ACOUSTIC INTENSITY MEASUREMENTS WITH SWALLOW FLOATS

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INTRODUCTION

A Swallow float is a deep water drifting float that contains four acoustic sensors: one hydrophone that measures acoustic pressure, and three orthogonal geophones that measure particle velocity in three dimensions. Each unit is free-floating, and also contains: a compass to derive the true heading of the float, all the data recording hardware, a ballast to control the float depth, and a high-frequency transducer for communication between the float and a nearby receiver. More information on the floats themselves can be found in D'Spain et al. [1]

The advantages presented by the Swallow floats are two-fold: first, the free floating ability reduces the flow noise to a minimum, producing very good quality data down to 0.5 Hz; second, the information from the four sensors can be combined to give measurements of vectorial acoustic intensity. Only one float is therefore needed to obtain both the magnitude and the directionality of the ambient noise field at one point in space.

ACOUSTIC INTENSITY

With the basic assumption that the acoustic field is stationary and ergotic, the following frequency domain representation of the mean acoustic energy density per frequency can be derived [2]:

$$E_{\text{tot}}(\mathbf{x},f)=\frac{1}{2}\frac{1}{\kappa_s(\mathbf{x})}\left(\left[\rho_0(\mathbf{x})c(\mathbf{x})\right]^2\sum_{j=1}^{3}S_{v_j}(\mathbf{x},f)+S_p(\mathbf{x},f)\right) \qquad (1)$$

where $\rho_0(\mathbf{x})$ = ambient density;
$c(\mathbf{x})$ = sound speed;
$\kappa_s(\mathbf{x})$ = adiabatic incompressibility;
$S_{v_j}(\mathbf{x},f)$ = one-sided spectral density function of geophone data;
$S_p(\mathbf{x},f)$ = one-sided spectral density function of hydrophone data.

The hydrophone autospectrum in equation (1) is proportional to the acoustic potential energy density spectrum, and the sum of the three geophone autospectra is proportional to the acoustic kinetic energy density spectrum. Also, the three-geophone spectrum can be used to derive an equivalent pressure autospectrum. In areas where the basic assumption is valid (as in the deep water column), both spectra should be equal.

The one-sided cross-spectral density function between the pressure signal $p(\mathbf{x},t)$ and the geophone velocity signals $\mathbf{v}(\mathbf{x},t)$ is defined as:

$$\mathbf{S}_{p\mathbf{v}}(\mathbf{x},f)=\mathbf{C}_{p\mathbf{v}}(\mathbf{x},f)-i\mathbf{Q}_{p\mathbf{v}}(\mathbf{x},f) \qquad (2)$$

where the real part $\mathbf{C}_{p\mathbf{v}}(\mathbf{x},f)$ is the coincident spectrum and the imaginary part $\mathbf{Q}_{p\mathbf{v}}(\mathbf{x},f)$ is the quadrature spectrum. The coincident spectrum (or active acoustic intensity) gives the direction and magnitude of the mean energy flow. The quadrature spectrum (or reactive acoustic intensity) represents the small scale spatial heterogeneity of the sound field at position $\mathbf{x}$.

IONEX 92 EXPERIMENT

In June 1992 a joint sea experiment took place (IONEX 92) between SACLANTCEN (Italy) and MPL (Marine Physical Laboratory, Scripps Institution of Oceanography, USA) on board NRV Alliance. A group of approximately ten MPL Swallow floats was deployed on two occasions in the Mediterranean Sea. For each deployment, six or eight floats were deployed at depths between 200 and 1500 m, and three floats were moored at the bottom (3000 m).

A typical ambient noise measurement for the band of 0 to 25 Hz is shown in Figure 1 for a selected three-minute period of the first deployment. The dashed line is the pressure spectrum derived from the hydrophone data; the solid line is an equivalent pressure spectrum computed from the three component geophone data (both spectra have units of dB // μPa^2/Hz). The deep water acoustic field being fairly homogeneous, the two spectra are about equivalent (the differences above 20 Hz are probably due to small calibration errors). Below 0.5 Hz, the geophone data is potentially contaminated by mechanical noise. The associated active intensity measurements are shown in Figure 2, in a true geographical plane. An intensity vector is associated to each frequency bin. The direction is given in degrees relative to true north. The magnitude in dB // μWatt/m^2/Hz is obtained by measuring the length of each individual vector along the y axis, starting at -80 dB. The vectors align themselves with the resultant acoustic flow at any particular frequency.

Above 10 Hz, the acoustic field is dominated by shipping noise. A main shipping lane is located south of the float field, and several ship lines can be seen (e.g. harmonic lines from a ship NW from the float field are shown with arrows in Figure 1). The background noise levels in that frequency range are approximately constant (apart from the individual ship lines) at around 85 dB, which is in agreement with noise levels of areas with high shipping traffic [3] The intensity plot also shows that the resultant acoustic flow at these frequencies is coming generally from the south.

Around 4-5 Hz, the noise levels display a minimum at approximately 75 dB, which is often observed at these frequencies. Below 5 Hz, the noise is dominated by wind noise and wave-wave interaction effects. During the second deployment, the wind increased from light to 17 kn (9 m/s), and the background levels below 4 Hz increased by approximately 10 dB during the same period. This increment also agrees with other published data [4, 5].

During the first float deployment, the winds were light throughout, and a cycle was visible both in the hydrophone spectral amplitude in the frequency band of 1-3 Hz (Figure 3, middle cluster), and in the amplitude of the vertical geophone signal (Figure 3, lower cluster, scale on the left of the plot). The period of the cycle was in the order of 12h, although only 20 hrs of data were collected, which increases the measurement uncertainty. Figure 3 also includes the bearing of the horizontal acoustic intensity vector (upper cluster, scale on the right of the plot) for the same float. The angle indicates that the acoustic flow generally comes from the Italian coast (NW) during the loud part of the cycle, but from the Mediterranean deep water area (SW) during the quiet part of the cycle, although there is an offset in time between the amplitude cycle and the directionality cycle. Notice that the directionality data is also much more scattered. Moreover, the cycle was present in the data of all floats, with a slightly higher amplitude in the bottom float data. Similar cycles have been observed by Bourke and Parsons at frequencies of 5, 10 and 32 Hz [6]; they associated the cycle with tidal forces. Their measurements however were made on ice floes at shallow water sites in the Arctic; also their measured noise may have been generated by tidal-induced stresses acting on ice floes. Other data from other deep water sites are at present investigated for similar cycles at frequencies below 5 Hz.

Another interesting effect could be seen during the experiment. To the south-west of the experimental site there is a subduction front area, or an area particularly rich in seismic occurrences. Throughout both deployments, a succession of transient signals were recorded by the floats. The signals were characterized by an increase in spectral levels below 5-10 Hz, and the same directionality for the active intensity vectors in that frequency band. Of all the catalogued events (>50), ≈95% were coming from the subduction area. Some of these events were also recorded by nearby seismic land stations in Italy and Greece. A comparison of the time series from the Swallow floats and some land stations demonstrate that Swallow floats have a higher sensitivity than land stations to earthquakes occurring below the sea bottom.

CONCLUSIONS

Acoustic intensity measurements have been made with several Swallow floats. The floats give an accurate measurement of ambient noise, both in amplitude and in directionality. They can be used to obtain intensity vectors from discrete sources such as ship lines, or more broadband sources like small earthquakes, with similar accuracy.

Some particular features of the sound field were measured. An increase in wind speed from 0 to 9 m/s increased by 10 dB the background spectral levels below 4 Hz. The effect was not observed above 4 Hz since the field is dominated by shipping noise at these frequencies.

The floats also detected a very low frequency signal in the band of approximately 1 to 3 Hz, which is potentially linked to tidal forces. Similar cycles have been observed at higher frequencies in shallow water sites covered with ice floes. The noise generation mechanisms in both environments might be different, and the tidal cycle hypothesis is still under investigation for the deep water sites.

Finally, the Swallow floats were used for the detection of seismic events from an active subduction front area located nearby. It was found that the Swallow floats have a greater sensitivity to these small earthquakes than the land-based seismic stations in the area.

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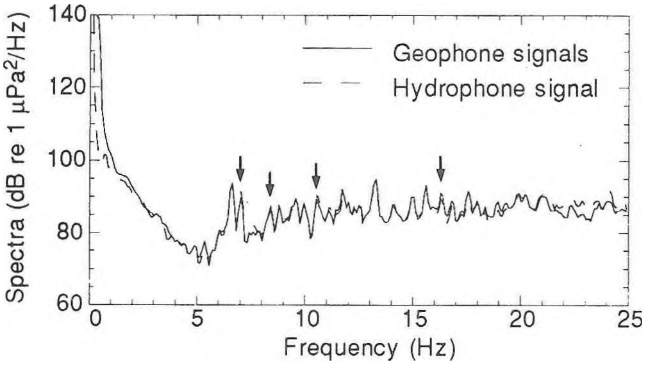

Figure 1. Ambient noise pressure spectrum from the hydrophone (dashed line), and equivalent spectrum from the three geophones (solid line). The time average is three minutes.

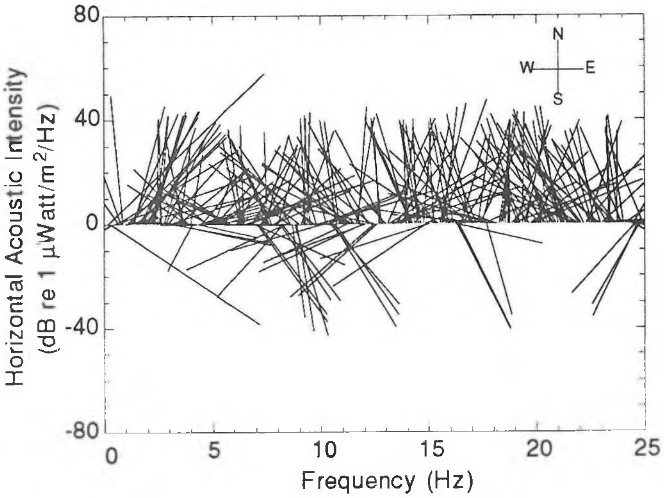

Figure 2. Active acoustic intensity measurement for the same time period as in Figure 1. Each vector is aligned with the resultant acoustic flow at a specific frequency bin (true geographic plane). The magnitude is obtained by measuring the length of each vector along the y axis, starting at -80 dB.

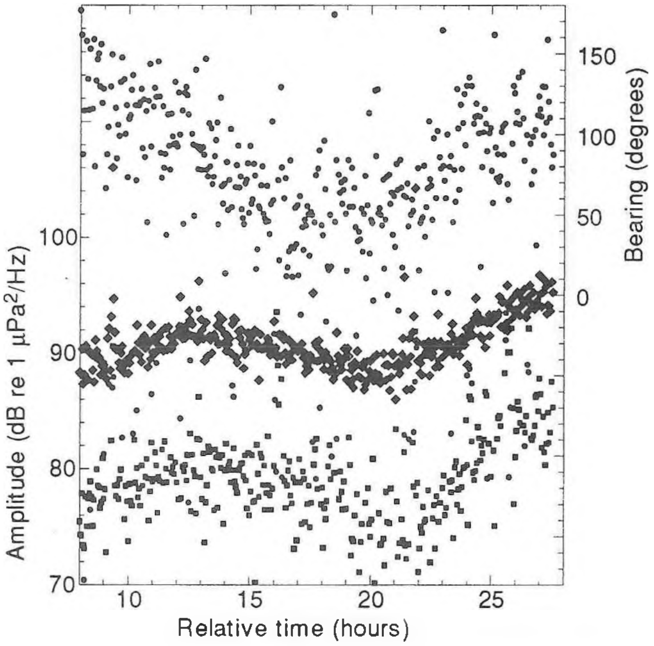

Figure 3. Left scale: middle cluster: hydrophone spectral amplitude; lower cluster: vertical geophone spectral amplitude. Right scale: upper cluster: bearing of the horizontal acoustic intensity vector (direction opposite from noise source). The frequency band is from 2 to 2.5 Hz.