obtained from Eq. 16 at a depth of 75m downward to 500m depth, as shown in Fig. (13a, b).

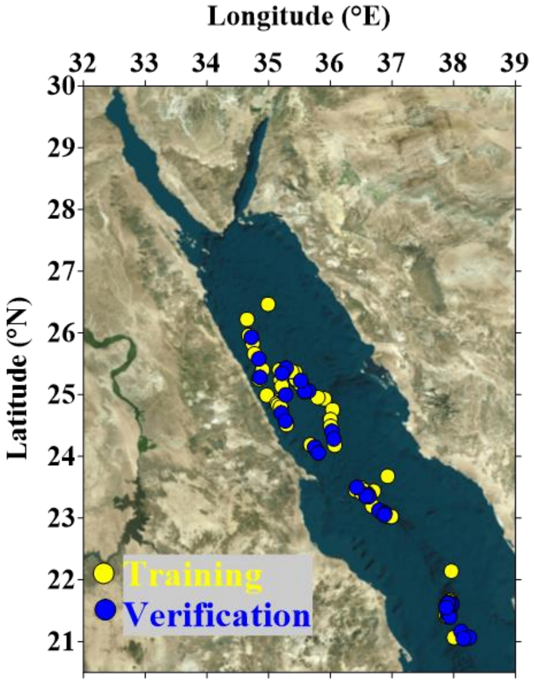

Fig. 12. Experimental and verification data profiles (2000 to 2018)

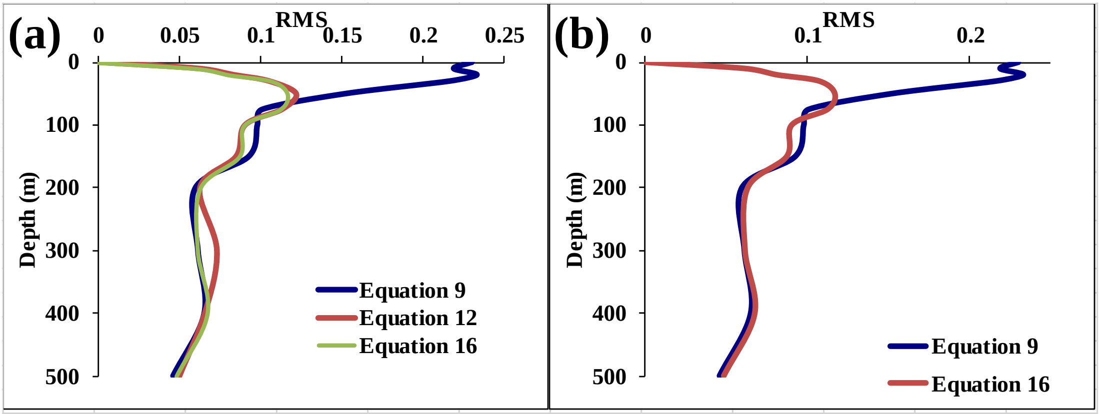

Fig. (13). RMS errors **(a)** for models (Eqs. 9, 12 and 16), RMS errors **(b)** for models (Eqs. 9 and 16)

CONCLUSION

The salinity observation (measurement) in the World Ocean presents special difficulty than the temperature; therefore, historical data on the salinity are non-uniform and extremely irregular. Recently, it is possible to find the main general statistical relations between the salinity and set of predictors like temperature, day of the year (season) as well as the geographical characteristics of these statistical relations, which allows us to use these relations effectively for estimating the ocean salinity. The method suggested here has an idea regarding the development of regression coefficients of the oceanographic data on the salinity and temperature using polynomial regression analysis of the relations between salinity (S), temperature (T), latitude (x), longitude (y), and day of the year (d), which helps estimate the salinity in any location of the Red Sea that provides the measurements of temperature values. Actually, the application of the method is specified to the Red Sea and a depth of 500m. In case that the surface salinity is available, the regression model represented by Eq. (16) is the best one to estimate salinity in the study area. While, if the surface salinity is not available, one can use the regression model represented by Eq. (9), which nearly coincides with results of Eq. 16 for the depth below 75m.

REFERENCES

Donguy, J.R.; Eldin G. and Wyrtki, K. (1986). Sea level and dynamic topography in the western Pacific during 1982-1983 El Nino. Trop. Ocean-Atmosphere Newsletter, 36:1-3.

Emery, W.J. and Brien, A.O'. (1978). Inferring Salinity from Temperature or Depth for Dynamic Height Calculation in the North Pacific, Atmosphere–Ocean **16** (4): 348–366.

Hansen, D.V. and Thacker, W.C. (1999). Estimation of Salinity Profiles in the Upper Ocean, J. Geophysical Research. 104(C4): 7921–7933.

Hussein, M.M.A., Said, M.A., Radwan, A.A. (2011). Estimating Salinity Profiles in the Southeastern Mediterranean Sea off the Egyptian Coast, JKAU Marine Science, 22(1):79-95.

Hussein, M.M.A. (2016). A Regression Model for Estimating Salinity in the South Eastern Mediterranean Sea, International Journal of Environmental Monitoring and Analysis, 4(2):56-64.

Korotenko, K.A. (2007). A Regression Method for Estimating Salinity in the Ocean, Oceanoloy, 47, (4):464-475.

Radwan, A.A. (2008). Hydrographic Structure and Water Circulation in the Red Sea and their Influences on the Sea Water Level, Faculty of Science, Alexandria University, Ph.D. thesis, pp 236.

Stommel, H. (1947). Note on the use of the T-S correlation for dynamic height anomaly calculations. Marine Research, VI: 85–92.

Thacker, W.C. (2007). Estimating salinity to complement observed temperature: 1. Gulf of Mexico. Journal of Marine Systems, 65:224-248.

Thacker, W.C. and Sindlinger, L. (2007). Estimating Salinity to Complement Observed Temperature: 2. Northwestern Atlantic, Journal of Marine Systems, 65:249-267.