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Your file Votre référence

Our file Notre référence

16 October, 1991

Dr. Alan Brandt
Office of Naval Research
800 N. Quincy St.
Arlington, VA 22217-5000

Dear Alan,

I enclose a copy of the technical report for Grant Number N00014-89-J-3162/P00001. Work covered analysis of DOLPHIN 90 data, OCEAN STORMS data, and CEAREX data.

There are some publications and preprints associated with this, including a PhD thesis, the latter resulting from the OCEAN STORMS project. I am sending these under separate cover, but append a list of them here.

Sincerely,

David Farmer

Encl.

References being sent under separate cover:

Czipott, P.V., M.D. Levine, C.A. Paulson, D. Menemenlis, D.M. Farmer and R.G. Williams. Ice Flexure Forced by Internal Wave Packets in the Arctic Ocean, accepted for publication in *Nature*.

Osborn, T.R., D.M. Farmer, S. Vagle, S. Thorpe and M. Cure. Measurement of Bubble Plumes and Turbulence from a Submarine, submitted to *Deep Sea Research*, 21 March 1991.

Zedel, Len, 1991. Near Surface Ocean Processes: Acoustic Observations, Ambient Sound and Langmuir Circulation, PhD thesis, Department of Oceanography, University of British Columbia.

Zedel, Len, and David Farmer, 1991. Organized Structures in Subsurface Bubble Clouds: Langmuir Circulation in the Open Ocean, *J. Geophys. Res.* 96 (C5), 8889-8900.

Zedel, Len, and David Farmer. Surface Wave Period Modulation in Near Surface Ambient Sound.

Zedel, Len, and David Farmer. Deep Ocean Wave Measurements Using Upward Looking Sonar.

Menemenlis, D., and David Farmer. Acoustical Current and Vorticity Measurements beneath an Arctic Flow, for submission to *JAO Tech.*

GRANT NO. N00014-89-J-3162/P00001 AND REVISION
FINAL TECHNICAL REPORT

Upper Ocean Boundary Layer Studies

Introduction:

This report covers the modification to the final stage of the DOLPHIN 90 submarine cruise project. This project was terminated prematurely. Nevertheless, a paper has been prepared and submitted covering the first brief period of the cruise prior to problems with the vessel generator.

The modification to the proposal involved support of analysis of (i) the OCEAN STORMS project and (ii) the CEAREX project.

Conclusion to DOLPHIN 90:

Although the cruise of the USS DOLPHIN was terminated by generator problems shortly after our first dive, the brief data set acquired has allowed a preliminary evaluation of combined turbulence and acoustic measurements of near surface conditions, together with simultaneous air photography. Probably the most important finding was that there appears to be an enhancement of the turbulent kinetic energy within the bubble clouds.

The data set is too short to be as convincing as we would like. What makes this whole problem so interesting is that the turbulent diffusivity within the bubble clouds is information essential to the proper modelling of dispersion in Langmuir convergence zones. We badly need some indication of the advection of turbulent kinetic energy, presumably introduced partly by wave-breaking events, into the convergence zone.

The results of this analysis have been submitted to *Deep Sea Research*. Present status is that generally favourable reviewer's comments have been received, and are being addressed. The revised manuscript will be returned shortly.

Reference:

Osborn, T.R., D.M. Farmer, S. Vagle, S. Thorpe and M. Cure. Measurement of Bubble Plumes and Turbulence from a Submarine, submitted to *Deep Sea Research*, 21 March 1991.

Analysis of OCEAN STORMS data set:

Analysis has been completed of data acquired in the OCEAN STORMS project. The results have led to several insights on the structure of the wind-driven upper ocean boundary layer, and of its acoustical expression. A PhD thesis on the OCEAN STORMS cruise results, "Near Surface Ocean Processes: Acoustical Observations, Ambient Sound and Langmuir Circulation", has been completed and successfully defended by our student Len Zedel.

The most important results of this work include:

1. Successful measurements of vertical velocities within bubble clouds. Average velocities in the core of the convergence zone at a depth of 8m were of order 6cm/s downwards.

2. Horizontal spacing of the Langmuir convergence zones included many very close structures, of order of 5m apart. Increased wind speed led to a larger number of more widely spaced structures (up to 20m at wind speeds above 10m/s).

3. Fluctuations in the ambient sound, presumably due to wave-breaking events, together with simultaneous sea surface elevation measurements directly above the instrument, were consistent with a model of breaking wavelets at the crest of each wave.

4. The structure of the Langmuir circulation, and in particular the presence of a broad range of scales in the observations, is examined theoretically with a two-dimensional vorticity model. Included in this study is a generation mechanism, not previously discussed, due to intensification of vorticity by vortex stretching in the wave field. In addition, the vorticity model reveals the presence of an inverse cascade of energy consistent with the observations, and provides additional insight on the influence on Langmuir circulation of a mixed layer of finite depth.

In addition to Zedel's thesis, one paper has appeared (Zedel and Farmer, 1991) and two others are ready for submission. A further paper, based on the theoretical study, is being prepared for submission.

References:

Zedel, Len, 1991. Near Surface Ocean Processes: Acoustic Observations, Ambient Sound and Langmuir Circulation, PhD thesis, Department of Oceanography, University of British Columbia.

Zedel, Len, and David Farmer, 1991. Organized Structures in Subsurface Bubble Clouds: Langmuir Circulation in the Open Ocean, *J. Geophys. Res.* 96 (C5), 8889-8900.

Papers prepared but not submitted:

Zedel, Len, and David Farmer. Surface Wave Period Modulation in Near Surface Ambient Sound.

Zedel, Len, and David Farmer. Deep Ocean Wave Measurements Using Upward Looking Sonar.

Analysis of CEAREX data:

Analysis of CEAREX data has proceeded with completion of a study of the interaction of the ice cover with internal waves, using a combination of our acoustical flow measurements, with ice tilt observations collected by Czipott. The results were interesting in that they demonstrated ice flexure due to very small disturbances, but a by-product of this study has been the demonstration of the extreme sensitivity of our acoustic current meter / vorticity sensor.

The instrument performance has been thoroughly analyzed and written up for submission. Measurements of vorticity in the ice-water boundary layer can be measured down to levels of 0.01f, and current measurements down to 0.1mm/s for data averaged over 60s. This sensitivity provides a uniquely suitable tool for studying very small motions beneath the drifting ice. Analysis has begun on turbulent fluctuations which appear to depend on the orientation of the flow. Future analysis will focus on the effect on the turbulence of flow direction. Part of the array was in the lee of a pressure ridge, allowing detection of turbulent fluctuations associated with its form drag.

References:

Czipott, P.V., M.D. Levine, C.A. Paulson, D. Menemenlis, D.M. Farmer and R.G. Williams. Ice Flexure Forced by Internal Wave Packets in the Arctic Ocean, accepted for publication in *Nature*.

Menemenlis, D., and David Farmer. Acoustical Current and Vorticity Measurements beneath an Arctic Floe, for submission to *JAO Tech.*.

Ice Flexure Forced by Internal Wave Packets in the Arctic Ocean

Peter V. Czipott, Murray D. Levine, Clayton A. Paulson,
Dimitris Menemenlis, David M. Farmer, and Robin G. Williams

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R. G. Williams, Scott Polar Research Institute, University of Cambridge, Lensfield Rd., Cambridge, England CB2 1ER.

Tiltmeters on the Arctic Ocean were used to measure flexure of the ice forced by an energetic packet of internal waves riding the crest of diurnal internal bores emanating from the Yermak Plateau, north of the Svalbard Archipelago. The waves forced an oscillatory excursion of 36 microradians in tilt of the ice, corresponding to an excursion of 16 micrometers per second in vertical velocity at the surface and of 3.5 millimeters in surface displacement. Strainmeters embedded in the ice measured an excursion of 3×10^{-7} in strain, consistent with ice flexure rather than compression. The measured tilt is consistent with direct measurements of excursions in horizontal current near the surface (12 centimeters per second) and in vertical displacement of the pycnocline 100 m below the surface (36 meters).

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Measurements of Bubble Plumes and Turbulence from a Submarine

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Abstract.

An experiment using turbulence probes and an array of side-scan and vertically pointing pencil beam sonars mounted on the US Submarine Dolphin was made to measure turbulence in near-surface regions of acoustic scattering, in particular those caused by subsurface bubbles produced by breaking wind waves. Although the experiment was curtailed by a failure of the submarine's generators, a short data set collected during winds of 5-9 m s^{-1} reveals the banded patterns of bubbles associated with Langmuir circulation, even though no surface manifestations were visible.
A forward pointing side-scan sonar determined the 'age' of bubble clouds after their generation by breaking waves. There is enhanced turbulent dissipation in the bubble clouds, and the dissipation rate close to the surface exceeds that predicted using conventional calculations based on the law of the wall and the buoyancy flux. The correspondence between bubbles and turbulence implies a horizontally patchy turbulent structure near the surface. Below the base of the bubble clouds the distance between turbulent patches increases and is much greater than that of the bubble clouds. The submarine provides an excellent platform for multi-sonar near-surface studies.

Near Surface Ocean Processes:
Acoustical Observations, Ambient Sound, and Langmuir Circulation

by

Len Zedel

B.Sc., The University of Victoria, 1982
M.Sc., The University of Victoria, 1985

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

in

THE FACULTY OF GRADUATE STUDIES

(Department of Oceanography)

We accept this thesis as conforming
to the required standard

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THE UNIVERSITY OF BRITISH COLUMBIA

August 1991

Abstract

This thesis describes a study of near surface ocean processes based on observations made with an instrument incorporating both active and passive acoustical systems. The topics addressed include the organization of bubble clouds by Langmuir circulation, the modulation of ambient sound levels by surface wave action, and the interactions of vortices associated with Langmuir circulation.

Observations in a deep ocean environment reveal bubble clouds organized into plumes of 100 m length and widths of about 5 m aligned with the wind through the action of Langmuir circulation. The depth of these plumes varies somewhat with wind speed with the greatest depths of 12 m occurring at wind speeds of 13 ms^{-1}. Using acoustic Doppler techniques, downward vertical velocities of 0.06 ms^{-1} are observed at 8 m depth within the bubble plumes.

Ambient sound observations at 8 kHz are used to search for possible relationships between wave breaking and Langmuir circulation: no systematic relationship is identified. This investigation does reveal the occurrence of modulations to ambient sound levels in phase with the long ($\sim$ 150 m) surface waves passing over the instrumentation (positioned at 30 m depth). A model of sound generation at the ocean surface suggests that individual sources must have spacings of less than 6 m to reproduce the observations. Increased breaking activity (or greater source levels) are required at long wave crests to explain these modulations: it could be caused either by interactions between long and short waves, or variations in wind stress over the long waves.

The observations of Langmuir circulation reveal many coexisting scales of spacing between the windrows. A mechanism capable of generating small scale vorticity of the appropriate orientation through wave breaking and vortex stretching is developed. The consequences of interactions between this small scale, two dimensional vorticity is then explored using a Lagrangian vorticity model. This model demonstrates that continuous injection of small scale vorticity close to the ocean surface can lead to circulation similar to that expected for Langmuir circulation: a distribution of circulations cell sizes results, down welling speeds exceed upwelling speeds, and the cell spacing scales vary in proportion to the depth at which a bottom boundary is placed in the model.

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 96, NO. C5, PAGES 8889–8900, MAY 15, 1991

Organized Structures in Subsurface Bubble Clouds: Langmuir Circulation in the Open Ocean

LEN ZEDEL

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DAVID FARMER

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Observations of the movement and distribution of subsurface bubbles reveal the structure of coherent motions near the ocean surface. The measurements were obtained in the open ocean from a freely drifting, self-contained acoustical instrument equipped with side scan sonar, dual-frequency echo sounders, and ambient sound recording systems. The bubble clouds are organized into long, narrow plumes aligned with the wind, consistent with windrows caused by Langmuir circulations. They have widths of about 3 to 5 m and lengths up to 100 m, with multiple scales coexisting. Their mean separation depends upon wind speed: below 5 m s^{-1}, mean spacings were about 5 m, increasing to 10 m when winds exceeded 10 m s^{-1}. The maximum depth to which the plumes were observed to penetrate depended to some extent on wind speed, with the greatest penetrations of 12 m occurring at the highest wind speeds (13 m s^{-1}). However, the time-averaged depth of observed bubble plume penetration bears only a weak dependence on wind speed. Whenever winds exceeded 5 m s^{-1}, a mean penetration depth of 6 m was observed. Associated with these bubble plumes were maximum downward velocities of about 0.06 m s^{-1}. These speeds were detected at 8 m depth in the center of the plumes; magnitudes decreased to zero near the surface and horizontally toward the boundaries of the plumes.

1. INTRODUCTION

Wave action, turbulence, and the complexities of a two-phase flow present significant challenges to the study of ocean surface phenomena. Although new measurement approaches are evolving to meet this challenge, our understanding of near-surface processes in the ocean remains limited. This is reflected, for example, in the continuing reliance on one dimensional models for predicting ocean mixed layer response [*McCormick and Meadows*, 1988]. Such models bury the details of mixing and momentum transfer in approximate parameterizations. The purpose of the present study is to contribute to the growing body of knowledge of two- and three-dimensional mechanisms that underlie these processes. Our measurements were focused on the processes at and just beneath the ocean surface and made use of various acoustical techniques.

The acoustical study of surface processes can be made both with active and passive devices. Active sonar is effective at identifying the surface itself and the clouds of bubbles that occur beneath a wind-driven surface. Passive measurement of the naturally occurring sound is particularly useful for the study of breaking waves, which appear to be a dominant acoustical source, as well as providing a background signal level that is closely related to the wind speed.

There have been numerous reports on bubble clouds created by breaking waves. These include various optical and acoustical attempts to infer bubble size distributions [e.g., *Walsh and Mulhearn*, 1987; *Medwin and Breitz*, 1989; *Farmer and Vagle*, 1989] as well as echo sounder studies of bubble concentration and spatial patterns such as those pioneered by Aleksandrov and Vaindruk, 1974 (as referenced by *Thorpe* [1982]) and vigorously developed by Thorpe and colleagues. In particular, *Thorpe and Hall* [1983] obtained images of horizontal features aligned with the wind which they attribute to the effects of Langmuir circulation.

The presence of Langmuir circulation in the open ocean has been demonstrated by *Weller and Price* [1988]. Weller and Price used modified vector averaging current meters (VACMs) deployed from Research Platform FLIP so as to obtain three-dimensional velocity observations through the ocean mixed layer. These revealed a downward component of velocity up to 0.3 m s^{-1} beneath windrows associated with Langmuir circulation. Although Weller and Price could not make instantaneous profiles with depth, their extensive set of measurements showed that the maximum vertical velocities occurred at about 20 m depth and that there was a coincident maximum in the horizontal downwind velocity of about the same magnitude.

Doppler sonar observations of the velocity field by *Smith et al.* [1987] (coordinated with the observations of Weller and Price) showed that some of the Langmuir cells documented by Weller and Price had spacings of up to 100 m. Visual observations of windrows indicated coexisting smaller scales down to several meters but their sonar system was restricted to a 23 m resolution. The large windrows were up to 2 km long and persisted for periods of at least 2 hours.

These studies help to identify the processes that are important to mixed layer dynamics. Breaking wind waves are important to the transfer of momentum between the atmosphere and ocean; they also inject bubbles into the ocean surface. When present, Langmuir circulation (at a variety of

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Surface Wave Period Modulations in Near Surface Ambient Sound

by

Len Zedel[1] and David Farmer[2]

September 18, 1991

1. Department of Oceanography, University of British Columbia, Vancouver, British Columbia V6T 1W5, Canada.

2. Institute of Ocean Sciences, Sidney, British Columbia V8L 4B2, Canada.

1 Abstract

Observations of near surface, high frequency ambient sound in the deep ocean demonstrate modulations at surface wave frequencies. Ambient sound was recorded at frequencies of 2 to 20 kHz at 30 m depth for a total of 65 hours through a variety of sea state and wind conditions. Throughout these observations, modulations in ambient sound level occur at surface wave frequencies and are in phase with the wave displacements directly above the acoustic observations. The modulations are present at all frequencies within the recorded bandwidth but are largest at higher frequencies; at 8 kHz, fluctuations in signal level of about 5 dB occur. A model which assumes continuous sound generation along the ocean surface with source levels adjusted in proportion to wave parameters is developed. Results from this model suggest that sound sources must be closely spaced compared to the dominant surface wave lengths to reproduce the observed fluctuations. For the data analyzed, sound sources must be continuous on a scale of 6 m or less to account for the observations. A possible cause for sound generation consistent with these observations is small wave breaking events triggered either by long wave short wave interactions, or by variations in wind stress over the long waves.

Deep Ocean Wave Measurements Using Upward Looking Sonar

by

Len Zedel[1] and David Farmer[2]

September 20, 1991

1. Department of Oceanography, University of British Columbia, Vancouver, British Columbia V6T 1W5, Canada.

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1 Abstract

Upward looking 200 kHz sonar is used to make estimates of (one dimensional) surface wave spectra. Two independent approaches are used to determine wave spectra from this system; direct measurement of surface range, and the vertical velocity estimate of the surface. The wave spectra estimated by this system are compared with observations from a Datawell Waverider buoy positioned directly above the acoustic system. Comparisons are provided for relatively calm conditions and also during a period of mixed swell and wind waves forced by a 13 ms^{-1} wind. Wave spectra from the three estimates appear qualitatively similar and agree in total wave energy density to within 10%.

Acoustical Current and Vorticity Measurements Beneath an Arctic Floe*

Dimitris Menemenlis† David M. Farmer‡

October 11, 1991

Abstract— **An acoustical instrument has been developed to measure path-averaged horizontal current and vorticity in the sub-ice boundary layer of the Eastern Arctic during the Spring of 1989. Transducers capable of both transmission and reception at 132 kHz formed the corners of a horizontal triangle of side 200 m. Measurements were made at depths of 8, 10, 20 and 85 m. Quadrature sampling is used to resolve the phase of the coded acoustic arrivals and measure travel time to within a small fraction of the carrier period. Mean current along each acoustic path is proportional to travel time difference between reciprocal transmissions. The instrument measures horizontal circulation and average vorticity relative to the ice, at length scales characteristic of high frequency internal waves in the region. The rms noise level of the measurements is less than 0.1 mm/s for velocity measurements and 0.01 f for vorticity, averaged over one minute. Except near the mechanical resonance frequency of the moorings, measurement accuracy is limited by multipath interference.**

Keywords— **acoustical current meter, vorticity, arctic boundary layer.**

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