New Sea Surface Salinity Product in the Tropical Indian Ocean Estimated from Outgoing Longwave Radiation

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Abstract- The sea surface salinity (SSS) product as derived from space-borne satellite measurements of Outgoing Longwave Radiation (OLR), based on the algorithms developed by [1], is discussed for the tropical Indian Ocean (TIO) during the period 1995-2000. The monthly variation of derived SSS for the TIO is found to be comparable with the climatological (Word Ocean Atlas 98) monthly SSS map highlighting that the differential hydrological cycle over the northern Indian Ocean basins could be captured by the atmospheric convection parameter, the OLR. Larger variation in SSS is noticed in the Bay of Bengal during southwest monsoon and fall season. The derived lower SSS north of Australia and around Madagascar in July-October, 1996 represent the inflow of low salinity waters from the Pacific and the influence of local precipitation respectively. The deviation of derived SSS from that of WOA98 SSS varied between-0.5 and 1.5 psu for winter and spring seasons. Larger deviations (-4 to 4 psu), however, are noticed during fall season in the Bay of Bengal. This means that satellite derived OLR seems capable of providing SSS values, but appears overestimated in the Bay of Bengal suggesting the immense contribution from river run off. The seasonal variation of derived SSS from one year to the other is quite comparable (with a standard deviation of ±0.3 psu during 1995-2000) with the seasonal WOA98 SSS.

I. INTRODUCTION

References [1] and [2] have introduced an oceanic parameter, the effective oceanic layer (EOL) that is linearly related to the OLR, the atmospheric parameter for convection. The EOL parameter represents the near-surface stratified layer (0-30 m) and has been defined as the geopotential thickness of this top layer thus considers both temperature and salinity. These authors reported higher correlations between OLR and EOL in each month which highlights that the atmospheric convection is closely linked to the near-surface oceanic conditions. The EOL parameter in turn is closely related to the SSS than the sea surface temperature (SST) (except during winter months in the Arabian Sea) since the mean temperature of the 0-30 m layer is nearly the same as that of SST. The closer relationship between EOL and SSS with higher correlation coefficient encourages one to estimate the SSS from the OLR through the use of statistical algorithms. Since the TIO experiences seasonal reversal of wind forcing and differential hydrological cycle, the statistical relationships have been separately developed for each of the regions such as the Arabian Sea (AS), Bay of Bengal (BOB), Equatorial Indian Ocean (EIO) and southern tropical Indian Ocean (SIO). In this way, we can envisage development of new SSS products for the TIO and also other Oceans where atmospheric convection plays a major role for salinity variations (eg., Western Pacific).

This paper addresses this new method for deriving the SSS from OLR in the TIO wherein the convection over the ocean is a regular seasonal phenomenon in association with the summer monsoon and the Intertropical Convergence Zone (ITCZ). Reference [2] describes this new method with a preliminary assessment of estimation of SSS over the Bay of Bengal using the OLR. The OLR measures the cloud top temperature and represents the measure of convection over the oceans and land areas. The intense convection will have the lowest cloud top temperature and hence the lowest OLR. Therefore, the zones of the lowest OLR could be the regions of intense convection over the tropical

Oceans [3]. Conversely, the zones of the highest OLR (say, 220 W/m^2) could be regions of little convection or cloud-free skies.

II. METHODOLOGY

This study is based on the idea that intense convection over the ocean is associated with warmer SSTs maintained by low SSSs formed due to convection-induced precipitation and compounded by large riverine input (as in the case of the Bay of Bengal) and advection of low salinity waters from the Pacific Ocean *via* the Indonesian Throughflow. It is envisaged that the sea surface salinity estimated in this way may be useful to improve the existing SSS climatologies of the TOI and Pacific Oceans. The near-surface stratified layer is characterized with a subsurface stability maximum. The EOL is defined as the geopotential thickness (m^2/s^2) of the stratified layer [[1, 2] and is computed from:

$$EOL = \int_0^{30} \alpha . dp$$

where α is the mean specific volume anomaly (m^3/kg) as a function of T, S, and P over the pressure interval (dp). The development of the algorithms to estimate the SSS from OLR is explained in [1] and the procedure is explained in "Fig. 1".

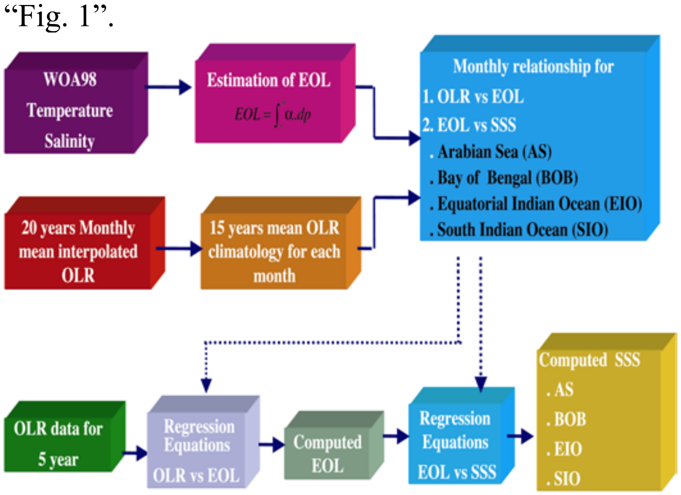
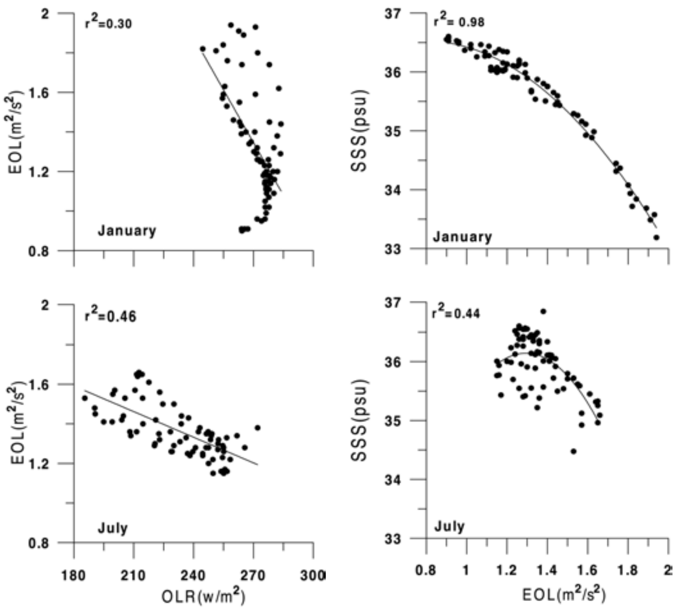


Fig.1.Schematic diagram explaining the computational methodology for estimation of SSS from OLR.

In this study we have used (i) daily OLR data at 2.5°x2.5° grids from January 1979 to December 2000 from NOAA polar-orbiting satellites obtained from NOAA-CIRES Climate Diagnostic Center, (ii) the monthly mean upper ocean data on temperature and salinity from the WOA98, (iii)monthly evaporation minus precipitation (E-P) data from 1980 to 1997 at 1°x1° grids compiled by [4] and (iv) the monthly rainfall or precipitation data at 2.5°x2.5° grids from the NOAA Climate Prediction Center Merged Analysis of Precipitation (CMAP;] [5].

In [1], we explained the treatment of the data sets and the algorithms development to estimate the SSS from OLR. The WOA98 data set was used to estimate the EOL. Out of 22 years of OLR data, the first 15 years data were used to make the monthly OLR climatology and the other 7 years OLR data were used for the estimation of SSS. Climatological monthly data of EOL and OLR were used for the construction of scatter plots to examine the relationships between OLR, EOL and WOA98 SSS for each of the regions separately. This is because each of the region experiences different hydrological cycle (balance of evaporation (E), precipitation (P) and runoff (R). While the Arabian Sea looses water due to excessive evaporation, the Bay of Bengal gains water from excess precipitation and also from the river inputs [6]. The equatorial region (5°N – 10°S) receives excess precipitation in the east and lesser precipitation in the west. We have also considered the E-P data and the rainfall data for choosing the regions. As an example, the relationships between OLR and EOL and between EOL and SSS are shown for the Arabian Sea "Fig. 2" only for the representative months of winter season (January) and southwest monsoon or summer (July) season. The relationship between OLR and EOL is linear with better correlation coefficients (r^2 between 0.30 and 0.46). Whereas the relationship between EOL and SSS is fitted with 2nd degree polynomial and the correlation coefficients varied between 0.98 and 0.44. Similarly, [1], [2] found fairly better relationships and correlation coefficients for each month in each of the regions of the TOI. From the algorithms developed, the SSS is estimated in two steps – firstly the regression equation between OLR and EOL has been used to estimate the EOL using the monthly OLR data from 1995 to 2000 and secondly the estimated EOL has been used in the regression equation between EOL and SSS to estimate the SSS for the month of OLR data. This procedure has been adopted for each region. The results of seasonal variation of the estimated SSS during 1996 are presented in "Fig.3". The deviations of the estimated SSS from that of WOA98 SSS have also been obtained and shown in "Fig. 4". The year-to-year variation of estimated SSS during 1995-2000 is presented at two selected locations in "Fig. 5".



(a) (b)

Fig. 2. Scatter plots showing relation (a) between OLR vs EOL and (b) EOL vs. SSS in the Arabian Sea during January and July.

III. RESULTS

The seasonal variation of the estimated SSS in 1996 "Figs. 3a-d" agrees quite well with the corresponding monthly WOA98 SSS. The low SSS in the Bay of Bengal, higher SSS in the Arabian Sea and the tongue of low salinity extending from Sumatra to 10°S, 60°E in the equatorial region are the conspicuous features in January "Fig. 3a". The SSS is dropped to lowest value in the eastern Bay of Bengal in July with the southwest monsoon. By October, the lower SSS occurs in the western Bay of Bengal. The low salinity waters are also seen in the northern Australia and also around Madagscar. The Bay of Bengal (north of Australian continent and Madagascar) experiences intense convection and receive precipitation during June-October, the northern (southern) summer (winter) months.

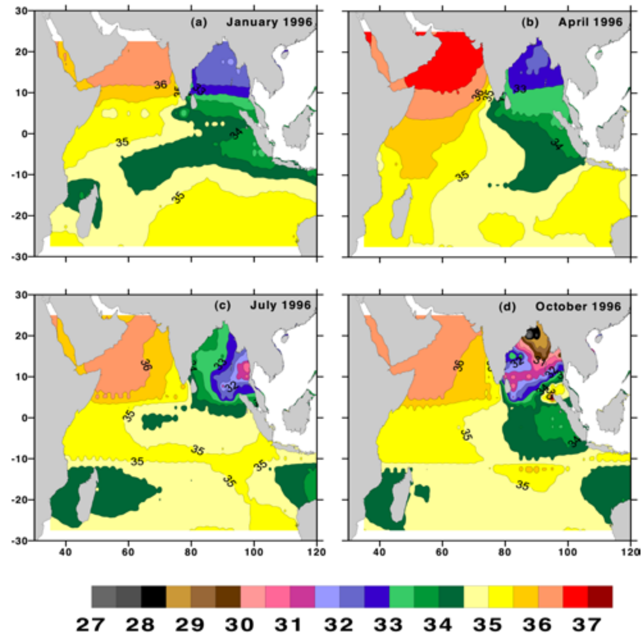


Fig. 3. Seasonal variation of estimated SSS in the tropical Indian Ocean in 1996 during a) January, b) April, c) July and d) October.

The deviations of the estimated SSS from the WOA98 SSS for each month are within ±1.0 psu in a larger area of the TIO. The deviations are typically large in the Bay of Bengal during July and October where the river run off and intensive convection lead precipitation control the SSS. The largest deviation in the SSS in July and October are the artifact of contouring near the coastal boundary of the Bay of Bengal.

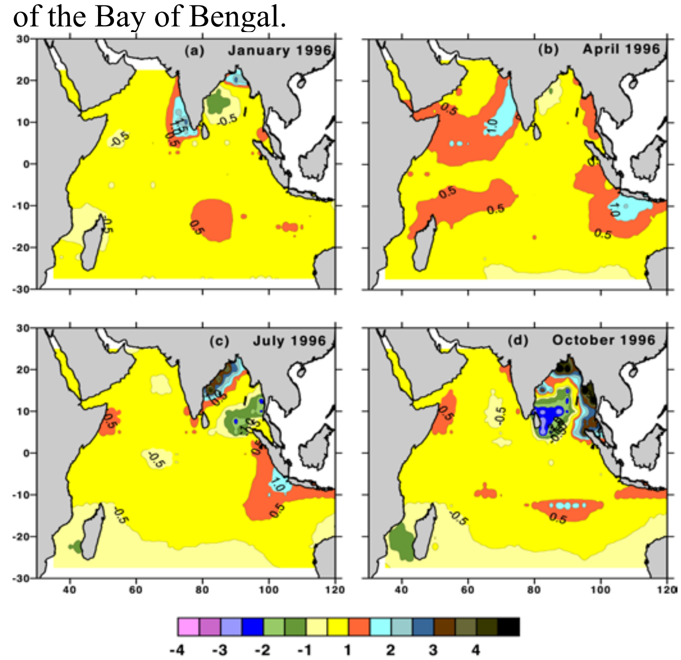


Fig. 4. Difference between estimated SSS and WOA98 SSS climatology in 1996 during a) January, b) April, c) July and d) October.

The deviations between the estimated and WOA98 SSS are more or less in the same range from one year to the other. However, slightly larger deviations have been occurred corresponding to the year-to-year variation in the OLR. In “Fig. 5”, we have examined the deviations of estimated SSS from that of WOA98 SSS at two locations – one in the Arabian Sea (20°N, 65°E) and the other in the SIO (20°S, 100°E). In the Arabian Sea location, the annual variation of the estimated SSS is similar to the WOA98 SSS; however, the minimum estimated SSS is relatively larger from that of WOA98 with a deviation of about 0.5 psu, while maximum estimated SSS is closer to the WOA98 SSS. In the SIO location, the minimum estimated SSS is closer to the WOA98 while maximum SSS shoots up the WOA98; however, the deviation is within 0.5 psu. The mean and standard deviation of the estimated SSS over 6 year period (1995-2000) and annual mean WOA98 SSS are comparable to each other at both the locations (shown in Fig. 5). Thus, the consistency in the deviations of estimated SSS from that of climatological SSS over a larger period of time encourages the use of OLR based algorithms for the estimation of SSS in the tropical Indian Ocean.

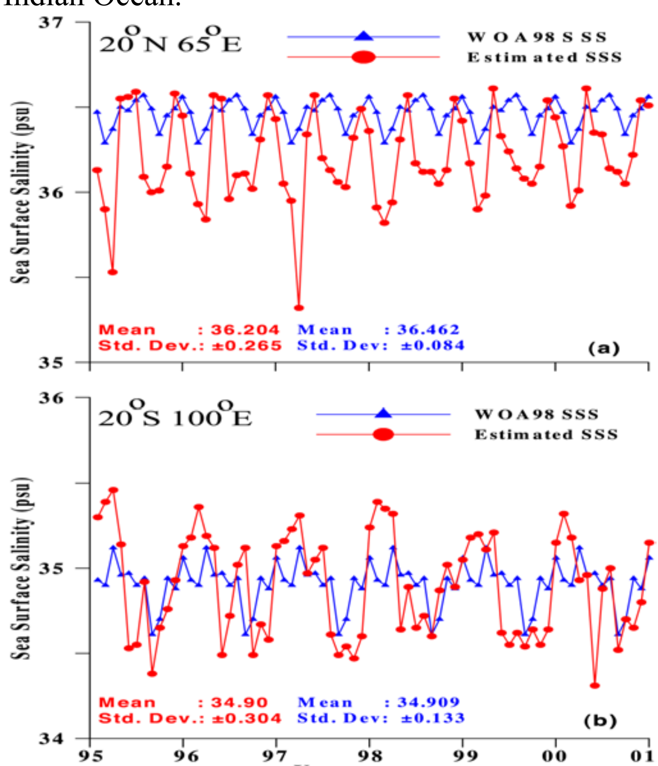


Fig.5. Comparison of interannual variation of estimated SSS vs WOA98 SSS.

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