EXTRACTING GREEN'S FUNCTIONS FROM NOISE CORRELATION OF SW06 DATA

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BACKGROUND

Abstract :

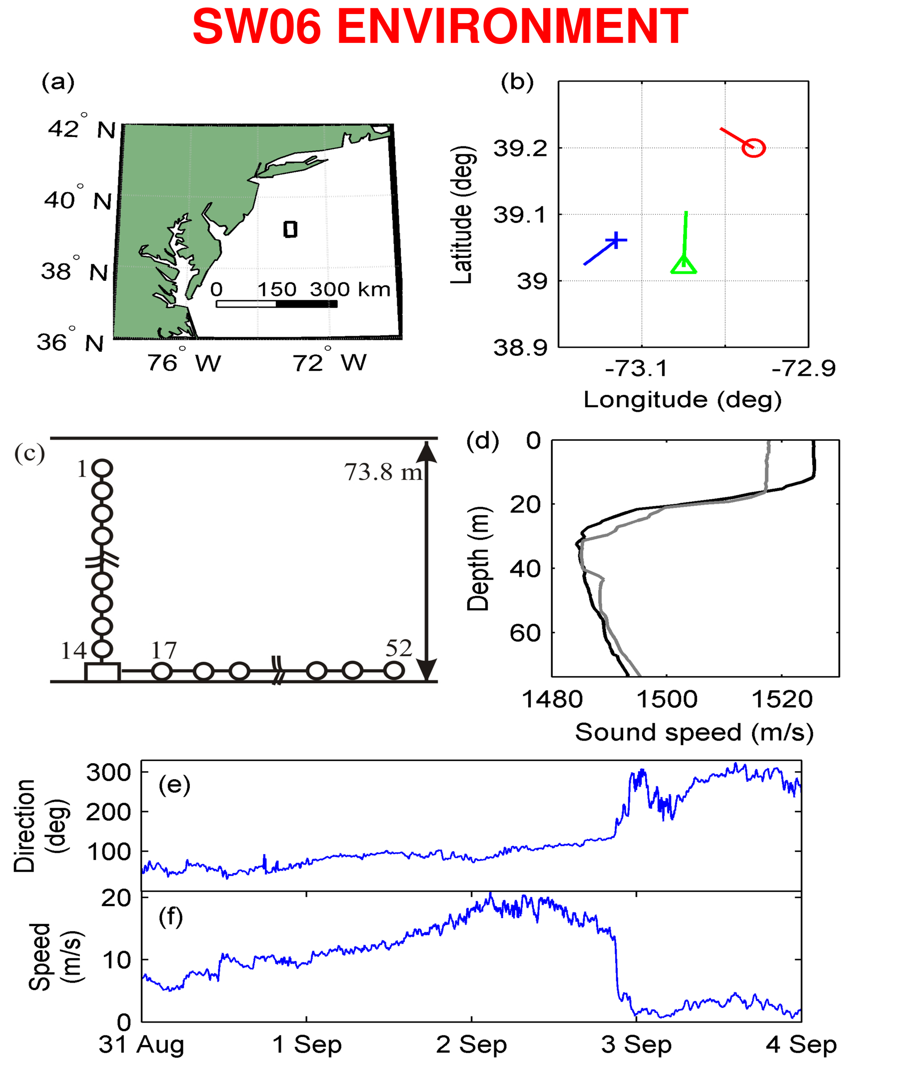
Ocean noise data, collected on three L-shaped arrays during the SW06 (Shallow Water 2006) sea trials, were cross-correlated in order to approximate Green's functions, a method referred to here as ocean acoustic interferometry. Acoustic travel times of the main propagation paths between hydrophone pairs were subsequently estimated. Examination of the individual noise spectra and their mutual coherence reveals that the coherently propagating noise is dominated by frequencies of less than 100 Hz, corresponding to ship noise. Both time and frequency domain preprocessing techniques, and their effect upon the resulting correlation, are investigated. Times corresponding to the envelope peaks of the time-derivatives of the noise cross-correlation are in agreement with the expected direct, and surface reflected, inter-hydrophone travel times. Summing the correlations between equi-spaced hydrophone pairs in a horizontal line array is shown to increase the signal-to-noise ratio. Temporal changes in short-time correlations highlight individual ship tracks and show that the sound field is more diffuse during the passing of a tropical storm.

References:

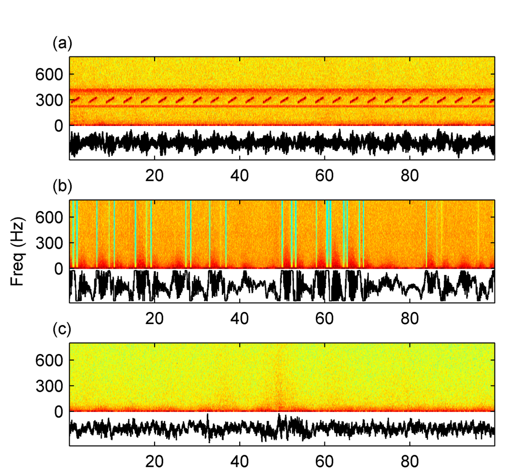
Brooks, LA and P Gerstoft (2007), Ocean acoustic interferometry, J. Acoust. Soc. Am., 121, 3377-3385, doi:10.1121/1.2723650.

Brooks, LA and P Gerstoft (2008), Ocean acoustic interferometry of 20-100 Hz noise, J. Acoust. Soc. Am., Submitted.

SW06 ENVIRONMENT

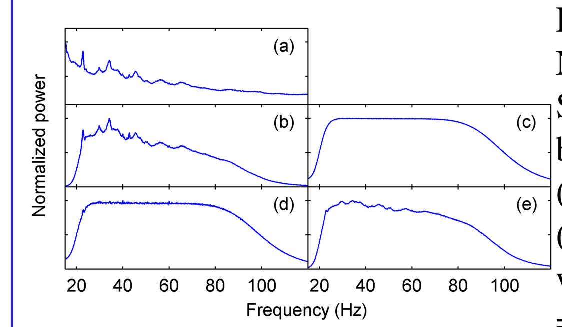


(a) Geographic location of experimental site (rectangle) on New Jersey Shelf. (b) The relative VLA locations of SWAMI52 (o), SWAMI32 (+), and Shark (Δ). The lines departing each VLA show the HLA orientation (array length scaled by a factor of 20). (c) SWAMI52 array geometry and hydrophone numbering system. (d) Sound speed profiles near SWAMI52 for August 30 (black) and September 6 (gray). Wind (e) direction and (f) speed (from *R/V Knorr* ship records) from August 31 to end of September 3.

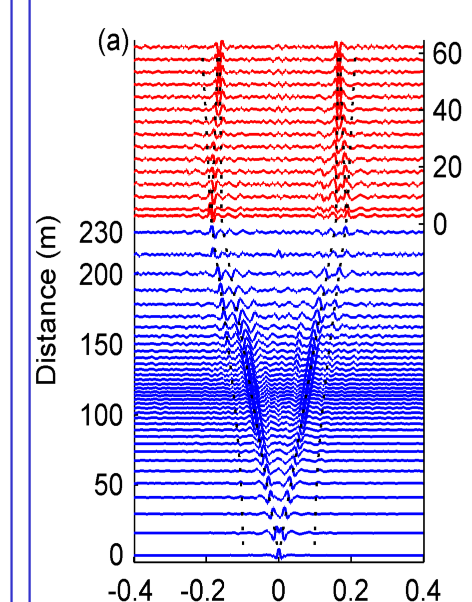


Spectrograms and time-series of September 2 data: (a) signal dominated by mid-frequency fixed sound sources (H-11, 0:29:25 Z), (b) clipped signal (H-1, 0:08:56 Z), (c) energy dominated by low frequency sources (H-11, 12:46:39 Z). Low frequency energy bursts are observable in (b)-(c).

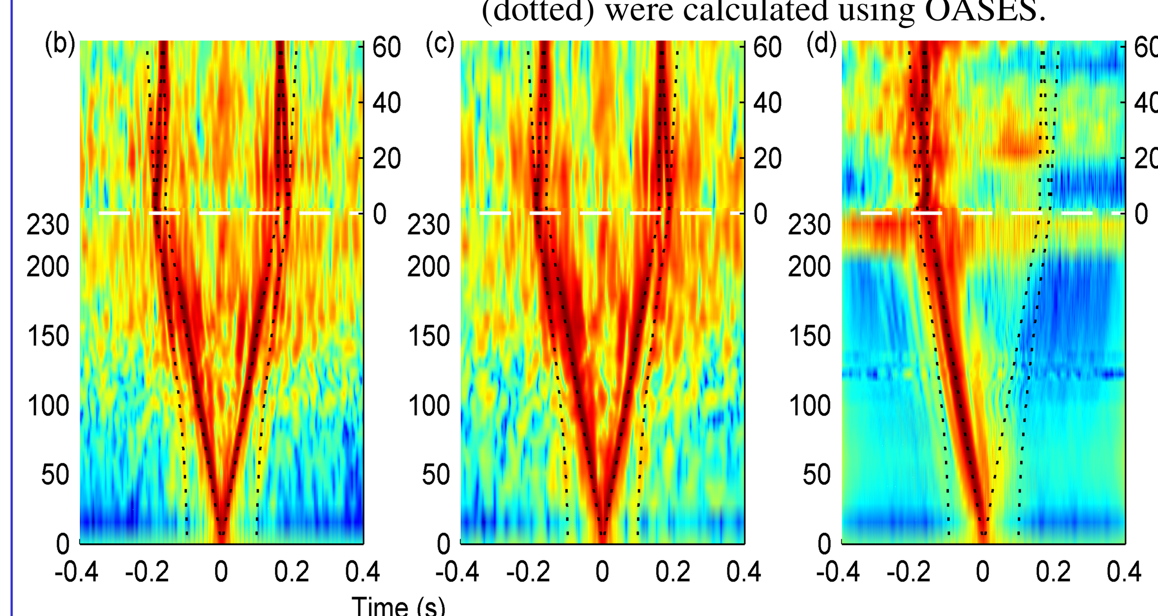
PROCESSING



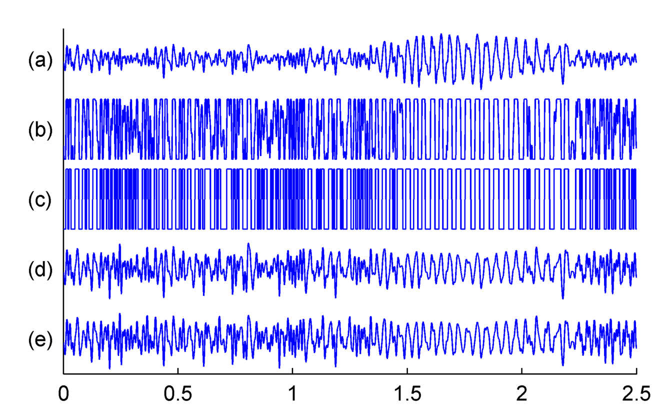
Frequency domain preprocessing: Normalized (linear) spectra of the September 2 signal recorded on H-40 before (a) and after (b)-(e) pre-filtering: (b) bandpass and time domain filter only, (c) absolute whitening, (d) smoothed whitening, and (e) partial whitening, β =1).

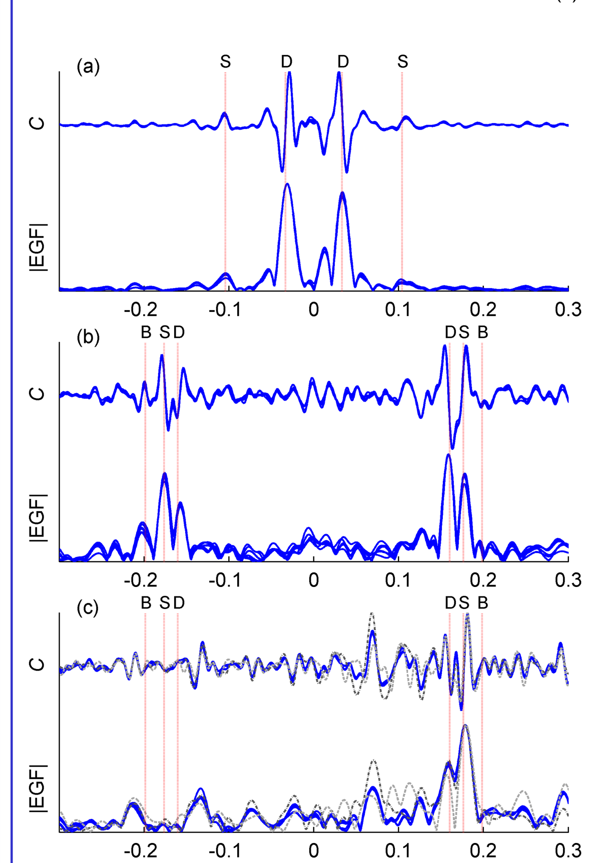


a) Correlations between H-52 and all other hydrophones for September 2 data using smoothed-whitening frequency filtering (20-100 Hz). (b)-(d) EGF envelope: (b) with smoothed whitening (20-100 Hz dB), (c) with no frequency normalization (20-100 Hz dB), and (c) with no frequency domain filtering or normalization. The lower traces are correlations with HLA hydrophones; their distance from the tail hydrophone (H-52) is shown on the left side axis. The upper traces are correlations with VLA hydrophones; their vertical distance from the seafloor is shown on the right side axis, which is offset by the horizontal distance of the VLA from the HLA tail. The simulated travel times between the hydrophones (dotted) were calculated using OASES.



Time domain preprocessing: Preprocessed waveforms for 2.5 s of 20-100 Hz filtered data from H-40 (at 12:48:45 Z) with normalization method: (a) none, (b) threshold clipping, (c) one-bit, (d) RCTVW, and (e) ECTVW.

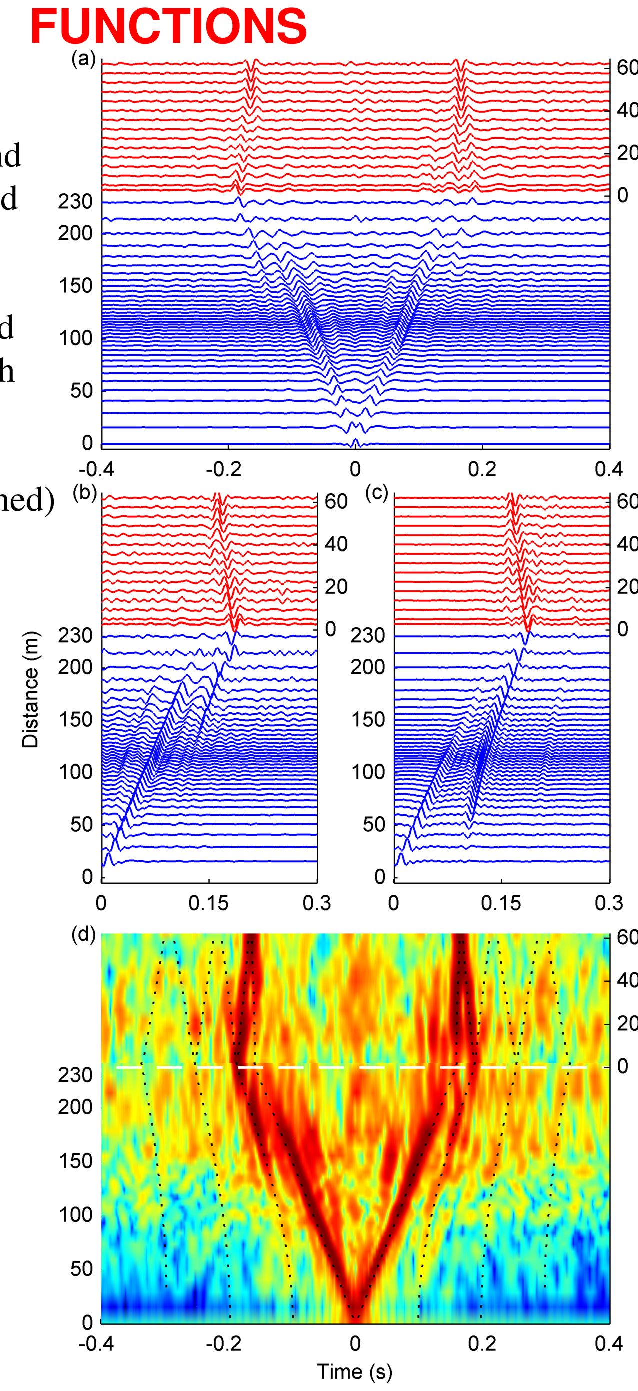




Summed correlations, *C*, and EGF envelopes, for all time normalization methods for H-52 and (a) H-48 [entire day (51.32 m horizontal separation)], (b) H-8 [entire day (230 m horizontal separation)] and (c) H-8 [10:24 min from 8:30 Z]. Simulated travel times of direct (D), surface (S) and surface-bottom (B) paths are shown as vertical dotted lines.

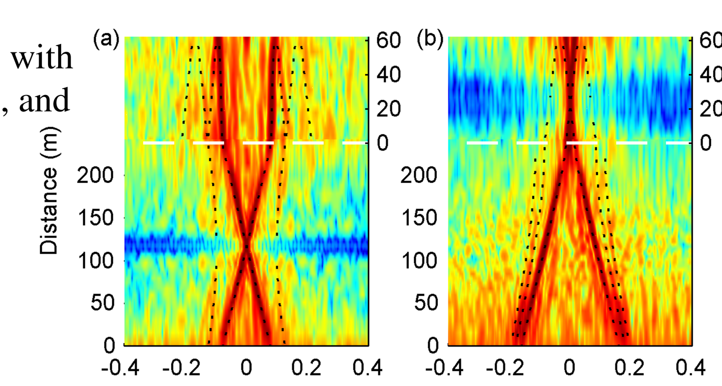
EXTRACTED AND SIMULATED GREEN'S FUNCTIONS

(a) Summed correlations and (b) EGFs, between H-52 and all other hydrophones for September 2. (c) Simulated Green's functions convolved with a 20-100 Hz bandwidth linear source. (d) EGF envelopes (dB) with the simulated travel times (dashed) between the hydrophones.

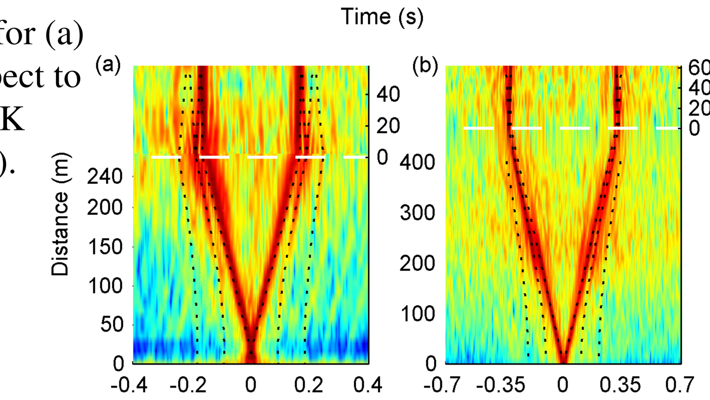


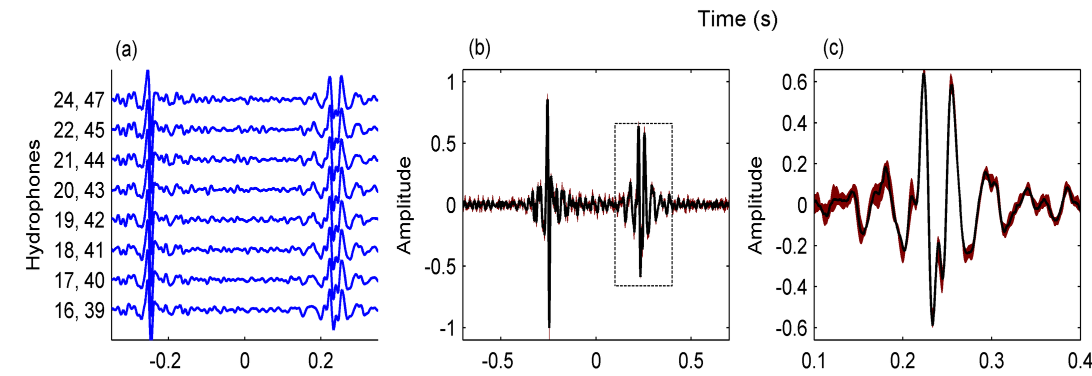
GEOMETRIC COMPARISONS

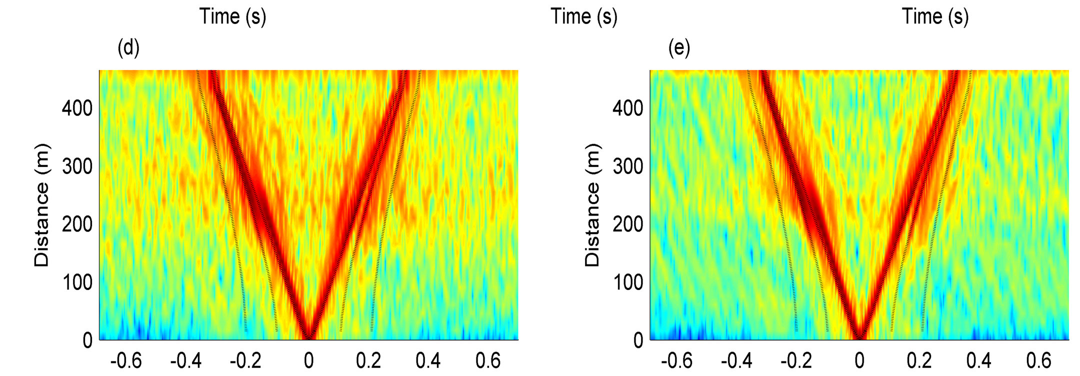
EGF envelope (dB) with respect to: (a) H-34, and (a) H-10.



EGF envelopes (dB) for (a) SWAMI32 (with respect to H-30), and (b) SHARK (with respect to H-16).

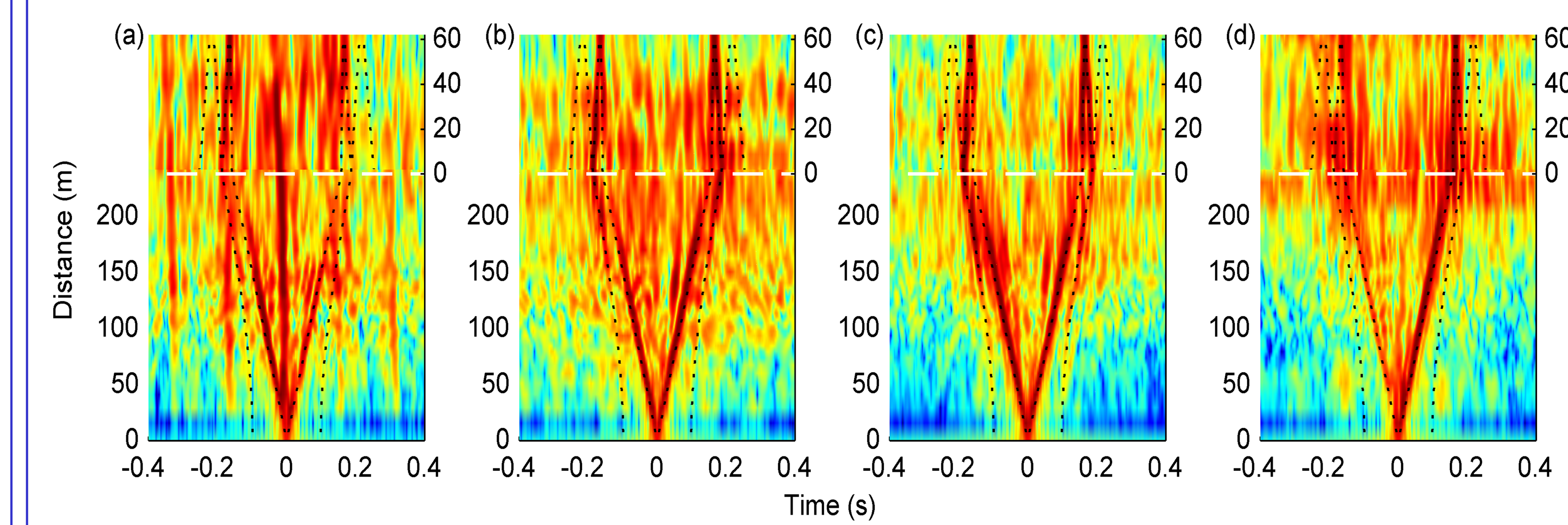




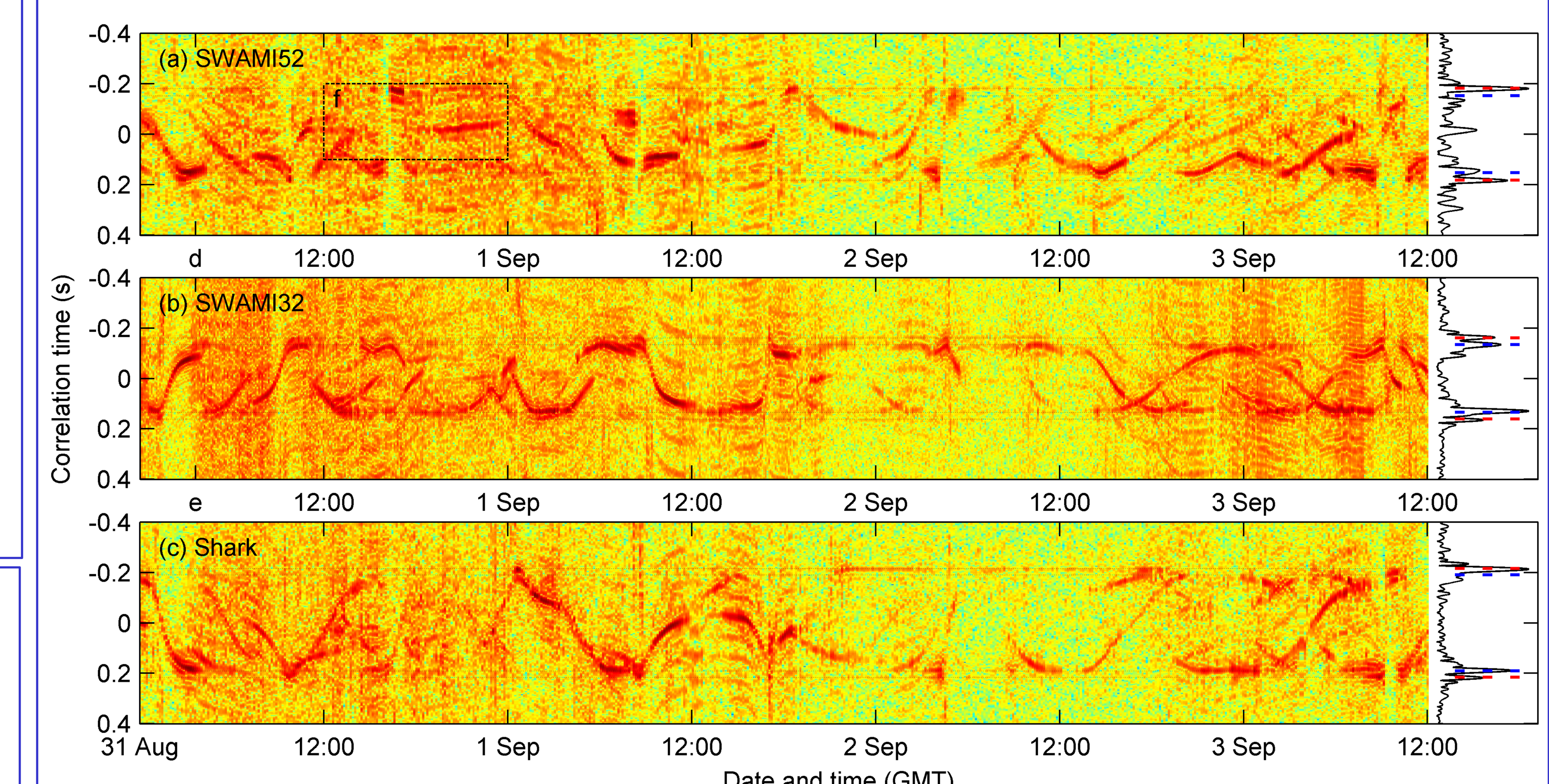


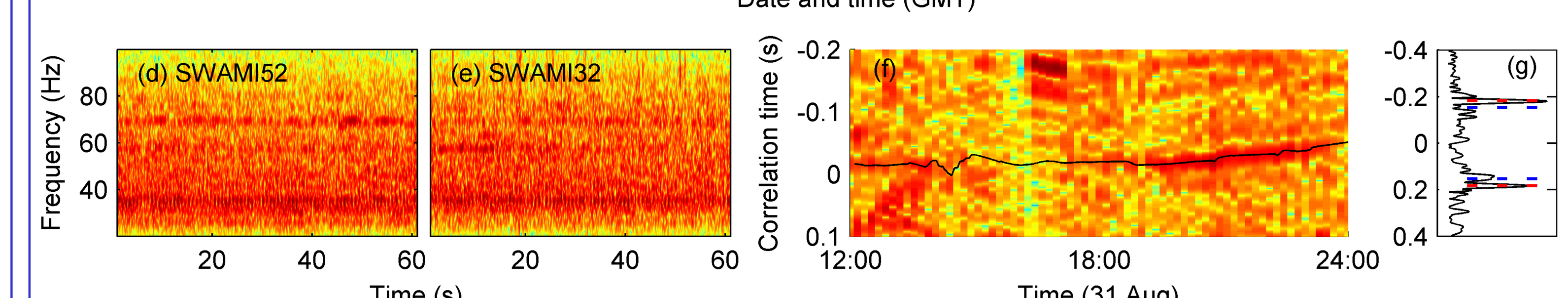
(a) Summed correlations over September 2 for SHARK hydrophone pairs separated by 345 m. (b) The median correlation from (a) overlies a shaded region between which all values lie. (c) Data from the dashed box in (b) is magnified. EGF envelopes (dB) are shown in (d) using only correlations between H-52 and all other HLA hydrophones only, and in (e) using the median correlations for all HLA hydrophone pairs.

TEMPORAL VARIATIONS



EGF envelope (dB) with respect to: H-52 for (a) August 31, (b) September 1, (c) September 2, and (d) September 3 (first 12 h only).





EGF envelope (dB) for: (a) SWAMI52 H-52 and H-17 (230 m separation), (b) SWAMI32 H-30 and H-15 (200 m separation), and (c) SHARK H-16 and H-35 (285 m separation). Simulated direct and surface reflected travel times (dashed lines) faintly overlaid. The envelope of the time gradient of the sum of all correlations (normalized by their peak amplitudes to minimize the effects of dominant signals)is shown at the right of each plot.(d)-(e) 20-100 Hz spectrograms from 3:36:40 Z August 31 for SWAMI52 H-52 and SWAMI32 H-30 (times denoted on (a) and (b) time axes as 'd' and 'e') respectively. (f) Enlarged view of SWAMI52 EGF envelope [boxed area from (a)] showing a dominant near-side signal, with calculated travel time difference (black line) from *R/V Oceanus* to the hydrophone pair. (g) The envelope of the time gradient of the sum of all correlations, excluding the period 12-24 Z August 31, for SWAMI52 data.

CONCLUSION

EGFs were determined from data collected during the Shallow Water 2006 experiment. Since ship noise is discrete, long correlation periods were required to give sufficient averaging for the emergence of the Green's function. EGFs were computed over one day, but shorter observation times could be used.The ocean environment is temporally non-stationary; however, the effect of temporal changes in the noise distribution on the EGF estimate are larger than environmental changes. The EGFs are therefore approximations of 'average', rather than instantaneous, Green's functions. For an appropriate bandwidth, different time and frequency domain normalization methods yielded similar correlation results. A major reason for this is the spatial averaging of the noise field which occurs when noise from many ship tracks are recorded.

Analysis of temporal variations in the correlations confirmed that the signal is, at any one time, generally dominated by only one or two sources. Correlations obtained from data recorded during Tropical Storm Ernesto were shown to be clearer than those obtained before and after the storm. This is due to a combination of a reduction in high energy discrete sources (most ships left the area during the storm), and an increase in overall sound levels. The source of a dominant spurious signal which is observed in the data on two separate non-consecutive days was identified, and its removal was shown to improve the EGF.