Oceanographic Variability and the Performance of Passive and Active Sonars in the Philippine Sea

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LONG-TERM GOALS

The Philippine Sea is one of the most dynamic oceanographic environments in world; moreover, the seafloor is rough. These two factors lead to doppler and range (time) spreading of forward scattered signals. ONR supported an multiyear experiment, PhilSea_09/10/11, where a water column vertical array (DVLA) by SIO, a towed array (FORA) MPL/SIO, SOFAR axis sources (T1 – T6) (SIO), J15 a moored and towed source (MIT & WHOI), and a SOFAR channel source (MP200) (U of Wash). All the sources and receivers were designed to operate in the 50 – 500 Hz band. The long term objective of the experiment is to characterize the short and long term variability of signal propagating in the Philippine Sea. A second long term goal is to measure the horizontal directivity of the ambient noise.

OBJECTIVES

The short term variability useful for charcterizing the performance of a sonar system can be specified by the scattering function. This function specifies the spreading terms of how a signal randomly redistibutes itself in a range (travel time) – doppler plane. This redistribution can be calculated as the two dimensional convolution of the signal ambiguity function and the scattering function in the range – doppler plane. [1] The first objective is to measure the scattering function in the Philippine Sea using the assets provided by the PhilSea_09 experiment. The scattering function changes in response to long term varying oceanographic conditions such as done by tomographic measurements. The second objective is to estimate the azimuthal directional noise using the FORA array during the execution of the PhilSea_09 experiment. The these objectives must be specified relative to source/receiver

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geometries for the PhilSea_09 experiments as described in last year's annual report. The available geometries are:

1) Measure the multipath structure as the signals turn at the critical depth (J15 – FORA) at a full convergence zone distance;
2) Measure the path structure and coherence of signals incident at ½ a convergence zone (J15 – DVLA);
3) Measure the path structure for a transit across several CZ's (J15 – FORA) and (T1 – DVLA) to determine bottom bounce and convergence zone paths;
4) Measure the ambient noise above and below the critical depth transition (DVLA) and the horizontal directivity (J15).

APPROACH

The PhilSea_09 experiment was an engineering test cruise for the DVLA and T1 mooring by SIO from the *R/V Melville*. It was supplemented by the FORA towed array from the *R/V Kilo Moana.* These equipment were recovered during 2009 and the results reported here are from the PhilSea_09 experiment. These equipment were redeployed during 2010. For PhilSea_10 we deployed a J15 source to transmit to the DVLA. Thhe DVLA and its data will be recovered on early 2011, so the results of the 2010 tranmissions will only be available next year.

The signals transmittted during PhilSea_09 were LFM (linear frequency modulated) chirps, a set of non overlapping in the frequncy domain tonals and M sequences. Each of these can be used to make estimates of "slices" of the scattering function. The LFM's provide a "slice" of the scattering fucntion along the range axis at a scale determined by the inverse of the bandwidth of the chirp. The tonals provide an estimate of the scattering function along the doppler azis according to inverse of the time duration of the tonal. Naturally, lesser bandwidths and time durations as well as multiple transmissions can be used whenever the scattering function is over resolved in order to use diversity to reduce the variance of the scattering function to be estimated.

In specific terms for the PhilSea_09 data there are four classes of data available:

1) Fixed – fixed: Transmissions from the T1 source to the DVLA and from the J15 source on station to the DVLA ;
2) Fixed – moving: Transmissions from the T1 source and the moored J15 source to the FORA towed array ;
3) Moving – fixed: Transmissions from the underway (towed) J15 source to the DVLA receiver;
4) Moving – moving: Tranmissions from the underway(towed) J15 source to FORA towed array.

The approach to the scattering function measurement for the range (travel time) axis is to match filter the received signals, compute square and average over realizations. This can be shown to replicate the convultion slice for the scattering function. The approach for the doppler scattering is two fold. First, the frequency shift and bandwidth of the tonals are estimated. Second, the long term cohernce of the matched filtered outputs can be related to the same convolution along a doppler slice. Figure 1 indicates the potential path structures and the sources and receivers used during PhilSea_09.

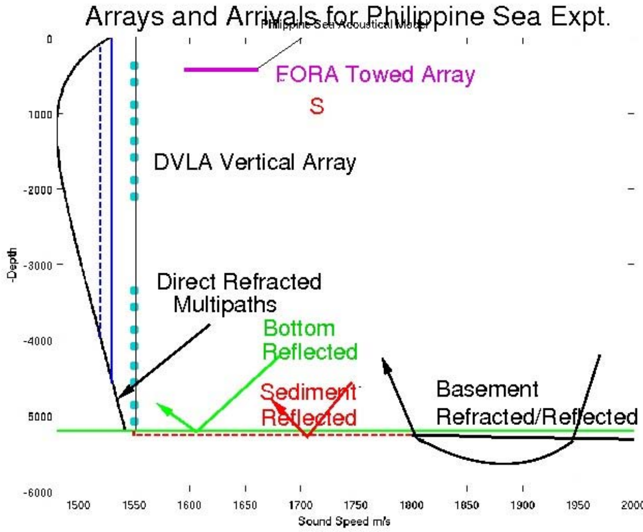

Figure 1: Cartoon for the receivers and the several possible paths present during the PhilEx_09 experiment.

WORK COMPLETE

The PhilEx_09 experiment was conducted in April – May 2009. The tracks and some very preliminary results were presented in last year's annual report. We have processed more data and presented prilinmary reults at the NPAL Airlie Workshop and the Fall 2010 Acoustical Society of America. We also completed the PhilEx_10 experiment towing the J15 source to the DVLA during July 2010.

RESULTS

The figures below are indicative of some the processed data. Figure 2 illustrates the receptions on the FORA array while it is transiting a circle at a full convergence zone from the J15 source.

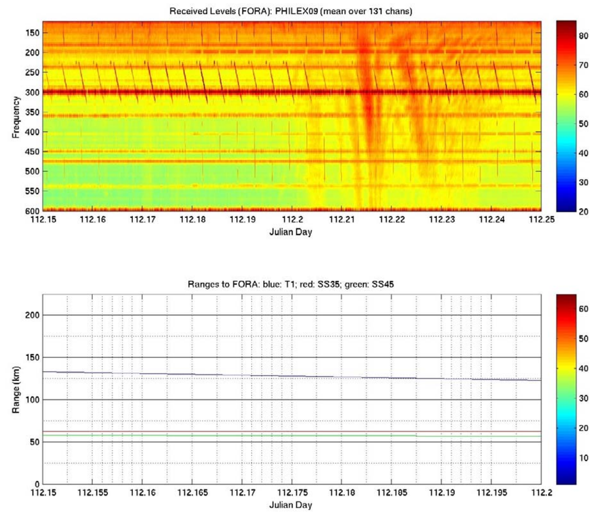

Figure 2: Broadband recording from the FORA Array from JD112.15 to JD 112.35. LFM's from two sources are present: T1 in the band 180 to 280 Hz; two bands of the J15 – the low band from 90 – 180 Hz and the high band (barely visible) from 400 – 500 Hz. There is some unknown ambient noise phenomenon present 2/3 across the panel. The second panel plots the separation of the sources and receivers from the DVLA.

Figure 3 indicates the long term temporal coherence at the output of a matched filter for the LFM's. For this we first matched filtered one channel on the DVLA output to produce a reference signal output. We then matched filtered adjacent channels for their outputs. These outputs were cross correlated with the reference signal and time aligned for slight shifts in the reption cycle of the J15 source. The normalized coherence was then calculated and plotted versus the amount of time separation from the reference channel. We note that the correlation lag on the figure is +/- three (3) hours with coherences of up to .8 for a one hour lag and .6 - .7 for up to three hours. This was not expected in the dynamic environment of the Philippine Sea.

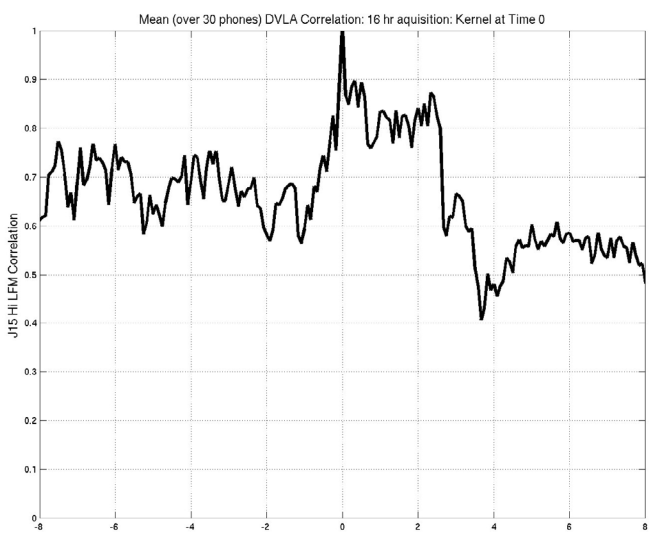

Figure 3: Broadband coherence over +/- three hours of J15 to DVLA transmissions at a ½ CZ range separation. Note that the coherence remains significant at .6 - .7 for time lapses of three hours.

Figure 4 indicates for reference the broadband noise levels. The levels versus frequency are nominal

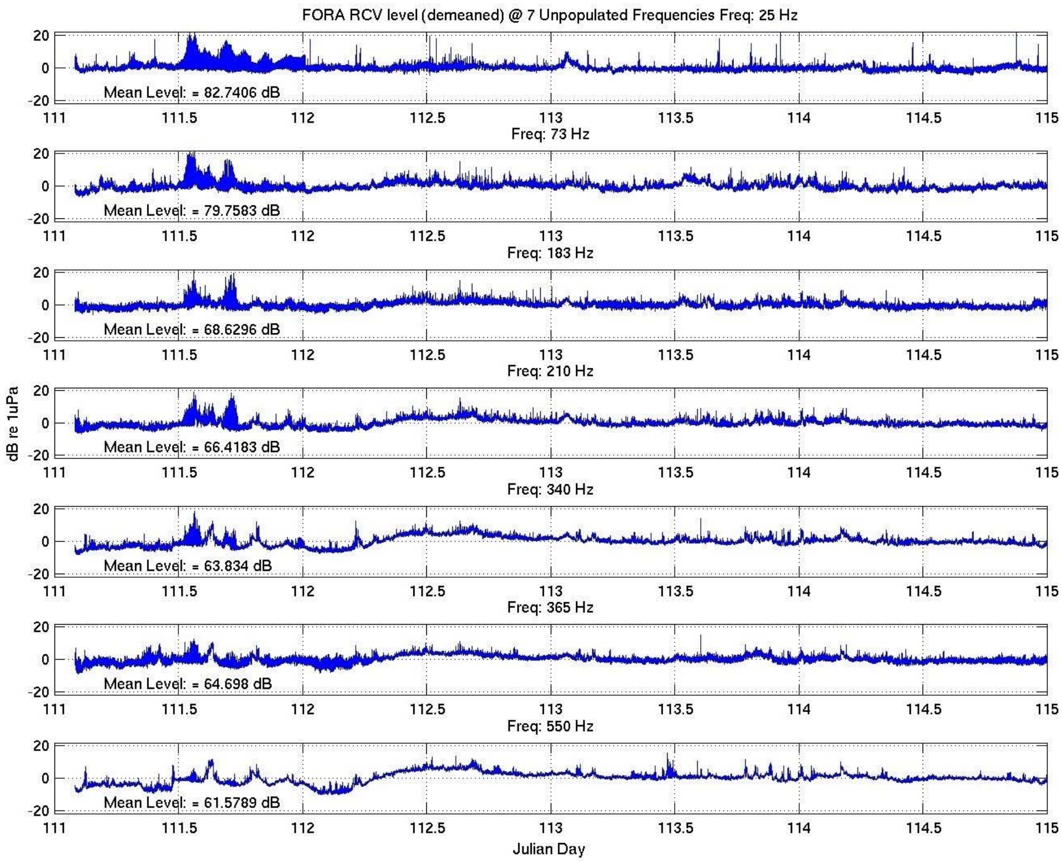

Figure 4: Ambient noise levels for seven frequency bands from 25 to 500 Hz. The levels are consistent with literature data.

compared to the literatue. There are variations of 20 dB particularly early in the experiment during a patch of rough weather, but except from this remained constant across the duration of the experiment.

IMPACT/APPLICATIONS

The Philippine Sea in a region of intense fleet interest. These data will provide fundamental guidance on the bistatic sonar signal processing parameters. The range (travel time) measurements of the scattering function will produce estimates of the time duration and structure of reverberation at ½, 1 and multiple convergence zones. The doppler measurements of same will produce estimated of how long a system can coherently integrate for SNR increases

RELATED PROJECTS

1) Performance prediction of adaptive arrays and acoustic communication systems using random matrix methods, N00014-08-1-0715

2) Persistent Littoral Undersea Surveillance (PLUS) INP, funded at MIT Lincoln Laboratory, (vector sensor processing and CONOPS)
3) WHOI MURI on acoustic communications
4) Submarine Superiority Technical Advisory Group (SSTAG), funded by N875 (all aspects of submarine soanr performance), (This group was initially formed in 1995 to monitor the APB program for the Navy)

REFERENCES

[1] Van Trees, H.L., Detection, *Estimation and Modulation Theory, Part III,* (Chapter 13), J.W. Wiley and Sons, 1971