

Water masses and property distribution in the EEZ of Mauritius

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Abstract - Water masses and their properties have been studied in the Mauritian waters during September-October, 1987. Surface water is characterized by two water masses: i) a warm (temp. $>27^{\circ}\text{C}$) and relatively saline water (salinity $>35.3 \times 10^{-3}$) which appears to be centred between 10° and 13° S Lat., has low density (σ_{θ}) lying between 22.9 and 23.3, low concentration of nutrients and high dissolved oxygen content ($4.5 - 5.0 \text{ml.l}^{-1}$), and (ii) a cold (temp. $<25^{\circ}\text{C}$) and less saline water (salinity $<34.8 \times 10^{-3}$) centred around $14 - 16^{\circ}$ S Lat. which is also characterized by low density (σ_{θ} 23.2 - 23.5), low nutrients and high dissolved oxygen concentration.

At intermediate depths three main water masses could be identified: (i) Salinity Maximum Water with salinities ranging from 35.05 to 35.64×10^{-3} in the thermocline just below the surface mixed layer in the density range (σ_{θ}) 24.8 - 26.0. It is associated with shallow oxygen minimum and relatively higher concentration of nutrients, (ii) Oxygen Maximum Water in the depth range 400 - 500m with oxygen concentrations in the range $3.4 - 5.2 \text{ml.l}^{-1}$ and density (σ_{θ}) 26.5 - 27.0. It is associated with relatively lower concentration of nutrients, and (iii) Salinity Minimum Water in the depth range 600 - 950m with salinity varying between 34.58 and 34.73×10^{-3} and temperature $6.1 - 7.8^{\circ}\text{C}$. It has high concentrations of nutrients and low dissolved oxygen content.

Properties of these waters and their sources have been discussed. An attempt has been made to use AOU as a tool to study the movement and properties of water masses that are formed at sea surface.

INTRODUCTION

This paper gives an account of the chemical observations carried out during the oceanographic survey of the EEZ of Mauritius on ORV SAGAR KANYA (Sept.15 - Oct.12, 1987) on the water mass structure and property distributions.

MATERIAL AND METHODS

Water samples were collected from standard depths (Fig.1) of upto 2500m using Nansen samplers having reversing thermometers. Temperature was read from the reversing protected and unprotected thermometers which enabled to apply the necessary correction to depths. Salinity was measured on Guildline "Autosal" salinometer while the nutrients nitrate, nitrite and silicate were estimated using Skalar Autoanalyser. Phosphate was analysed by the method of MURPHY and RILEY (1962). Dissolved oxygen was estimated by the modified method of Winkler (CARRITT and CARPENTER, 1966). All the analyses were carried out on board the ship immediately after the collection.

RESULTS AND DISCUSSION

To illustrate the vertical distribution of properties in this area, profiles of salinity, temperature, oxygen, nitrate, phosphate and silicate have been drawn for one typical station on the eastern side of the archipelago, and one station on the western side (Figs.2&3). In addition vertical profiles of these parameters have been drawn along a N-S section between 10° and 19°S along 56°E meridian (Figs.4a-4f).

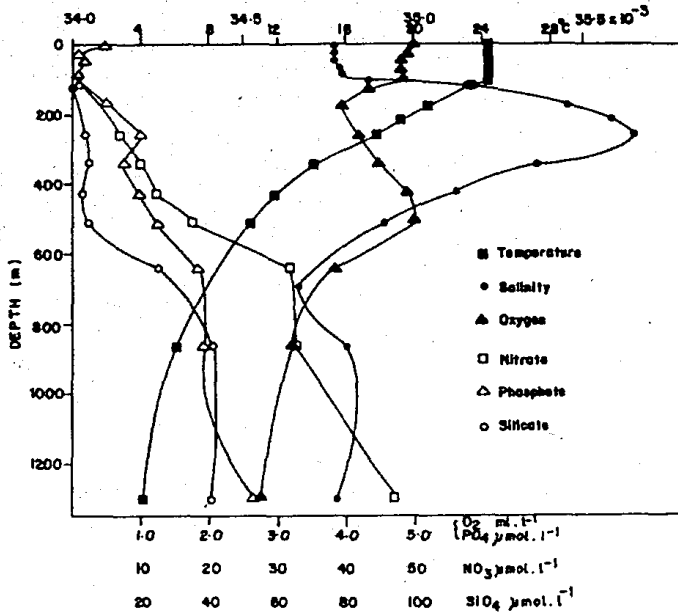


Fig.2. Vertical profiles of temperature, salinity, oxygen, nitrate, phosphate and silicate at station SK 35 - 62.

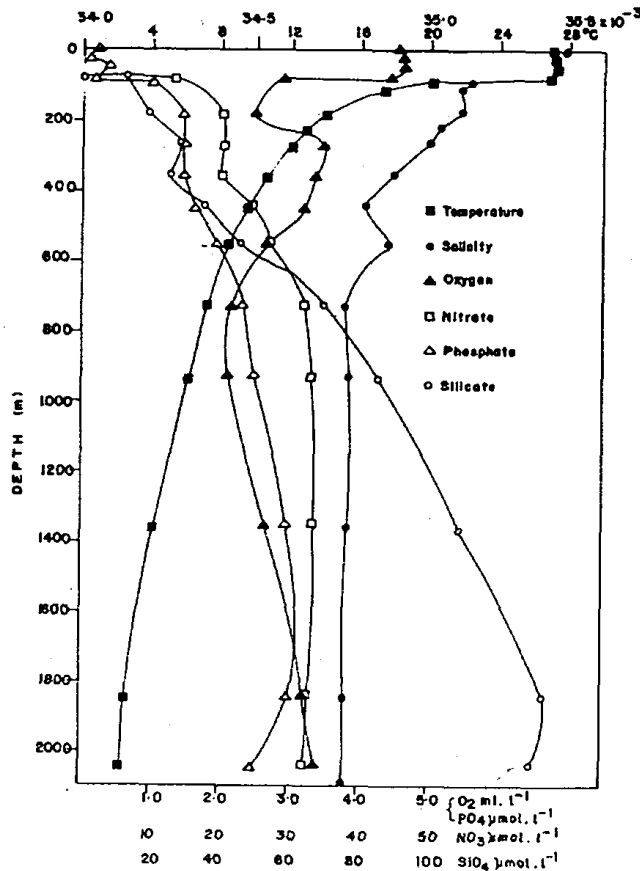


Fig.3. Vertical profiles of temperature, salinity, oxygen, nitrate, phosphate and silicate at station SK 35 - 120

Surface mixed layer

This layer extends from surface down to about 100m depth and is characterized by high concentration of dissolved oxygen associated with low concentration of nutrients (Figs.2,3&4) and salinities ranging between 34.67×10^{-3} and 35.39×10^{-3} . There are two water masses present in this layer (Figs.2,3&4) (i) a warm (temp. $>27^{\circ}\text{C}$) and relatively saline water (salinity $>35.3 \times 10^{-3}$) and, (ii) a cooler (temp. $<25^{\circ}\text{C}$) and fresher (salinity $<34.8 \times 10^{-3}$) water. The warm saline water which appears to be centered at around 10°S Lat. spreading upto about 13°S is clearly seen in Figs. 3&4 as a 80m thick layer of warm saline water overlying fresher and cooler water below. It is characterized by other properties which are typical of tropical surface water, i.e., low density (σ_{θ} 22.9 - 23.3), low NO_3 ($<0.1 \mu\text{mol.l}^{-1}$), low PO_4 ($<0.2 \mu\text{mol.l}^{-1}$), low SiO_4 ($<0.5 \mu\text{mol.l}^{-1}$) and high concentration of dissolved oxygen ($4.5 - 5.0 \text{ml.l}^{-1}$) which is near its saturation value. This water was also observed by WARREN, STOMMEL and SWALLOW (1966) in the Somali Basin as far north as 6°N Lat. The latter authors have termed it as a "band of very warm, fresh, equatorial surface water" stretching across the entire Indian Ocean. The cooler and fresher water, on the other hand is centered around Lat. $14^{\circ} - 16^{\circ}\text{S}$ and is also characterized by low density (σ_{θ} 23.1-23.5) low nutrients and high dissolved oxygen. WARREN (1981a) has suggested two possible sources for this water (i) influx of low salinity water from the Pacific through the Indonesian Archipelago which is subsequently carried westwards by South Equatorial Current, and, (ii) the effect of local excess of precipitation over evaporation resulting in low salinity surface water which then spreads southwards, probably aided by South Equatorial Current.

Intermediate depths (100-1000m)

The intermediate water is marked by the following characteristics: (i) a prominent salinity maximum just below the surface layer, associated with a shallow oxygen minimum, (ii) an oxygen maximum, (iii) a salinity minimum, and (iv) an intermediate oxygen minimum.

Table 1. Depth, temperature, salinity, DO, NO_3 , PO_4 and SiO_4 of the core 'Salinity Maximum Water'

Stn No.	Depth m	Temp $^{\circ}\text{C}$	S $\times 10^{-3}$	DO ml.l^{-1}	NO_3 $\mu\text{mol.l}^{-1}$	PO_4 $\mu\text{mol.l}^{-1}$	SiO_4 $\mu\text{mol.l}^{-1}$
43	200	19.0	35.57	4.35	5.0	1.00	43
55	220	19.4	35.56	4.00	6.0	0.50	29
60	250	18.5	35.6	-	-	-	-
62	260	18.3	35.64	3.95	7.0	1.00	4
63	230	18.5	35.56	3.90	5.5	0.60	4
69	200	18.8	35.20	3.05	15.0	1.00	12
73	185	20.1	35.37	-	-	-	-
76	260	15.3	35.26	3.10	17.0	1.20	19
86	230	16.6	35.41	3.65	7.0	0.60	6
90	200	15.6	35.28	-	-	-	-
93	230	16.1	35.3	2.80	20.0	1.10	20
95	150	17.0	35.05	-	-	-	-
99	220	15.8	35.31	2.95	20.0	1.50	25
104	170	17.5	35.22	3.15	10.3	1.25	-
120	150	15.5	35.09	2.50	20.0	1.45	29
123	140	19.1	35.2	2.90	16.0	1.35	21
126	220	17.5	35.5	3.15	8.5	0.70	6
130	240	17.5	35.29	-	-	-	-
131	260	17.7	35.54	3.90	5.5	0.40	4
133	280	17.3	35.53	-	-	-	-

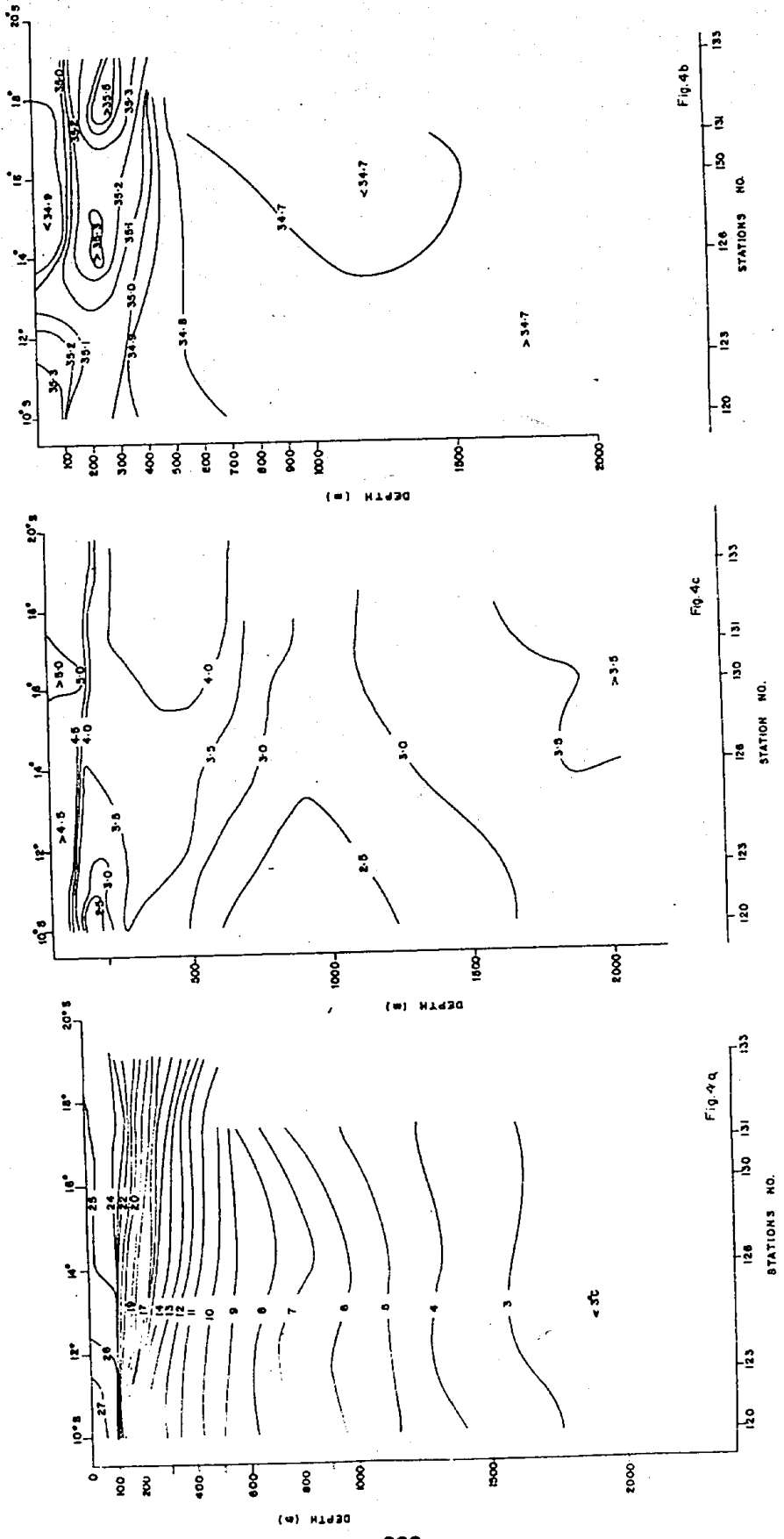


Fig.4 (a, b & c). Vertical profiles of temperature, salinity and dissolved oxygen respectively along 56°E Long.

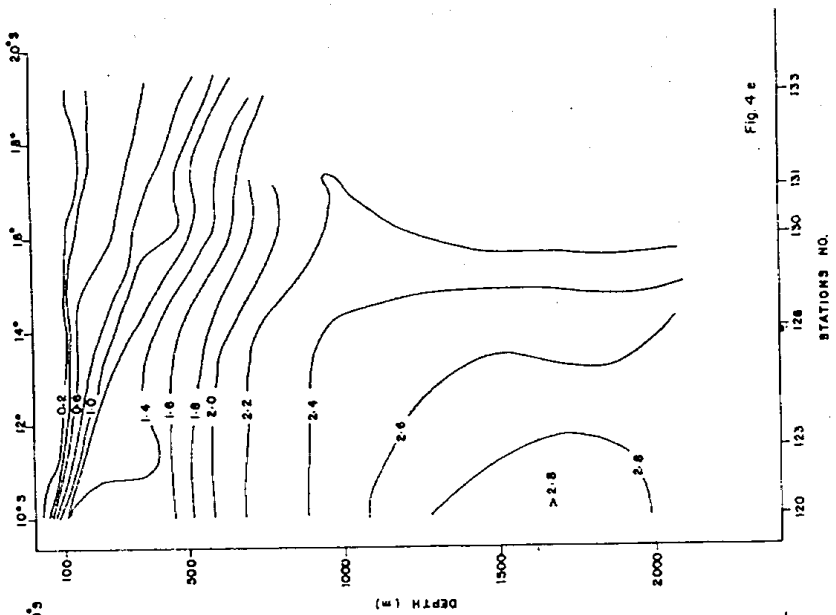


Fig. 4e

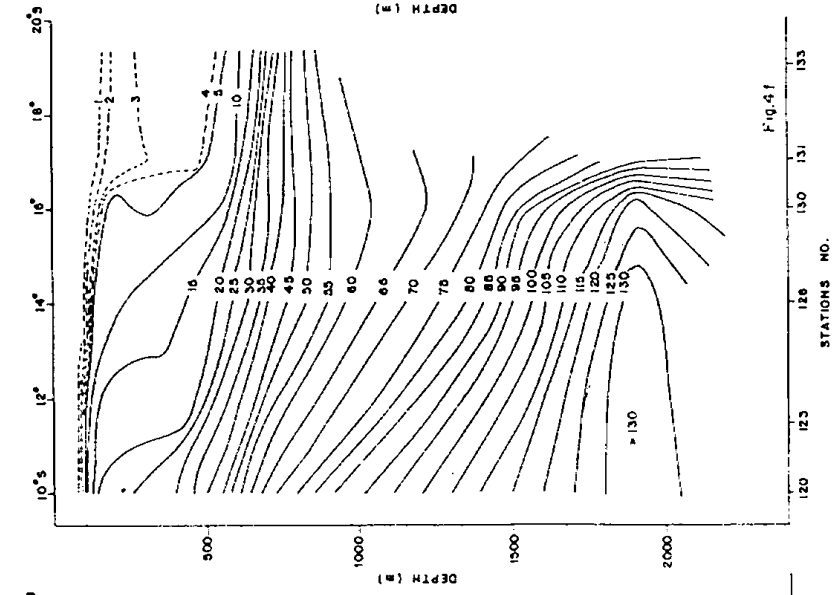


Fig. 4f

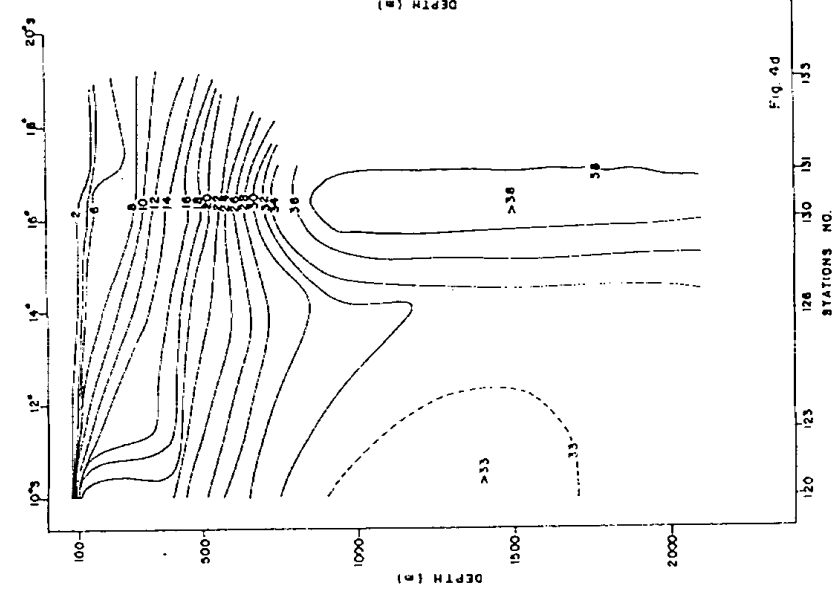


Fig. 4d

Fig. 4 (d, e & f). Vertical profiles of nitrate, phosphate and silicate respectively along 56°E Long.

Salinity maximum

A salinity maximum ($35.05-35.64 \times 10^{-3}$) layer extending from 100m to about 400m depth is observed in the thermocline just below the surface mixed layer (Figs.2,3&4b). As seen in the above figures and Table 1 the intensity of the maximum decreases northwards from over 35.5×10^{-3} in the southern stations to just over 35×10^{-3} in the north (stations 95 & 120) where its salinity decreases probably due to mixing with the low salinity water coming from the Indonesian Archipelago (WARREN, 1981a) carried westwards by South Equatorial Current (SHARMA, 1972). At station 120 (Lat. 10°S) it is seen as a very faint maximum (Fig.3) almost masked by the high salinity surface water present at this station. The salinity maximum is strongly associated with a shallow oxygen minimum whose intensity increases northwards with oxygen concentrations decreasing from 4.35ml.l^{-1} at station 43 (Lat. $20^{\circ}21'\text{S}$) to as low as 2.50ml.l^{-1} at station 120 (Lat. 10°S). Nutrients concentrations in this layer are relatively high showing increasing trends northwards (Table 1) - NO_3 increasing from $5 \mu\text{mol.l}^{-1}$ at station 43 to $20 \mu\text{mol.l}^{-1}$ at station 120, while the corresponding increase in PO_4 is from $1.0 \mu\text{mol.l}^{-1}$ to $1.45 \mu\text{mol.l}^{-1}$. Silicate does not show any trend in variation in this layer. WYRTKI (1973) has termed this high salinity water as 'Subtropical Surface Water' while WARREN (1981a) has suggested this water to originate at sea surface in latitudes 25° to 35°S , the high salinities resulting from excess of evaporation over precipitation in these latitudes. As this water moves northwards, it diminishes in strength due to mixing with low salinity water until its presence is almost not felt at around Lat. 10°S . The sharp oxygen minimum which is associated with the salinity maximum has been explained to be due to the *in situ* biological consumption of oxygen (WARREN, 1981a&b). According to the above author the rate of oxygen consumption decreases exponentially with depth, thus resulting in the oxygen minimum whose strength increases as the water moves north. As the consumption of oxygen due to oxidation of organic matter proceeds, inorganic nutrients are released and as the intensity of oxidation in this layer increases towards north so do the amount of Apparent Oxygen Utilization (AOU) and the concentration of nutrients. The observed increase in AOU and the concentration of NO_3 and PO_4 towards lower latitudes (Table 1) is consistent with the above.

Oxygen maximum

An oxygen maximum is observed below the salinity maximum, centred at 400 - 500m depth (Figs.2,3&4c) with intensity decreasing northwards (Table 2). The concentration of dissolved oxygen in the maximum ranges between 3.4 and 5.2ml.l^{-1} , the highest concentrations observed being in the southernmost stations and decreasing northwards. The salinity of the oxygen maximum core is in the range $34.82 - 35.20 \times 10^{-3}$. The oxygen maximum is associated with relatively lower concentrations of nitrate ($10-30 \mu\text{mol.l}^{-1}$), phosphate ($0.5-1.55 \mu\text{mol.l}^{-1}$) and silicate ($4-29 \mu\text{mol.l}^{-1}$), the lowest concentrations being in the southernmost stations and showing increasing trend towards north. As is seen in Fig.4c the oxygen maximum is strongly developed in the southern latitudes and weakens as the water moves northwards. The oxygen maximum lies in the temperature range $8-14^{\circ}\text{C}$ and is believed to be formed by a deep vertical convection in Lat. 40° - 50°S . MCCARTNEY (1977) showed that in late winter the surface mixed layer in these latitudes extends upto 400-500m. As this water moves northwards it sinks below the lighter, salinity maximum water and loses part of its oxygen due to oxidation of organic matter with the liberation of inorganic nutrients in lower latitudes. The relatively lower concentration of nutrients associated with low AOU values and high O_2 concentration in a water layer well below the euphotic zone in southern stations suggests that this water has overturned relatively recently from the surface layer, while in lower latitudes the same water shows lower O_2 concentration associated with higher

AOU and higher nutrients thus suggesting longer transit time of this water since it left the surface at the place of its formation.

Table 2. Depth, temperature, salinity, DO, NO₃, PO₄ & SiO₄ of the core 'Oxygen Maximum Water'.

Stn. No.	Depth m	Temp °C	S x10 ⁻³	DO ml.l ⁻¹	NO ₃ μmol.l ⁻¹	PO ₄ μmol.l ⁻¹	SiO ₄ μmol.l ⁻¹
43	550	11.7	34.90	5.20	10.4	0.95	-
55	400	12.6	35.20	5.00	10.0	0.50	17.0
62	510	10.3	34.91	5.00	17.5	1.25	5.0
63	400	13.3	35.21	4.25	13.0	1.05	9.0
69	400	10.6	34.95	4.85	16.0	1.05	5.0
76	580	9.3	34.76	4.90	16.5	1.30	8.0
81	470	9.4	34.82	3.39	21.6	1.52	22.0
86	500	10.4	34.89	5.05	7.0	1.00	5.0
93	450	10.5	34.82	4.60	24.0	1.35	18.0
95	420	10.6	34.85	3.81	30.0	1.35	21.0
99	340	11.5	34.98	3.40	20.5	1.55	21.0
104	275	12.1	35.05	3.75	14.0	1.20	-
120	270	11.7	34.98	3.50	20.5	1.45	29.0
123	375	10.4	34.86	4.00	17.0	1.35	17.0
130	467	10.6	34.89	4.97	16.0	1.00	5.2
131	470	10.4	34.86	5.05	16.0	1.05	4.0

Table 3. Depth, temperature, salinity, DO, NO₃, PO₄ & SiO₄ of the core 'Salinity Minimum Water'.

Stn. No.	Depth m	Temp °C	S x10 ⁻³	DO ml.l ⁻¹	NO ₃ μmol.l ⁻¹	PO ₄ μmol.l ⁻¹	SiO ₄ μmol.l ⁻¹
43	760	7.30	34.58	4.60	25.0	1.85	-
62	700	7.80	34.66	3.55	33.0	1.95	31.4
63	500	7.50	34.69	3.30	31.0	2.10	36.0
69	600	7.80	34.68	4.00	28.0	1.60	28.0
76	750	6.80	34.58	3.70	28.0	2.00	40.0
81	740	6.70	34.73	2.56	30.0	2.37	64.0
86	680	8.00	34.69	3.85	10.1	2.05	20.0
90	720	6.70	34.73	2.66	39.2	2.41	78.0
93	690	7.20	34.73	2.55	39.5	2.35	68.0
95	670	7.28	34.72	2.63	-	2.11	64.0
99	730	7.15	34.73	2.00	36.5	2.00	77.0
104	550	7.85	34.71	2.20	26.5	2.20	-
120	730	7.10	34.76	2.20	32.5	2.30	70.0
126	800	6.80	34.69	3.00	28.0	2.20	42.0
130	945	7.00	34.68	2.85	38.8	2.19	56.8
131	740	6.10	34.60	3.30	34.0	1.95	39.0

Salinity minimum

Below the oxygen maximum there is a salinity minimum in the depth range of 600-950m (Table 3, and Figs.2,3&4b). The salinity of the core water lies in the range 34.58-34.73x10⁻³ and temperature 6.1-7.8°C. The other characteristics of this water are: comparatively lower oxygen concentrations (2-3.7ml.l⁻¹) associated with higher nutrients NO₃ (25-39.5μmol.l⁻¹, PO₄ (1.6- 2.6μmol.l⁻¹) and silicate (28-77μmol.l⁻¹). This water has been identified as the Antarctic Intermediate Water (WARREN, 1981a) which forms near the Polar Front. The relatively higher salinities which increase northward, observed in the present study as compared with those observed by WARREN (1981a) at Lat.18°S suggest that this water gradually mixes with higher salinity water as it moves northwards.

The observed lower concentrations of oxygen associated with higher nutrients concentrations in the northern stations compared with their values at higher latitudes, are consistent with the suggestion (WARREN, 1981a) that the northward movement of this water is slower than that of oxygen maximum water, and that higher amounts of oxygen are consumed accompanied by the release of higher amounts of nutrients during its longer transit time.

Intermediate oxygen minimum

This layer is found below the salinity minimum layer in the depth range 670-1150m. It is associated with very low concentrations of oxygen and high nutrients. This layer is common to all deep sea stations and is caused by *in situ* oxygen consumption by oxidation of organic matter.

AOU as a tracer of water movement

An attempt has been made to use the Apparent Oxygen Utilization (AOU) as a tracer for the movement of water masses. This is based on the assumption that a water mass which is formed at sea surface is saturated with oxygen at the place of its formation. However, as this water mass moves in one direction or the other after sinking to its density level, it loses part of its oxygen due to oxidation of organic matter. At any point along the flow path of this water, the amount of oxygen lost (AOU) by it must be related either to the distance covered by the water mass since it left the surface at the place of its formation, or to the time elapsed since the water mass left the surface. Hence, if the rate of loss of oxygen with respect to either time t or distance d covered in the direction of flow is known and the values of temperature and salinity of the core water at any point along its path of flow are measured then one should be in a position to predict the oxygen concentration and AOU of this water at any point along the path of flow as follows:

For a given water mass the rate of loss of oxygen with respect to distance, i.e., $\Delta \text{AOU}/\Delta d$ can be obtained from the regression of AOU values observed at various points along the path of flow of the water, against the distance of these points from a reference point P also on the path of flow. The slope of the regression will give the rate of loss of oxygen with respect to distance ($\Delta \text{AOU}/\Delta d$). Now, if AOU_0 is the value of AOU at the reference point then the value of AOU at any other point P_1 along the path of flow at a distance d_1 from the same reference point will be given by

$$\text{AOU}_1 = (\Delta \text{AOU}/\Delta d) \times d_1 + \text{AOU}_0 \quad (1)$$

and the concentration of dissolved oxygen at that point will be given by

$$\text{O}_2 = \text{O}_2' - \text{AOU}_1 \quad (2)$$

where O_2' is the value of oxygen solubility in that water, which can be computed from the relation given by WEISS (1970), and using the measured values of temperature and salinity.

Combining equations (1) and (2)

$$\text{O}_2 = \text{O}_2' - (\Delta \text{AOU}/\Delta d) \times d_1 - \text{AOU}_0 \quad (3)$$

One should also be able to determine the place of formation of that water assuming that at that place the water is saturated with oxygen, i.e., where $\text{O}_2 = \text{O}_2'$ and $\text{AOU} = 0$. This point should be given by the intercept on d -axis of AOU Vs d regression at $\text{AOU} = 0$.

From relation (1) we have, at $\text{AOU} = 0$

$$(\Delta\text{AOU}/\Delta d) \times d + \text{AOU}_0 = 0$$

$$d = - \frac{\text{AOU}_0}{\Delta\text{AOU}/\Delta d} \quad (4)$$

Equation (4) gives a relation to determine the distance of the place of formation of the water mass from a given reference point. The application of this could also be extended to further studies such as predicting the concentrations of nutrients NO_3 and PO_4 under normal conditions. However, for this one should have additional data such as oxidative ratios $\Delta\text{AOU}/\Delta\text{PO}_4$ and $\Delta\text{AOU}/\Delta\text{NO}_3$, and the 'reserved' fractions of these quantities (reserved PO_4 and reserved NO_3). Complications may arise to this simple model due to several factors such as;

- i) The rate of movement of water may not be uniform
- ii) The rate of loss of oxygen and the consequent rate of change of AOU with respect to either time or distance, i.e., $\Delta\text{AOU}/\Delta d$ or $\Delta\text{AOU}/\Delta t$ may not be uniform throughout the flow path.
- iii) At any point along its path additional amount of oxygen may be lost due to oxidation of additional organic matter raining down from upper layers and reaching this water in unoxidized or partly oxidized forms.
- iv) Additional changes in oxygen concentration may also be brought about by processes like mixing, diffusion, convection, etc.
- v) Water may be supersaturated or undersaturated with oxygen at its place of formation.

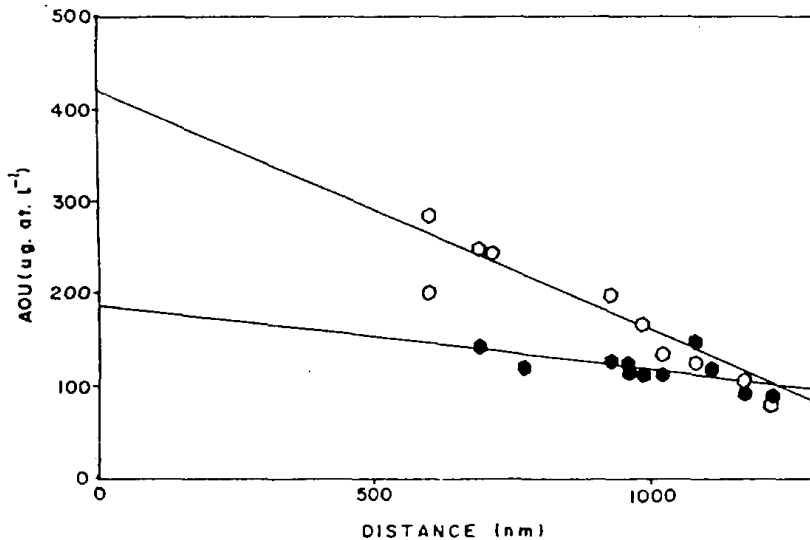


Fig.5. Regression of AOU over distance (1) Salinity Maximum Water (o—o), (2) Oxygen Maximum Water (•—•).

To test this model, we have considered two watermasses in the South Indian Ocean (1) The Salinity Maximum Water, and (2) The Oxygen Maximum Water. We plotted the AOU values of the core of each of these watermasses observed at various stations against the distance of the station from the Equator (Fig.5). The best fits for the regressions are given by the equations:

$$\text{AOU} = -0.261d + 421.37 \quad (5)$$

and,

$$\text{AOU} = -0.0688d + 187.58 \quad (6)$$

for the two watermasses respectively, where d is the distance of the station from the Equator expressed in nautical miles (nm) and AOU is expressed in $\mu\text{gat.l}^{-1}$. The slopes of the two lines are -0.261 and -0.0688 respectively, while the respective correlation coefficients are 0.893 and 0.579 . It is interesting to note the similarity between relation (1) and relations (5) and (6). The negative slopes of the two lines are because the distance d is measured in a direction opposite to the direction of flow of water.

From equation (5) it can be deduced that at $\text{AOU} = 0$, $d = 1614.44\text{nm}$ which roughly corresponds to 27°S Lat. That means that this watermass forms at sea surface at Lat. 27°S where it is assumed to be saturated with dissolved oxygen and the AOU is zero. From WYRTKI'S (1971) data it can be deduced that the dissolved oxygen in surface sea water in this area at 27°S Lat. had a mean concentration of $428.5\mu\text{gat.l}^{-1}$ while the solubility of oxygen at the prevailing mean temperature of 22.4°C and mean salinity of 35.5×10^{-3} is $442 \mu\text{gat.l}^{-1}$. This gives a value of $13.5 \mu\text{gat.l}^{-1}$ for AOU, which is close to zero and is consistent with our results. This is in good agreement with the findings of WARREN (1981a) who had suggested that this water forms at sea surface in Lat. 25 to 35°S where the high salinities which are caused by excess of evaporation over precipitation, are found across the breadth of the Indian Ocean. Similarly, using equation (6) for the Oxygen Maximum Water it can be deduced that at $\text{AOU} = 0$, $d=2726.45\text{nm}$ from the Equator towards south, which roughly corresponds to $45^{\circ}30'\text{S}$ Lat. and agrees fairly well with the watermass 'Central Water' of IVANENKOW and GUBIN (1960) who had suggested that this water forms south of Lat. 40°S .

It is, thus, seen that AOU can be used to trace the origin of a watermass which forms at sea surface. This parameter could also be used to follow the movement of such a watermass, and to predict the concentrations of properties like dissolved oxygen, nitrate and phosphate in this water at any point. However, a lot more data are needed to develop this idea further and confirm the model.

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REFERENCES

- CARRITT D.E. and S. H. CARPENTER (1966) Comparison and evaluation of currently employed modification of the Winkler method for determining dissolved oxygen in sea water. *Journal of Marine Research*, 24 , 286-318.
- IVANENKOW V.N. and F. A. GUBIN (1960) Watermasses and hydrochemistry of the Western and Southern parts of the Indian Ocean. *Transactions of the Marine Hydrophysical Institute, Academy of Sciences of the USSR., Physics of the Sea, Hydrology*, 22 , 29-99.
- MCCARTNEY M.S. (1977) Subantarctic Mode Water. In: *A voyage of discovery: George Deacon 70th anniversary volume*, M.V. Angel, editor, supplement to Deep Sea Research, Pergamon Press, Oxford, pp.103-119.
- MURPHY J. and J.P. RILEY (1962) A modified single solution method for the determination of phosphate in natural waters. *Analytica Chimica Acta*, 27 , 31-36.
- REDFIELD A.C., B.H. KETCHUM and F.A. RICHARDS (1963) The influence of organisms on the composition of seawater. In: *The Sea*, Vol.2, M.N. Hill, editor, Interscience, New York, pp.26- 77.
- SHARMA G.S. (1972) Water characteristics at 200 cl/t in the intertropical Indian Ocean during the southwest monsoon. *Journal of Marine Research*, 30 , 102-111.
- WARREN B. (1981a) Transidiantic hydrographic section at Lat 18°S : Property distributions and circulation in the South Indian Ocean. *Deep Sea Research*, 28A , 759-788.

- WARREN B. (1981b) The shallow water minimum of the South Indian Ocean. *Deep Sea Research*, 28A , 859-864.
- WARREN B., H. STOMMEL and J.C. SWALLOW (1966) Watermasses and patterns of flow in the Somali Basin during the southwest monsoon of 1964. *Deep Sea Research*, 13 , 825-860.
- WEISS R.F. (1970) The solubility of nitrogen, oxygen and argon in water and seawater. *Deep Sea Research*, 17 , 721-735.
- WYRTKI K. (1971) *Oceanographic Atlas of the International Indian Ocean Expedition*. National Science Foundation, Washington D.C., 531pp.
- WYRTKI K. (1973) Physical Oceanography of the Indian Ocean. In: *Ecological studies. Analysis and synthesis*, Vol.3, B. ZEITSCHEL, editor, Springer-Verlag, Berlin, pp.18-36.