The Sound of the Surf

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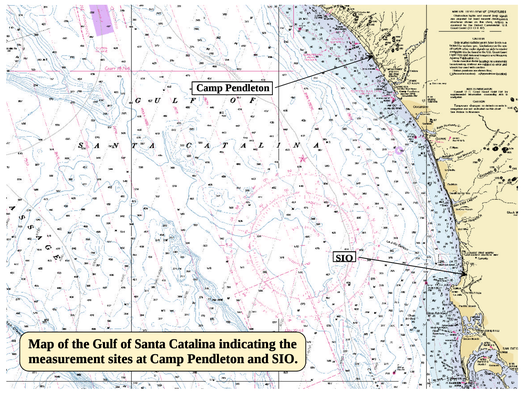
Introduction

Waves breaking on a beach generate what is one of nature's most soothing sounds. It may be better to leave its description to the poets, but in recent years acoustical oceanographers have taken an interest as applications in shallow water expand to include the need for a better understanding of the acoustics in the surf zone. In the fall of 1996 the Marine Physical Laboratory at SIO conducted the Adaptive Beach Monitoring (ABM) experiment at Red Beach, Camp Pendleton, California. The ABM experiment was designed to use active and passive acoustics to monitor the surf zone and beach. As part of the ABM experiment, the authors measured the ambient sound across the surf zone along with supporting measurements of surface waves, currents and local meteorological conditions over a period of three weeks in November 1996. These measurements were supplemented by additional data from La Jolla Shores Beach at SIO during the fall of 1997. We present these measurements of ambient noise in the surf zone and relate them to local wind-generated waves, swell and the tides.



Map of the Gulf of Santa Catalina indicating the measurement sites at Camp Pendleton and SIO.

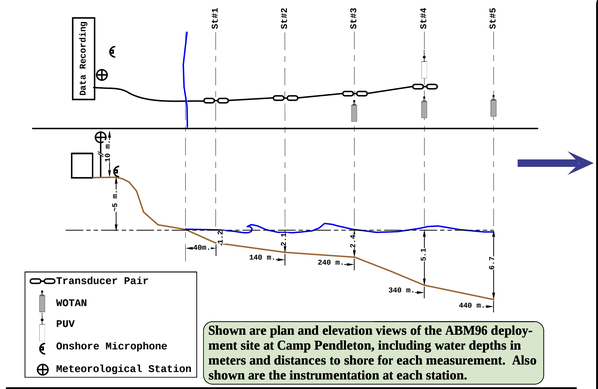
Conclusions

- Noise across the surf zone is generated by waves breaking on the beach and by wind generated waves breaking in deeper water.
- The ambient noise is modulated at diurnal and semidiurnal periods due to sea breeze effects and at synoptic time scales associated with swell from storms.
- Sound generated by waves breaking at the shore is rapidly attenuated across the surf zone by the intervening bubble clouds.
- Sound levels on the outer edge of the surf zone during storms increase at low frequency (< 1 kHz) and decrease at high frequency (4-14 kHz) with increasing incident wave height.
- Ambient noise may prove to be a useful tool in passive monitoring of surf conditions.

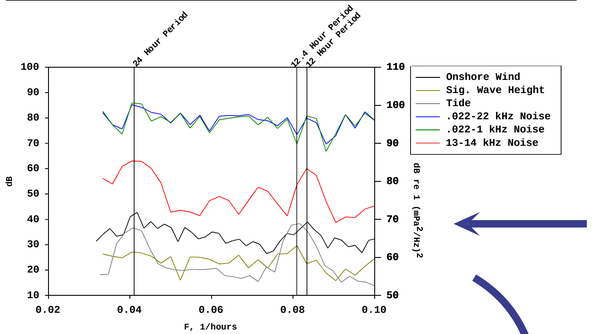
Acknowledgements

We are grateful to our many colleagues at MPL/SIO who were involved in the planning and logistics for the ABM experiment. This work was supported by ONR (Acoustics).

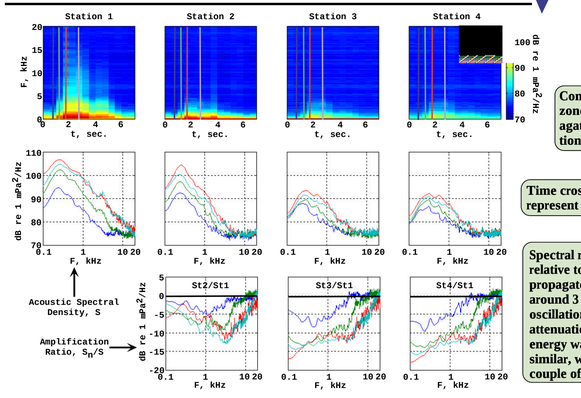
Adaptive Beach Monitoring, Camp Pendleton 1996



Shown are plan and elevation views of the ABM96 deployment site at Camp Pendleton, including water depths in meters and distances to shore for each measurement. Also shown are the instrumentation at each station.



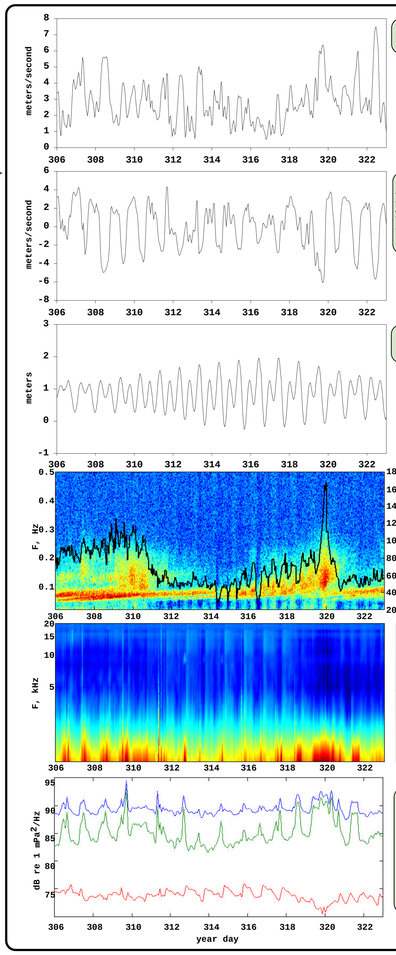
Shown are spectra of the ambient noise energy in the .022 - 1 kHz band (green), the 13 - 14 kHz band (red), and the total ambient noise energy (blue), in units shown on the right hand y-axis. Also included are spectra of the onshore wind, significant wave height, and the tides in units of arbitrary dB shown on the left. Diurnal variations in ambient noise energy are more clearly seen for higher frequency bands than for lower frequency bands. The 12 and 24 hour peak periods indicate a closer relationship between the higher frequency ambient noise and onshore wind than with wave and tide conditions, which have periods around 12.4 hours.



Concurrent spectrograms of a breaking event recorded at 4 stations across the breaking surf zone by the hydrophone array. The wave broke in the vicinity of station 1 and the sound propagated offshore to stations 2-4. The four colored, vertical lines correspond to time cross sections shown in the figures below.

Time cross-sections of a breaking event. The four spectra in each figure represent cross sections taken at the positions shown in the figures above.

Spectral ratios of a breaking event. The ratios of spectral amplitude were taken for stations 2, 3, and 4 relative to station 1 to illustrate the attenuation of ambient noise generated by a breaker as the sound propagated through the surf zone to deeper waters. The spectral ratio for St2/St1 indicates a peak around 3 kHz, coincident with the peak in ambient noise measured at St1. If this peak is due to the oscillations of individual bubbles near St1, that sound energy is not propagating offshore. Additionally, attenuation levels for the peak around 3 kHz do not increase significantly past St2, indicating that the energy was dissipated primarily inside of the surf zone. Because the ratios for stations 3 and 4 are so similar, we may assume that most of the modification of the ambient noise signal occurs within only a couple of hundred meters of the coastline.



Wind magnitude over the 17 day window of observation at ABM96.

Onshore component of the wind. Differential rates of heating and cooling of inland and coastal air provided for a diurnal variation in wind direction, the seabreeze effect. Typically, the wind direction would shift from offshore to onshore in the early afternoon.

Tide level measured by the pressure sensor on the PUV meter.

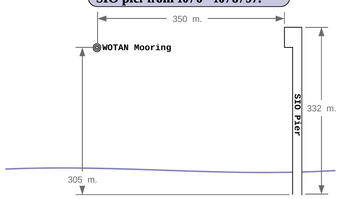
Wave height spectrogram and $H_{1/3}$. Using linear wave theory, pressure measurements taken by the PUV were converted to surface displacement. Of particular interest are the two swell events between days 306-312 and 316-321. For each event, the longer period waves are seen to reach the measurement site first, with the shorter period waves arriving on the tail end of the swell. The approximate 12-hour cycle seen in the wave height measurements are due to effects from the tide.

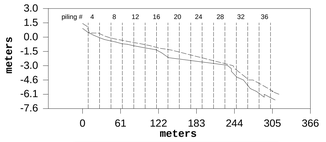
Ambient noise spectrogram from WOTAN Station 3. Spectra are averaged over 10 minute sampling periods taken hourly. For the period of relatively small surf (days 311-319), a 24-hour cycle is apparent. Typically, noise levels rose in the afternoon as the seabreeze increased. During the two periods of high surf (days 306-312, 316-321), an associated rise in low frequency noise was seen. Note also the decrease in high frequency noise during periods of high surf.

Cross sections of the ambient noise spectrogram shown above and total ambient noise energy over ABM96. It can be seen that low frequency noise (< 1kHz, green) contributes most to the total noise energy (blue) in the water. Higher frequency noise (13-14kHz, red) shows a nearly inverted behavior to that of low frequency noise. In particular, the swell cycle of days 316-321 shows a marked decrease in higher frequency noise. This is attributed to attenuation by bubbles.

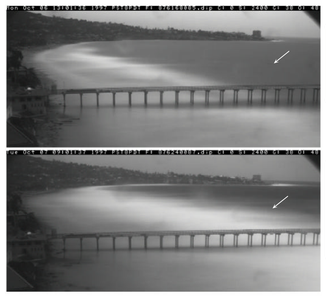
SIO/La Jolla Shores Beach Experiment 1997

Mooring location of the WOTAN during the deployment south of SIO pier from 10/6 - 10/8/97.



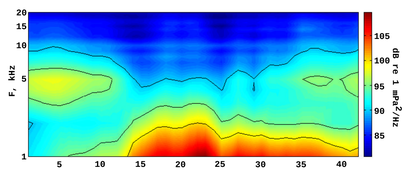


Bathymetry representative of La Jolla Shores beach during the deployment.

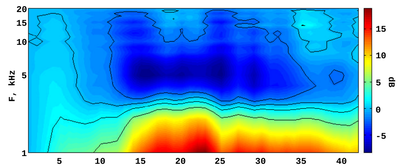


Time exposure of the surf zone around SIO pier, 13:01 10/6/97 (courtesy Rob Holman, OSU). The arrow indicates the WOTAN mooring location. At the time of this exposure, $H_{1/3}$ was approximately 64 cm.

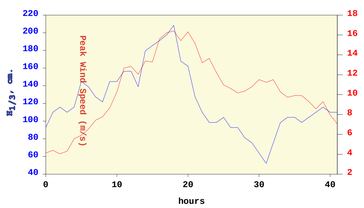
Time exposure of the surf zone around SIO pier, 9:01 10/7/97 (courtesy Rob Holman, OSU). By the morning of 10/7, the significant wave height had risen to 202 cm and extended the boundary of the surf zone by several hundred meters. Here, the WOTAN is at the edge of the surf zone.



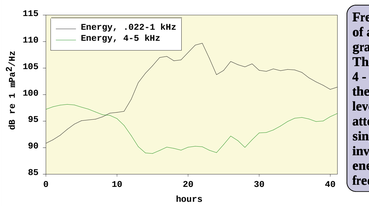
Frequency spectrogram of the ambient noise recorded by the WOTAN over a 42-hour period. Hour 0 corresponds to 14:00 PDT, 10/6/97. During the deployment wave height more than tripled in the first 18 hours. This figure shows the rise of ambient noise under 2 kHz and the concurrent drop in higher frequency noise.



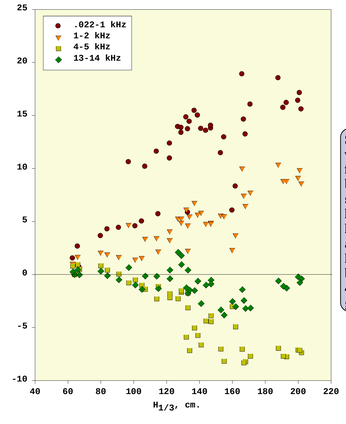
This spectrogram shows the ambient noise levels recorded by the WOTAN relative to those measured during the first 10-min. sampling period (a ratio of hour t/hour 0). Ambient noise below 1 kHz was found to increase from "calm" surf levels at hour 0 by approximately 17 dB. During the same period, noise levels between 4 - 6 kHz dropped by nearly 7 dB.



Significant wave height and peak wind speed measured at SIO pier between 14:00 10/6 and 10:00 10/8.



Frequency cross sections of ambient noise spectrogram from the WOTAN. The bins .022 - 1 kHz and 4 - 5 kHz were chosen as they showed the maximum levels of amplification and attenuation during the passing storm. Note the nearly inverted behavior of the noise energy between the two frequency bins.



Significant wave height vs. ambient noise amplification for two frequency bins relative to their "calm" surf level at hour 0. The lowest frequency bin (.022-1 kHz) showed the greatest amplification relative to its hour 0 level for all frequency bands up to 22 kHz. The 4-5 kHz band showed the greatest attenuation.