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Your file Votre référence

Our file Notre référence

5 February, 1992

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

Dear Alan,

I enclose a final technical report on contract N00014-91-J-1036 relating to SWAPP. I also enclose four preprints that have arisen from this research. All of these are in the category of "Accepted for Publication", and will appear this year.

Although this contract is technically finished, I would like to emphasize that the *publications are only just the beginning.* Now that we have demonstrated the validity of our technological approach, we are moving along with the science. The bubble measurements are leading to (a) better descriptions of bubble size distribution under different wind conditions (with Svein Vagle), (b) better descriptions of the spatial patterns due to Langmuir circulation (with Al Plueddemann and others), and (c) calculation of the influence of bubbles on gas flux (with my student Craig McNeil).

The critical comparison of our breaking wave properties with model results depends upon directional wave spectra to be provided courtesy of Jerry Smith. We hope these will soon arrive and allow us to carry out a particularly intriguing component of SWAPP science.

In concluding this contract I would like to record my appreciation for having had the opportunity of working on a particularly fascinating and challenging project.

Yours sincerely,

David

David Farmer

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Encl. Ding, Li, and D.M. Farmer, A signal processing scheme for passive acoustical mapping of breaking surface waves, to appear in *J. Atmosph. & Ocean. Tech.*

Farmer, D.M., and L. Ding, Coherent acoustical radiation from breaking waves, to appear in *J. Acoust. Soc. Am.*.

Farmer, David M., and S. Vagle, Bubbles near the ocean surface, to appear in *Acoust. Bull.*

Vagle, S., and D.M. Farmer, The measurement of bubble size distributions by acoustical backscatter, to appear in *J. Atmos & Ocean. Tech.*, 1 July, 1992.

Zedel, L., and D.M. Farmer, Surface wave period modulation in near surface ambient sound, submitted to *J. Geophys. Res.*

cc DTIC
Administrative Grants Officer

Statement A per telecon Dr. Alan Brandt
ONR/Code 1122
Arlington, VA. 22217-5000

NWW 3/13/92

Final Technical Report: Acoustic Studies of Ocean Surface Processes in SWAPP

Contract: N00014-91-J-1036
D. M. Farmer
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P.O. Box 6000
Sidney, B.C. V8L 4B2

This report covers work done as a result of participation in the SWAPP cruise in conjunction with FLIP. We participated with the IOS vessel PARIZEAU and obtained extensive data sets using two rather novel approaches. We used Active sonar systems to detect bubble clouds and bubble size distributions, and Passive hydrophones to map the distribution and properties of breaking surface waves. Each of these approaches not only involved the development of specialized hardware, but also required development of novel signal processing schemes so as to handle the very high data rates. Each approach is described in sequence. A publication list resulting from this work is also included.

Active Sonar Observations of Bubble Clouds

The drifting sonar developed at IOS detects bubbles both with 'fan-beam' sidescan sonars which are directed almost horizontally, and with vertically oriented narrow-beam sonars. These sonars are deployed on self-contained internally recording instrument suspended at a depth of 25-30m from a small float using a rubber bungy cord (Figure 1). The rubber cord serves to decouple the instrument from rapid wave-induced motions at the surface. The added mass of water near the upper and lower damper plates effectively restrains the instrument's motion to residual orbital displacements of the swell. This rather modest motion is readily detected with an accelerometer and tiltmeters, and corrections are made in the data analysis where appropriate. Additional sensors, which are not discussed here, include an array of broad band hydrophones for detecting breaking surface waves; a more complete technical description of the instrument is given by Farmer, Teichrob, Elder & Sieberg, 1990.

The vertical structure of the bubble clouds can be probed with the vertically oriented sonars. Vertical sonars transmit simultaneously with the fan-beam sonars at intervals of 0.6s. Operating at six frequencies (28kHz to 400kHz) with a pulse length of only 0.5ms, they can be used to detect the bubble concentration at different resonant radii with a range resolution of 37cm. Figure 2 shows a short section of target strength as a function of depth and time at 120kHz. Target strength measurements are referenced to the sea surface, which therefore appears flat in the image. The surface itself is identified by a steep rise in signal strength (Vagle and Farmer, at press) The bubbles move slowly relative to the orbital wave displacements. Care must therefore be taken to correct the apparent depth scale distortion for each transmission, due to the effect of surface waves. This is carried out using the dispersion relation for deep water gravity waves, with the correction applied for each Fourier component of the measured surface displacement time series.

The analysis technique involves a fast algorithm for numerical inversion of the data to recover bubble size distributions as a function of depth and time. Initially, an iterative technique was developed to take account of the fact that acoustic resonance 'tails' ensure that some of the signal detected at a given frequency is contaminated by reflections from bubbles of radius different to the resonant radius. Although accurate, this approach proved too time-consuming for the processing of large data sets.

A second technique was developed that used analytic representations of the bubble response function so as to calculate bubble size distributions directly. The algorithm was incorporated on a fast signal processing board (AT&T), allowing real time processing of the data as it is read. A description of this technique, together with some results is given in the enclosed paper (Vagle & Farmer, at press). A detailed analysis is also given of various errors that can occur in this type of measurement. Figure 3 shows a short time sequence of bubble size distributions. Over the few minutes represented by this sequence, a significant increase in the relative proportion of larger bubbles occurs, almost certainly associated with a downwelling of bubbles from the surface. The size distributions are clearly related to near-surface circulation. In addition to being passive tracers of near-surface flow, bubbles play a very significant role in enhancing air-sea gas flux. Effort is presently being invested in modelling the SWAPP bubble field for the two primary species (Nitrogen, Oxygen).

Sidescan sonar measurements of near surface bubble clouds show coherent features that may be identified with Langmuir circulation (Thorpe, 1982; Thorpe, 1984; Zedel & Farmer, 1991). The acoustical visualization arises from the clouds of small bubbles introduced to the surface layer by breaking waves. The bubbles that are of interest here are not those which can be visually observed as whitecaps, and which have a lifetime of just a few seconds, but microbubbles of radius 20-400 microns which persist in clouds for several minutes.

The sidescan sonars operate at 100kHz. They are therefore primarily sensitive to bubbles of radius 32 microns which are resonant at this frequency. The general concept that seems applicable in this case is that microbubble clouds, which might be randomly injected by breaking waves at the surface, collect in Langmuir convergence zones. The smaller bubbles are drawn downwards and probably go into solution at a depth of order 10m; larger bubbles may rise to the surface. A bubble of radius 32 microns has a rise speed of approximately 0.3cm/s (Thorpe, 1982), which may be compared with average measured downwelling speeds in Langmuir convergence zones of 2-6cm/s (Zedel & Farmer, 1991).

A sidescan sonar directed perpendicular to the wind direction will therefore look across rows of bubble clouds collecting in successive Langmuir convergence zones. Normally there will be some cross-wind component of drift of the instrument, so that the convergence zones will gradually change position with respect to the measurement range. Thus, signal intensity displayed on a plot of range against time will show a sequence of thick lines, the slopes of which are determined by the cross-wind drift rate (Figure 4). Such images provide a basis for inferring Langmuir cell spacing and related properties. When the sonar is directed upwind or downwind, the well defined streaks appearing in Figure 4 are replaced by a mottled image. It is likely that in this case the sonar is primarily sensitive to deeper or denser parts of the bubble clouds which are evidently not distributed in any readily apparent and coherent fashion.

The fan-beam sonars provide signal strengths (and Doppler shift which was not used from this instrument in SWAPP) as a function of range. At any given range the insonified volume describes a narrow but deep element of spherical surface approximating an arc. There is no discrimination as to the depth of the target and our interpretation is based on independent knowledge that the bubble clouds are confined to the surface layer; nevertheless the scatter is presumably distributed with respect to depth. It is interesting that the scatter due to bubbles far exceeds that from the sea surface at the shallow angles used with fan-beam sonars.

In general, target strength of the vertical bubble soundings decays exponentially with distance from the surface, with an e-folding depth of 1-3m. But there is very great temporal variability, both in the concentration, penetration depth and other bubble distribution parameters. The relationship between these vertical profiles of acoustic backscatter and the sidescan images is discussed in Zedel & Farmer (1991). It is evident from this that the coherent streaks of high backscatter detected with the fan-beam sonars are coincident with the bubble clouds detected with the vertical sonars. On the other hand, the relationship between depth or strength of the vertical profiles with the target strength of the corresponding signature in the fan-beam records is not always so well defined.

Passive Acoustical Measurements of Breaking Surface Waves

An important goal of our contribution to SWAPP was the determination of the distribution and properties of breaking surface waves. The plan was to detect these with a very simple hydrophone array using the time-delay processing technique. Having determined these properties, the intended analytical approach was to carry out comparisons with modelled wave-breaking using directional spectra obtained from FLIP.

As in the case of the active sonar techniques, specialized digital signal processing software had to be developed. Some risk was inherent in the experiment, as we had no *a priori* evidence that the technique would actually work. Fortunately, it turns out that the breaking events can, in fact, be precisely located even with such a simple array. Signal processing posed a very significant challenge because of the very high data rates. The techniques finally adopted are described in the accompanying paper (Ding & Farmer, at press), and were successfully implemented for real time processing on a Motorola 56001 chip.

The analysis did lead to an unexpected finding. The signal coherence between our spaced hydrophones yielded a coherence that was highly anisotropic. This anisotropy turns out to be due to the anisotropic spatial extent of the source (quite obvious with hindsight!). This result is discussed and modelled in Farmer & Ding (1992), where it is argued that the coherence field itself provides additional information with which to probe the source.

Figure 5 shows an example of coherence for two hydrophone pairs, and Figure 6 shows some results of the calculated properties of breaking event distributions during a short portion of the SWAPP experiment. It is apparent that, for example, the direction of propagation is not simply the wind direction or the somewhat different swell direction, but is distributed between them.

A second feature of the ambient sound is the apparent modulation of the field at the dominant wave frequency, with the maximum value being just beneath the wave crest. This issue has been pursued in the paper Zedel & Farmer (submitted), a copy of which is also enclosed. Detailed numerical modelling suggests that in this case the source is distributed, rather than concentrated in localized bursts, as inferred from the hydrophone array measurements. We think we are probably seeing evidence of small capillary or very short-scale waves breaking at the wave crest. This is an issue worth pursuing further, because selective phase locked wave-breaking of this sort could be a useful probe of energy extraction from the wave field (depending on the precise phase involved).

A primary goal outstanding is the reconciliation of the observed properties such as speed, duration, direction, group structure, etc., with predictions based on a linear surface wave representation. (A non-linear model has also been implemented, but is not expected to be significantly different.) This next stage awaits the availability of essential FLIP directional wave spectrum data to be supplied by Jerry Smith.

Bibliography

Ding, Li, and D.M. Farmer, A signal processing scheme for passive acoustical mapping of breaking surface waves, to appear in *J. Atmosph. & Ocean. Tech.*

Farmer, D.M., and L. Ding, Coherent acoustical radiation from breaking waves, to appear in *J. Acoust. Soc. Am.*.

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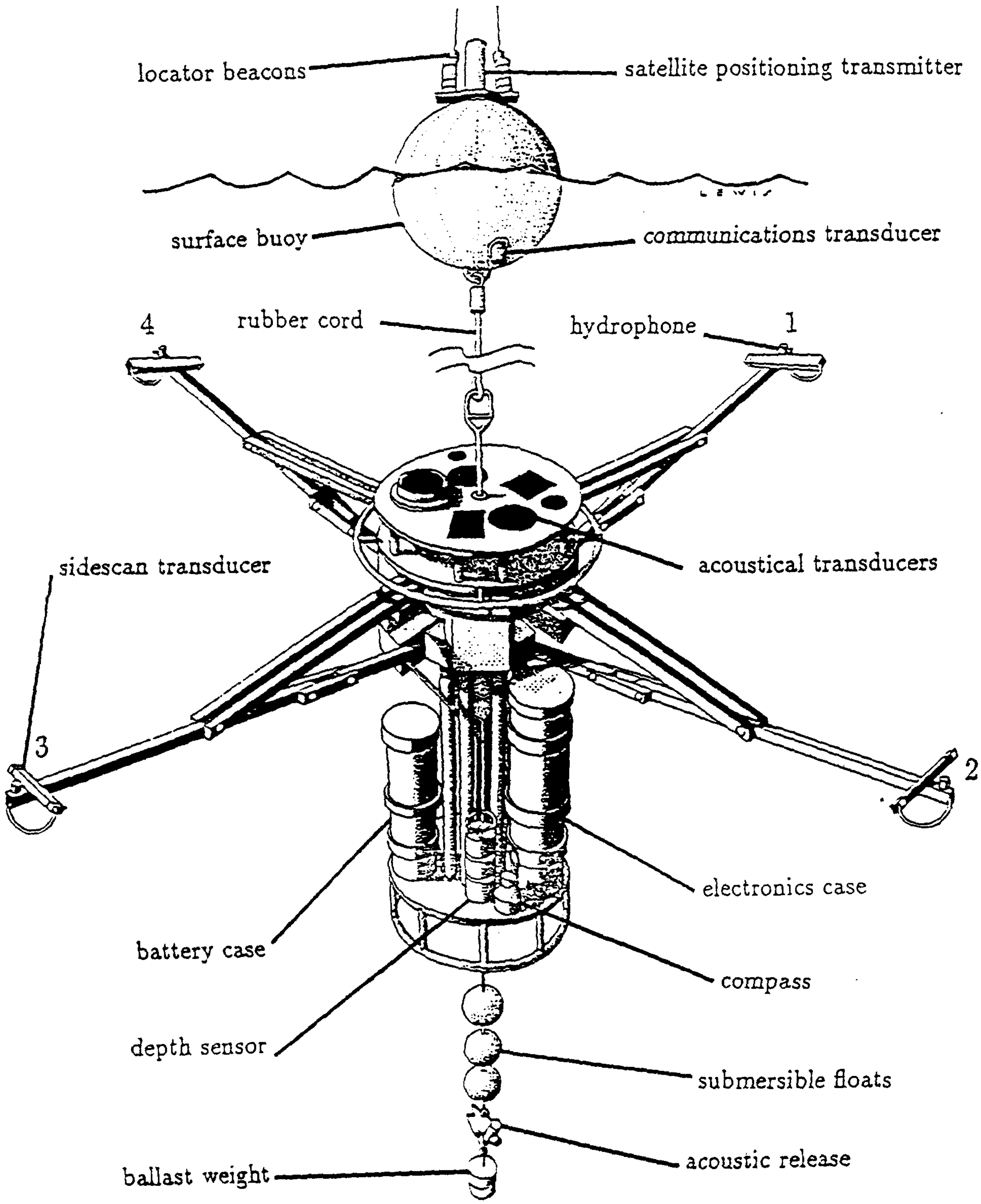
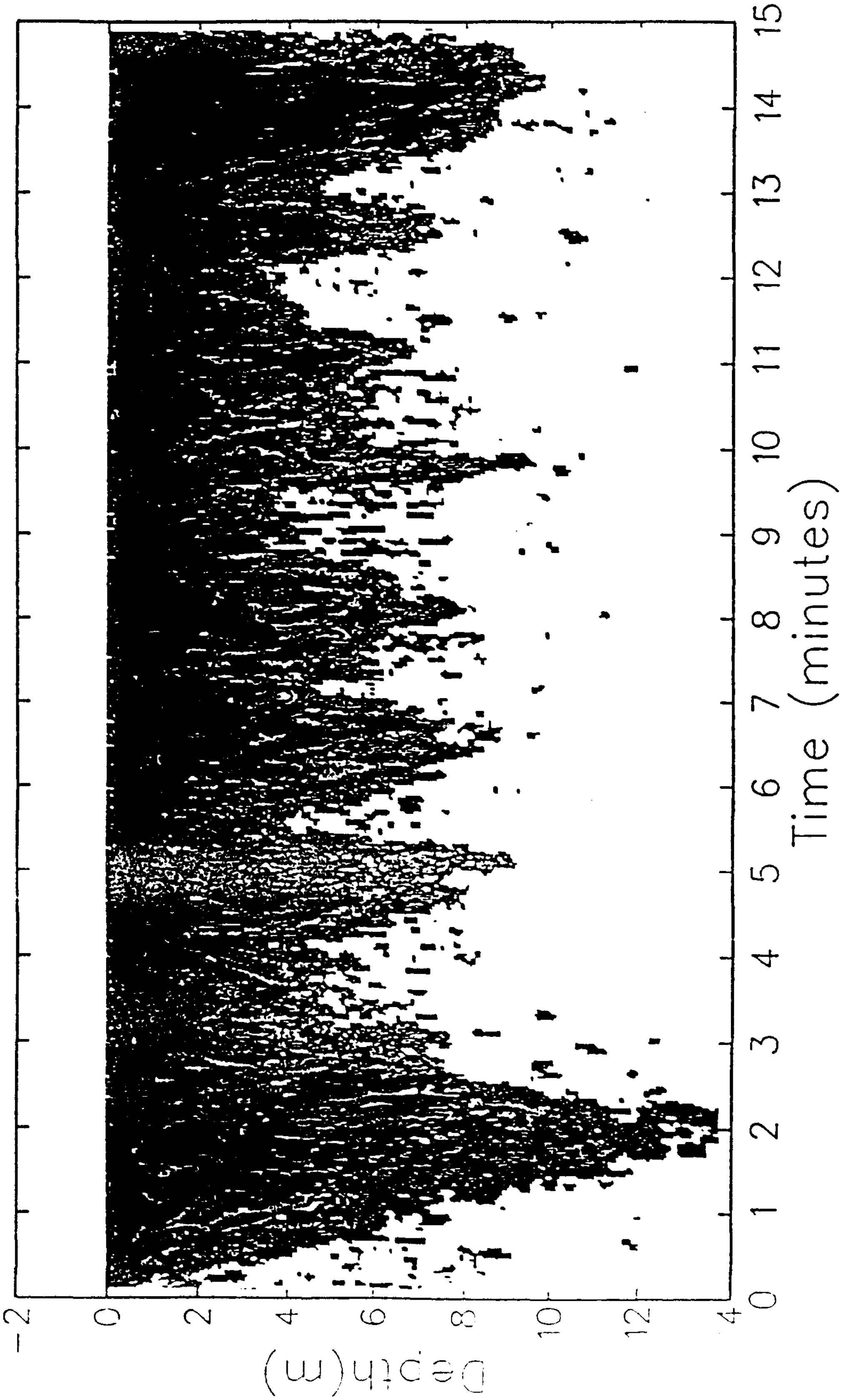
Zedel, L., and D.M. Farmer, Surface wave period modulation in near surface ambient sound, submitted to *J. Geophys. Res.*

Farmer, D.M., R.C. Teichrob, C.J. Elder and D.G. Sieberg, 1990, Novel acoustical instrumentation for the study of ocean surface processes, *IEEE-OCEANS* '90.



locator beacons
satellite positioning transmitter
surface buoy
communications transducer
4
rubber cord
hydrophone
1
sidescan transducer
acoustical transducers
3
2
electronics case
battery case
compass
depth sensor
submersible floats
acoustic release
ballast weight

Figure 1.



Time (minutes)
Depth (m)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
-2
0
2
4
6
8
10
12
14

Figure 2.

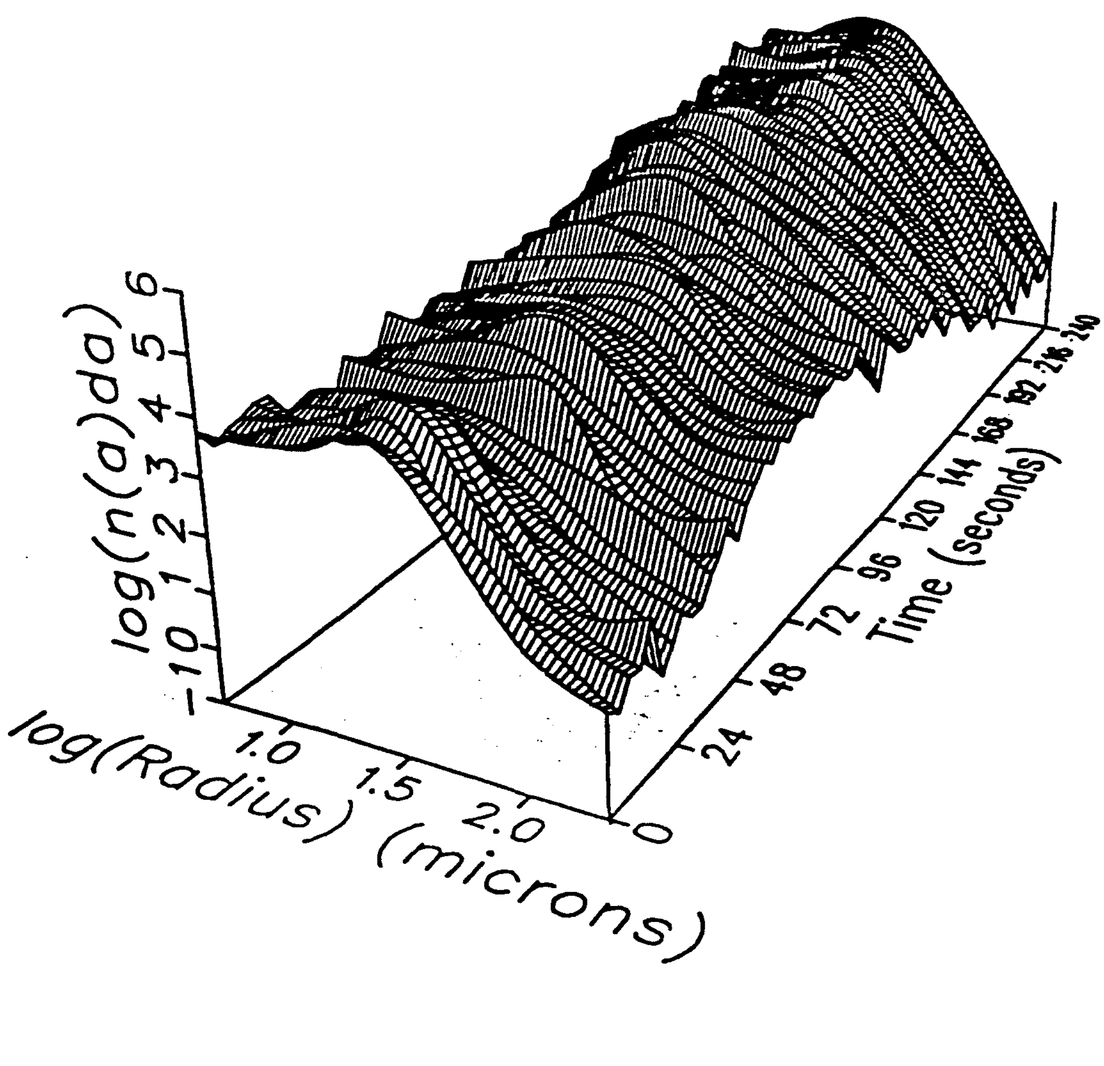

log(n(a)da)
-1
0
1
2
3
4
5
6
log(Radius) (microns)
1.0
1.5
2.0
Time (seconds)
0
24
48
72
96
120
144
168
192
216
240

Figure 3.

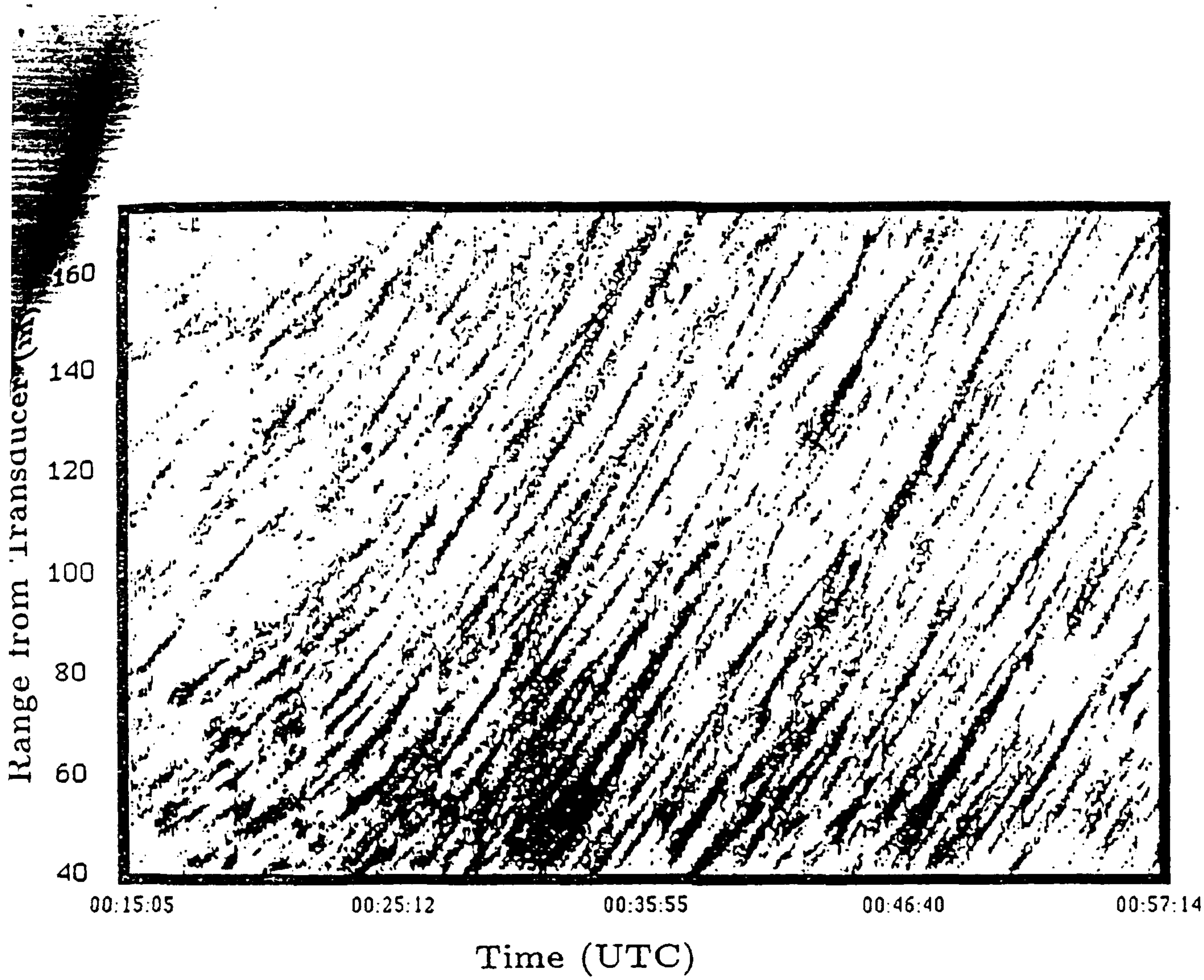
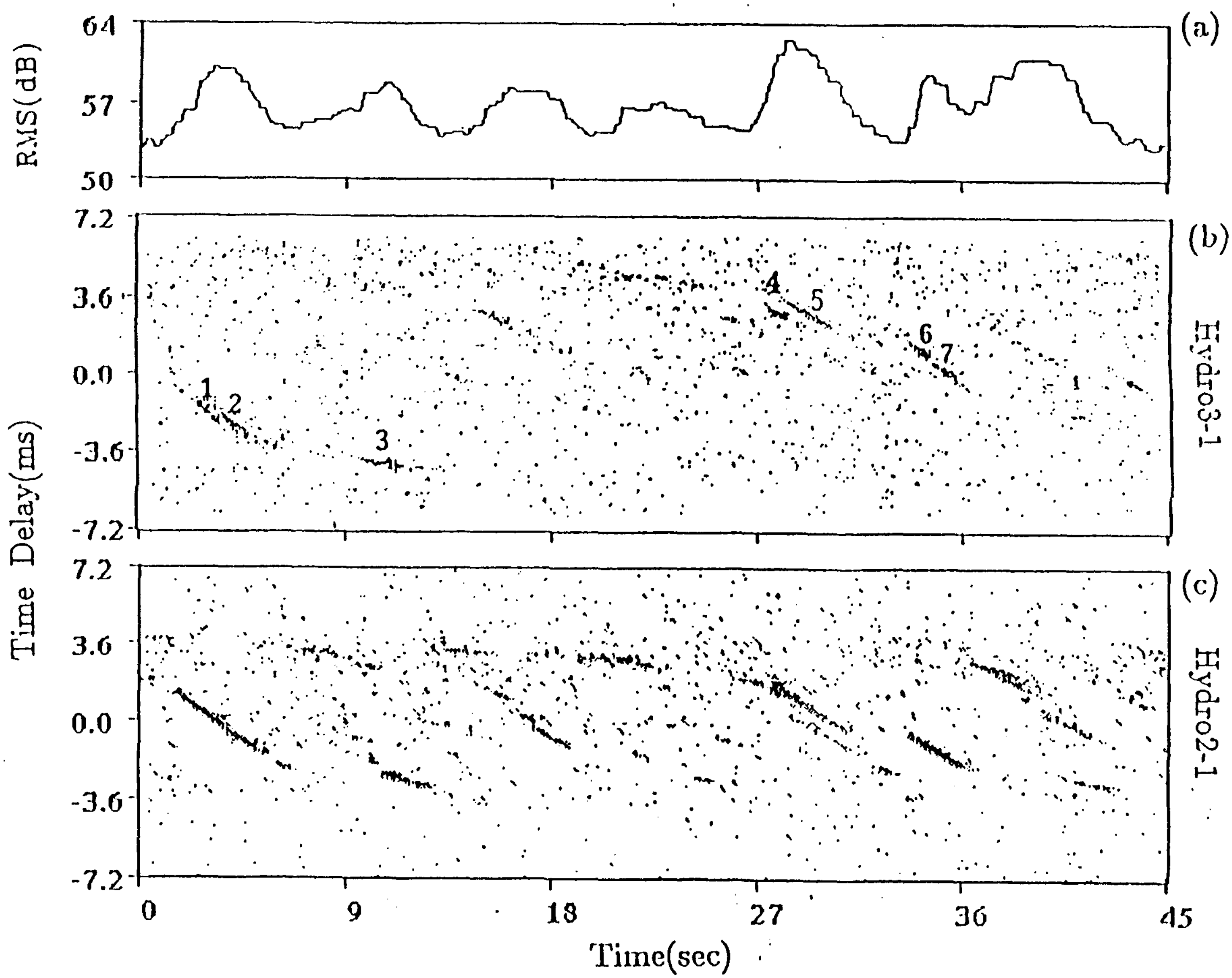
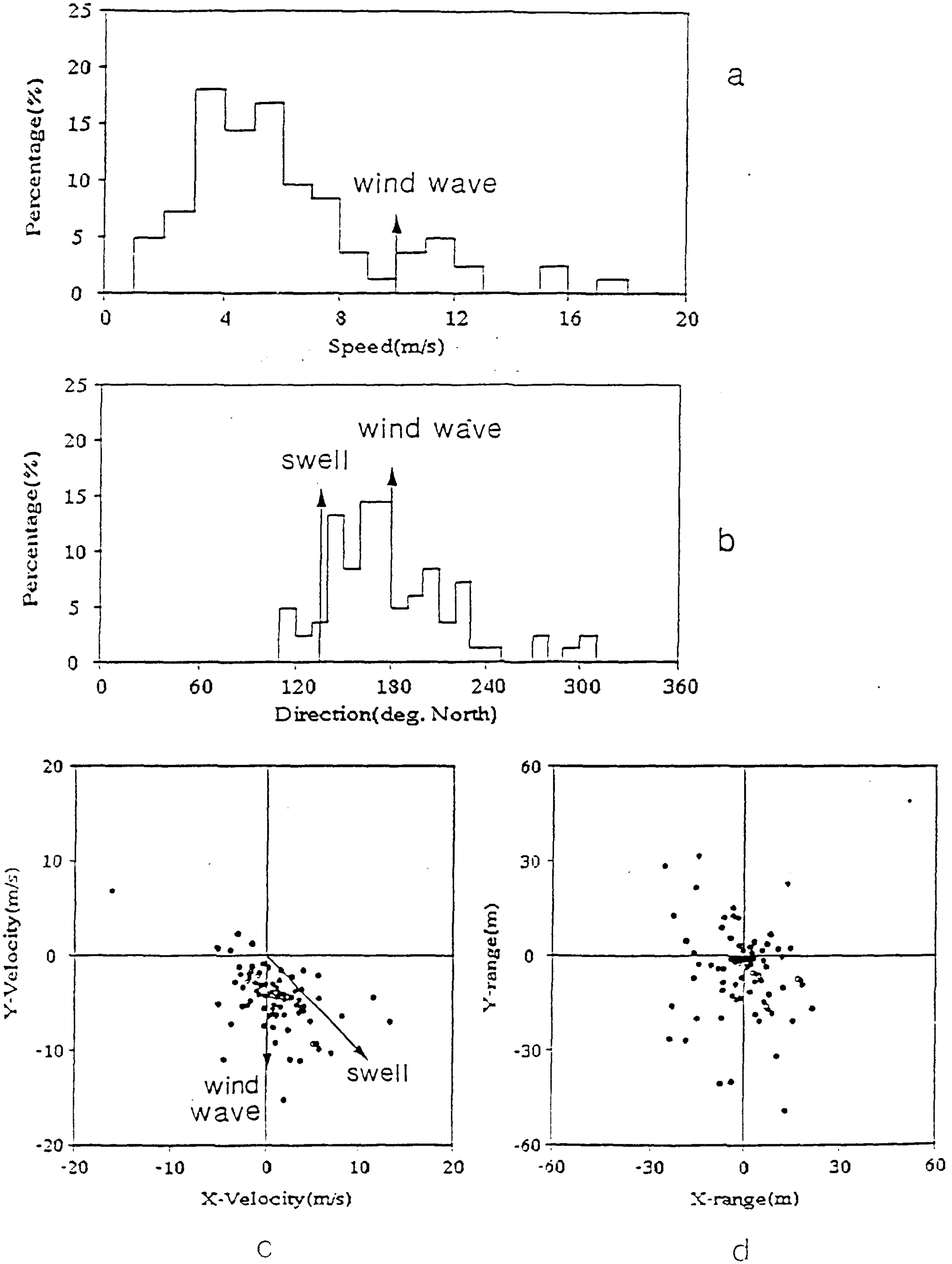

Range from Transducer (m)
160
140
120
100
80
60
40
00:15:05
00:25:12
00:35:55
00:46:40
00:57:14
Time (UTC)

Figure 4.

Figure



(a)
(b)
Hydro3-1
(c)
Hydro2-1
RMS(dB)
64
57
50
Time Delay(ms)
7.2
3.6
0.0
-3.6
-7.2
1
2
3
4
5
6
7
0
9
18
27
36
45
Time(sec)



a
wind wave
Percentage(%)
Speed(m/s)
b
wind wave
swell
Percentage(%)
Direction(deg. North)
swell
wind
wave
Y-Velocity(m/s)
X-Velocity(m/s)
c
Y-range(m)
X-range(m)
d

Figure 6.