Low-frequency acoustic signature of tropical storms Ernesto and Florence

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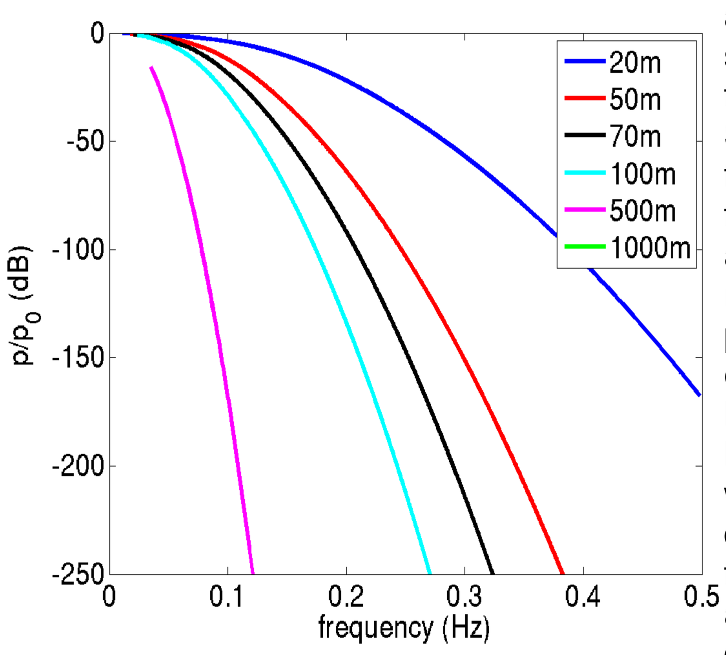
BACKGROUND

Abstract : The ambient noise level variations produced by tropical storms Ernesto and Florence were observed by the SWAMI32, SWAMI52 and SHARK arrays as the waves generated by these storms passed over the SW06 (Shallow Water 2006) site. Pressure variations in the water column were dominated by signals from 0.02-0.15Hz, while microseisms were detected by a land based seismometer from 0.15-0.4Hz, suggesting the double-frequency signals detected on land were not generated at the SW06 site.

Microseisms: Microseism signals are ubiquitous low-amplitude signals attributed to the interaction of ocean waves with the Earth's crust. The peak of the microseism spectrum is found at twice the frequency of ocean surface waves.

A theoretical consideration of ocean waves has shown that two opposing waves of equal frequency can produce a standing wave, which oscillates at double the frequency of the two traveling waves [Longuet-Higgins, 1950]. Unlike traveling waves these double frequency waves do not decay with depth. As the decay of pressure waves with depth is substantial, (see figure below, the line at 70m corresponds to this experiment) these double frequencies offer an explanation for the double frequency microseism signals. As the strength of these signals are not depth dependent they may be produced throughout the ocean wherever opposing waves occur. Primary waves by contrast can only interact with the crust in very shallow coastal regions.

However, recent work [Bromirski, 2002, Friedrich,1998, Tanimoto, 2007] has suggested that the microseism signals detected by land-based seismometers are produced in shallow coastal waters.



Pressure at the seafloor: The strength of surface-wave induced pressure oscillations at the seafloor relative to the surface values. The 70m trace corresponds to the SW06 experiment. High frequency signals are poorly transmitted to the seafloor, and given a linear mechanism, seafloor pressure variations would be expected to be dominated by low-frequency signals. Double-frequency standing waves do not decay with depth but remain constant throughout the water column and would be expected to dominate the ocean bottom pressure variations in all but the shallowest water environments.

References:

J. Traer, P. Gerstoft, P.D. Bromirski, W.S. Hodgkiss, L.A. Brooks, "Shallow-water seismo-acoustic noise generated by Tropical Storms Ernesto and Florence", J. Acoust. Soc. Am. (submitted) (2008)

M.S. Longuet-Higgins, "A theory of the origin of microseisms", Philo. . Trans. R. Soc. London 1-35 (1950)

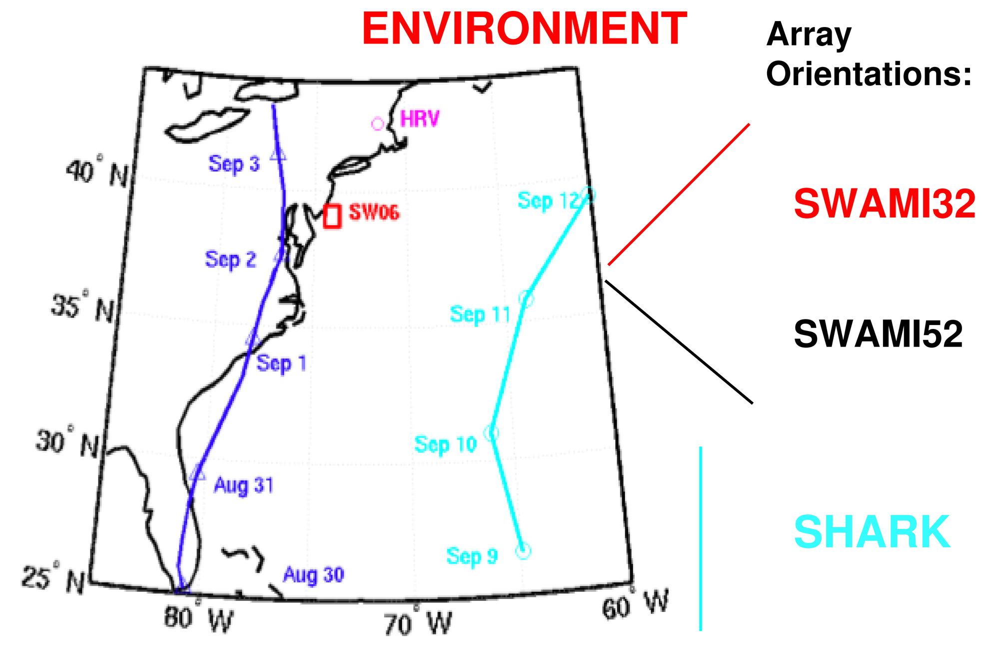
P. D. Bromirski, F. K. Duennebier, The near-coastal microseism spectrum: Spatial and temporal wave climate relationships Journal J. Geophys. Res., 107, 2002

A. Friedrich, F. Kruger, and K. Klinge, Ocean-generated microseismic noise located with the Grafenberg array, J. Seismol. 2, 47-64 (1998).

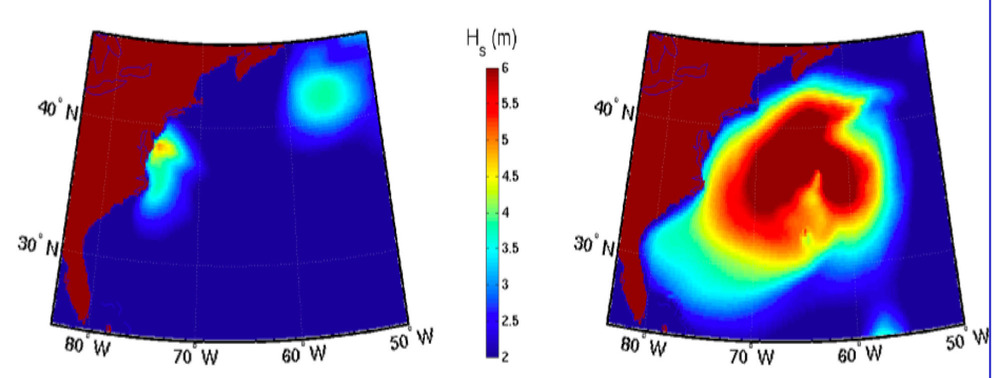
T. Tanimoto, Excitation of microseisms, Geophys. Res. Lett. 34, L05308 (2007).

P. Gerstoft and T. Tanimoto, A year of microseisms in southern California, Geophysical research letters, 34, 2007

ENVIRONMENT

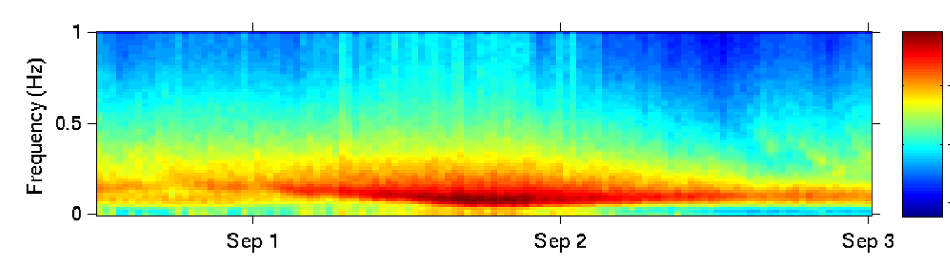


Storm paths: Ernesto (dark blue) primarily affected shallow costal waters. Florence (light blue) remained in deep waters.

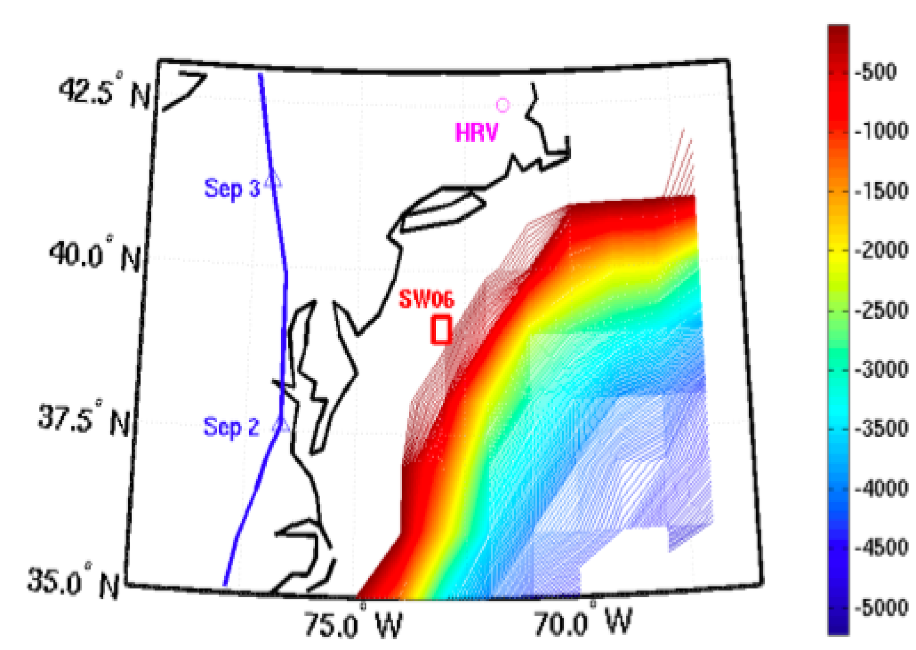


NOAA Hindcasts of Ernesto: Ernesto excited a small area of waves in coastal waters.

NOAA Hindcasts of Florence: Ernesto excited much larger waves over a much larger area of deep mid ocean water.



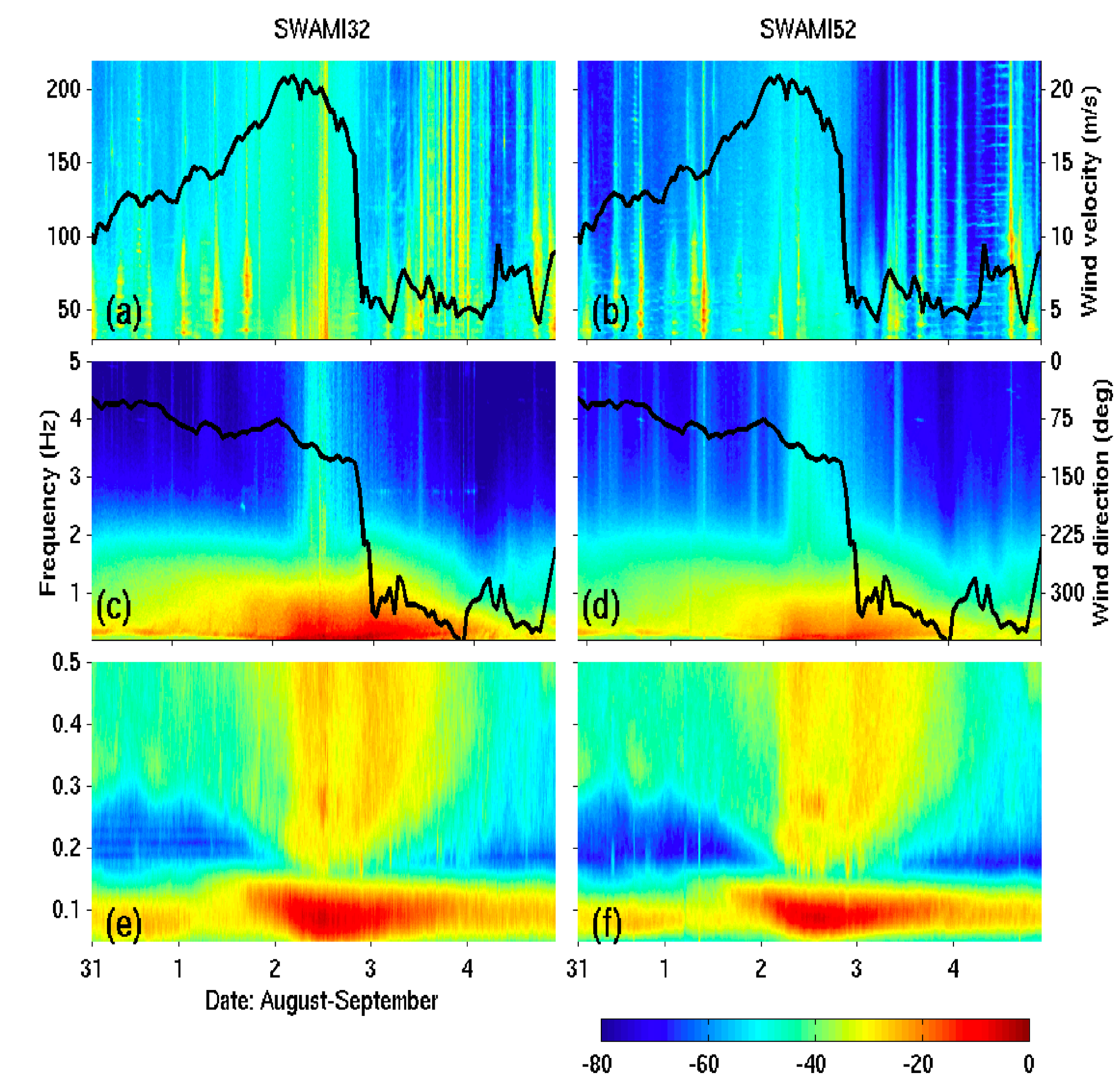
Spectra of waves generated by Ernesto: The waves at the SW06 site (as measured by the ASIS buoy) were large from early Sep 1 through Sep 3. The waves peaked just before Sep 2. The dominant wave frequency at the peak was about 0.07Hz.



The Site: The SW06 experiment was located about 130km east of the New Jersey coast on the edge of the continental shelf.

If double frequency near-coastal microseisms are generated by reflections off the coast, then Ernesto and Florence, which both generated westward propagating waves, might be expected to produce double-frequency signals at SW06.

ACOUSTIC SPECTROGRAMS



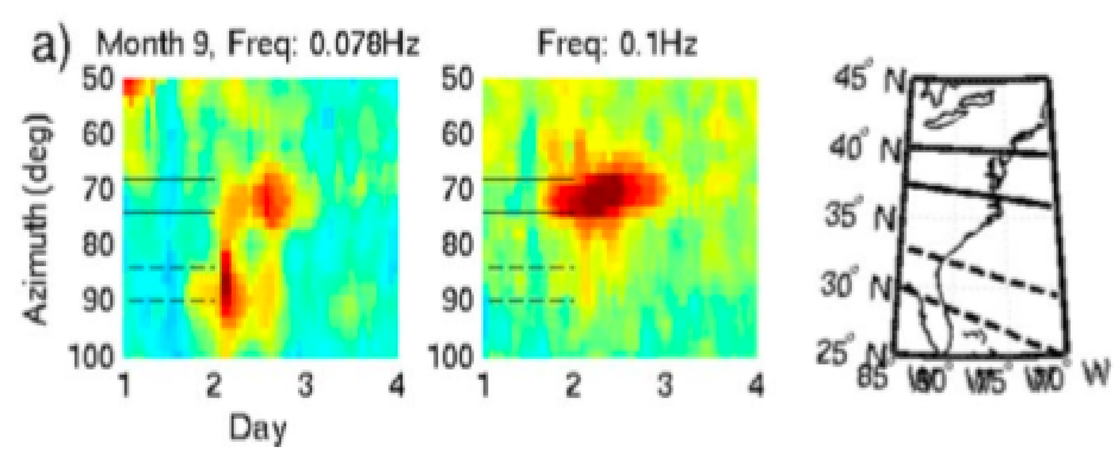
Acoustic Spectrograms: Two arrays of seafloor mounted hydrophones measured noise levels at the sea-floor (depth ~70m) throughout Ernesto. Each spectrogram is normalized to the highest output within the given time and frequency range.

The noise levels from 30-220Hz [(a) and (b)] appear well correlated with the local wind speed.

Below 2Hz [(c) and (d)], the acoustic levels remain high for two days or so after the winds die, suggesting these signals are generated by surface waves. Due to the rapid decay of high frequency pressure variations with depth, these signals are likely double-frequency waves.

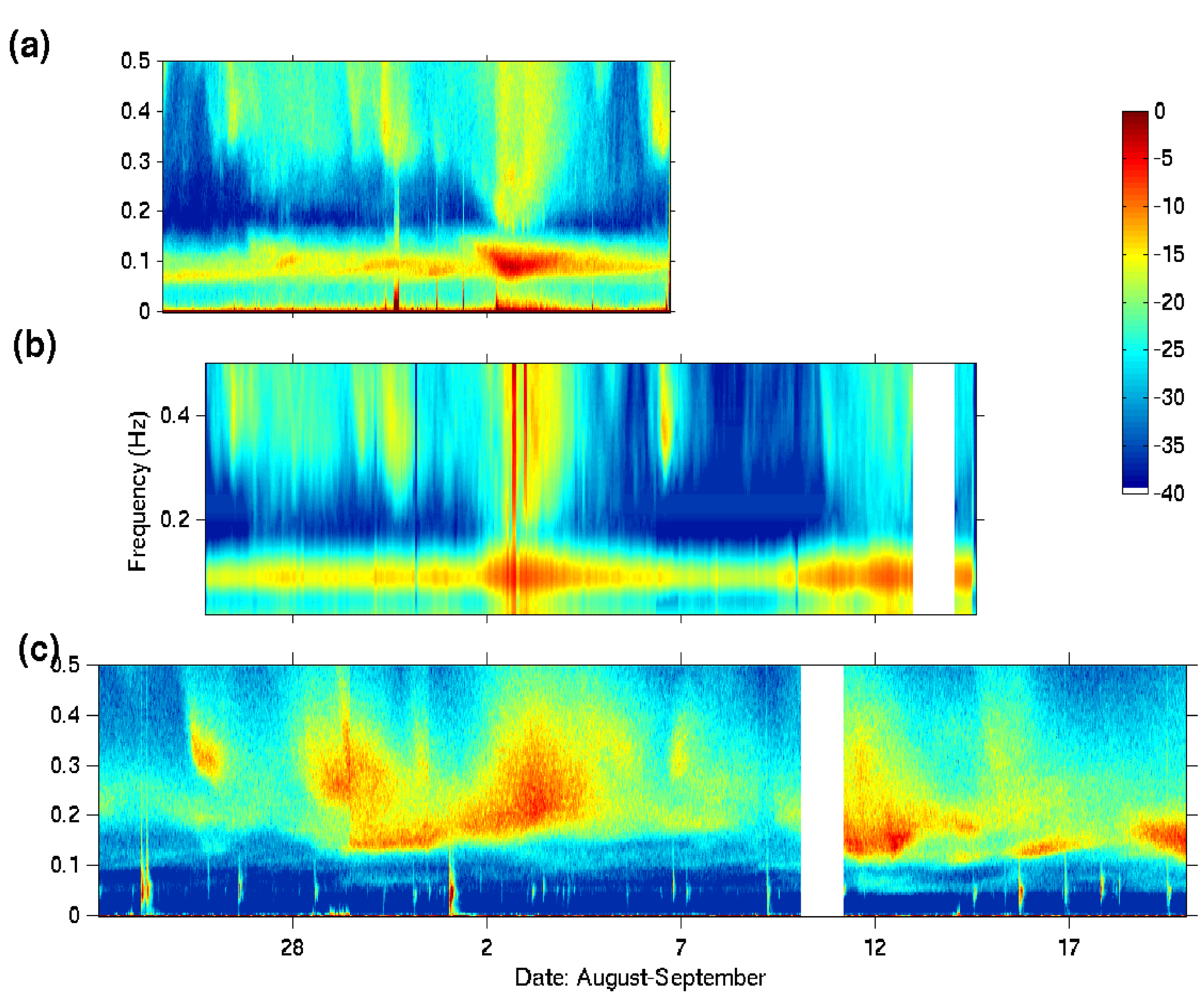
In addition there is a surge in energy on Sep 3 [(e) and (f)] that is associated with a change in wind strength and direction [(c) and (d)]. This is consistent with double frequency signals which will be increased by rapid changes in wind direction.

The dominant signal recorded is a primary wave signal from 0.02-0.15Hz [(e) and (f)]. Just above this signal is a region of very low signal, suggesting there are negligible opposing waves at low frequencies at the SW06 site.



Seismic Beamforming: Beamforming with a seismic array in California [Gerstoft, 2007] detected low frequency signals on Sep 2 incident from a direction consistent with the SW06 site. This indicates the primary frequency pressure wave observed by the SW06 hydrophones is coupling to seismic energy somewhere in the local region.

SEISMIC SPECTROGRAMS



Seismic Spectrograms: The HRV (Harvard) seismic station recorded data throughout both storms allowing a direct comparison between acoustic measurements at the seabed and the microseisms that propagated to shore for waves generated by Ernesto.

- The output of the SWAMI52 array throughout it's entire deployment. Waves from Ernesto appear on September 2.
- The output of the SHARK array throughout it's entire deployment after corrections were made to calibrate the output to the SWAMI array output. Waves from Florence appear on September 11.

The general structure of the spectra generated by Florence's waves is similar to that of the waves generated by Ernesto. The signal is dominated by a primary frequency component. Double frequency components appear above 0.2Hz but are very weak from 0.12-0.2Hz.

(c) The output of the HRV seismic station. In contrast to the direct pressure recordings these microseism signals have a very weak signal at primary wave frequencies. The dominant signals appear at about 0.12-0.18Hz, a frequency band which showed consistently low signal in the acoustic arrays.

Both storms produce similar microseism spectra, despite the significant differences in the storm sizes and paths. This suggests it is only the waves that propagate to shallow water that contribute to this seismic signal. Signals from Ernesto generated waves appear on Aug 30 when Ernesto impacts the coast of Florida. The signal remains consistent as the storm moves up the coast, growing higher in frequency as the fetch of the storm decreases and the associated waves are higher frequency.

CONCLUSION

The land based seismometer measurements showed the microseism signals produced by the waves of both Ernesto and Florence were dominated by double frequency signals between 0.12-0.2Hz. This is consistent with previous measurements and theory of storm generated microseisms.

A direct measurement of pressure variations at the bottom of the water column contained a relatively weak signal in this frequency band and was instead dominated by primary frequency pressure signals. These primary frequency signals were weaker than the double frequency signals in the land-based seismogram measurements.

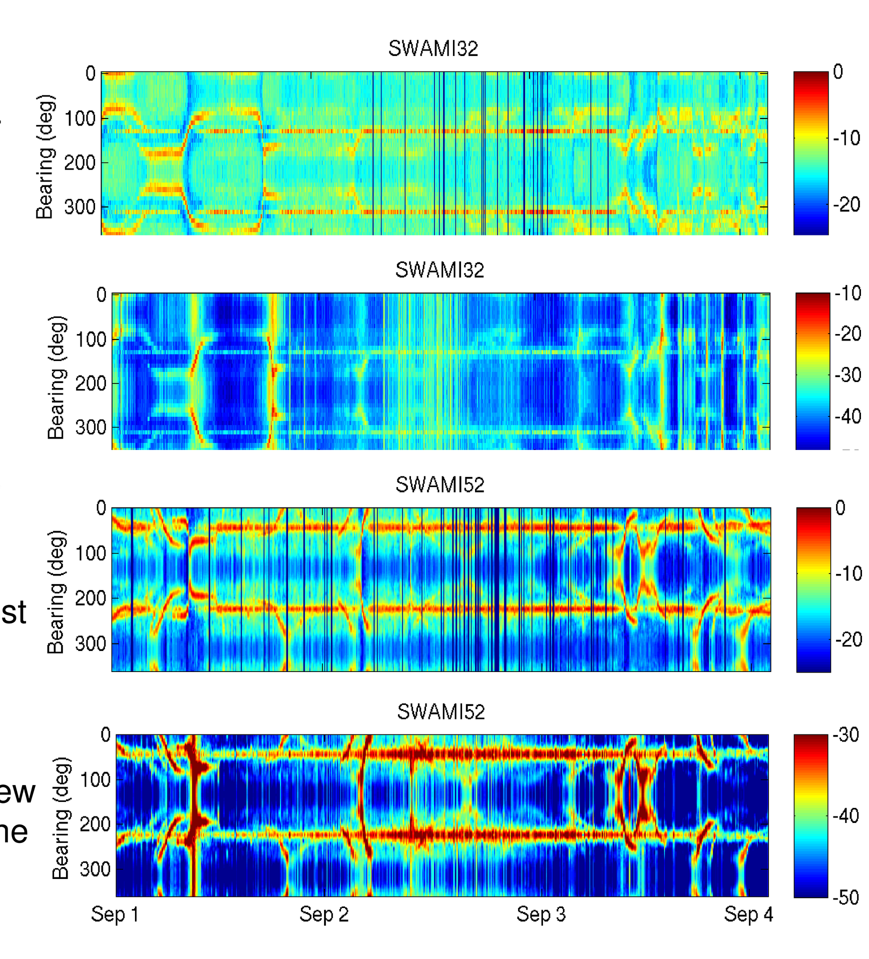
The SW06 site was situated at the edge of the continental shelf and many of the detected storm generated waves passed over the 130km expanse of shelf to the shore. The interaction of these waves with the sea-floor would likely have increased as the water depth decreased. This suggests that there is a significant primary frequency pressure signal at the seafloor across the entire continental shelf.

The dominance of double frequency signals in the microseism spectra suggests that either the double-frequency signal couples more readily into seismic energy, or that the microseism generation is spatially homogenous and very strong double-frequency signals are produced locations outside the SW06 site. Variations in bottom topography may make some areas more prone to the generation of opposing waves that others.

Florence excited much larger waves than Ernesto over a much larger area and yet produced equivalent microseism signals in agreement with the previous work suggesting microseisms are generated in shallow coastal waters.

BEAMFORMING

40-80Hz



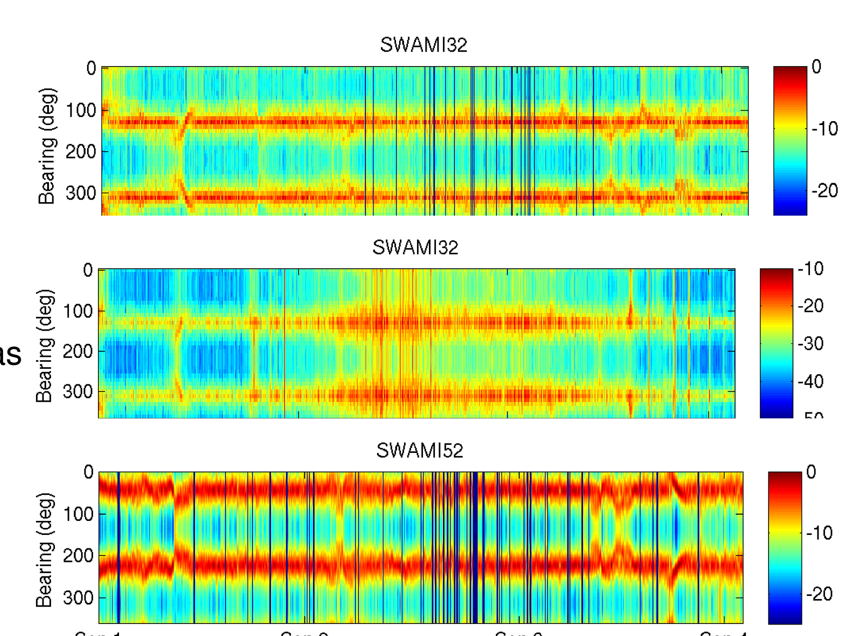
Phase-only: Provides a clear record of local ship traffic.

Amplitude: Shows a surge of energy with the storm arrival

Phase-only: Few ship traces are recorded during the storm, as most ships evacuated the area

Amplitude: dominated by a few large ships and the storm noise.

15-30Hz



Phase-only: Dominated by surface noise appearing at broadside

Amplitude: shows the storm arrival as an increase in surface noise.

Phase-only: A few very loud ships perturb the trace

Amplitude: Only very large ships perturb the surface signal.

Beamforms with normalized data (phase-only) show fairly constant surface noise. Beamforms with non-normalized data show the surface energy surge in strength with the arrival of the high winds and waves associated with the storm. Dark blue lines indicate samples rendered unusable by clipping. Each beamform is normalized to the highest beamformer output observed from Sep 1-Sep 3 between 5-100Hz.