**Acoustical Horizontal Array Coherence Lengths and the “Carey Number”**

The late Bill Carey came up with the rule of thumb that the horizontal array coherence length in shallow water is, on the average, 30 wavelengths.

**Introduction**

Though the genesis of this paper is of a somewhat sad origin (the passing of close friend and colleague Bill Carey of Boston University last year) the outcome is representative of what occurred when people interacted with Bill – he made them think about interesting problems. In organizing and participating in some memorial sessions for Bill (at both the Underwater Acoustics meeting in Corfu, Greece and the upcoming Providence ASA meeting), we looked at one of Bill’s signature research areas, horizontal array coherence, and decided to focus on that. It is an area that all of the authors have worked in, and so we thought we could nicely elucidate the physics of one of Bill’s coherence results, specifically that the horizontal array coherence length in shallow water is measured to be ~20-40\(\lambda\) (average 30\(\lambda\)) at frequencies around 400 Hz (Carey, 1998). However, the physical origin of that number, and even the measurements of it, were not as simple to summarize as we thought, and so in digging back into Bill’s research, we again were given something to think further about.

Array signal coherence is of interest because it (in part) determines the overall array gain, the amount an array “amplifies” a signal against the noise. Specifically, it determines the signal related part of the array gain. For an N element array, array gain (AG), quoting Urick (1983) “is by definition the ratio, in decibel units, of the signal to noise of the array to the signal to noise of a single element, so that

\[
AG = 10 \log \left[ \sum_{i=1}^{N} \sum_{j=1}^{N} \rho_{(s)ij} \right] / \left[ \sum_{i=1}^{N} \sum_{j=1}^{N} \rho_{(n)ij} \right]
\]

The gain of the array therefore depends on the sum of the cross-correlation coefficients between all pairs of elements of the array, for both noise and signal.” The array signal gain (ASG), which is the quantity that Carey concentrated on in his work, is the numerator of the above AG expression. The noise effect which appears in the denominator, is also a very interesting and complicated entity, but it is not the focus of what we want to look at here. Regarding the array gain for a simple case, if the signal is coherent, the ASG against white noise goes as \(N^2\) whereas if the signal is incoherent, it goes as \(N\). The difference between an \(N\) and an \(N^2\) dependence can be many dB of gain, so understanding the ASG is of great practical value.
Beam-formers and Decoherence

Before getting to details of how the decorrelation/decoherence of a signal causes loss of array signal gain, it would be good to quickly review how basic array beam-formers work. There are two types that are of interest to us: plane wave beam-formers (for sources “at infinity”) and focused beam-formers (for sources in the near-field, i.e. where wave-front curvature effects are important.) In Figure 1a, we show a simple (discretely sampled) plane wave beam-former. The additional distance \( \Delta r_n \) that the plane wave travels to each additional element along the array is simply given by \( \Delta r_n = n \Delta l \sin \theta \).

If we compensate the extra distance by a time delay, we get \( \Delta t_n = \Delta r_n/c \), which we can also express as a frequency \( \omega \) dependent phase shift, \( \Delta \phi_n = \omega \Delta t_n \). For focused arrays, we also work to cancel the additional path, which is now (in continuous form) \( \Delta r = (\Delta l)^2/2R_0 \). Again, we can use \( \Delta r = \Delta t \) for the time delay and \( \Delta \phi = \omega \Delta t \) for the equivalent phase shift. Note that we concentrate on phase variation here. To first order, the amplitude varies smoothly for an individual multipath, since it is subject to cylindrical spreading and medium attenuation, which vary slowly.

If we had perfect plane wave or spherical wave arrivals, we would be done here, and the ASG would go as \( N^2 \). But a variety of things distort the acoustic wave-fronts: fronts (shelf-break and tidal mixing fronts are the larger ones), internal waves (nonlinear and linear), internal tides (large internal waves at tidal frequencies), eddies, spice (density compensated temperature structure in the ocean), surface waves, bottom geo-acoustic properties (how the bottom reflects and absorbs sound), and bathymetric roughness (assuming the larger scale bathymetry is known). We could also consider unaccounted for array deformations in the list of things that effectively decohere the signal, but as this is a (supposedly) correctable instrumental effect, we will ignore it in our list for now. As mentioned, noise enters into the overall array gain as well, but not into the signal gain, so we will also ignore it here. But even without looking at noise and array deformation, this is a formidable shopping list of sound refractors and scatterers to deal with. (Katznelson et al, 2012).

Before leaving this section, we will also note that we are doing something a bit different philosophically from the AG definition above. Specifically, we are looking at the deterministic change of phase across an array due to specific ocean features, which we represent by suitably simplified feature models. We can look at averages and statistics of our deterministic results later, and so reconcile our results to Urick’s definition. But our work here will really be an instantaneous look at how an ocean process affects phase across an array, and thus the instantaneous beam-forming power output.

Methods for Obtaining \( L_{coh} \)

Given that we are dealing with an impressively complex environment for acoustic propagation and scattering, how do we deal with getting some concrete numbers for the array signal gain? There are, at the present time, four alternatives for obtaining coherence length estimates: 1) large numerical models (oceanographic plus 3D acoustics), 2) wave propagation in a random medium calculations (WPRM), 3) “simple forms” for scattering (to be discussed later), and 4) direct measurement. However, when Bill Carey first did his work in the early 1980’s, the first three alternatives weren’t really available. Numerical modeling of the ocean and 3D acoustic propagation were still in their infancy, WPRM methods were just being...
developed for deep water (with shallow water being largely ignored), and the “simple model” approach to looking at scattering from the above list of ocean and seabed objects didn’t have enough knowledge of the ocean and seabed available as input to make it feasible. The Navy wanted operational numbers for array performance as quickly as possible, and so only one real option was available—direct measurement. As money for at-sea work was more plentiful then than today, that was in fact an attractive option. Thus Bill Carey took to sea and made his direct measurements.

In doing at-sea measurements of the horizontal array coherence, there are a number of issues which have to be dealt with carefully. The first concern is geometry. A geometry where the array is broadside to the source is preferred, as this obviates the problem of the ambiguity of the horizontal beam steering angle versus the vertical multipath angle. In a broadside geometry, all the multi-paths arrive on the same zero degree steered beam. The next concern is signal to noise ratio (SNR). Ambient noise from continuous sources in shallow water “Kuperman-Ingenito noise,” (Kuperman and Ingenito, 1980) produces very short (fraction of a 400 Hz wavelength) horizontal correlation scales, and so one needs to be well above this noise level to see longer scales experimentally. Noise from large, discrete sources (e.g. ships) mimics the multi-paths from the experimental source, and can give spurious results (larger correlation lengths, if the noise source is on the experimental source-to-receiver line and smaller lengths if off it). Source or receiver motion (or both) is yet another concern. This motion quickly produces a large number of realizations of the environment, and even can affect the statistics of the measurement if the environment one passes through is non-stationary. Using a fixed source and receiver geometry cures this, in that one has a bathymetrically stationary system and an oceanographically more slowly varying environment to deal with.

Another experimental issue is broadband versus narrowband signals. Generally, the longer integration time needed to get good SNR with narrowband signals is a disadvantage, but given a fixed geometry, longer times (up to several minutes) are often available. A final experimental consideration is adequate measurement of the ocean and seabed condition, so that one can correlate the coherence length measured to the regional and seasonal ocean condition. Carey’s measurements provided this “general context” of where, when, and in what ocean condition the data were taken, but they did not have the detail to comment on all the individual acoustic scattering mechanisms that were discussed above. That level of experimental detail of the environment would have to wait for the “Shallow Water 2006” (SW06) experiment performed two decades after Carey’s experiments (Tang et al, 2007).

**Measurements of $L_{coh}$**

At this point, it is appropriate to show both Carey’s measurements and the later SW06 measurements, to see the experimental story. In Figure 2, we show a synopsis of his data, along with some calculated points from our “simple theory”, which we will discuss soon. Carey’s 400 Hz data, at first glance, shows a $20-40\lambda$ spread of $L_{coh}$, with an average of about $30\lambda$. One also might suspect that the coherence length is increasing with source-to-receiver range, which could be due to higher mode stripping by differential attenuation of (seabed-interacting sound) or other effects.

**Figure 2**: A synopsis of Bill Carey’s coherence measurements, along with two theory points based on “simple” calculations of shelf-break front effects. Four of the experiments had multiple source/receiver ranges.
In Figure 3, we show similar data (at 200 Hz) from SW06, where a 465m horizontal array was deployed on the bottom, and listened to fixed sources. This was not a broadside geometry, due to deployment issues; however, each multipath was filtered and compensated for that in the processing (Duda, Collis et al, 2012). Of interest in this figure is that the spread from 20-40$\lambda$ is apparent at first in panel 3, but then it drastically decreases when a nonlinear internal wave train passes through. This decrease was in fact predicted by Oba and Finette (2002) using numerical models, and Katznelson and Pereselkov (1997) long before the SW06 experiment was performed, and initially observed by Badiey et al. (2002). After the waves pass by, $L_{coh}$ returns to the 20-40$\lambda$ range. The SW06 data shown are at only one range, due to the source being moored. They are also shown for one only frequency, as that is the only one that has been extensively processed, and we hope the other frequencies transmitted (100, 400, 800 Hz) might be looked at in the future for $L_{coh}$. The SW06 data set is useful in that: 1) it corroborates Carey’s basic numbers, 2) it actually represents a time series, which augments Carey’s single snap-shots at multiple ranges, and 3) it has an enormous amount of supporting environmental measurements, which will allow us to dissect the scattering processes that contribute to the measured $L_{coh}$. (As we have already seen from Figure 3 nonlinear internal waves are one process that strongly affects the measured number.)

Before leaving this data, we should note that there is a bit of variety in the literature in how $L_{coh}$ is defined, and due to this there can be a factor of two or more between what various authors report or calculate. We will not attempt to reconcile all the definitions in this rather descriptive article, but would note that when one finally gets down to detailed inter-comparisons, these definitions need to be considered.

**Theory for $L_{coh}$**

Having looked at the data, let us now look at attempts to theoretically describe where the number comes from in shallow water. Let us start with ocean numerical models. A rather seminal early numerical study was conducted by Finette and Oba (op cit) in which they combined the shallow water oceanography of a weak linear internal wave field with that of a stronger, nonlinear internal wave field (a dnodal soliton wave packet), and showed that the effect on the coherence length at 400 Hz (a popular frequency, as it is close to “optimal” for long range, shallow water propagation) was strongly dependent on the angle of the acoustic track to the soliton packet; indeed $L_{coh}$ became very small when the soliton wavecrest direction was close to the acoustic track direction. This is exactly what the SW06 data discussed above shows, and their paper also included a very nice calculational prediction of the 3D acoustic ducting by solitons, which was observed and published in the same year (Badiey et al., 2002). Their computer prediction of the coherence length for the case of the acoustic track being perpendicular to the soliton wave crests was very large (order 600m, or 150$\lambda$), which is consistent with our simple model, and also would seem to indicate that, for this across-crest geometry, the nonlinear (plus linear) internal waves do not dictate $L_{coh}$, which is the smaller 30$\lambda$ number (Duda et al., 2012).
More recently, work is being conducted under an ONR program called “IODA” (Integrated Ocean Dynamics and Acoustics), which ties in very modern coastal oceanography models, with virtually all of the physical oceanography described above incorporated into it, with fully 3D acoustics models. This is a very ambitious extension for both the acoustics and oceanography, as it attempts to reach down to sampling scales of meters and seconds, as opposed to the hours and kilometer scales that are the usual state of the art. Acoustics is sensitive to small-scale ocean phenomena with large horizontal temperature and sound-speed gradients, so in order to fully model the acoustic field, we need to reach such spatial and temporal resolutions. In weighing whether or not to use such models, one notes that the model generates full 3D acoustics realizations of the pressure field, from which one can generate $L_{coh}$ and much more. Moreover, one can generate space-time series and statistics from such a model, and use these instead of running the model for each case.

However, the price you pay is that you have to know how to run (and have the input for) state of the art ocean and acoustics models. These models also have some hefty computer requirements associated with them, and they are not easy-to-use, general public tools.

Another theoretical approach is the “wave propagation in a random medium” approach, which is well known to the public due to its famous application to astronomy (star twinkle). In this approach, as applied to ocean acoustics, one goes from the statistics of the medium (e.g. sound-speed) fluctuation to the statistics of the fluctuations in the acoustic amplitude or phase. Calculations in WPRM (Flatte, 1979 and Colosi, 2013) tend to be a bit mathematically involved, but a simple example of what type of form one obtains (from Carey et al, 2002) shows that the phase variance between two receivers goes as a double integral over the paths to the two receivers (including vertical ocean structure), with the “kernels” of the integrals containing known background quantities and the correlation function containing our statistical knowledge of the ocean. The strength of this approach is that it only asks for basic statistics of the ocean variability as input. However, this is not as easy a thing to provide as it sounds, as the ocean has (as discussed above) numerous processes going on in shallow water with a variety of scales, and moreover they are spatially and temporally inhomogeneous and anisotropic. However, one can often get adequate answers with even an approximate correlation function, which can be based on either ocean dynamics and scales or direct measurements. Such an approximate correlation function, based on shallow water oceanography measured in the 1996 PRIMER experiment off New England, produced a 30$\lambda$ average horizontal correlation length, in agreement with the SW06 data above (Lynch et al., 2003). Both PRIMER and SW06 were conducted in the Mid Atlantic Bight region, and close to the shelf-break and its associated front, so the agreement between these two results is less surprising than it would be for two very distantly separated sites. These two measurements also make one begin to think that the shelf-break oceanography (perhaps the front) is a large contributor to the 30 wavelength result.

The question now arises – how do we separate the effects of the various pieces of oceanography and the seabed from one another? We can turn various pieces of oceanography “on and off” in the large numerical models, and even do so (using individual process dynamic models) in the correlation functions. But while this tactic may produce answers, it produces comparatively little insight into the physics, and one has to run models over large, multidimensional parameter spaces to get a complete set of answers. So where do we go?

“Simple” Feature Models and $L_{coh}$

A recent, and ongoing, attempt to answer that question has been to employ simple “feature models” of the ocean and seabed. In this approach, which has been successful in both oceanography and acoustics (A. Robinson and D. Lee (eds.), 1994 and Lynch et al., 2010), one reduces the ocean features to simple geometric forms (e.g. eddies become circles, fronts become straight linearly sloping (in depth) features, nonlinear internal waves become square shaped instead of hyperbolic cosecant squared shaped, etc.). The feature’s internal structure (i.e. the ocean interior sound-speed profile) also can be simplified, so that the vertical and horizontal temperature/ sounds-speed profiles of the ocean features become very convenient to deal with geometrically. Indeed, this allows one to use simple
Euclidean geometry in the horizontal direction and equally simple first order perturbation theory forms for the features when including their vertical structure. Beginning work on this using depth averaged ocean features was discussed in the Bill Carey memorial session of the UA in Corfu (Lynch et al, 2013), and showed the basic equations for $L_{coh}$ for a number of the ocean features we listed, as well as numerical results for a shelf-break front (based on the SW06 region parameters). In this paper, we are extending that work to show numbers for the effects of nonlinear internal waves, so that we can cross compare two of the “major players” in creating acoustic field spatial decoherence. We will, given the limited space, stick to the simplest “depth averaged ocean” and “resolved modes” cases, and hope to eventually include the whole feature model story (interfering modes and rays, and the many other ocean/seabed effects) in a future article.

A simple 2-D depth averaged model of a nonlinear internal wave train propagating across an acoustic track is shown in Figure 4. In this figure, $\theta$ is the angle between the acoustic track and the direction of propagation of the internal wave train, $L$ is the width of each internal soliton (kept constant here for simplicity), and $R_{perp}$ is the distance from the source to the center of the broadside array. D is the distance between the individual solitons (again, kept constant), but it is not D we need so much in this case, as the phase integral used to get $L_{coh}$ does not care about the soliton spacing. We also need to consider the acoustic frequency $\omega$, the average water column sound-speed $c_o$, and the depth averaged sound-speed $c_o$ perturbation due to the internal waves, $\Delta c_{pert}$. When we do so, and after a very small amount of geometric manipulation, we get the simple form:

$$L_{coh} = \left( \frac{\pi}{2} \right) \left( \frac{1}{\omega} \right) \left( \frac{c_o^2}{\Delta c_{pert}} \right) \left( \frac{R_{pert}}{NL} \right) \cos \theta \tan \theta$$

This form is very clean in terms of containing the basic ingredients of the system: the acoustic frequency and source receiver separation, the sound-speed perturbation due to the waves, their size and their number, and the angle between the acoustic track and the orientation of the oceanography of interest. The answer depends strongly on this relative orientation angle, as one would expect. There are two interesting features to this expression, one obvious, and one not as obvious. The obvious feature is that the expression becomes infinite at $\theta = 0$. This is actually not unexpected for a straight line internal wave interacting with something that is nearly a plane acoustic wave. The subtler problem for this equation is that it breaks down for acoustic propagation along and in between the internal wave crests. In this case, one physically sees 3D ducting of sound between the internal waves, and our simple equation above becomes inadequate.

Figure 4: Plan-view schematic of a train of (two) nonlinear internal waves, with an acoustic propagation track crossing them at an angle $\theta$.

The answer we get from Equation 2 is qualitatively similar to what one sees in Finette and Oba, i.e. a very large $L_{coh}$ at small $\theta$, and small $L_{coh}$ for $\theta$ large. If we put in numbers typical of Carey’s experiments, i.e. $f = 400$ Hz, $R_{perp} = 10$ km, $N=10$, $L=200$m, and $\Delta c_{pert}=40*(10/100) m/s$, we get that the 30$\lambda$ point is at about 77°, which corresponds to “close to along-shelf” propagation. Carey did his experiments primarily near shelf-breaks and at constant isobaths, so this is not an inconsistent result. However, other experiments, e.g. SW06 above, show the 20-40$\lambda$ result for smaller cases as well, and it is not amiss to think that other ocean processes (e.g. fronts, see Lynch et al, 2013) drive the coherence length down from the large number that both our simple theory and other models predict in that angular regime due to just nonlinear internal waves.

Even in the context of a very simple depth averaged model, there are some things that we have omitted that one could point to, and ask about their importance. These include: the true “sech squared” nature of the individual solitons, their rank ordering (decreasing soliton amplitude as one goes further into the wave train), the curvature of the solitons in the x-y plane, the horizontal refraction of sound by the soliton waves, and mode coupling. Preliminary calculations show these to be of second order importance to $L_{coh}$, but a more careful study needs to be (and is being) done.

One thing that can be done very easily with our “simple forms” is an error analysis. Error in the environmental parameters ($N, \Delta c, L$ and $\lambda$) is translated directly into $L_{coh}$ via the displayed $L_{coh}$ equation. Given an error tolerance in $L_{coh}$ that a user specifies, one can immediately see just how good the environmental input has to be
from a numerical model or data. In terms of our soliton work, this is particularly useful, as solitons are a nonlinear phenomenon, and even the best model/data will show substantial enough changes in \( N, \Delta c, L \) and \( \lambda \) due to this effect. This is in addition to the normal fluctuation in the internal waves due to changing density stratification and currents. Seeing how big such fluctuations are, and how they affect useful acoustic quantities such as \( L_{coh} \) is part of our ongoing research.

In the depth averaged approach to estimating \( L_{coh} \), simplification was achieved by just considering the vertical average of the sound-speed perturbation. However, we can also use the simple perturbation theory forms to look at the detailed vertical sound-speed structure. This is most easily done in the acoustic normal mode picture, which happily is also a very good descriptor of low frequency, shallow water acoustics. The results obtained will now be on a mode-by-mode basis, i.e.; \( L_{coh} \rightarrow L_{coh}(n) \) each mode now has its own coherence length. The perturbed phase accumulation over each modal path to the broadside array, \( \Delta \varphi = \int L_{coh} L_C \) can be expressed using a simple background waveguide (e.g. the “hard bottom” waveguide, with analytic eigenvalues)

\[
k_{o,n} = \left( \frac{\omega^2}{c_o^2} - \frac{(n - \frac{1}{2})^2 \pi^2}{H^2} \right)^{1/2}
\]

which is perturbed by a mixed layer and internal waves below the mixed layer. In a simple “square wave soliton” approximation (Lynch et al., 2010), we can write the perturbed wavenumber as

\[
\Delta k_{IW} = - \left( \frac{1}{k_{o,n}} \right) \frac{\omega^2}{c_o^2} \frac{\Delta c}{c_o} \left( \frac{H_{IW} - D}{H} \right)
\]

The modal form is just as simple as the depth averaged form, and now has the added richness of including the water column vertical structure in the \( \Delta k_{IW} \) term. This form can also include bottom property variability, and be used to compare bottom versus water column effects. We would note that in experiments where one can filter the modes in time (e.g. SW06), the coherence along a horizontal array on a mode by mode basis shows clearly, as shown by Figure 5. The left three panels visually show coherence when no strong internal wave train is present. Ignoring the top panel, the second panel down shows the first four mode arrivals on a vertical line array, and the bottom panel shows the arriving modal wave-fronts on a 465m horizontal line array lying on the seabed. The right three panels, again ignoring the top, show the arrivals during a period of strong internal wave activity – it is obvious that the coherence length drops as the nonlinear internal waves pass through the acoustic track, and the numbers for \( L_{coh} \) have been presented in Figure 3, panel 3. We have not pursued the coherence versus mode number in detail, but we do see the qualitative decrease versus increasing mode number we predict above in the SW06 data.

As a last note on the modal picture (See figure 5), we can also look at groups of interfering (unresolved) multipaths, if we wish. This pushes us to looking at the complex pressure, and makes a little more mess, but can be treated largely similarly to what we have shown above. The coherence length then will be some amplitude-weighted average of the coherence lengths of the individual modes. 
Future Directions
We have concentrated here on the internal wave field as one of the “major players” in determining $L_{coh}$ in shallow water, but as we said at the beginning, it is only one of a number of shallow water oceanography processes that affect the overall coherence length. We still have a number left to treat: internal tides, eddies, linear internal waves, spice, bottom geo-acoustic properties and bathymetric scattering. These will be treated similarly to what we have done with nonlinear internal waves here, and so this paper hopefully gives a good representation of our work. An interesting question that will need to be answered when we get through the list is: what are the dominant effects? The overall coherence length measured (whether modal or otherwise) will be some sort of weighted average of all these effects, with the smallest (limiting) length of a strong process probably determining the result the most. We can’t linearly superpose $L_{coh}$ results, so some reasonable scheme for weighting will need to be devised.

Another useful direction for this work is to look at source/receiver motion through the ocean (feature model) medium. For sources and receivers that move quickly compared to the ocean features (generally true, with the exception of surface waves), the ocean can be taken as “frozen” and useful results obtained quickly from the forms we have been considering.

Yet another major direction for the work is to look at other important acoustic quantities with this simple feature model approach. Of first order interest will be: the transmission loss (TL), the scintillation index (SI), and the mode coupling matrix ($C_{mn}$). All of these, based on some preliminary work, should be amenable to this approach, and we look forward to completing these extensions in the future.

Acknowledgements
We thank ONR for their support of this work throughout the years. We also thank Allan Pierce for his critical reading of our paper. Thanks too to Art Newhall for his help with the figures. And again, we thank Bill Carey for his inspiration.

Biosketches

Dr. James Lynch obtained his B.S. in Physics from Stevens Institute of Technology in 1972 and his Ph.D. in Physics from the University of Texas at Austin in 1978. He then worked for three years at the Applied Research Laboratories of the University of Texas at Austin (ARL/UT) from 1978 to 1981, after which he joined the scientific staff at the Woods Hole Oceanographic Institution (WHOI). He has worked at WHOI since then, and currently holds the position of Senior Scientist. His research specialty areas are ocean acoustics and acoustical oceanography. He also greatly enjoys occasional forays into physical oceanography, marine geology, and marine biology. Dr. Lynch is a Fellow of the Acoustical Society of America, a Fellow of IEEE, a former Editor-in-Chief of the IEEE Journal of Oceanic Engineering, and current Editor-in-Chief of the Journal of the Acoustical Society of America Express Letters. His hobbies include amateur astronomy and computer gaming.
Timothy F. Duda (M’05–SM’09) received the B.A. degree in physics from Pomona College, Claremont, CA, in 1979 and the Ph.D. degree in oceanography from the Scripps Institution of Oceanography, University of California, San Diego, in 1986. He worked at the University of California, Santa Cruz, from 1986 to 1991. He has been a Scientist at the Woods Hole Oceanographic Institution, Woods Hole, MA, since 1991. His three primary fields of study are ocean acoustic propagation, ocean internal gravity waves, and ocean mixing processes. His research into these has included theoretical and observational physical process studies, development of new measurement tools, and computational acoustic modeling. Dr. Duda is a member of the IEEE Oceanic Engineering Society. He is also a member of the American Meteorological Society, the American Geophysical Union, and the Acoustical Society of America (Fellow).

John A. Colosi received his B.A. degree in Physics from the University of California, San Diego in 1988, and a PhD in Physics from the University of California, Santa Cruz in 1993. He is presently a Professor of Oceanography at the Naval Postgraduate School (NPS) in Monterey California. Before his arrival at NPS in 2005 he was a tenured Associate scientist at the Woods Hole Oceanographic Institution (WHOI) in the department of Applied Ocean Physics and Engineering (AOPE), and he was an active faculty member in the Massachusetts Institute of Technology (MIT)/WHOI Joint Program. He has authored/co-authored over 50 refereed publications on the topic of ocean acoustics and physical oceanography. He was the recipient of the 2001 A.B Wood Medal, and the 2011 Medwin Prize in Acoustical Oceanography, and he was recently elected Fellow of the Acoustical Society of America. His scientific interests are in wave propagation through random media, acoustical remote sensing, and internal waves and tides.

References


