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14. ABSTRACT
The primary long term goals of this program have been to measure and model high frequency acoustic propagation and scattering near the sea surface. Processes of particular interest are scattering from surface gravity waves and the effect of whitecaps and bubble clouds on underwater acoustic communications. Secondary long term goals were to 1. exploit measurements of breaking wave noise and photographic images of whitecaps to infer bubble cloud populations at the sea surface and 2. study ambient noise in coastal Arctic regions.

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Shallow Water Propagation and Surface Reverberation Modeling

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LONG-TERM GOALS

The primary long term goals of this program have been to measure and model high frequency acoustic propagation and scattering near the sea surface. Processes of particular interest are scattering from surface gravity waves and the effect of whitecaps and bubble clouds on underwater acoustic communications. Secondary long term goals were to 1. exploit measurements of breaking wave noise and photographic images of whitecaps to infer bubble cloud populations at the sea surface and 2. study ambient noise in coastal Arctic regions.

OBJECTIVES

The standard approach to modeling high-frequency, forward scatter from the ocean surface is to use statistical methods. Surface arrival intensities, for example, are often characterized in terms of probability density distributions. This approach has the advantage that deterministic details about the physical properties of the surface wave field do not need to be known. However, this lack of knowledge can also be a disadvantage if propagation models and underwater acoustic communications systems algorithms do not incorporate all the relevant scattering physics. For example, the transient focal regions created by surface swell over short ranges contain micro-paths with regular patterns of significant, time-varying Doppler shifts, which introduce errors into channel equalizers. The result is a decrease in ACOMS performance in what would appear to be a benign environment (short propagation range with swell and low wind speed). These micro-path properties only become obvious when individual wave-focused arrivals are studied.

An alternative approach is to measure and model surface reflections as a deterministic process. This approach allows the properties of surface-reflected arrivals to be studied in detail and ensure that the physics of surface scatter is adequately understood. 'Adequate' in this context means with sufficient insight to predict the performance of ACOMS systems in a variety of shallow-water and surface conditions. Ultimately, detailed information about the ocean surface is discarded, but only after the deterministic physics underlying the statistical formulations has been proven. This study is necessary because of the complexity of surface scattering. Surface waves range in scale from centimeters for gravity-capillary waves up to 100's of meters for swell, and break over a range of scales depending on fetch and wind speed. Breaking waves also inject bubbles into the upper ocean boundary layer, which have a spatially-diverse and frequency-dependent impact on surface reverberation. There is no complete physical model describing these processes. Ultimately, the validity of assumptions about surface scattering processes built into propagation models and ACOMS algorithms need to be assessed against the real ocean, and deterministic studies are one means of doing this.

Given this background, the program objectives are to build computationally efficient, deterministic models of scatter from surface gravity waves and to measure the second order statistics relating sound focusing by gravity waves and wave-induced Doppler shift. Given the important role of sub-surface bubbles on surface reverberation in wind-driven seas, an additional objective has been to study the role of sub-surface bubbles on the attenuation and scattering of acoustic signals, including determining methods for quantifying bubble populations with video footage of the sea surface and developing models of bubble acoustical effects.

A final objective has been to characterize the time-frequency characteristics of ambient noise in coastal, Arctic regions. The study of undersea ambient noise in the Arctic is extensive and extends back to the 1960's, with early results focusing on noise associated with processes in the ice margin. Much of the work on Arctic noise since has been concerned with the generation, propagation and statistical properties of noise generated by sea ice, consistent with the observation that the interaction of the ice cover with the air and water boundary layer is the primary source of noise. More recently, there has been a growing interest in the underwater noise in Arctic fjords, particularly those that contain the terminus of one or more glaciers. The program objective was to measure the directionality of underwater ambient noise in a glacial fjord in Spitzbergen and characterize the noise directional properties in terms of frequency band and generating mechanisms.

APPROACH

The technical approach is divided between field and laboratory campaigns and propagation and surface scattering model development.

Field Deployments. The field experiments related to this project were the SPACE02 and SPACE08 UW COMMS deployments (which happened before the beginning of this project) and the KAM11 deployment executed in the fall of 2011. Data from the SPACE02 and SPACE08 experiments were analyzed for percentage whitecap coverage of the sea surface, ambient noise levels and the properties of surface-scattered arrivals along 20 m and 200 m propagation paths. For the KAM11 deployment, the goal was to test the capability of the Wavefronts model to model the high-frequency ACOMS environment. Water column sound speed profiles and time series of surface wave height will be used to predict the amplitude, intensity and time delay statistics of surface-scattered arrivals. The final field study was the TREX13 experiment. Our task in the TREX13 campaign was to characterize surface reverberation conditions during wind-driven seas using remote observations of whitecaps. Whitecaps are a visible consequence of bubble entrainment by wave breaking and are expected to be a robust indicator of the importance of bubbles in modifying forward-scattered sound from the sea surface. Our observing system consisted of a high-frame rate, high-resolution camera mounted on the mast of the R/V Hugh R. Sharp looking down at the ocean surface. Images from the system were collected with a high storage capacity computer system. Two GPS receivers were mounted midship to provide ship heading and speed.

Scattering Model Development. The SPACE08 propagation data was modeled deterministically with the Wavefronts acoustic model. Surface waves were measured during the SPACE08 experiment with a high-frequency, upward-looking sonar mounted on the seafloor, mid-way along the 60 m propagation path deployed by Andone Lavery at WHOI. Amplitude, delay and Doppler shift of surface-reflected arrivals will be modeled using the Wavefronts code with the wave height time series as an input and compared with the SPACE08 data. An initial analysis has shown that accurate estimates of the surface-reflected arrival delay can be made using the wave height data once the acoustic and wave height data streams have been synchronized. The comparison will be extended to focusing intensifications and Doppler shifts. The ultimate goal is to understand the connection between the properties of the surface-scattered field and the amplitude statistics of the gravity wave field.

Data Set Analysis. The photographic investigation of sub-surface bubble plumes is based on data collected during the Surface Processes and Acoustic Communications Experiment in October and November of 2008 (SPACE08). Digital sea surface images were acquired using a 5 mega pixel Arecont Vision digital CCD camera with a 17.5 mm lens, mounted on the Woods Hole Oceanographic Institution Air Sea Interaction Tower (ASIT) at a height of 23 m above the mean sea level and an angle of 59° from the nadir. The mean image footprint was 339 m^2, which varied by ±5% depending on the water depth at the ASIT, resulting in a mean pixel resolution of less than 1 cm^2. The image sampling frequency varied from 3 - 6 fps. Three days with images suitable for analysis were chosen from the total dataset, covering a range of wind speeds from about 5 - 14 ms^{-1}. Camera images were analyzed using a computer automated whitecap thresholding technique followed by foam patch identification and quantification. Foam area was computed for each selected breaking event, providing a time series of foam area growth and decay.

Scale Model Laboratory Experiments. Two separate scale model experiments were conducted to study the connection between sub-surface bubble plumes and the reconstruction of surface wave profiles from scattered sound. The sub-surface plume experiment was carried out in the glass-walled wave channel at SIO. A range of breaking types from spilling through plunging were generated, and the sub-surface and surface patterns of air entrainment were recorded with high-speed imaging cameras. The goal was to draw quantitative conclusions about the physics controlling the observed patterns of foam decay in the SPACE08 field data (described above) through laboratory observations of foam and sub-surface bubble plumes generated by breaking waves. When combined with observations of bubble size distributions within the bubble plumes (taken as part of earlier experiments), this data also provides a means of calculating the acoustical properties of the sub-surface bubble plumes.

The second experiment was a scale model tank experiment (also conducted in the glass-walled wave channel) to test the surface shape inversion work that extended Berry's echo-based studies of ice shape. These acoustic scattering experiments were carried out at a range of frequencies between 100 - 300 kHz using ITC 1089D spherical transducers. Sound scattered from surface gravity waves generated by a mechanical flap at one end of the wave channel was recorded along with wire wave gauge measurements of the water surface elevation. The overall approach is to test the acoustic model and surface shape inversion algorithm using reverberation from a real surface in a controlled environment.

Arctic ambient noise
A month long field campaign was undertaken in Brepollen fjord, Spitzbergen. The work was based out of the Polish polar station located approximately 1 mile from Hans glacier. The measurement system (the directional acoustic buoy or DAB) consisted of two broad-band hydrophones mounted on a vertical mast that was deployable from a small boat. The mast topside included a GPS receiver, a magnetic compass, and roll and tilt sensors. Signals from the hydrophones were recorded on digital audio tape along with data from the orientation and navigational systems. DAB was used to map the frequency dependent directivity of ambient noise in the fjord at 8 locations throughout the fjord on 4 separate days.

Collaborations. Some of the work during this project was done in collaboration with Dr. James Preisig at WHOI and Prof. Chris Tindle at the University of Auckland, New Zealand. Dr. Preisig, one of the world's leading experts in the development and application of signal processing techniques to UW ACOMS, took data and model products developed as part of this project and incorporated them into models of communication performance and improved algorithms for signal detection.

WORK COMPLETED

Field Work.

The field work undertaken and completed during this project were the KAM11 experiment off Hawaii in 2011, the TREX13 experiment off Florida in 2013 and measurements of ambient noise in a coastal bay in the Arctic during the summer of 2013.

The KAM11 Experiment.

The KAM11 experiment took place at the Pacific Missile Range Facility (PMRF), 117 nautical miles off Honolulu from 23 June through 12 July, 2011. The UNOLS ship R/V Kilo Moana operated by the University of Hawaii was used to deploy and recover all equipment. The Chief Scientist for the experiment was Bill Hodgkiss from SIO, and the cruise included participants Woods Hole Oceanographical Institution and the College of Marine and Earth Studies at the University of Delaware. Three systems were prepared and deployed by the PI during the KAM11 experiment: an autonomous array of vector sensors, a high-resolution camera system to monitor whitecap formation and a commerical acoustic system to measure populations of micro-bubbles in the upper ocean boundary layer.

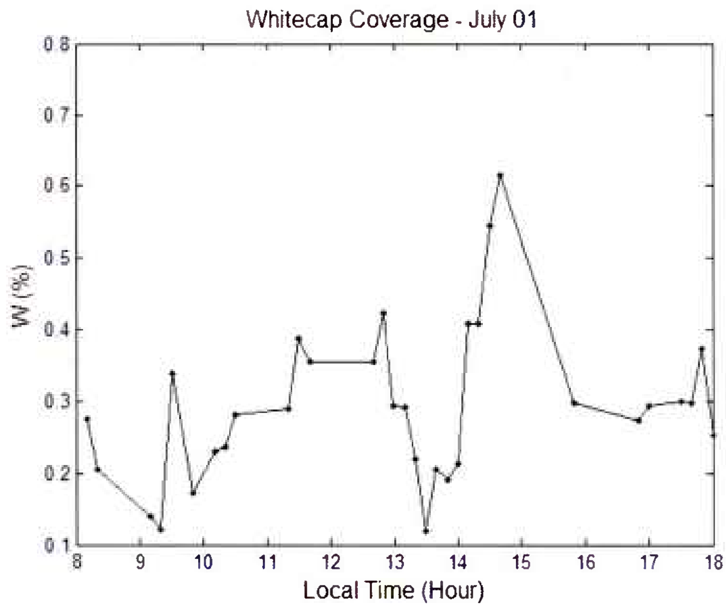


Figure 1. A plot of a small segment of the fractional coverage of whitecaps expressed as a percentage versus time on July 1st, 2011 during the KAM11 experiment. Approximately 18,000 images were analyzed. The data show variations in whitecap coverage associated with changes in wind speed.

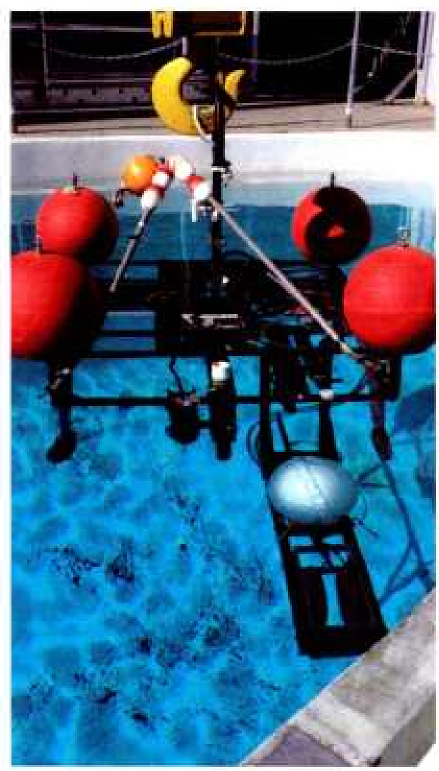


Figure 2. The surface-following environmental frame, which housed the Acoustical Bubble spectrometer to measure wave-induced bubble plumes. The frame was tethered to the stern of the Kilo Moana and left to drift approximately 100 m behind the vessel.

The surface-monitoring camera system consisted of a 5 Mega-pixel POE-based camera mounted inside a weatherproof housing. The camera was mounted on one of the ships masts and the tilt and direction of the camera system controlled remotely from the data collection laboratory. Data was streamed to hard drive at a rate of 10 frames per second during recording intervals. Data was collected during periods of moderate to high winds when whitecaps were visible. When analyzed in terms of fraction whitecap coverage, this data will provide quantitative information about air entrainment rates and the spatial distribution of sub-surface populations of micro-bubbles injected into the upper ocean boundary layer by breaking waves.

During periods of high wind speed, these bubbles significantly impact sound reflected by the sea surface at coherent underwater communications frequencies by scattering and absorption. Fig. 1 shows an analyzed segment of data taken during the daylight hours on July 1, 2011.

The acoustic vector sensor array was designed, built and tested by the Deane Laboratory and the Technology Applications Group at SIO. An array of 4 VS-205 Wilcoxon acoustic vector sensors was mounted on a spar buoy with a 33 cm element spacing at a depth of 20 m, providing a freely-drifting, autonomous platform deployable for a period of up to 4 hours. The spar buoy decoupled the array from surface motions which helped minimize levels of flow noise on the velocity sensor elements. The vector sensors were adjustable for data acquisition at 5.0 kHz or 45.045 kHz depending on the configuration, the latter being without anti-aliasing filters. A National Instruments Data Acquisition Software package was written to acquire and store the vector sensor acoustic and orientation data. The spar buoy was tested in the near-shore waters off the La Jolla Shores Beach before being packed and shipped to Hawaii for the KAM11 experiment. The system was successfully deployed three times during the source of the experiment.

The third system deployed during KAM11 was the Acoustical Bubble Spectrometer (ABS) manufactured by Dynaflow, Inc. The ABS is an acoustic system designed to quantify bubble size distributions with air fractions of 10^{-7} up to around 10^{-4}. It was deployed on the surface-following environmental frame shown in Fig. 2. The ABS acoustic transducers are the gray disks visible on the lower right hand side of the picture. This system worked in laboratory tests and on the deck of the Kilo Moana but failed to collect data when deployed in the ocean. The failure mode for the instrument remains to be determined, but the most likely scenario is rejection of data by the instrument because of interfering underwater noise from the Kilo Moana's differential positioning system. Moving into years two and three, we are pursuing the construction of in-house acoustical resonators to replace this commercial system. Preliminary discussions to collaborate with scientists at the Institute of Ocean Sciences in British Colombia, Canada who have successfully built and deployed acoustical resonators in the open ocean have been favorable.

Acquisition of whitecap data during TREX13 deployment

The data acquisition system described in the approach section was successfully deployed on the R/V Sharp and used to acquire roughly 1 TByte of image data documenting sea surface state during a variety of meteorological conditions. The camera and GPS locations are shown in Figure 1 along with an inset sample image taken during the experiment. Data products from this system, such as wave breaking rate and whitecap coverage, will be processed and offered to any interested participants in the TREX13 experiment. The integration of this dataset with acoustic transmissions and other environmental measurements was discussed at the TREX13 workshop held Dec 7-8, 2013 in San Franscisco.

Figure 3. Image acquisition system for monitoring surface conditions during the TREX13 campgain on the The R/V Hugh R. Sharp. A sample image from the expeirment is inset in the top right of the figure. This data will help interpret the characteristics of sound scattered from the surface during different meteorological conditions.

Glacial ambient noise

This experimental campaign was undertaken and successfully completed in August 2013. An overview of the sites at which recordings were made in Brepollen fjord are overlaid on a picture of the terminus of Hans glacier in Fig. 4. Note that the satellite image of the glacier was taken in 2010 and the 2013 terminus is actually located further north, thus measurement location 3C was actually considerably further from the terminus than appears in the image. The inset at the bottom of the figure shows a rose plot of the ambient noise directionality measured at location 3C in 2 frequency bands: (0.1-3 kHz) in red and (2-5 kHz) in blue.

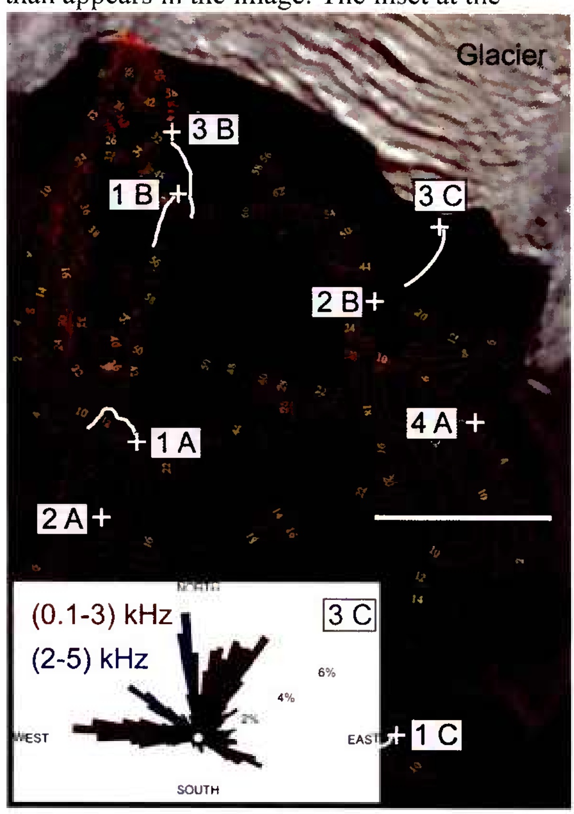


Figure 4. A summary of deployment locations during the Arctic ambient noise survey campgain in August, 2013. Approximately 30-60 minutes of data were collected at each deployment site labeled 1A through 4A using the Directional Acosutic Buoy described in the text. The white tracks indicate the boat path during recording, and the horizontal, white scale bar marks 500 m. The sites are placed on a satellite image of Hans Glacier taken in 2010. The red lines annotated with yellow numbers are depth contours in the fjord in m. The inset at the bottom left of the figure shows a sample of ambient noise data taken at site 3C close to the glacier front. The noise has been divided into two frequency bands (blue and red) and processed into arrival angle.

The rose plot shows that the undwater ambient noise field is both highly directional, and the directionality is a function of frequency. Our working hypothesis for this result is that different physical mechanisms generating the noise are associated with distinct spectral bands and are distributed non-uniformly in space.

Laboratory studies and theoretical modeling.

The Analysis of SPACE08 Whitecap Data and Laboratory Flume Study

As the surface expresison of sub-surface bubble clouds, whitecaps provide a valuable tool for improving our understanding of the acoustical properties of the ocean surface. The analysis of whitecap decay times is a relatively new activity; previous studies have been anecdotal and limited to less than a dozen images. The completed study consists of decay time curves for 552 discrete wave breaking events. The breaking events have also been analyzed to provide an estimate for the Phillips parameter, which provides information about the wave breaking kinematics. Following the decay time analysis, two hypotheses for the behavior of whitecap decay were proposed. These hypotheses (discussed in the results section) were tested in the laboratory flume study.

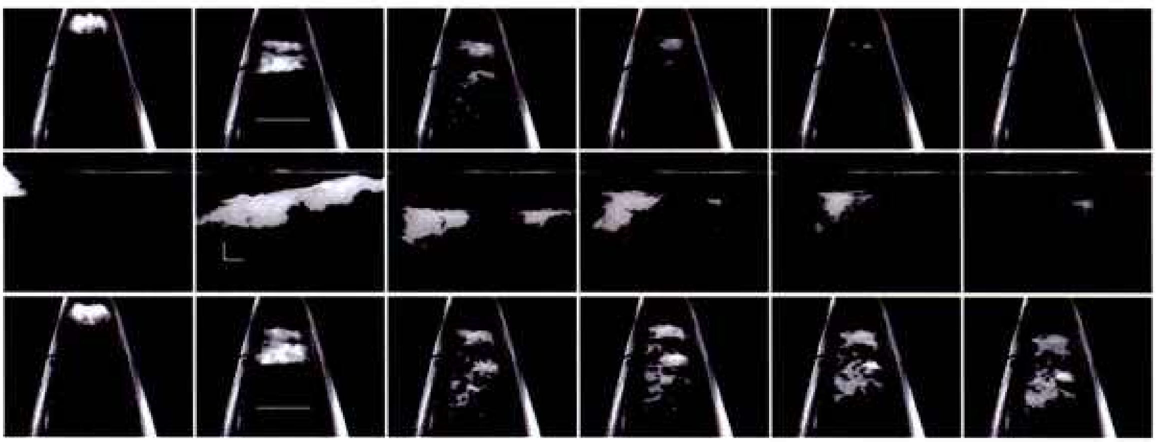


Figure 5. A film strip of images of breaking waves from an overhead and side-view camera in the laboratory flume study. Consecutive images in each row are separated in time by 2/3 s. The middle row shows the bubble plume images as seen through the side wall of the flume. The top and bottom rows show surface foam without (top row) and with (bottom row) the addition of a surfactant to stabilize the foam. The horizontal white lines in the second image from the left in the top and bottom rows are 42 cm in scale. The length of the tank in these images is 2.8 m. The horizontal and vertical white lines in the second image in the middle row are 10 cm in scale. These images show that surface foam and sub-surface bubble plume persistence times are the same in the absence of surfactants. When surfactants are present, surface foam persists on time scales longer than the sub-surface plumes.

The flume experiment was designed to enable us to relate the surface properties of whitecaps to the sub-surface bubble plumes entrained by spilling and plunging seawater waves. The experiment was divided into surfactant-free and surfactant-added phases to study the effects of seawater chemistry on foam persistence. A sequence of breaking events using a mechanically-generated wave packet of specified amplitude, slope and underlying horizontal scale were executed during each phase. A total of 20 breaking events were analyzed into time series of foam patch area and cross-sectional area of bubble plume.

Determining Surface Waves from Acoustic Transmissions

The work completed in this phase of the project consists of: 1) the creation of an inversion algorithm to determine the shape of the ocean surface from the inteference structure of reflected acoustic pulses, 2) the successful application of the algorithm to an existing high-frequency, scale model tank experiment and 3) the completion of a second experiment to test some critical concepts that arose during the first data set analysis, which are discussed in detail below.

Laboratory study of surface scattered sound

The 2012 project report describes the creation of an inversion algorithm to determine the shape of the ocean surface from the interference structure of reflected acoustic pulses and the successful application of that algorithm to a high frequency scale model tank experiment. The additional work completed during this reporting period is the successful completion of a second scale model experiment to study the benefits of using multiple receivers in the inversion algorithm. In addition, surface reflected data from the SPACE08 field campaign has been analyzed using the surface scattering model and inversion algorithm. The inversion of field data is considerably more challenging than data from scale model tank experiments, but is expected to yield unique insights into surface scattering. For example, we are hoping to separate the effects of coherent gravity wave focusing, scattering from small scale surface roughness, and the scattering and absorbtion due to sub-surface bubble clouds under wind driven seas. This data analysis is in an early phase but is yielding promising results for relatively benign conditions with low winds and moderate swell.

SPACE08 data analysis

Anecdotal data on the performance of mid-frequency underwater communication systems suggest that the underwater communications channel under wind driven seas is more benign than calm seas. One hypothesis to explain this observation is that bubbles entrained by wind-driven wavesbreaking scatter and absorb acoustic signals incident on the surface, thereby reducing surface reverberation. Since surface reflected energy is both scattered and Doppler shifted by gravity waves, its removal can improve the performance of communications systems. Motivated by this process, a model of bubble entrainment by near surface turbulence has been formulated and compared with SPACE08 transmission data. The results of this model and comparison with observation are presented in the Results section.

RESULTS

Deterministic modeling of surface reverberation

Data from the SPACE08 underwater acoustics experiment have been analyzed to study the link between surface wave activity and intensifications in the surface-reflected sound associated with surface gravity waves. Fig. 3 shows one of the results of this study.

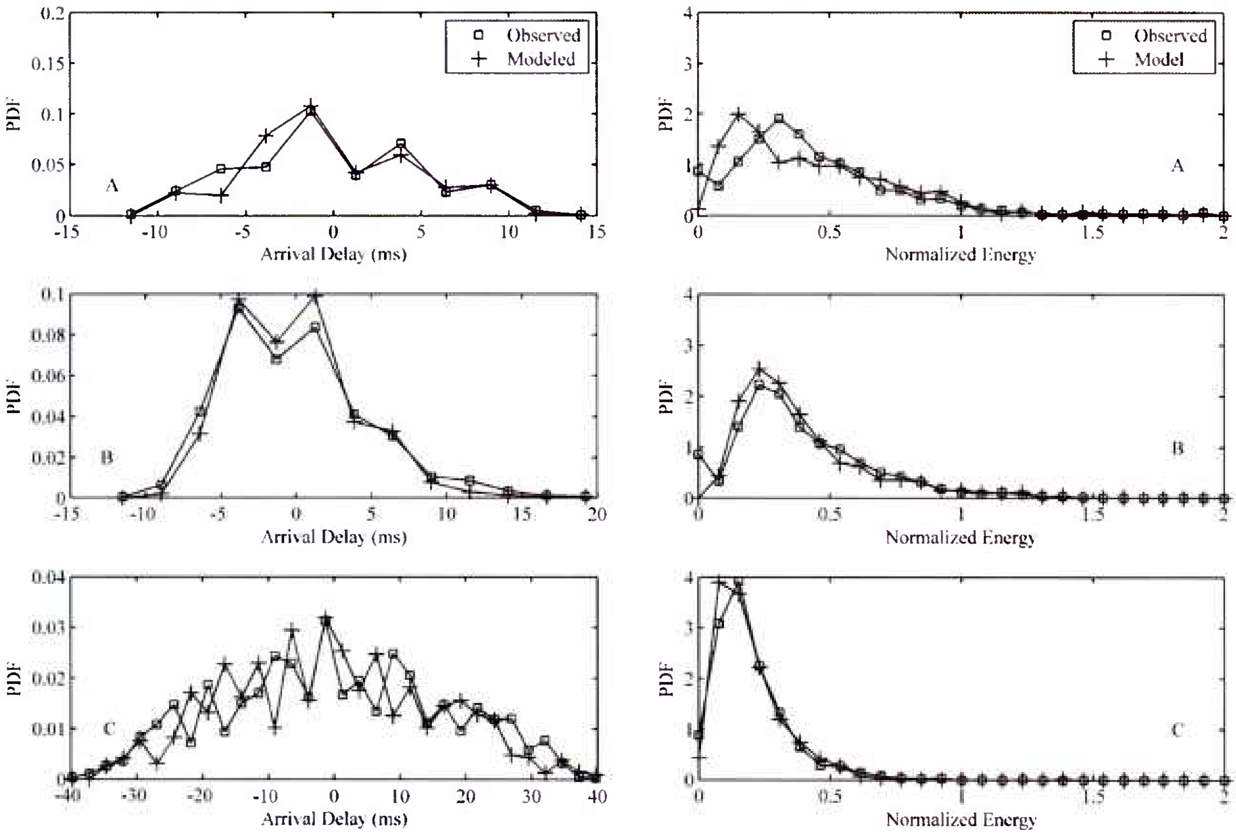


Figure 6. A collage of the arrival delay (left-hand column) and normalized energy (right-hand column) of acoustic pulses scattered from the sea surface during three different sea states. The first row corresponds to 1 m significant wave height swell. The second row is also for a 1 m significant wave height, but for a wind and swell-mixed sea. The third row corresponds to a 3 m significant wave height, wind-driven sea. Squares indicate measured data and pluses indicate model results. The model predictions include an *ad hoc.* term to account for absorption and scattering by bubble clouds.

The data show that the statistics of surface reverberation arrival time and energy are sensitive to both the energy in the surface gravity wave field, and the distribution of that energy in frequency. This is experimental verification of an important theroretical result, which is that the intensity of surface-reflected arrivals depends on the curvature of the surface gravity waves, which is a function of both wave amplitude and frequency. The implication is that any predictive capability of underwater acoustic communications performance based on acoustic models that include surface reverberation must include realistic parameterizations of the surface gravtiy wave spectrum.

The good agreement between the data and model calculations suggests that the scattering calculations used here are of sufficient fidelity to accurately model surface scattering processes. Plots similar to those shown in Fig. 6, but on a logarithmic scale (not shown here) show that the agreement between theory and experiment continues well into the arrival amplitude distribution tails and extends over two orders of magnitude in energy.

Model calculations based on the scattering theory indicate that an optimal geometry to avoid intensifications associated with gravity wave focusing is a source placed as close as practical to the sea surface and a receiver placed as far below the sea surface as practical.

Important effects remain to be studied, including out of plane scattering associated with three dimensional wave field effects, wave-induced Doppler shifts and the effects of sound speed profiles in the water column on acoustic-surface interactions. Acoustic arrivals that have undergone more than a single surface interaction face the interesting possibility of being focused more than once, and the distributions of these arrivals need to be modeled.

Analysis of SPACE08 Whitecap Data and Laboratory Flume Study

A key result of the SPACE08 data analysis and flume study is shown in Fig. 7. This figure shows that, in the absence of surfactants, the lifetime of sub-surface bubble plumes is strongly correlated with the persistence of surface foam. This is true for high air-fraction bubble plumes containing large (> 0.3 mm radius) bubbles that are acoustically relevent to surface scattering at underwater acoustic communications frequencies.

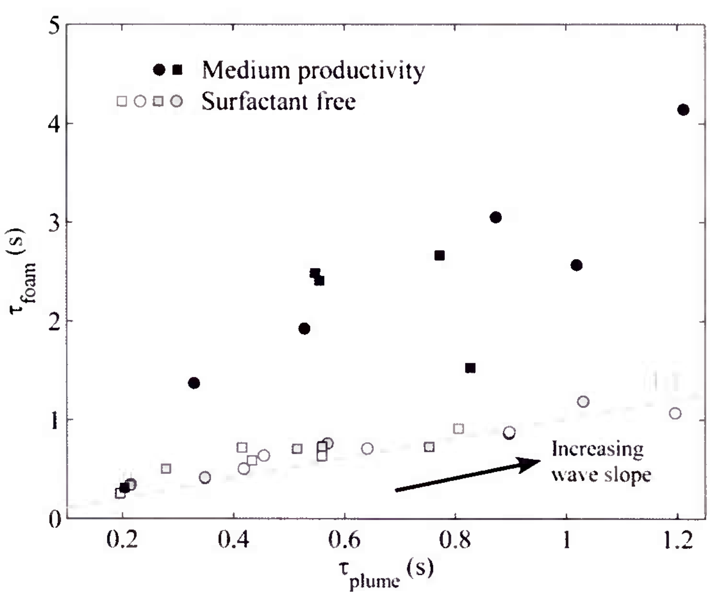


Figure 7. Foam decay time versus plume decay time for various wave slopes in surfactant-free (open and gray filled symbols) and surfactant-present (black filled symbols). Surfactant concentration in the surfactant-present study was equivalent to oceanic regions of medium biological productivity. Values of sub-surface bubble plume decay time were varied by varying the slope of the breaking wave generating the foam and bubble plume. Circles and squares correspond to waves of different

horizontal scale. The dashed, gray line represents a 1:1 correspondence between foam and plume decay times.

A major impediment to studying these plumes has been their transient and shallow nature, making imaging with sonar systems difficult. In fact, despite their importance to surface reverberation, very little is known about how their penetration depth and persistence vary with wind speed and sea state. Considerably more is known about the plumes of small bubbles (< 0.1 mm radius) that persist on time scales of 100's of seconds, but they are less significant acoustically in the 10 kHz - 30 kHz frequency band than the denser plumes under study here. These results open the door to studying sub-surface bubble plumes through images of surface foam, which are relatively easy to collect. When coupled with measurements of near-surface fluid turbulence, analysis of whitecap imagery will enable us to predict transitions in surface scattering regimes (from wave-dominated to bubble-screened) as a function of wind speed and and acosutic frequency.

Determining Surface Waves from Acoustic Transmissions

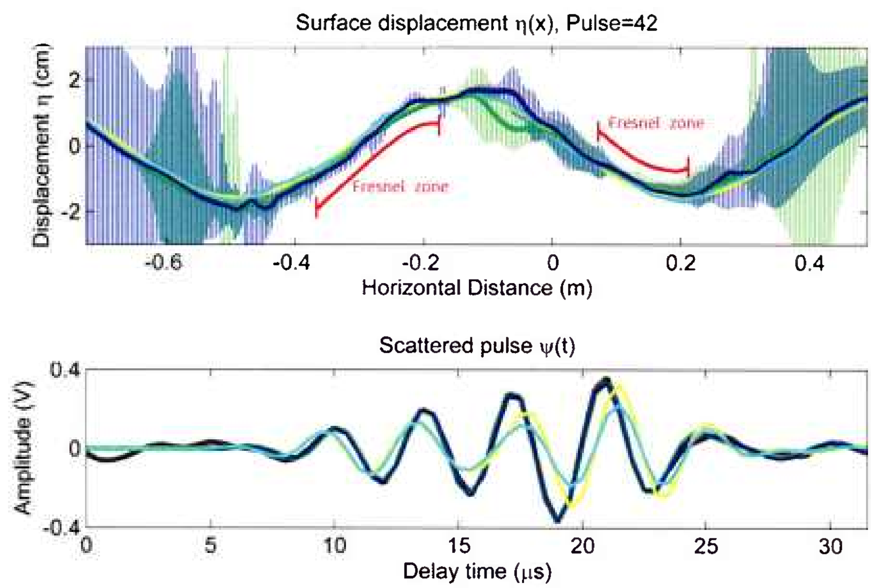


Figure 8. Example of a surface profile inversion from the scale model tank experiment. See text for further details.

A key result of the surface inversion work is verifying that surfaces can be reconstructed accurately only in a Fresnel zone around specular reflection points. This is illustrated in Fig. 8.

The top plot shows the reconstructed wave from an initial profile of a sine wave (green line) and wire wave gauge measurements (blue line). The yellow and cyan lines show the initial sine and wave gauge profiles. Vertical lines show the level of uncertainty in the inversion. The bottom plot shows the observed and reconstructed pulse shapes when scattered from the surface. This example shows two isolated specular reflection points with highly divergent optimized surface profiles between the two Fresnel zones. Even though the optimized scattered signals in the lower panel are in very good agreement, the diverging optimized surface profiles around $x = -.1$ m illustrate that outside of Fresnel zones the surface cannot be accurately known.

A means to circumvent the limitation imposed by a Fresnel zone length is to use multiple receivers, thereby introducing more specular reflection points along the surface. This is illustrated in Fig. 9.

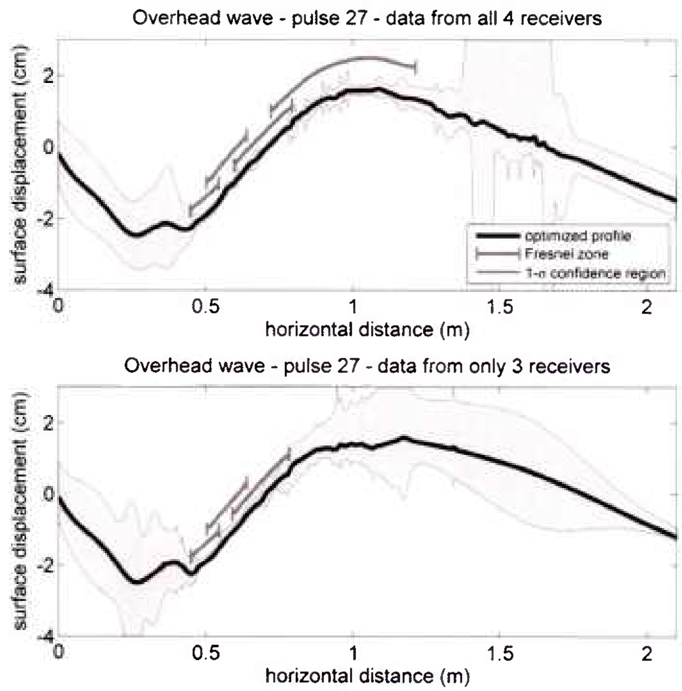


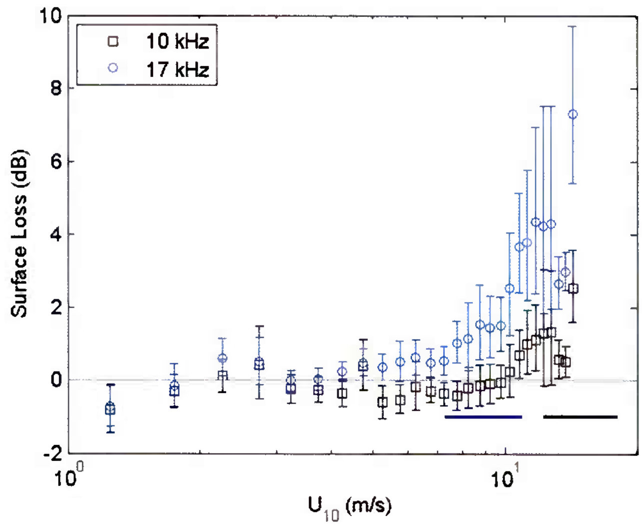
Figure 9. Surface reconstruction using data from four receivers (top panel) and data from only three receivers (bottom panel) using data taken from a scale model tank experiment. Data from receiver R4 (top plot) increases the extent of surface reconstructed accurately by a factor of 2. Also the slight overlap in the Fresnel zone from R3 and R4 increases confidence of the inversion in that region.

The use of multiple hydrophones creates regions of overlapping Fresnel zones, extending the horizontal extent of accurate reconstruction of surface shape.

Screening of the surface by wave-induced bubbles

Figure 10 shows observations of surface screening by wave-induced bubbles using data taken through the SPACE08 campgain. Each symbol shows average surface bounce loss as a function of wind speed at 10 kHz (black squares) and 17 kHz (blue circles). The data show a rapid increase in surface bounce loss for wind speeds above roughly 8 ms^{-1}, with losses at 17 kHz rising more rapidly and earlier than losses at 10 kHz. The increase in surface bounce loss with increasing frequency is partly due to the scattering and absorption of sound by bubbles trapped directly beneath the surface by fluid turbulence. When present in sufficient concentration, absorption and scattering by bubbles has the effect of screening the surface from incident sound. The horizontal blue and black lines show model calculations of the range of wind speeds over which the screening effect is expected to take place. The reasonably good agreement between data and model indicates that the model is suitable for use as a tool for underwater communications performance prediction.

Figure 10. A summary of surface bounce loss data taken during the SPACE08 campgain. Surface loss in dB is plotted as a function of wind speed for 10 kHz (black squares) and 17 kHz (blue circles) pulses. A transition from low loss to high loss can be seen at around approximately 8 m s^{-1} at 10 kHz and 10 m s^{-1} at 17 kHz. The blue and black horizontal lines show model calculations of the expected range of winds speeds for the transitional behavior.



IMPACT/APPLICATIONS

The analysis and modeling of the SPACE08 data has application to the development of a predictive capability for underwater acoustics performance and improved algorithms for acoustic communications systems. The scale model experiments further our understanding of focussing and Doppler shifts induced in scattered sound by surface waves and will be used to study the second-order statistics relating these two effects. The bubble model predicts 'regime shifts' in the underwater acoustic environment, and has practical application to determining optimal source-receiver geometries in different meteorological conditions. In addition, the modeling effort also suggests that there is an optimal source-receiver geometry available to help mitigate the effects of surface-focused arrivals on underwater acoustic communications equipment. The work on screening of the surface by bubble clouds also has implications for this technical area. Finally, characterizing the amplitude and statistical properties of ambient noie in an Arctic coastal region has application to the operation of underwater communications equipment, sonars and any other devices that use underwater sound in these regions.

RELATED PROJECTS

WHOI Subrecipient Agreement No. A100530 on Prime ONR Grant No. N00014-07-1-0738: Underwater Acoustic Propagation and Communications: A Coupled Research Program.

PUBLICATIONS

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