# Panama City 2003 Acoustic Coherence Experiments: Environmental Characterization

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**Abstract.** During June 2003, the Naval Research Laboratory conducted a series of acoustic propagation experiments to measure both high (20 to 150 kHz) and low (1 to 10 kHz) frequency spatial and temporal coherence in very shallow water. Environmental data collected to support the acoustic measurements included water column current, bottom current, sea-surface wave height, tide height, CTD water column profiles and mid-water time series, two-dimensional micro-scale seawater temperature, and weather parameters. Wave periods varied from 3 to7 seconds and wind speeds ranged from 4 to 35 knots throughout the experiment. Temperature and salinity profiles characterized periods when the water column was isovelocity and periods when the water column was stratified with a strong depth dependence of temperature and salinity. Current magnitudes were always less than 25 cm/s. Experimental geometry and methods of environmental data collection are briefly described and environmental conditions and their impact on the propagation environment are emphasized.

## INTRODUCTION

In June 2003 the Naval Research Laboratory (NRL), conducted a series of acoustic propagation experiments to measure both high and low-frequency spatial and temporal coherence. The high-frequency propagation measurements spanned 10 to 150 kHz while the low-frequency measurements spanned a frequency band from 1 to 10 kHz. Acoustic measurements were made as a function of frequency, source to receiver range, and receiver separations [1]. Environmental measurements made in support of the acoustic exercise included near-bottom and water column currents, sea-surface wave spectra, conductivity-temperature-depth (CTD) profiles, and time-series, micro-scale seawater temperature, weather, and tides. The objective of the environmental measurements was to first generally characterize the propagation environment in terms of the physical oceanography and second, attempt to quantify the variability in the environment that affects high-frequency propagation. All measurements took place in an area just off the coast of Panama City Florida in a water depth of approximately 8.8m.

## ENVIRONMENTAL SENSOR CONFIGURATION

Environmental sensors were mounted on each acoustic tower and deployed at locations near the acoustical path of the experiment (Fig. 1)[1]. The two towers, one configured with acoustic sources and one configured with acoustic receivers, were deployed parallel to the shoreline approximately 545 m seaward of the beach in 8.8m of water. During the experiment, the receive tower's position was fixed while the source tower was repositioned to obtain data sets at two ranges (70 and 150 m).

Figure 1 shows the location of the environmental sensors while Table 1 gives a synopsis of the environmental data collected by each. An ADCP, two tower-mounted CTDs, and two temperature arrays (TMMS and FRTS) were each powered from shore and their data transmitted to shore with the acoustic data stream. As a result, these data were recorded in real-time, but only during acoustic data runs. A wave and tide gauge, Trident wave buoy, and S4 current meter were autonomous instruments that were powered and logged data internally. They recorded data on a programmed schedule, were later recovered and downloaded. A Davis weather system recorded barometric pressure, temperature, UV radiation, solar radiation, humidity, wind speed and direction, and rainfall from an integrated suite of sensors. This sensor suite was mounted on a 10m tower, approximately 100m from the shoreline. In addition to mounted and moored sensors, CTD profiles were collected from an inflatable boat at times permitted by the experiment schedule and weather conditions. Acoustic properties of the bottom sediments were measured during previous NRL experiments at this site.

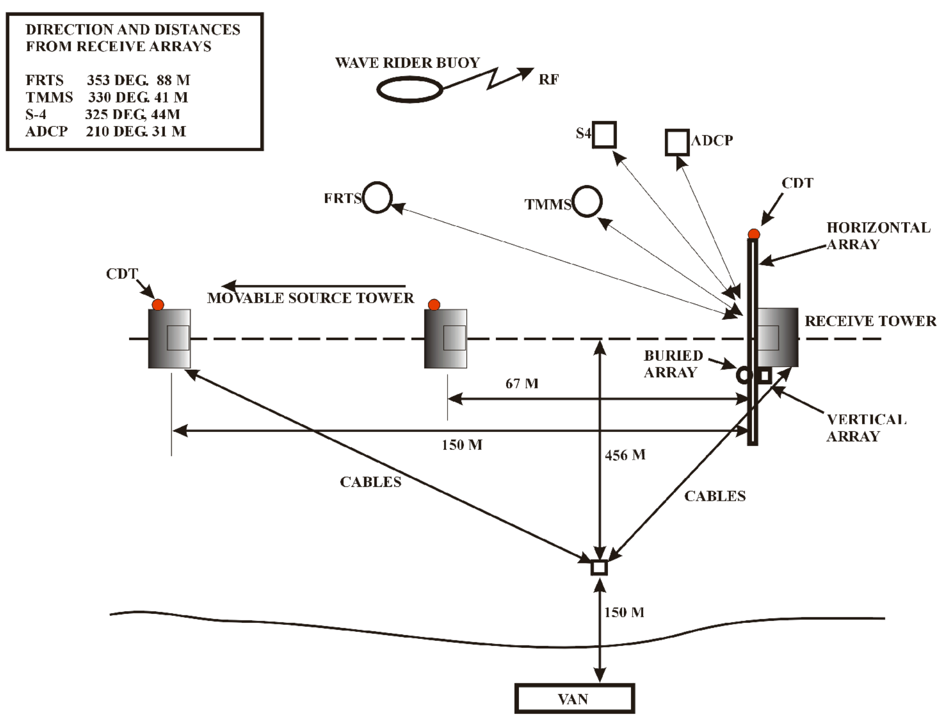


**FIGURE 1**. Experimental configuration schematic diagram.

**TABLE . Synopsis of environmental date collected during Panama City 2003 experiment.**

| Measurement | Instrument | Recording Period |
|---|---|---|
| Tide and Wave height | InterOcean Model WTG 904 | Sampled Time-series (4min. wave, 10min. tide); Internal power and data recording |
| Sea-surface wave height and period | Neptune Sciences Trident Wave Buoy | Processed time-series (17min each hour); internal power and data recording |
| Currents, Water Col. | RDI 1200 kHz ADCP | Real-time during LF and HF acoustic runs; Shore power and data recording |
| Currents, Near-btm | InterOcean Model S4 Current Meter | Sampled Time-series (4 min) Internal power and data recording |
| Cond-Temp-Depth | | |
| Time Series (Receive Tower) | SeaBird SBE49 CTD | Real-time during LF and HF acoustic runs; Shore power and data recording |
| Time Series (Source Tower) | SeaBird SBE49 CTD | Real-time during LF and HF acoustic runs; Shore power and data recording |
| Profiles | Ocean Sensors OS 200 CTD | Multiple casts on acoustic data collection days; Internal power and data recording |
| Temp. vert. structure | NRL thermistor array (FRTS) | Real-time during LF and HF acoustic runs; Shore power and data recording |
| Temp. microstructure. | NRL TMMS system | Real-time during LF and HF acoustic runs; Shore power and data recording |
| Weather, Local | Davis Health Enviromonitor | Sampled time-series (30 min); Shore power and data recording |

## ENVIRONMENTAL CONDITIONS

A thorough description of the general area is available in Salsman and Ciesluk [2]. Data collected during the Panama City 2003 experiment characterize the local environmental conditions and quantify the variability in the environment. Weather during the experiment was typical of the northeastern Gulf Coast during summer. Most days were sunny with high temperatures in the mid-80º F. Generally, wind speeds were less than 18 knots with the direction depending on the existence of an afternoon sea breeze. Periods of higher winds occurred and acoustic data were collected during both periods of high and low winds (Fig. 2).

Tide height measured by the WTG904 wave and tide gauge compared favorably to data from NOAA's tide station 8729210 located in Panama City Beach, FL and indicated a maximum tidal range of ~1.0m. When overlaid with collection times of the acoustic data runs, these data illustrate the variety of tidal conditions under which acoustic experiments were conducted (Fig. 3).

Wave height, period, and direction data, collected by Neptune Science's Trident wave buoy, characterized the sea surface during the acoustic data runs. The time series in Fig. 4 shows that wave heights were typically less than 1m with a general decrease in wave height over the course of the experiment that correlates well with wind speed (See Fig. 2). Each datum from the wave buoy is the result of a 17-minute average, which is a time period comparable to a single acoustic run and does not address the degree of variability that may exist within sea-surface wave trains. An indication of this variability in sea-surface waves may be seen in directional wave spectra computed from wave buoy data (Fig. 5). Examples from two separate days, approximately 1 hour apart are plotted with intensity as a function of the wave direction and wave period. Most spectra show a number of wave periods ranging from approximately 2 to 7 seconds.

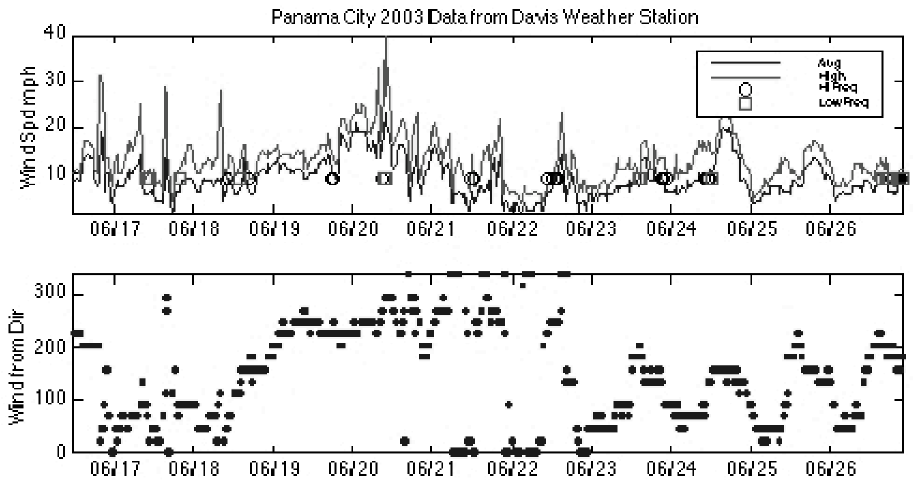


**FIGURE 2**. Local wind speed and direction during Panama City 2003 experiment with times of acoustic data runs.

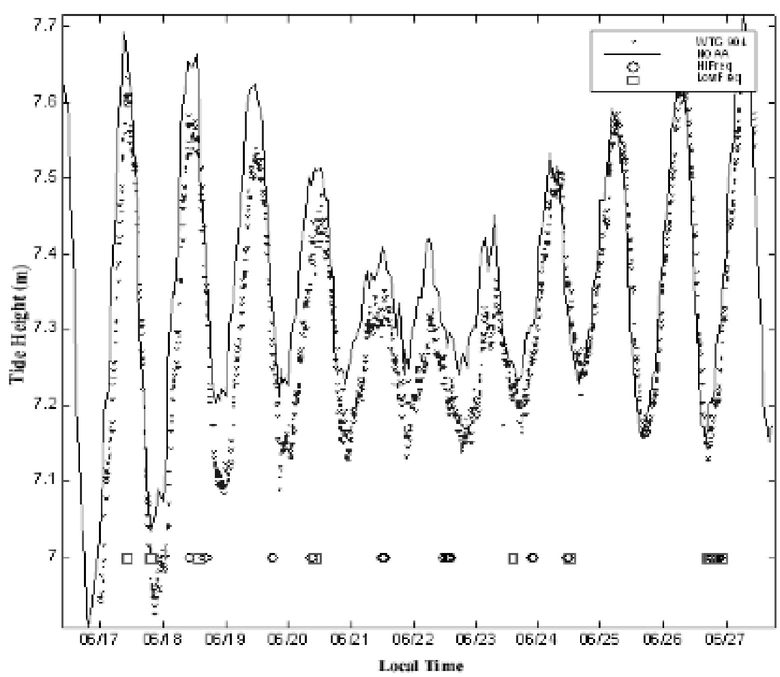


**FIGURE 3**. Measured tides and acoustic data run times .

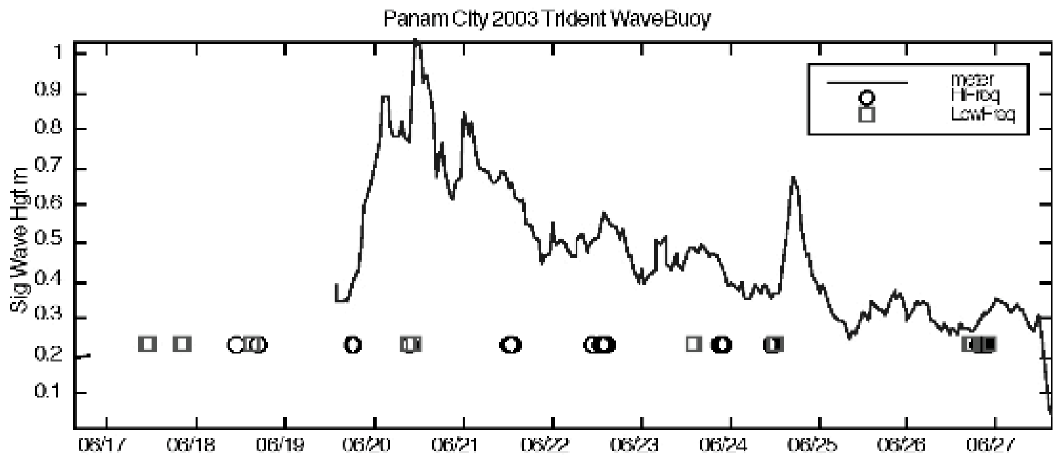


**FIGURE 4**. Significant wave height measured by the Trident wave buoy.

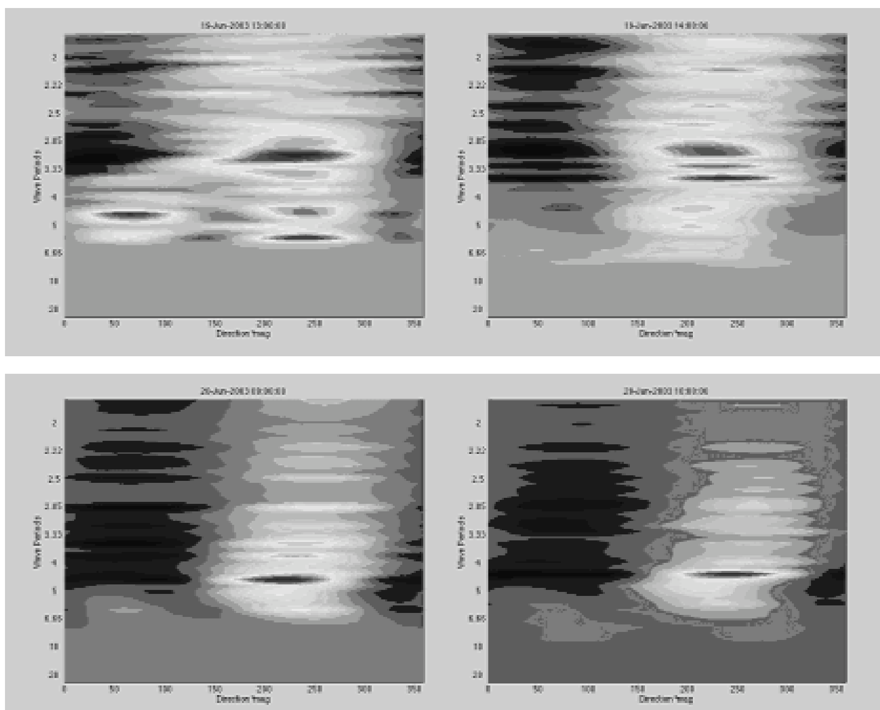

**FIGURE 5**. Computed directional wave spectra from 2 separate days, ~1 hour apart; 19 June (top), 20 June (bottom).

Two prevalent current directions are indicated from ADCP water column current data collected during each acoustic run (Fig. 6). When currents are low (less than 7 cm/s) the direction tends to be more variable, but when currents are higher (greater than 12 to 15 cm/s) the direction is almost always either approximately 125° Mag. (long-shore current towards the east) or ~320° Mag. (long-shore current towards the west). Figure 6 also shows current standard deviation increases as current magnitude increases, indicating that higher currents introduce greater current fluctuations.

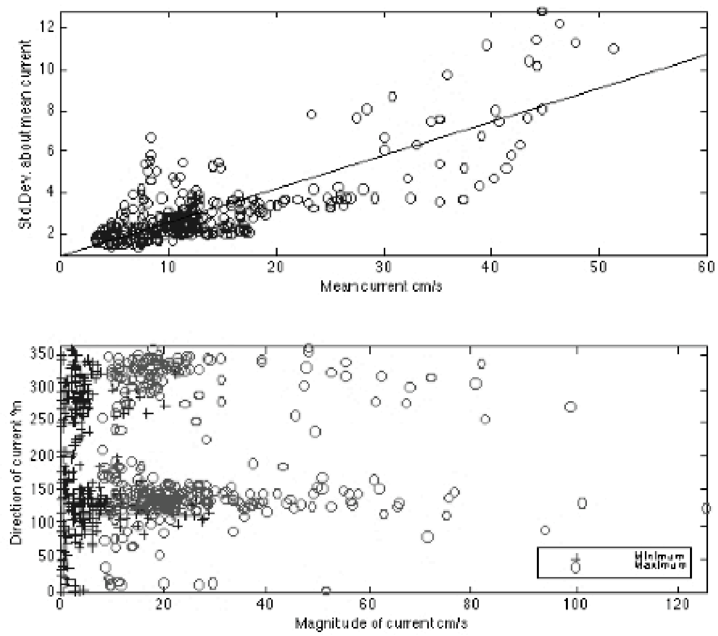


**FIGURE 6**. Typical water column current magnitude and direction (ADCP).

Near bottom currents were measured by a S4 current meter moored to the bottom and generally agreed well with ADCP water column results in magnitude and direction. The S4 provided a time-series from the entire 12-day measurement period. Figure 7 shows this current spectrum for both north and east components. It is notable that the lower frequency (corresponding to periods of ~1.5 - 30 minutes) components agree quite well with the predictions of isotropic turbulence for frequency dependence (straight line).

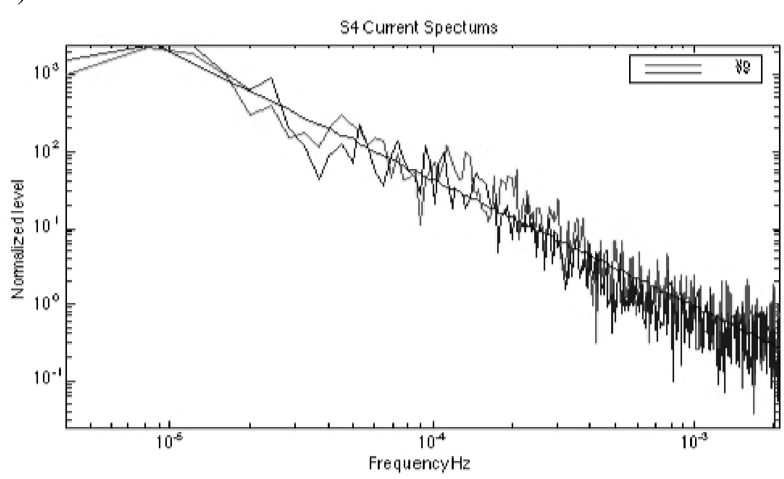


**FIGURE 7**. Bottom current spectra.

Profiles of temperature, salinity, and computed sound speed were used to characterize the propagation environment. CTD casts were collected from a small boat along an offshore transect at stations that can be typically described as (1) seaward of the buoy field, (2) within the propagation path, and (3), shoreward of the buoy field. Over the course of the experiment, water column properties ranged from profiles with isovelocity conditions to profiles with distinct layers. Figure 8 shows examples of computed sound speed versus depth for two days of sampling plus a temperature vs. salinity diagram for each day to identify density structure. In this figure, 18 June is an example of a well mixed, nearly isovelocity water column. A low salinity filament, running diagonally through the acoustic measurement path, was indicated in salinity profiles, is easily identified in the Temperature/Salinity diagram. This lower salinity filament produces a sound speed change of approximately 0.7 m/s, but since it extends to less than 3m depth, it should have minimal influence on mid-water high-frequency propagation. The mid-water sound speeds appear stable in the profiles collected within the acoustic measurement path. 21 June is an example of layered water where the Temperature/Salinity diagram illustrates the similarity of these profiles and the density stratification in the water column. This stratification of density produces a mid-water sound channel axis near 4 m depth.

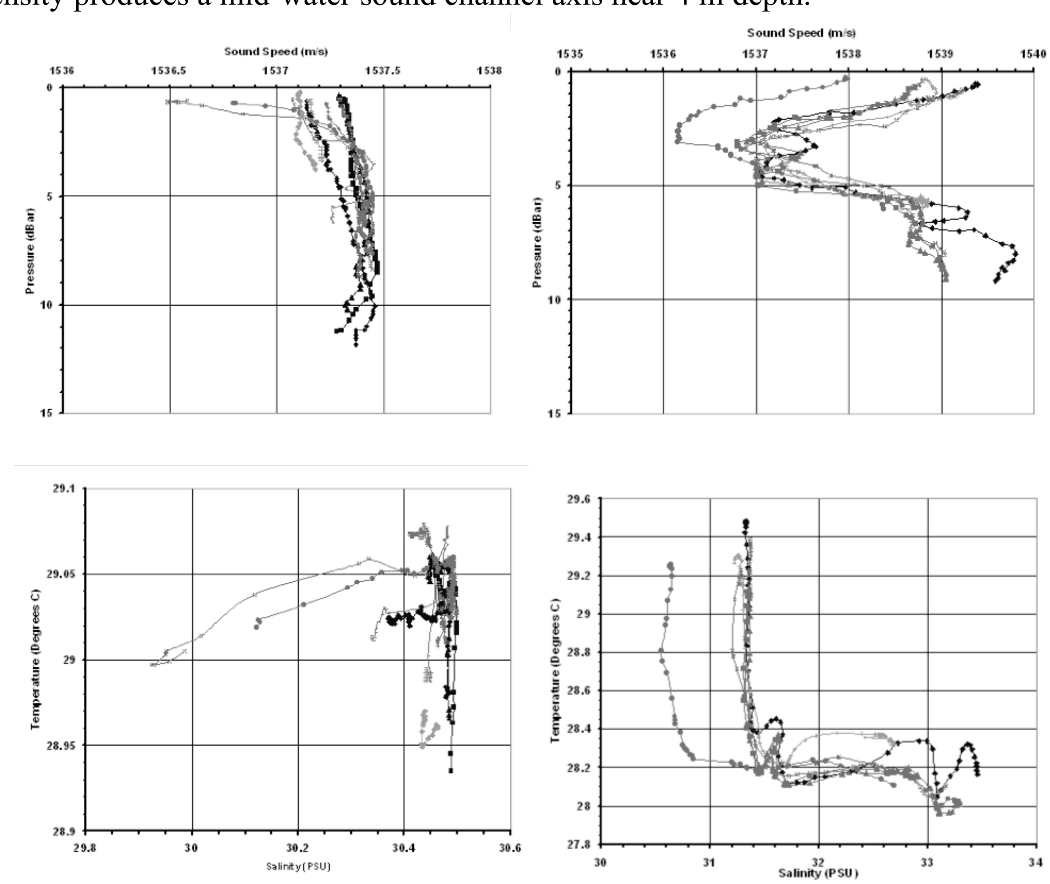


**FIGURE 8**. CTD profiles indicating isovelocity conditions on 18 June (left column) and a layered water column on 21 June (right column).

Tower mounted CTD's measured temperature, salinity, and pressure time series at approximately a 5 Hz sampling rate during all acoustic runs, but only for Runs 1 through 5 at the source location. Examples of time-series in Fig. 9 illustrate the fluctuations measured.

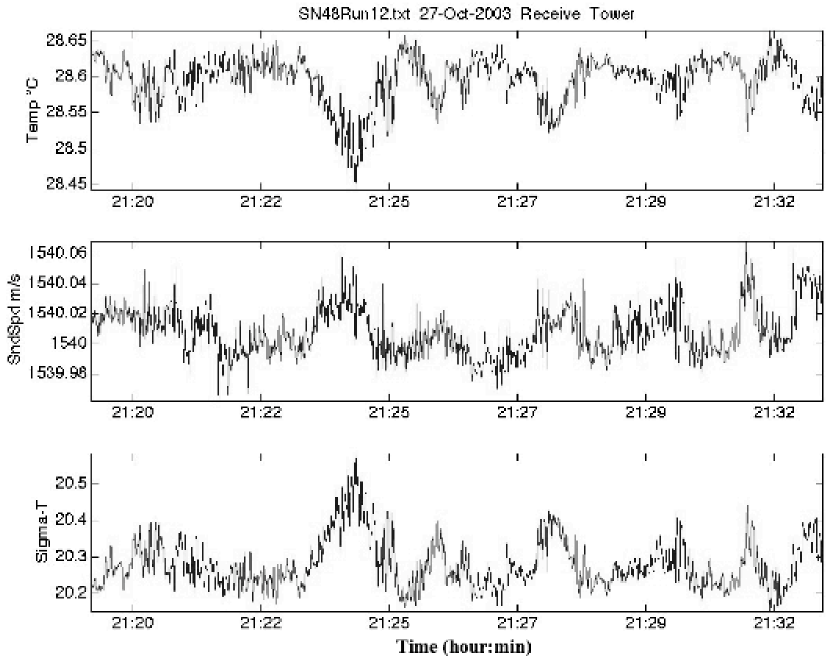


**FIGURE 9**. Temperature, computed sound speed, and sigma-t time-series from the receive tower CTD during acoustic Run 12 (short range).

High resolution, small scale temporal, and two-dimensional spatial changes in ocean temperature were measured by TMMS which can distinguish temperature changes as small as 0.007°C with absolute temperature accuracy of 0.05°C. As an example of TMMS data, Fig. 10 gives the average temperature spectra during Run 11. In this figure, spectra from TMMS vertical and horizontal arrays are nearly identical except in the periods ranging 8-10 seconds. The spectral slope generally agrees well with that predicted by isotropic turbulence; represented by the straight line. A two-dimensional index of refraction can be estimated from the temperature field as can the two-dimensional spatial scale.

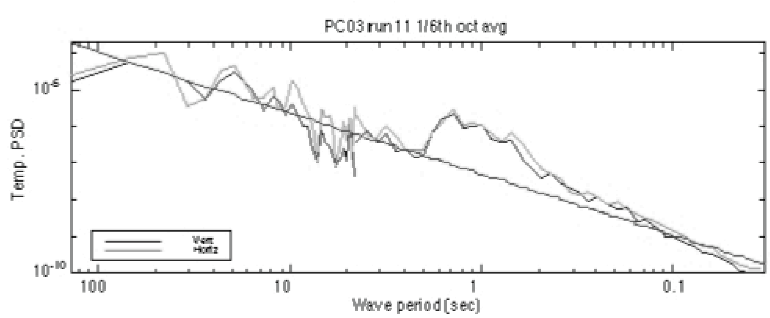


**FIGURE 10**. Temperature array spectra computed from TMMS data.

Water column temperature structure was also characterized during acoustic runs by the Fast Response Temperature System (FRTS) vertical thermistor array. Examples over the course of the experiment include a nearly uniform temperature profile and a profile showing colder water near the bottom and at the surface with warmer water near the acoustic source depth (Fig. 11).

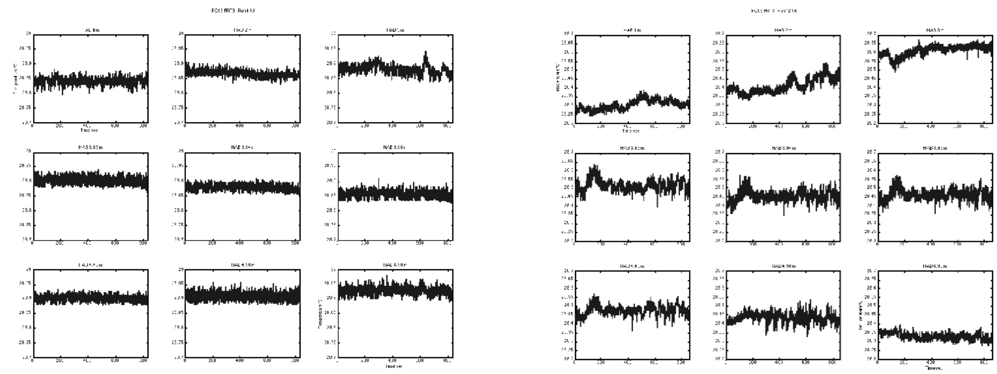

**FIGURE 11**. FRTS temperature time-series spanning the water column showing a nearly uniform temperature profile (Run 4 - Left) and a stratified profile with colder water near the bottom and at the surface and warmer water near the acoustic source depth (Run 12 - Right).

Table 2 summarizes the general environmental conditions during seven sample acoustic runs and presents several two-dimensional micro-scale temperature fluctuation parameters calculated from the TMMS data

Table 2. Summary of environmental conditions during Panama City 2003 Experiment

| **Parameters** | **Short Range Acoustic Runs** | | | | **Long Range Acousti** | |
|---|---|---|---|---|---|---|
| | **Run 2** (6/17/2003) (10:05:00 AM) | **Run 4** (6/17/2003) (7:42:00 PM) | **Run 6** (6/18/2003) (2:13:00 PM) | **Run 12** (6/20/2003) (9:20:00 AM) | **Run 26** (6/23/2003) (2:19:00 PM) | **Run 35** (6/24/2003) (11:57:00 AM) |
| Wind | | | | | | |
| Wind Speed (mph) | 8-10 | 5-10 | 8-15 | 20-40 | 8-12 | 12-15 |
| Wind Direction (°Mag) | 100 | 75 | 150 | 250 | 170 | 150 |
| Currents - Water Column | | | | | | |
| Current Magnitude @ srce dpth (cm/s) | 4 | 7.4 | 9 - 12 | 20 - 30 | 4-6 | 7 - 9 |
| Current Direction @ srce dpth (°mag) | 180° | 110° | 300° | 140° | 300 | 20° |
| Bottom Current Magnitude (cm/s) | < 5 | < 5 | < 5 | < 5 | < 5 | 10 |
| Conductivity - Temperature | | | | | | |
| CTD Profiles | - | | isovel.>2m | | 2 layers TS spikes | 2 layers up refract |
| CTD Computed Sound Speed (m/s) | - | ±0.5 | ±0.5 grad increase | 0.05 | 0.3 TS spikes | ±0.05 oscillatory |
| Tide Height (Water height) | | | | | | |
| Water Depth (m); Wave-Tide Gauge | 8.6 | 8.6 | 8.6 | 8.5 | 8.3 | 8.3 |
| Wave Height and Direction | | | | | | |
| Signif. Wave Ht.(m); Wave-Tide Gauge | 0.6 | 0.5 | 0.8 | 1.6 | 0.7 | 0.6 |
| Signif. Wave Height (m); Wave Buoy | - | | | 0.8 | 0.5 | 0.4 |
| Wave Direction (°Mag); Wave Buoy | | | | 240 | 190 | 200 |
| Wave Period | | | | | | |
| Wave Period (sec); Wave-Tide Gauge | 4.4 | 4.4 | 4.4 | 3.9 | 4.5 | 4.2 |
| Wave Period (sec); Wave Buoy | - | | | 5.5 | 6.5 | 5.5 |
| Microscale Temperature (TMMS) | | | | | | |
| Brunt-Väisälä Frequency (cy/hr) | unstable | 4 | 2 | unstable | 19 | 9 |
| Vertical AutoCorrelation Time (Sec) | 0.57 | 0.54 | 0.62 | 0.69 | 0.87 | 0.62 |
| Vertical Spatial Coherence Length (m) | 0.46 | 0.39 | 0.48 | 0.6 | 0.29 | 0.24 |
| Horizontal AutoCorrelation Time (Sec) | 0.62 | 0.53 | 0.69 | 0.6 | 0.87 | 0.65 |
| Horiz. Spatial Coherence Length (m) | 0.51 | 0.56 | 0.57 | 0.55 | 0.51 | 0.51 |

For example, the Brunt - Väisälä frequency (or natural buoyancy frequency) indicates that both stable and unstable water conditions were encountered during the experiment. Vertical and horizontal autocorrelation times were computed for consecutive five-second windows for each thermistor. An average over the ensemble of thermistors for each array (vertical or horizontal) is reported in the table. Similarly, the cross-correlation as a function of separation length (array element spacing) for each five-second window was calculated to compute the thermal spatial coherence length. Five seconds was chosen as a reasonable compromise between the acoustic pulse length and the nominal sea-surface swell period.

## SUMMARY

Environmental data were collected that characterized the propagation environment in terms of the physical oceanography and quantified variability in the environment that may affect propagation. During the experiment, environmental conditions were encountered that included different tidal stages, different sea-surface wave heights and periods, high and low winds, high and low currents, water column conditions that were both stable and unstable, and sound speed profiles that ranged from isovelocity to stratified.

## ACKNOWLEDGMENTS

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2. Salsman, G.G. and Ciesluk, A. J. "Environmental Conditions in Coastal Waters Near Panama City Florida" Naval Coastal Systems Center, NCSC TR-337-78, Aug 1978.