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SHORT COMMUNICATION

Arabian Sea Mini Warm Pool and its Influence on Acoustic Propagation

P.V. Hareesh Kumar, K.V. Sanilkumar and C.V.K. Prasada Rao
Naval Physical & Oceanographic Laboratory, Kochi–680 021

ABSTRACT

A systematic experiment was conducted in the eastern Arabian Sea for the first time exclusively to study the characteristics of the Arabian Sea mini warm pool[1]. The analysis revealed complex nature of the thermohaline and sonic layer distributions across the Arabian Sea mini warm pool. This mini warm pool was identified between 67.5 °E and 75 °E, where the sea surface temperature was in excess of 30.25 °C. At the core of this mini warm pool, warmer (>31.2 °C) and low saline (<34.6 PSU) waters were noticed. Further, very thin sonic layer (< 5 m) was noticed at the mini warm pool core, which increased eastward and westward. In this study, the acoustic propagation characteristics across and outside of the core, i.e., (i) within the mini warm pool core, (ii) eastern side of the mini warm pool core, and (iii) western side of the mini warm pool core, were assessed based on the output of a range-dependant acoustic model. In general, the occurrence of this mini warm pool was found to alter the propagation characteristics. Better propagation was obtained when the simulation was carried out on the eastern side of this mini warm pool, with source near the coast (i.e., downslope condition).

Keywords: Arabian Sea mini warm pool, acoustic propagation model, transmission loss, acoustic propagation

1. INTRODUCTION

Anomalously warmer waters (> 30 °C) appear annually in the upper layers of the southeastern Arabian Sea prior to the onset of south-west monsoon, which is believed to drive the onset vortex of the south-west monsoon[1]. Since the area occupied by this waterbody is smaller and warmer compared to that of the well known Indo-Pacific warm pool (> 29 °C), this waterbody is named as the Arabian sea mini warm pool. The evolving stage of this warm pool is believed to start with the formation of Laccadive High resulting from the incoming Rossby waves[2-5] during November/December. Consequently, a large-scale anti-cyclonic gyre develops. Moreover due to pre-monsoon heating, heat accumulates in the surface layers of the Arabian Sea. In addition, incursion of low saline Bay of Bengal watermass produces more stratification in the upper layers, which in turn trap the heat in the near-surface layers and intensify the heating. All these processes lead to the formation of the mini warm pool. Consequently, a shallow mixed layer forms at the core of the mini warm pool with deep mixed layers on either side[1]. This environmental setting can significantly influence the acoustic propagation characteristics. However, no study has been carried out on this aspect. Hence, an attempt has been made to study the influence of this mini warm pool on the acoustic propagation characteristics.

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2. DATA COLLECTION

A spatial survey was carried out in the Arabian Sea during 13-19 May 2000 along 9 °N transect across the mini warm pool, i.e., between 67 °E and 76 °E, onboard Defence Research and Development Organisation's research vessel, INS *Sagardhwani*. During this survey, temperature and salinity profiles were collected from all the stations along this zonal transect, separated by 0.5° interval, using a mini CTD system (conductivity, temperature and depth system; accuracy: temperature ± 0.01°C, salinity ± 0.02 PSU; make: SAIV, Norway).

3. THEORETICAL BACKGROUND

Propagation models are the most common type of underwater acoustic models in use and their application is fundamental to the solution of all types of sonar performance problems[6]. Various acoustic propagation models are mentioned in the literature based on the theoretical approach employed. In one approach known as range-dependent case, it assumes that the properties of the ocean medium vary as a function of range and azimuth from the receiver, in addition to depth dependence. This type of model includes sound speed and bathymetry. In this study, the acoustic propagation based on parabolic equation method[7] was utilised, which was thoroughly reviewed by Davis[8], *et al*.

The basic wave equation is

$$\nabla^2\phi = \frac{1}{C^2}\frac{\partial^2\phi}{\partial t^2} \qquad (1)$$

where, ∇ is the Laplacian operator, ϕ is the potential function, C is the speed of sound, and t is the time. After incorporating harmonic solution to obtain the time-dependent Helmholtz equation, the Eqn (1) reduces to

$$\nabla^2\phi + k^2\phi = 0 \qquad (2)$$

Here, $k = \omega/c = 2\pi/\lambda$ is the wave number, ω is the source frequency and λ is the wave length.

The parabolic approximation approach replaces the elliptic wave equation with a parabolic equation. The parabolic equation is derived by assuming that energy propagates at speed, either the shear speed or compressional speed, as appropriate. Then the basic equation of acoustic propagation can be written as

$$\nabla^2\phi + k_0{}^2 n^2\phi = 0 \qquad (3)$$

Here, n is the refractive index.

The Eqn (3) can be rewritten in cylindrical coordinates as

$$\frac{\partial^2\phi}{\partial r^2} + \frac{1}{r}\frac{\partial\phi}{\partial r} + \frac{\partial^2\phi}{\partial z^2} + k_0{}^2 n^2\phi = 0 \qquad (4)$$

where the azimuthal coupling has been neglected but the index of refraction retains a dependence on azimuth. Further, assume a solution of the form $\phi = \psi(r,z).S(r)$ and obtain an equation in ψ and another equation in S. The equation in S has the solution given by Hankel function of first kind. The equation in ψ, after applying the far-field and paraxial approximation, can be written as

$$\frac{\partial^2\psi}{\partial z^2} + 2ik_0\frac{\partial\psi}{\partial r} + k_0{}^2(n^2-1)\psi = 0 \qquad (5)$$

that is, the parabolic wave equation. Here, n depends on depth z, range r and azimuth θ. This equation can be numerically solved by implicit finite difference (IFD) method.

In the parabolic equation approximation, the Helmholtz equation is converted to a parabolic equation with only first derivatives in the range variable. This allows efficient numerical solution by non-iterative marching techniques. The size of the range steps in the marching allows for inclusion of range-dependent interfaces comprising the ocean bottom and sub-bottom structure as well as range-varying oceanic features such as internal waves, fronts, eddies, thermohaline structure, etc.

These two major capabilities, viz., efficient numerical solutions on small computers and the ability to accurately model complex ocean environmental features have made the ocean acoustic parabolic equation models the most popular choice of both researchers and the operational modelers. This prompted to use the range-dependent propagation model based on parabolic equation approximation[9] to study the influence of mini warm pool on the propagation characteristics.

4. RESULTS AND DISCUSSION

4.1 Warm Pool Characteristics

The surface layers along 9 °N during mid May was characterised by the presence of warm (> 30.25 °C) and low saline (< 35.2 PSU) waters, except near the coast and west of 68.5 °E [Fig. 1(a)]. The surface waters were still warmer in the eastern Arabian Sea, i.e., between 71.5 °E and 74 °E longitude (> 30.75 °C) with its core centered at 73.5 °E, i.e., around the Laccadive Island. At the mini warm pool core, high temperature (> 31.2 °C) and low saline (< 34.6 PSU) waters were noticed in the upper 5 m. Such regions of high temperature (> 31.2 °C) are quite unusual in the other parts of the world oceans. From the mini warm pool core (i.e. from 73.5 °E), temperature decreased towards eastward and westward. Moreover, the isotherms showed an upslope towards the coast from deeper depth levels, i.e. from east of 73 °E, indicating the occurrence of upwelling in this region. As a result, reduction in temperature from the core of the warm pool towards east was rapid (1.6 °C over 220 km, i.e., from 31.2 °C at 73.5 °E to 29.6 °E at 75.5 °E), while it was gradual towards west (1.2 °C over 600 km, i.e., from 31.2 °C at 73.5 °E to 30 °C at 68 °E).

A notable observation during this period was the occurrence of a shallow and very thin mixed-layer depth (MLD) and sonic-layer depth (SLD), i.e. < 5 m, at the core of the warm pool [Fig. 1(b)]. The presence of low saline waters in the surface layers [Fig. 1(a)] along with the accumulation of heat due to pre-monsoon heating stratified the upper layers (figure not presented), resulted in the formation of this shallow surface layer. The mixed-layer depth and sonic-layer depth deepened towards east (up to 74.5 °E) and west from the mini warm pool core [Fig. 1(b)]. East of 74.5 °E, the mixed layer depth and sonic-layer depth shoaled towards the west coast due to the coastal upwelling [Fig. 1(a)]. The

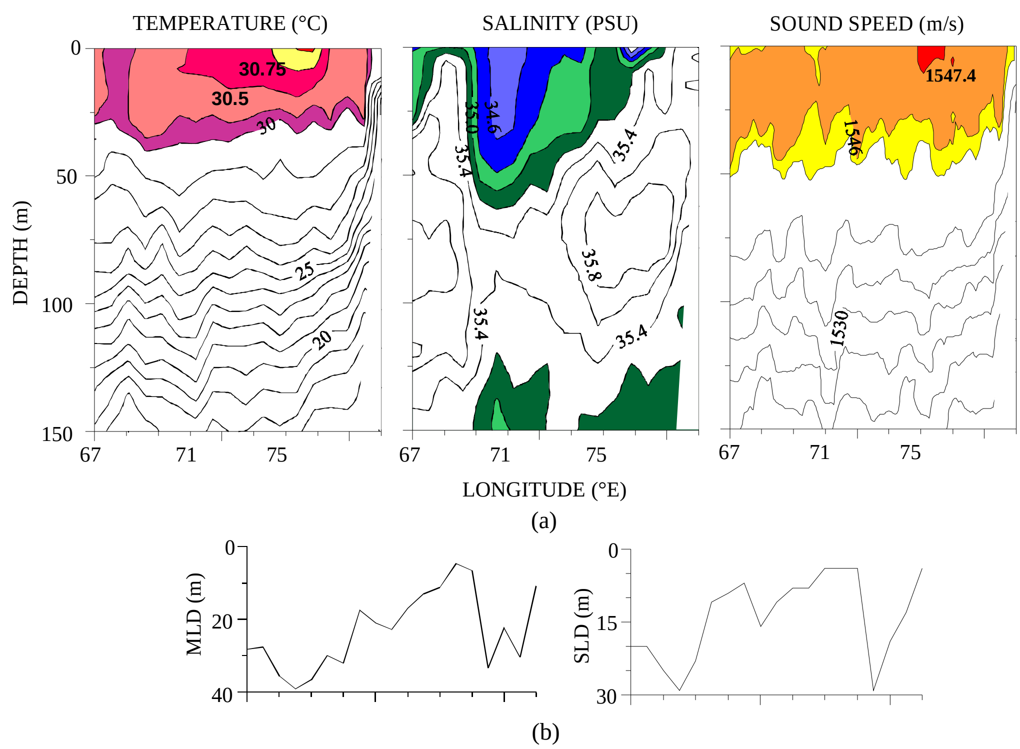

Figure 1. (a) Depth-space sections of temperature[1], salinity[1] and sound speed, (b) mixed layer depth (MLD) and sonic layer depth (SLD) variations along 9 °N.

observed deepening of mixed-layer depth and sonic-layer depth on the western side was due to an anti-cyclonic Eddy, as evident from temperature and salinity field [Fig.1(a)]. Presence of this Eddy in the eastern Arabian Sea during the pre-monsoon season is well known[2-5], and in fact, the mini warm pool is found to occur within this Eddy.

4.2 Theoretical Studies

The above analysis revealed the complex nature of the thermohaline fields and sonic layer distribution along 9 °N in the Arabian Sea mini warm pool region due to many factors, viz., prevailing coastal upwelling off the west coast of India, occurrence of low saline water near the Laccadive island, accumulation of energy due to pre-monsoon heating, presence of eddy fields, etc.

To study the propagation characteristics in such highly variable oceanic environment, the range dependent acoustic propagation model based on PE approximation was utilised. The model was run across different segments of the warm pool region by taking different combinations of sound speed profiles and sound depth, but kept the source frequency constant (100 Hz). From the observations, the sound speed profiles were interpolated at every 5 km interval and these interpolated profiles were utilised in the model run. The model outputs are presented as the transmission loss mosaics (Figs 2, 3, and 4).

In the first model run [Fig. 2(a)], all the sound speed profiles (i.e., interpolated to 5 km interval) across the mini warm pool were used by keeping the source at 7 m depth. The 80 dB transmission loss mosaic, the minimum transmission loss mosaic,

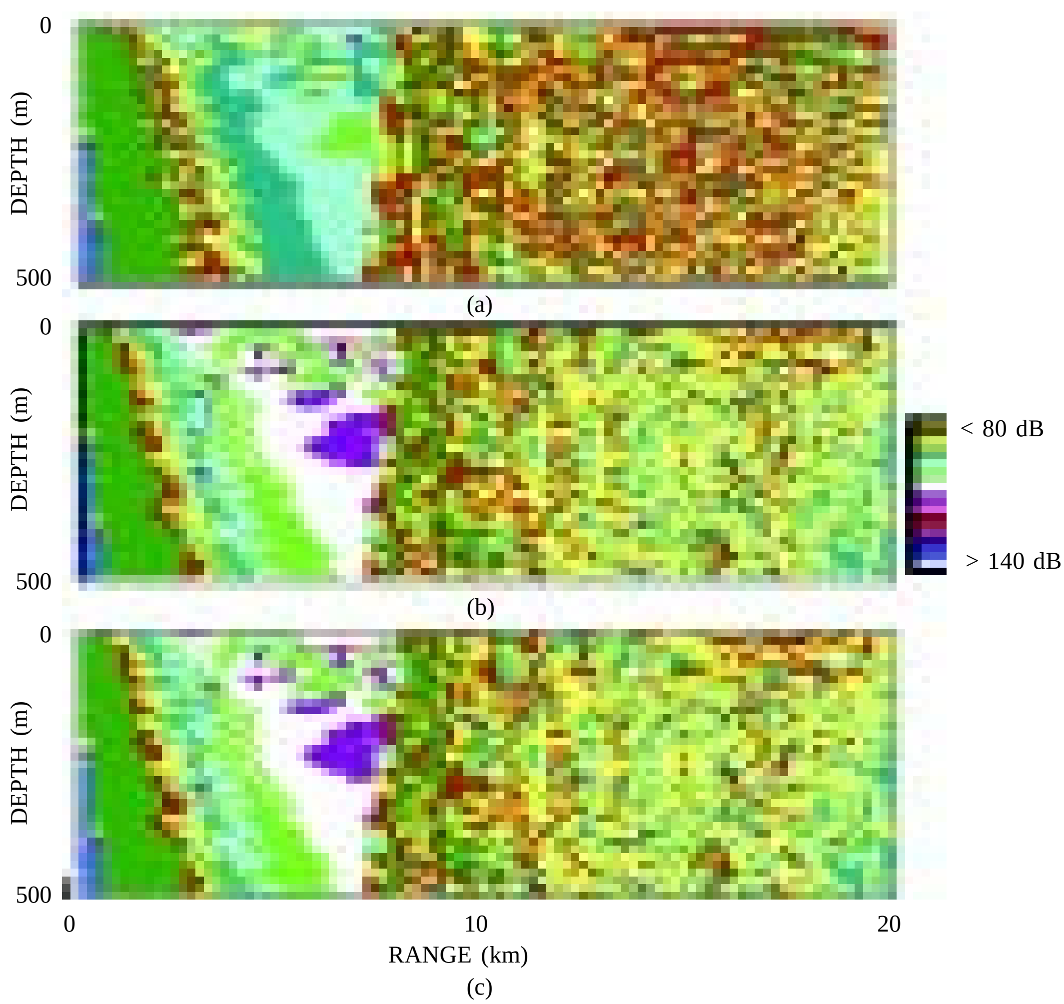

Figure 2. Transmission loss mosaics across the mini warm pool core: (a) source at 7 m and real environment, (b) source at 4 m but environment same as in case (a), (c) source at 4 m and single profile.

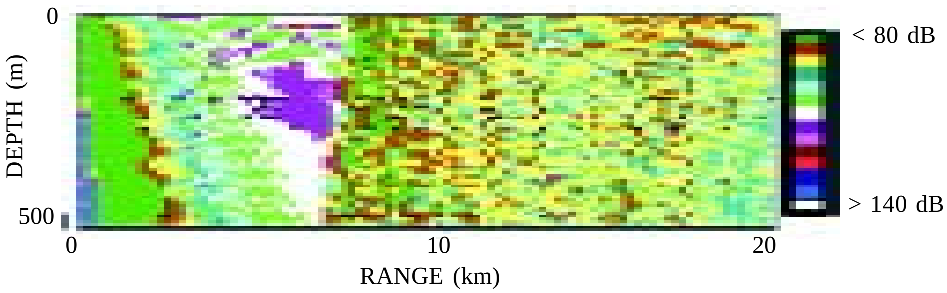

Figure 3. Transmission loss mosaic on the western side of the mini warm pool with full profiles and source at 7 m.

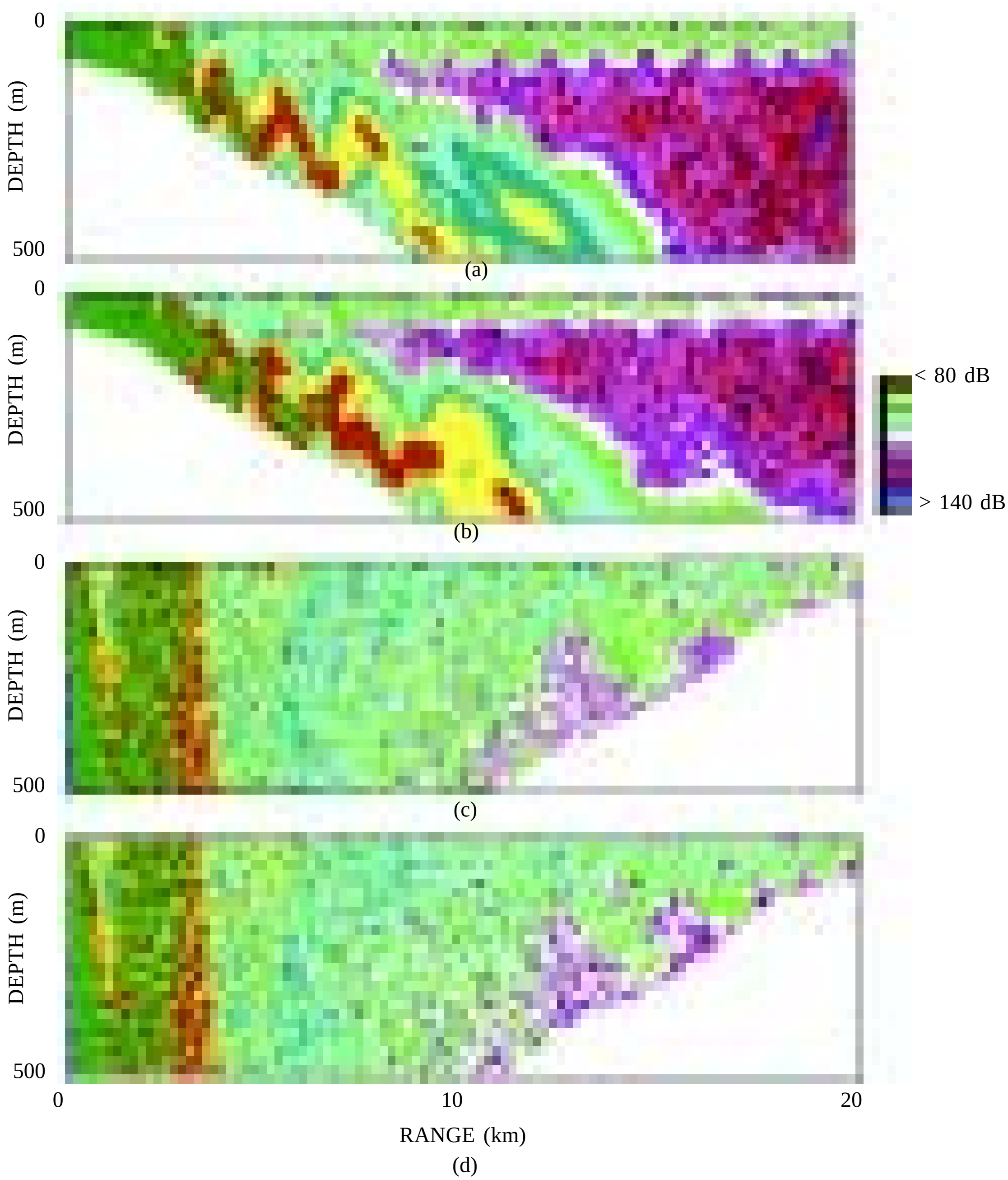

Figure 4. Transmission loss mosaic on the eastern side of the mini warm pool with source at 7 m: (a) downslope with full profiles, (b) downslope with single profile, (c) upslope with full profiles, and (d) upslope with single profile.

extended towards deeper levels within 2 km in the horizontal while the maximum loss (>100 dB) was noticed between 2 km and 8 km range.

When the source was kept in the surface mixed layer, i.e. at 4 m [Fig. 2(b)], transmission loss marginally increased with slight reduction in zone of minimum transmission loss values, i.e. < 80 dB mosaic. At the same time, between 2 km and 8 km, the transmission loss increased by 10 dB to 15 dB. When the simulation was carried out with a single profile taken from the mini warm pool core, the low transmission loss region (< 80 dB) further reduced and was associated with an increase in the high transmission loss region.

This study suggested that, in general, the presence of a warm pool alterer the detection range. The simulation was further repeated on the western side (20 km east of 72 °E) of the mini warm pool (Fig. 3), where deeper sonic layers were noticed. In this case, the results were found similar to that of Fig. 2(b).

On the eastern side of the mini warm pool, the proximity to the west coast of India resulted in the variation of bottom topography as well as in the medium characteristics. Simulation was carried out for both the upslope and downslope scenario for a 100 Hz source kept at 7 m. The results indicated noticeable difference between the downslope [Figs 4(a), 4(b)] and upslope [Figs 4(c), 4(d)] conditions. Horizontal detection range was found to be more in the downslope condition (8 km) than in the upslope condition (1-2 km). In the downslope scenario, the transmission loss characteristics were further changed when all the sound speed profiles were included in the model run [Fig. 4(a)] instead of a single profile [Fig. 4(b)]. In the first case [Fig. 4(a)], transmission loss was more along the downslope, whereas it was less in the surface duct region. Similarly, change was noticed in the shape of the shadow region also.

5. CONCLUSION

During the pre-monsoon season of 2000, an experiment was conducted in the eastern Arabian sea to study the characteristics of the Arabian Sea mini warm pool. During this period, the mini warm pool (> 30.25 °C) was noticed between 67.5 °E and 75 °E, with core values of temperature in excess of 31°C, salinity < 34.6 PSU, and sonic layer < 5 m. From the core, sonic layer increased eastward and westward. The shoaling of the sonic layer near the coastal region was attributed to upwelling. Influence of the mini warm pool on acoustic propagation was studied utilising a range-dependent propagation model based on parabolic equation method. In general, it was found that the occurrence of mini warm pool altered the propagation characteristics. Moreover, significant variations were noticed in the propagation characteristics when different segments, viz., (i) within the mini warm pool region, (ii) between west coast of India and mini warm pool core, and (iii) beyond westward of the mini warm pool core, were considered in the model run. Better propagation was obtained in the downslope condition on the eastern side of the mini warm pool core. In all the cases, the transmission loss characteristics change considerably when the range-dependent sound speed profiles were included in the model run instead of a single profile. In the shadow zone, significant changes were noticed between upslope and downslope conditions.

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REFERENCES

1. Sanilkumar, K.V.; Hareesh Kumar, P.V.; Joseph, J. & Panigrahi, J.K. Arabian Sea mini warm pool during May 2000. *Current Science*, 2000, **86**, 101-103.

2. Bruce, J.G.; Johnson, D.R. & Kindle, J.C. Evidence for Eddy formation in the eastern Arabian sea during the northeast monsoon. *J. Geophys. Res.*, 1994, **99**, 7651-664.

3. Bruce, J.G.; Kindle, J.C.; Kantha, L.H.; Kerling, J.L. & Bailey, J.F. Recent observations and

modelling in the Arabian sea Laccadive High region. *J. Geophys. Res.*, 1988, **103**, 7593-600.

4. Shankar, D. & Shetye, S.R. On the dynamics of the Lakshadweep high and low in the southeastern Arabian sea, *J. Geophys. Res.*, 1997, **102**, 12, 551.

5. Rao, R.R.& Sivakumar, R. On the possible mechanisms of the evolution of a mini warm pool during the pre-monsoon season and the genesis on the vortex in the southeastern Arabian sea. *Quart. J. Royal Meteorol. Soc.*, 1999, **125**, 787-09.

6. Etter, P.C. Underwater acoustic modelling. E& FN SPON, London, 1996.

7. Collins, M.D. Higher-order Pade approximations for accurate and stable elastic parabolic equations with application to interface wave propagation. *J. Acoust. Soc. Am.*, 1991, **89**, 1050-057.

8. Davis, J.A.; White, D. & Cavanagh, R.C. NORDA Parabolic Equation Workshop, 31 March to 3 April, 1981, Naval Ocean Research Development Activity, 1982. Tech. Note No. 143.

9. Balasubramanian, P.; Radhakrishnan, K.G. & Muni, M.M. PRAN (Sonar Range Predication model Ver 1.0), Naval Physical & Oceanographic Laboratory, Kochi, 1997. NPOL Report No. RR 6/97.

Contributors

Dr P.V. Hareesh Kumar obtained his MSc (Oceanography) and PhD (Oceanography) from Cochin University of Science and Technology (CUSAT). Presently, he is working as Scientist F at Naval Physical & Oceanographic Lab., Kochi. His field of specialisation is Air-sea interaction, Mixed layer dynamics, Thermohaline structure, Ocean modeling, Sonar Oceanography. He has 39 research papers in national/ international journals. He is a member of Indian Meteorological Society, Indian Society of Remote Sensing, and Administrative Staff College of India Association, Hyderabad.

Dr K.V. Sanilkumar obtained his MSc (Oceanography) from Cochin University of Science and Technology (CUSAT). Presently, he is working as Scientist E at Naval Physical & Oceanographic Lab., Kochi. He has Oraganised, executed and participated in more than 30 field experiments at sea. He has 20 research papers to his credit. He has been awarded Dr BN Desai award in 1995-96. His interest includes: Indian Ocean circulation, thermohaline structure, Sonar Oceanography. He is a member of Indian Meteorological Society, Indian Society of Remote Sensing.

Dr C.V.K. Prasada Rao obtained his MSc (Oceanography) from Andhra University and PhD (Marine Sciences) from Cochin University of Science & Technology. He is working as a senior scientist in DRDO (NPOL, Cochin). He has 30 years of R&D experience in planning and executing oceanographic programmes that are relevant to underwater sensors and systems. He has about 50 research publications in journals and conference proceedings. Presently, he is heading a group on Ocean Sciences at NPOL.