Fluctuations, Coherence and Predictability of Shallow Water Acoustic Propagation

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LONG-TERM GOALS

We seek to understand the effect of mesoscale fluctuations of western boundary currents on the generation and ducting of internal waves on to the shallow in-shore shelf and, in turn, the effects of these internal wave fields on acoustic fluctuations and coherence.

OBJECTIVES

The immediate objective is to quantify and compare statistics of temporal and spatial variability of acoustic signals over a broad range of frequency to the statistics of the internal wave field.

APPROACH

The approach is mostly experimental. The experiments were designed to resolve SRBR arrivals in time for broadband signals and to study fluctuations, coherence and predictability in a parameter space of frequency, range and experimental geometry. The measurement system and signal processing are described by (Nguyen, 1996). Summarizing the experiments briefly, a multi-frequency broadband source was moored at a range of 10 and 20 km from a vertical and two horizontal arrays that were connected to shore by fiber-optic cables. The source transmitted pulses (m-sequences) with center frequencies of 100 200, 400, 800, 1600 and 3200 Hz. In each case, the bandwidth of the pulse was 25%of the center frequency (q=4). Environmental moorings measured temperature and conductivity at 10 depths and at two locations along the range. Range dependence of c(z) and bathymetry were minimized by transmitting parallel to shore along a nearly constant depth contour(145m).

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14. ABSTRACT

We seek to understand the effect of mesoscale fluctuations of western boundary currents on the generation and ducting of internal waves on to the shallow in-shore shelf and, in turn, the effects of these internal wave fields on acoustic fluctuations and coherence.

15. SUBJECT TERMS

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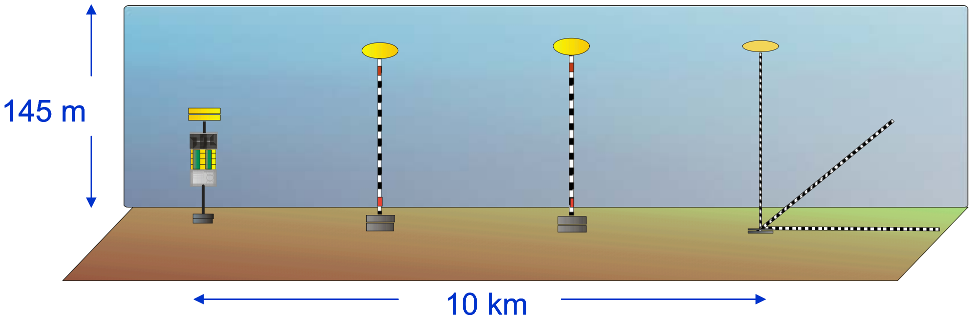


Figure 1. Experimental geometry for the Florida Straits propagation measurements.

WORK COMPLETED

Analysis of data continued for the two 1-month long experiments. The source transmitted continuous m-sequences for 1 hour at each of the 6 carrier frequencies and then repeated the cycle for 28 days. Hadamard transforms were used to compress the m-sequences to obtain pulse responses of the propagation channel for 1 minute averages of the receptions at each frequency. The resulting pulses responses are the basic element of the analysis. PE and Normal Mode propagation models were used to identify pulse arrivals. Statistics of fluctuations, such as moments, scintillation index, temporal and spatial coherence were computed for the individual arrivals and for the combined multi-path. Next, the temperature and CTD data were used to compute spatial and temporal statistics of the temperature and sound speed field. For example, we compute the potential energy of the internal waves and form a time series to be compared with time series of the acoustics fluctuations. A consistent feature of the channel pulse response arrival pattern for all frequencies was found to be a group of separable arrivals from the SRBR modes followed by a single late RBR group arrival. Figure 2.

RESULTS

The location of the experimental site, on the shelf inside of the Florida Current, is shown to be strongly influenced by the passage of offshore mesoscale eddies. (Olson, 2004). As the eddy passes south to north over a period of a fortnight, first colder water is forced shoreward along the bottom. A strong downward refracting sound speed gradient is formed with a thin iso-velocity layer along the bottom owing to mixing from boundary turbulence. The resulting profile is approximately a COSH(z) in shape which is found to be a perfect focusing lens. That is, all RBR modes have the same travel time and coalesce to form a single late arrival that is usually 20 dB higher that the individual arrivals of the SRBR modes which are spread out in time and arrive earlier. Figure 3 shows a PE (bottom) and Normal Mode (top) prediction of the arrival times for the 800 Hz reception. At each frequency there are about f/100 SRBR mode arrivals and another f/100 RBR that have nearly the same travel times and overlap. The shallow water invariant, β, helps to interpret the finding (DeFerrari 2003). Usually, $1/\beta$ is positive for SRBR modes and negative for RBR modes. The observed profile which is approximately COSH(z) near the bottom results in $1/\beta=0$ hence perfect focusing. Ideally, a caustic appears at all ranges at the depth of the source.

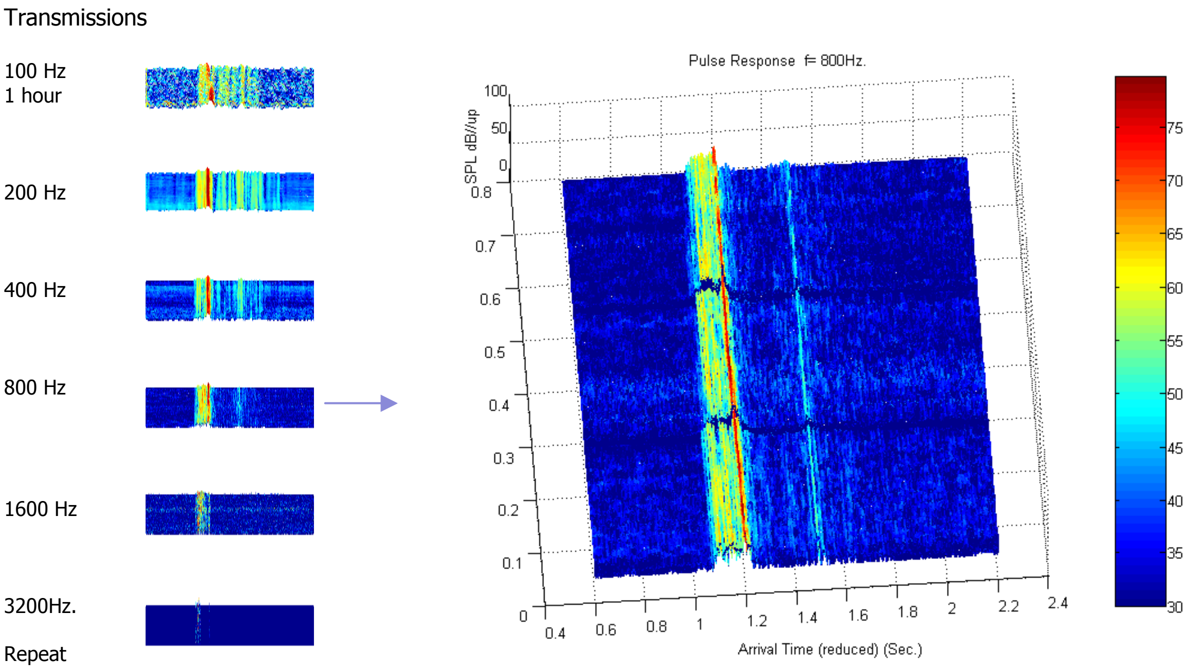


Figure 2. Left: 1-hour time history of 1 minute pulse responses at six carrier frequencies. Right: Three 1-hour segments separated by 6 hours for the 800 Hz transmission.

Later, as the eddy passes, warmer inshore water is swept seaward and the C(z) becomes nearly iso-velocity top to bottom. The intense BRB group disappears and the SRBR arrivals dominate.

The complex pulse responses can be used to compute the temporal coherence. Figure 4 Top, shows 1 hour of pulse responses for a 400 Hz transmission, and Bottom, the coherence as a function of time for every arrival time of the received pulse. The first arrival is the lowest order SRBR modes which has the longest coherence time. As the mode number increases the arrival time increases as does the angle and the number of the bottom interactions causing the coherence falls off. The most intense arrival, the late RBR group of modes (i.e. the focused arrival) has the lowest coherence. This is explained by the fact that the individual SRBR arrivals are separable in time whereas the RBR group has several overlapping arrivals and suffers coherence loss from multipath interference.

Several weaker arrivals appear after the RBR group for the low-frequency signals. The paths or modes are not readily predictable from mode or PE models even with detailed knowledge of the sub-bottom. They appear to be out of plane SRBR modes or from interactions with the sloping bottom west of the propagation site – a result reported by Ross Chapman. What is surprising is that most are remarkably coherent in time even though they are much lower in level than the direct predictable arrivals. In contrast, horizontal coherence along the path of propagation is about 100 to 150 wavelengths for all modes at all frequencies but much less for week reverberant late arrivals (Figure 5).

During the past year, research has focused on relating measures of temporal coherence at all frequencies to the energy level of the internal wave field. Measures of the IW field along the path of propagation varies by factors of 100 or more on a day to day basis as does the temporal coherence. Surprisingly, there is little correlation between events. For decades, the relation between relation between internal waves and acoustic fluctuations has been an axiomatic principle of underwater acoustics yet we see little evidence of this in our time series. The problem is puzzling and complex and we continue to study and try an make sense of these observations.

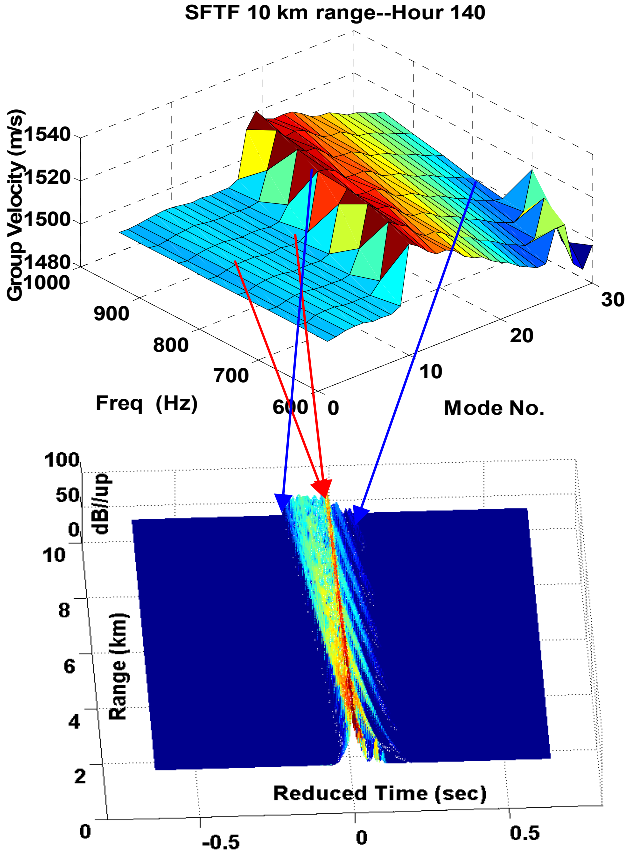
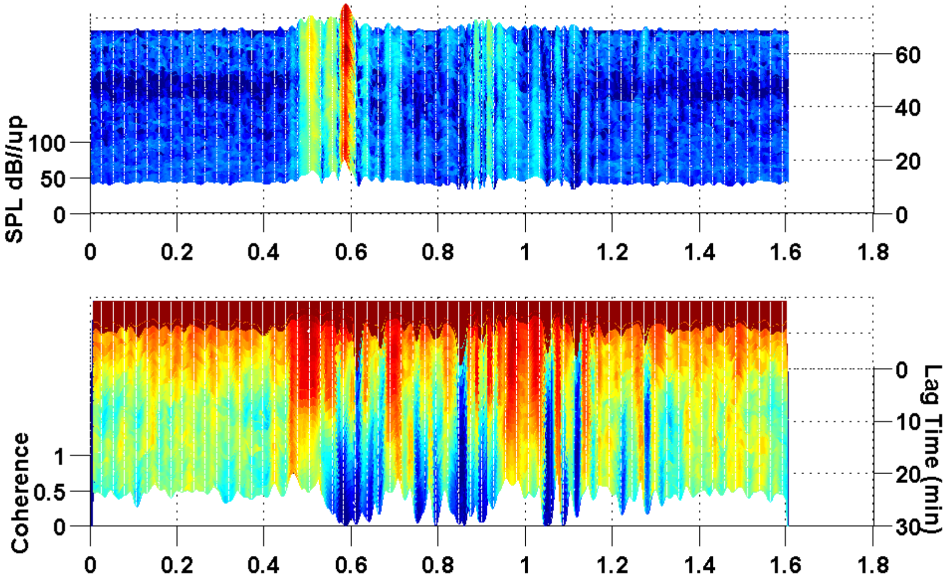


Figure 3. Top, Normal mode calculation of group velocity for the 800 Hz pulses Bottom, PE model prediction of pulse response versus range. Dispersion curves of the SRBR modes appear.

Figure 4. Top: pulse responses for 1 hour of the 400 Hz reception. Bottom: temporal coherence computed from the complex pulse responses. Late week arrivals have coherence time comparable to the more intense and predictable arrivals from modes.



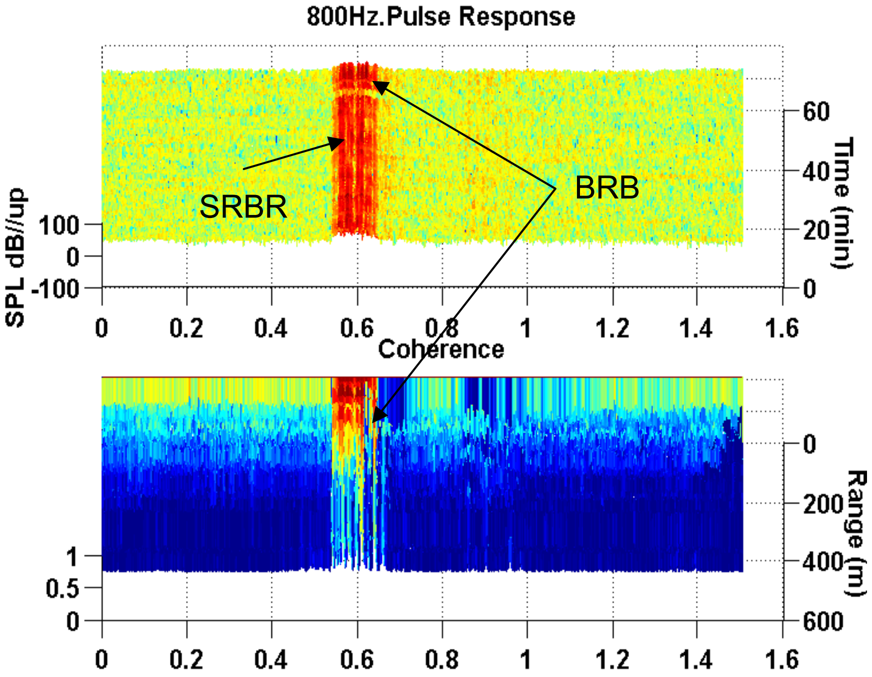


Figure 5. Horizontal coherence along the path of propagation computed with a 1-hour sample of the 800 Hz complex pulse responses.

IMPACT/APPLICATIONS

Areas of the East and South China Sea have very similar oceanography to the Florida Straits. Both are inside strong western boundary currents that have entrained edge eddies that, in turn, determine the acoustic conditions on the shallow in-shore shelf. The unique acoustic focusing effects described here will likely occur in these important tactical areas and are most important to sonar performance and prediction. In fact, simple calculations show that active sonar FOM will increase by as much as 36 dB when detecting a submarine operating at mid depth because of focusing of the ensonifying signal and the return signal. Further, it is possible to detect and track eddies with satellites and thereby predicting sonar conditions.

The primary source of low frequency noise is shipping which is coupled to SRBB modes. But deep noise sources (passives sonar targets) couple more strongly to RBR modes. The shift in energy between mode types depending of influence of off shore eddies that is reported here is most important to understanding passive sonar performance.

The coherence calculations suggest much of the reverberation and clutter that plagues shallow water active sonar may have very long temporal coherence times – the order of minutes just like the predictable mode arrivals. In contrast, the horizontal coherence of reverberant arrivals is not evident. This finding suggests that adaptive processing can be used to track and subtract out the reverberant fields to reduce false alarms.

TRANSITIONS

There are two transitions to report:

1) Acoustic Observatory Propagation Experiments. The AO program has reviewed results and the experimental approach of the FS experiments and has requested proposals to repeat similar experiments using the UM multi-frequency source to transmit to the AO receiving arrays for 1 month. The plan is to have the UM source in place and begin the experiments immediately upon completion of the array installation.

2) Continuous Active M-sequence Sonar (CAMS) a SBIR Phase I program for NAVAIR. A new approach to bi-static active is being investigated (DeFerrari 2001). The approach is to transmit and receive long m-sequences continuously. The direct arrival and all its leakage is eliminated by Hyperspace Cancellation by Coordinate Zeroing (HCCO) based on a method and theory developed by (Chang 1992). There are two main advantageous: 1) gain from longer coherence integration times (36 dB at 1600 Hz.), and doppler detection on a noise limited background rather than a reverb limited. FS data were used to demonstrate robustness of the method for real ocean transmissions.

RELATED PROJECTS

The receiver arrays of the Acoustic Observatory (AO) were be installed just a few km from the site of the Florida Straits (FS) experiments reported here. The status of the AO project is uncertain at the present time. The FS results have had significant influence on the selection of the AO site and location. There is a continuing exchange of modeling results, coherence and fluctuation data and ambient noise data with the AO program to help in the design and planning.

FS data has also proven valuable in geo-acoustic inversions research by to Dr. Ross Chapman aimed at extract bottom properties from propagation data. An active on-going collaboration continues.

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