LAGRANGIAN AMBIENT NOISE DRIFTER

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Abstract - The Defence Research Establishment Atlantic has carried out an experiment to study the relationship between ambient noise and oceanographic features in regions of pronounced oceanic currents, such as the Gulf Stream or its eddies, using a field of purpose built, long life drifting buoys developed and maintained at sea by Seimac Limited, of Dartmouth, Canada. These Lagrangian Ambient Noise Drifters (LANDs) comprise a drogued free floating buoy which employs telemetry over ARGOS satellites to report hourly measurements of the underwater ambient noise spectrum, as well as the surface wave energy spectrum, wind speed and direction, Global Positioning System geographic position, and water temperature at the sea surface and at the hydrophone. This paper presents the various aspects of the design of the LAND buoys, with particular emphasis on the techniques for measuring and processing the ambient noise and surface wave height data. Comparative data for these parameters are presented.

Le centre de la recherche pour la défense Atlantique a fait une expérience pour étudier la relation entre le bruit ambiant et les charactéristiques océanographiques dans des régions où les courants de l'océan sont prononcés, comme par exemple dans le Gulf Stream ou ses remous, en utilisant un champ de bouées à la dérive et ayant une longue vie, spécialement construit et maintenu en mer par Seimac Limited de Dartmouth, Canada. Ces bouées Lagrangian à la dérive mesurant le bruit ambiant emploient un système télémetrique utilisant les satellites ARGOS pour rapporter à chaque heure le spectre du bruit ambiant sous-marin en plus du spectre d'énergie des vagues à la surface, la vitesse et la direction du vent, la position géographique du système de positionnement global et la température de l'eau à la surface de l'océan ainsi qu'à la position du hydrophone. Cet exposé présente les aspects divers de la conception des bouées flottantes, en accordant une importance plus particulière aux techniques utilisées pour mesurer et analyser le bruit ambiant et la hauteur des vagues à la surface de la mer. Des données comparatives pour ces paramètres seront présentées.

I. INTRODUCTION

The undersea environmental acoustic research carried out at the Defence Research Establishment Atlantic (DREA) recently included studies to investigate the relationships between ambient noise and wind and wave conditions within areas of strong oceanic currents, in particular the Gulf Stream, for comparison with data collected outside the current. It was decided to employ a field of eight suitably instrumented drifting buoys, configured as Lagrangian drifters so as to move with the prevailing subsurface current, and to collect data over a fourteen day period in order to allow a variety of wind and wave conditions to prevail; however, in order to keep the trial geographically bounded over this period, the drifters were deployed in a warm core eddy of the Stream, rather than the Gulf Stream itself.

The drogued, free-floating, drifting buoys known as Lagrangian Ambient Noise Drifters (LANDs), use the ARGOS satellite system to telemeter hourly measurements of seven environmental parameters to a land-based station. The measured parameters include the underwater ambient noise spectrum, the surface wave energy spectrum, wind speed and direction, water temperature at the surface and at the hydrophone, and the geographic location of the buoy as determined by an onboard Global Positioning System (GPS) unit. Measurements are also stored in the internal memory of the system.

The drifters were developed to DREA's specification by Seimac Limited, a manufacturer of specialized oceanographic products including a range of purpose-built, free-floating drifting buoys. As part of the contract between DREA and Seimac the company was also responsible for maintaining the operability of the drifters during the experiment, and for collecting and decoding the ARGOS data received from the ARGOS ground station. The LANDs were deployed from the Canadian Forces Auxiliary Vessel QUEST in a warm core eddy of the Gulf Stream during late April 1994, after prototype models had undergone a number of tests described below in section VIII.

This paper will discuss the design of the LAND buoys and their performance at sea, and will present representative samples of data including wave height data measured with a commercial wave-buoy system for comparison with the corresponding LAND data.

The work was funded by the Canadian Department of National Defence under contract number W7707-2-2098/01-OSC.

0-7803-2056-5

II. SYSTEM OVERVIEW

Figure 1 is a diagram of the LAND system. It comprises a drogued cylindrical float fitted with atmospheric and underwater sensors, of which a wind sensor, a GPS receiver antenna and a satellite transmitter antenna project above the float. A compliant suspension system supporting the drogue and a hydrophone fitted with a temperature sensor are streamed beneath the float. The float contains a battery power supply, electronics for satellite data telemetry and navigation, an accelerometer, a flux gate compass, a water temperature sensor, transducer signal conditioning, and digital electronics. A microcontroller equipped with data storage memory activates the various subsystems.

The system is highly programmable and can be reconfigured using the microcontroller prior to deployment. The sample interval and duration, the centre frequencies and dynamic range of the acoustic measurements, the information stored in the internal memory and the satellite data message are all under program control. This feature allows the system to be customized to suit the experimental application.

III. WIND MEASUREMENTS

The LAND wind sensor is mounted on a 1 meter high fibreglass mast. Wind speed is determined by directly counting pulses from the sensor using a pulse squaring circuit buffered into a microcontroller port line. Wind direction is sensed using analogue signal conditioning circuitry and an analogue-to-digital converter. The direction measurement is corrected for both wave motion and drifter orientation. Orientation of the wind sensor with respect to magnetic north is determined using a flux gate compass. Sensor movement due to wave motions is corrected by weighting a number of wind direction samples by the wind speed and averaging over the samples.

The LAND is also equipped with a GPS receiver for determining geographic position, which is typically measured to an absolute accuracy of less than 100 meters. These data can be used to find the true wind speed and direction from the measured apparent wind by accounting for the measured drift of the instrument.

IV. WAVE HEIGHT MEASUREMENTS

The LAND is designed to measure wave height spectral energy. A uniaxial accelerometer and signal conditioning circuitry in the surface float are used to collect a time series of the vertical accelerations of the buoy. The wave height spectrum is calculated using Fast Fourier Transform (FFT)

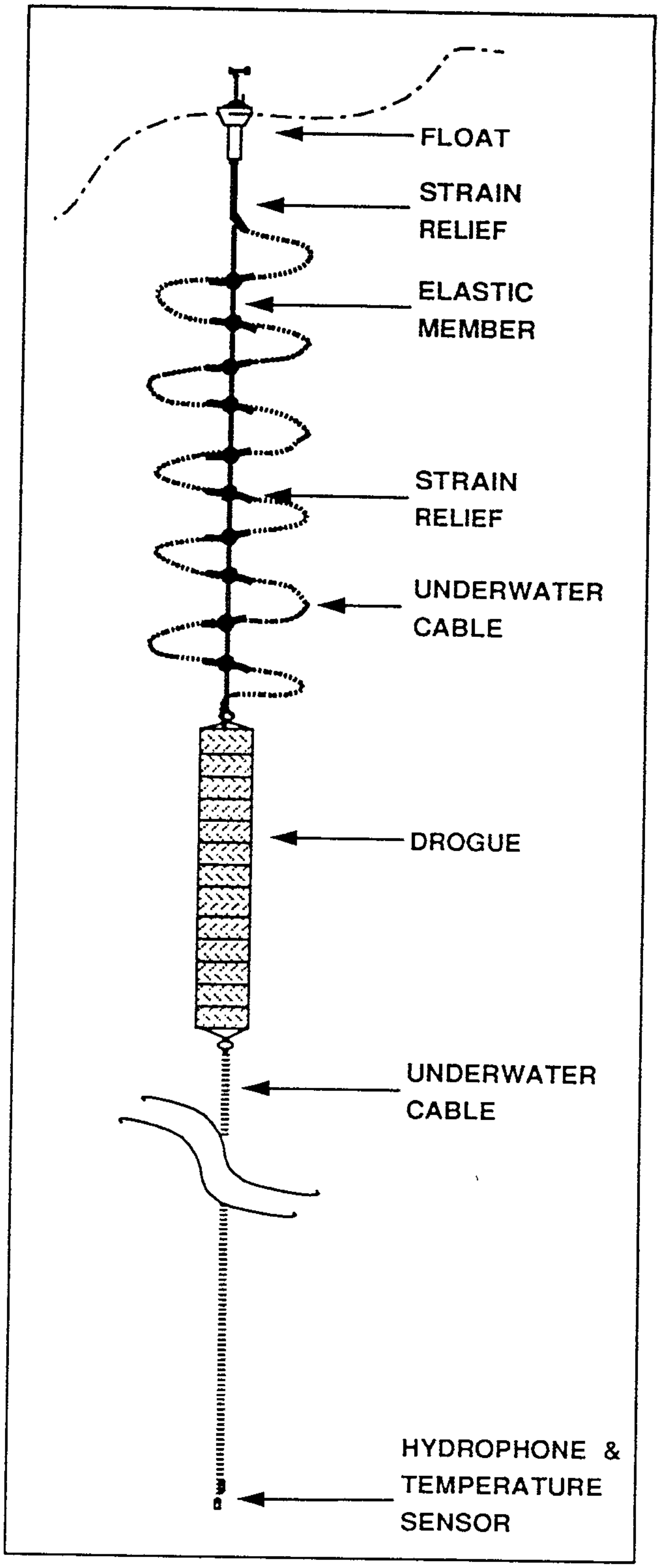

Fig. 1 A diagram of the Lagrangian Ambient Noise Drifter. The hydrophone is suspended at 100 meters depth, the drogue is 10 meters in length. The drawing is roughly to scale.

based signal processing operations performed with the floating point routines in the microcontroller.

Although simple in concept, considerable attention is paid to the process of signal conditioning and the mathematical details of calculating the wave height spectral content from the acceleration time series. First a time series of 1280 points is multiplied by a scaling factor to convert the data to units of [m/s^2]. Then the data are shifted so that the signal has a zero average and split into four 50% overlapping sets of 512 points after which the data sets are taken in pairs, windowed and interleaved in a complex array. FFT operations are performed on the two 512-point complex arrays, and the results are averaged to get an estimate of the frequency content of the time series.

In order to calculate wave height spectral energy, the acceleration spectra are squared and then normalized for each frequency bin. This approach gives acceleration spectral energy in units of [m^2/s^4/bin]. To convert to units of wave height spectral energy [m^2/Hz], the data in each bin are divided by its angular frequency raised to the fourth power and then divided by the bin width. With 256 bins to represent frequencies up to the Nyquist at 1.6 Hz, the bin width is 1.6 Hz / 256 = 0.00625 Hz.

A condensed version of the wave height information is included in the ARGOS transmissions, while more detailed data are stored in the controller memory for retrieval when the buoy is recovered.

V. UNDERWATER AMBIENT NOISE

A. Basic Method

The LAND makes spectral level measurements in nine discrete 1/3 octave bands spaced at octave intervals over the range 50 to 12,800 Hz. A calibrated hydrophone containing an integrated preamplifier is suspended 100 meters below the surface. Signal conditioning circuitry consists of programmable gain and filter stages, several fixed gain stages, an RMS-to-DC converter circuit and an analogue-to-digital converter. Ambient noise samples are processed using floating point routines and stored in the internal memory. Processed data are stored and telemetered to the satellite as the spectral level SL(f_c) at each centre frequency in units of dB//1 uPa^2/Hz.

A number of assumptions concerning the characteristics of the ambient noise spectrum are embodied in the measurement system design. It is assumed that, in the absence of biological and shipping activity, the average noise level remains constant during the hourly noise sampling period of approximately 5 minutes. In addition, adjacent frequency bands one octave apart will have mean amplitudes that do not differ by more than 12 dB. Also there may be a spread of nearly 30 dB in mean amplitudes in a given band during the course of an experiment.

B. Bandpass Filter Characteristics

The one-third octave programable bandpass filter can be set to sample any of 256 different centre frequencies between 50 and 12,800 Hz. The out-of-band attenuation of the filter prevents a high mean level at one centre frequency from unduly influencing the mean level being measured at an adjacent frequency. High shipping density combined with low wind speed is the worst case scenario.
The one-third octave, 4-pole bandpass filter offers 34 dB of attenuation at one octave from the centre frequency, and 49 dB at two octaves resulting in negligible crosstalk between channels.

Another important filter characteristic is the filter bandwidth (Δf) defined by the noise equivalent bandwidth (NEB). NEB is found by equating the area under the filter frequency response curve to an ideal response curve of equivalent area. In practice, we have found that the bandwidth is best determined by empirical measurement using a white noise signal generator and a frequency analyzer.

C. Averaging Time

The averaging time constant (τ) is the time needed to sample the noise field to obtain an accurate measurement of the average spectral level. It is inversely proportional to centre frequency (f_c). The criterion used to determine τ is that the time-bandwidth product for averaging be equal to or greater than 100, ie:

$$\tau = \frac{100}{\Delta f} \qquad (1)$$

At a centre frequency of 50 Hz τ is almost 20 seconds. This large time constant is impractical to realize with analogue circuitry so an average of many samples is used. The acoustic signal is fed into an RMS-to-DC converter circuit with an averaging time constant of 0.25 seconds. The output is sampled n times at 16 Hz for the required averaging time ($n = 16\tau$) and stored in memory. The sampling frequency of 16 Hz is well above the Nyquist anti-aliasing criterion imposed by the 4 Hz (0.25s) time constant of the RMS to DC converter.

The analogue-to-digital converter samples (v_n) are proportional to the RMS (root mean square) voltage at the input of the RMS-to-DC converter. To calculate the RMS value of the signal voltage level over the averaging time, the samples are averaged according to:

$$V_{rms}^2 = \frac{1}{n}\sum_n V_n^2 \tag{2}$$

D. Calculating Spectral Level

The RMS voltage computed according to Eqn. (2) is converted to the **voltage signal level** (*VSL*) in decibels re 1 volt by converting from analogue-to-digital converter (ADC) counts to equivalent voltage level in decibels. This is achieved by multiplying by the ADC full scale voltage, dividing by the full scale counts, and applying the relation,

$$VSL = 20\log_{10}V_{rms} \quad [\mathrm{dBV}] \tag{3}$$

VSL is measured with a bandwidth of Δf at the input to the analogue to digital converter. This number is then converted into the **sound pressure level** (*SPL*) at the hydrophone by subtracting the gain of the circuit (A_v) and the hydrophone sensitivity (H_{sens}) at the centre frequency. For example, the sensitivity of the hydrophone at 50 Hz is -157.5 dB re 1 volt/uPa. The gain of the circuit at 50 Hz is 61.8 dBV. The *SPL* at the hydrophone expressed in dB re 1uPa is found from the *VSL* using:

$$\begin{aligned} SPL &= VSL - A_v - H_{sens} \\ &= VSL - 61.8 + 157.5 \\ &= VSL - 95.7 \quad [\mathrm{dBre1uPa}] \end{aligned} \tag{4}$$

The last step in determining the **sound spectrum level at the centre frequency** $SL(f_c)$ is to convert the SPL into the level which would have been measured if the filter had a bandwidth of 1 Hz and if the spectrum level were uniform throughout the bandwidth Δf. This is done by applying the formula,

$$SL(f_c) = SPL - 10\log\Delta f \quad [\mathrm{dB//1uPa^2/Hz}] \tag{5}$$

E. Pre-whitening

To equalize the expected mean levels for the various frequency bands at the input of the analogue-to-digital converter, the gain is varied for each band using a programmable gain stage. This process is termed "pre-whitening the spectrum [illegible] converter with an input range of 0 to 5 volts, the desired maximum voltage input after amplification is 3.0 [Vrms], or +9.5 dBV. The required gains (A_v)for each band are calculated from,

$$SL(f_c)_{max} + H_{sens} + A_v + 10\log\Delta f = 9.5 \quad [\mathrm{dBV}] \tag{6}$$

F. Summary of Ambient Noise Measurements

A combination of analogue and digital techniques are employed to report calibrated underwater ambient noise spectral levels. The analogue circuit design issues are the dynamic range of the circuit, the analogue averaging time, the filter bandwidth and roll-off characteristics, the pre-whitening of the spectrum, and the determination of the total gain required. Floating point routines in the microcontroller are used in the averaging of the analogue outputs and the conversion to a calibrated spectrum level from analogue-to-digital converter counts. Gain and filter stages are under program control, allowing the sampling frequencies and dynamic range to be easily adjusted to meet user requirements.

VI. DATA EXAMPLES

Two examples of data collected by LANDs during the April 1994 experiment are included to provide an indication of the quality and comprehensiveness of the experimental results obtainable with these buoys.

On several occasions an ENDECO WAVE-TRACK™ wave-measurement buoy was deployed near LAND buoys to assess the accuracy of the LAND measurements of wave energy, wind speed and wind direction. Good agreement was generally achieved over a wide variety of sea states. An example of such agreement is provided by Fig. 2, which compares a data sample collected by LAND buoy #9 in a moderate sea state with one collected concurrently by the reference system.

The measurement of weather-dependent effects calls for long data collection periods. The time dependence of several experimental variables measured by LAND #6 over a 15 day period is displayed in Fig. 3. Three of the nine available 1/3 octave ambient noise bands are represented in the topmost box. The noise levels at the higher frequencies are seen to be well-correlated with wind speed, which is displayed in the second box. The strongest wave energy spectrum level and its frequency are illustrated in the two lowest boxes. Again there is a marked correlation with the acoustic noise at higher frequencies, except that the beginning of each storm, diminishing as long-period swells develop. The gap in data results from a buoy repositioning operation. The other available parameters of temperature at the surface and at the hydrophone, wind direction, wave energy spectrum, and the GPS-defined drift track are not included in Fig. 3 owing to space limitations.

VII. DATA TELEMETRY

The use of ARGOS satellites to receive data from the LANDs allows a large area of ocean to be monitored remotely. The satellite transmissions are used for monitoring data quality, and provide some redundancy for the internal higher resolution data storage. The amount of data capable of being telemetered is governed by the message size (256 bits) and maximum repetition rate of each transmitter (90 seconds) and by the orbits of the satellites.

ARGOS is carried by the NOAA 11 and NOAA 12 satellites which are in circular, near-polar, sun-synchronous orbits with periods of approximately 102 minutes. On any given day the distribution of satellite passes will be similar in terms of number of passes and satellite elevations. At the earth's middle latitudes, there are two long gaps in satellite visibility, each lasting over 5 hours, at noon and at midnight. If each drifter were to continuously broadcast one message containing only the two most recent hourly samples, the maximum possible percentage of hourly samples collected is calculated to be 62%. Given that the performance ratio of an at-sea ARGOS transmitter is reported to be between 0.43 and 0.87, the likely percentage degrades to between 27% and 54%.

The LAND employs a multiplexing scheme called "ID multiplexing" to collect over 90% of the hourly samples. A drifter continuously broadcasts eight hourly samples using one transmitter programmed with four satellite platform terminal identification numbers. This results in all daily samples being broadcast during at least two satellite passes. The net result is greater than a 90% sample recovery.

This method can be used to increase the precision of the telemetered data simply by increasing the number of platform identification numbers used. For example by increasing from four to eight, it is possible to double the precision of the measurements reported over the satellite link. The theoretical limit to the increase in precision is imposed by the repetition rate and the duration of each transmission and could allow an increase in data throughput by two orders of magnitude. However, there is a requirement that transmitters slightly randomize the interval between messages in order to avoid message collisions at the satellite receiver. This requirement and the other practical

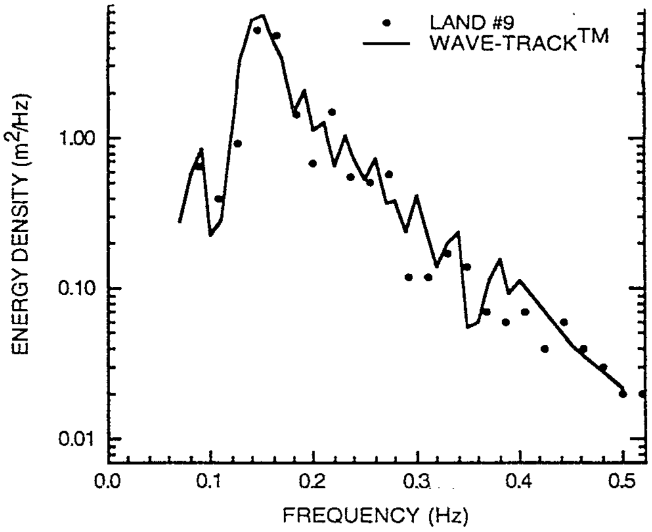

Fig. 2. Comparison of wave energy spectrum for LAND buoy #9 and ENDECO WAVE-TRACK™ buoy.

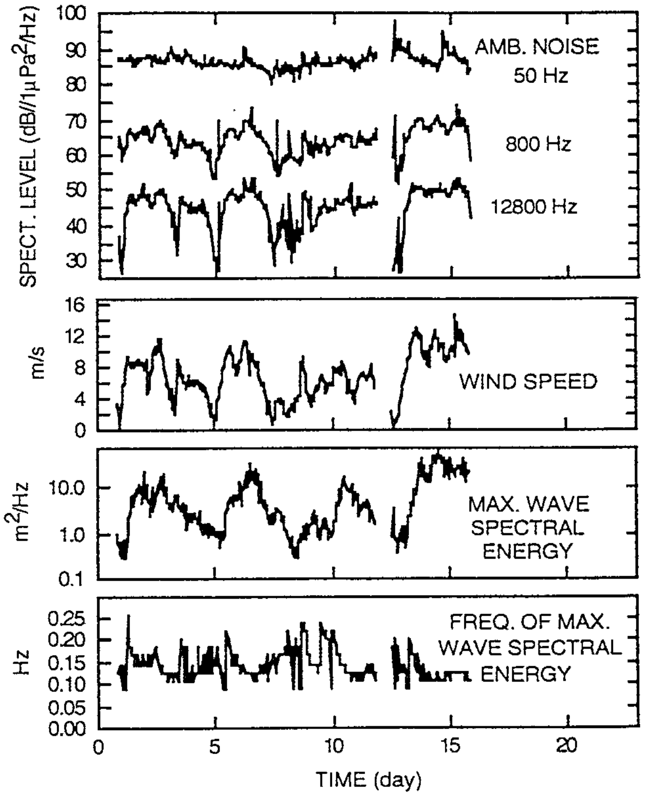

Fig. 3. Time series of several environmental variables as measured with LAND buoy #6; zero time is 0000Z on 22 Apr 1994; data gap occurred while buoy was being repositioned.

consumption probably limits the feasible increase in reported precision to a factor of ten.

VIII. SEA TRIALS AND EXPERIMENTS

The two-year-long LAND system development program incorporated a number of key experiments involving field tests and the use of DREA laboratory facilities.

Initial tests performed in the DREA anechoic chamber and at the Bedford Basin Acoustic Test Facility were followed by a three week field test in the North Atlantic in April 1993. These tests proved the basic viability of the LAND and the accuracy of the wind and noise measurements.

Further development of the LAND concentrated on refinements to the suspension system and the wave measurement circuitry and algorithms. Controlled wave motion measurements were carried out employing a DREA sea state simulator normally used for sonobuoy evaluations. The suspension system was proven by mooring prototypes at the DND Osborne Head Range outside Halifax Harbour for six weeks in the late summer and autumn of 1993.

Finally, the development program concluded with a scientific trial comprising a two week experiment during late April 1994 in and near a Gulf Stream warm core eddy. A field of eight buoys was deployed in and near the eddy and the research ship was used to maintain the field. Maintenance activities included repositioning operations comprising over fifty recoveries and deployments.

The performance of the LANDs during this trial was evaluated on the basis of the quantity and quality of the data

measurements, were required from each buoy in order to make the required comparisons. Against this criterion, the field of eight LAND buoys operated with a performance of 83% over the two week period. The weather during the experiment included three gales, with the strongest delivering sustained winds of 40 knots.

IX. CONCLUSIONS

A novel instrumentation suite was developed and incorporated into Lagrangian drifting buoys by Seimac Limited for use in collecting data on behalf of the Defence Research Establishment Atlantic. The LANDs proved to be robust and reliable units capable of enduring high sea states, and able to be deployed and recovered numerous times without sustaining damage from handling. The design objectives for the LANDs appear to have been achieved, and early comparisons with data collected by ship-based systems show a high degree of correlation.

ACKNOWLEDGEMENTS

T.G. Parsons, A. Lees, D.L. Wall, A. Macdonald G. LaPierre and J.C. Grant of Seimac Limited were the technical team in the design and construction of the drifting buoys. R. Bellefontaine, R. Cushing and other staff at the Defence Research Establishment Atlantic also made significant technical contributions. R. Cunningham (Pernix Technology), P. Huntley (Tavel), T. Deaveau and G. Murray (Seimac) also contributed their skills. Sonya Fowler (Seimac) and B.A. Brennan (Public Works and Government Services Canada) managed the financial and contractual aspects of the project.

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