Report on the Scripps Pier Bubble Experiment, Spring 1997

by Peter H. Dahl

Technical Memorandum
APL-UW TM 3-97
April 1997

Applied Physics Laboratory University of Washington
1013 NE 40th Street Seattle, Washington 98105-6698

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1. INTRODUCTION

This report provides an overview of the data gathered by APL-UW using its SALMON (Shallow water Acoustic Lightweight MONitor) system during the Scripps Pier Bubble Experiment conducted 24 February – 14 March off the Scripps pier facility in San Diego.

The primary objective of the experiment was to measure properties of a bubble field, such as its spatial and temporal scales, its density, and its size distribution, within a near-shore environment, this effort serving as a pilot experiment for a future, full-scale experiment on this subject. Data from this and future experiments will be interpreted vis-à-vis the coastal oceanography and used to model the effect of bubbly environments on sonar system performance.

2. EXPERIMENT

To accomplish this objective, instruments for measuring bubbles, ambient noise, CTD data, currents, and surface waves were assembled from NRL-SSC, IOS, APL-UW, SIO, NCPA, and NRL-DC, and deployed off the north side of the Scripps pier. Drs. Jerald Caruthers (NRL-SSC) and Steve Stanic (NRL-SSC) were responsible for overall coordination of the experiment.

The SALMON system (Fig. 1) consists of four upward-looking transducers (frequency 240 kHz), which simultaneously measure vertical profiles of acoustic volume scattering from bubbles from four separate locations. The data from this system will be used to estimate

- the vertical scales and vertical transport of the bubble field
- large-scale horizontal features and horizontal transport of the bubble field through inter-comparison of the four spatially separated transducers
- temporal fluctuations in acoustic scattering and attenuation due to both time variation within the bubble field and advection processes

in support of the primary experimental objective described above. The acoustic volume scattering data will also be compared with the other measures of bubble density and size distribution obtained during the experiment.

The four transducers each transmitted a 6° beam simultaneously at 0.5-s intervals; the pulse length was 0.1 ms, giving a vertical resolution of approximately 8 cm. Each unit was equipped with a pressure gauge and tilt meter. Pressure data were

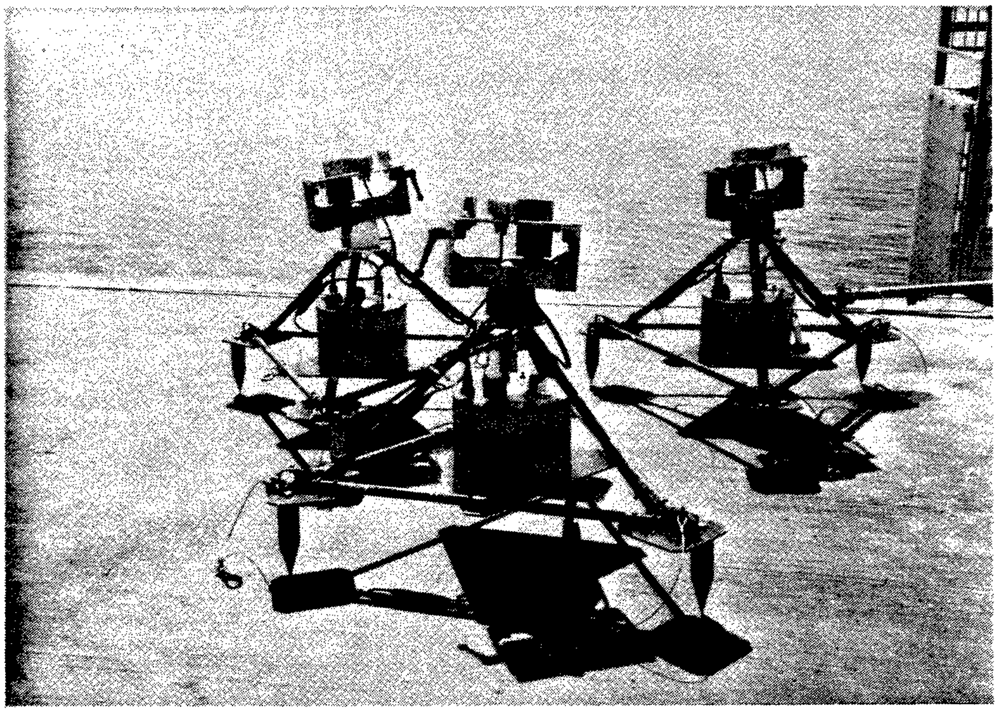

Figure 1. Photograph of three of the four units that compose the SALMON system, made just prior to deployment off the Scripps pier. The base of the tripod is approximately 1 m.

recorded simultaneously along with the acoustic data but at 0.25-s intervals; these data will used for determining the location of the air/sea interface during periods of severe acoustic attenuation from bubbles. Figure 2 displays a surface waveheight spectrum measured by the pressure gauge within one of the units, showing a swell peak frequency of 0.12 Hz. The tilt meters were used to verify transducer orientation as mentioned further below.

The NRL-SSC Delta Frame, an equilateral triangle with sides of approximately 10 m, established the primary locus of measurement activity for instruments fielded by NRL-SSC and IOS. Figure 3 shows the location of the Delta Frame with respect to the Scripps pier and the location of the four SALMON transducers. Two of four transducers (numbers 1 and 2) were located along a line parallel to the anticipated seaward flow of bubbles, and two transducers (numbers 3 and 4) were offset. This layout was intended to maximize ability to measure the (larger) spatial scales of the bubble field as it advected over the Delta Frame area. Acoustic transmissions and data-gathering periods for the SALMON system and all instruments located on, or within the vicinity of, the Delta Frame were synchronized with each other using timing pulses provided by Steve Stanic.

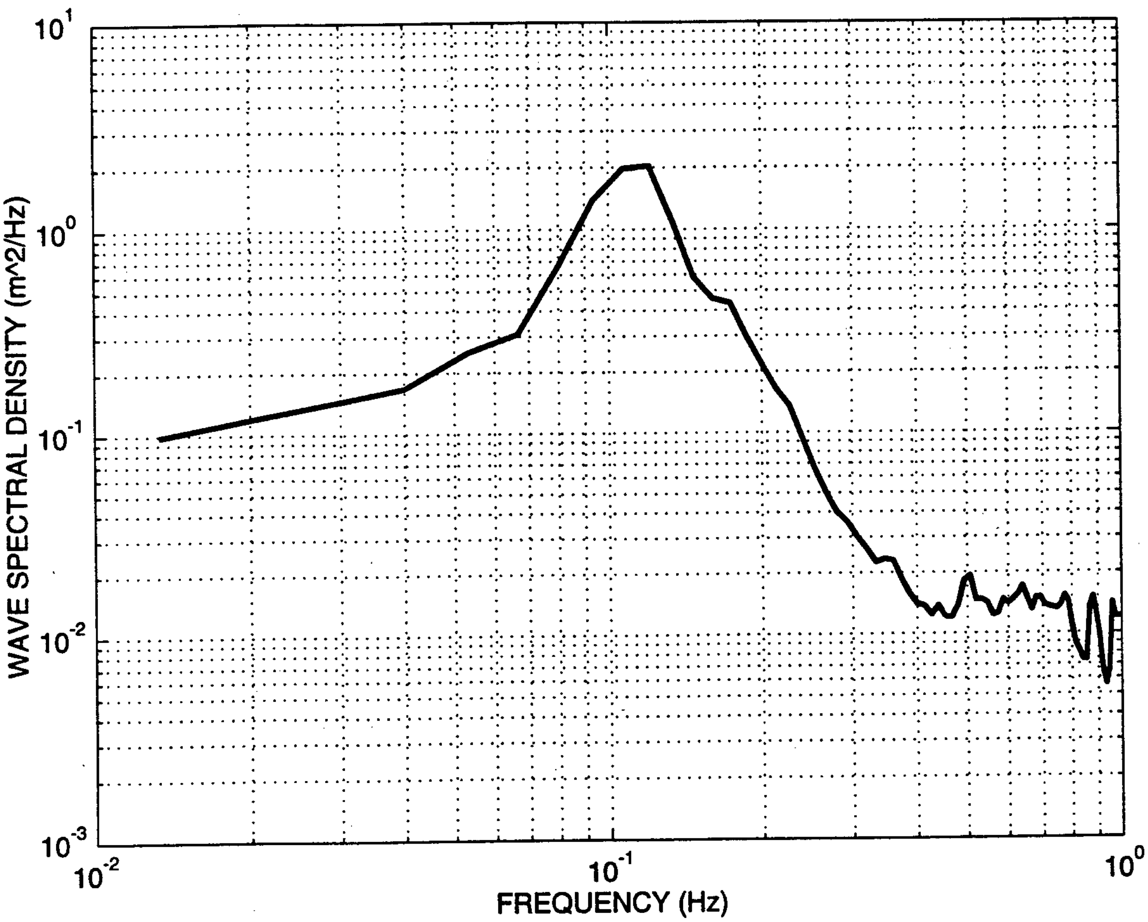

Figure 2. Typical surface waveheight spectrum showing a swell peak at about 0.12 Hz. The spectrum was taken during Run 10 with unit 3's pressure gauge.

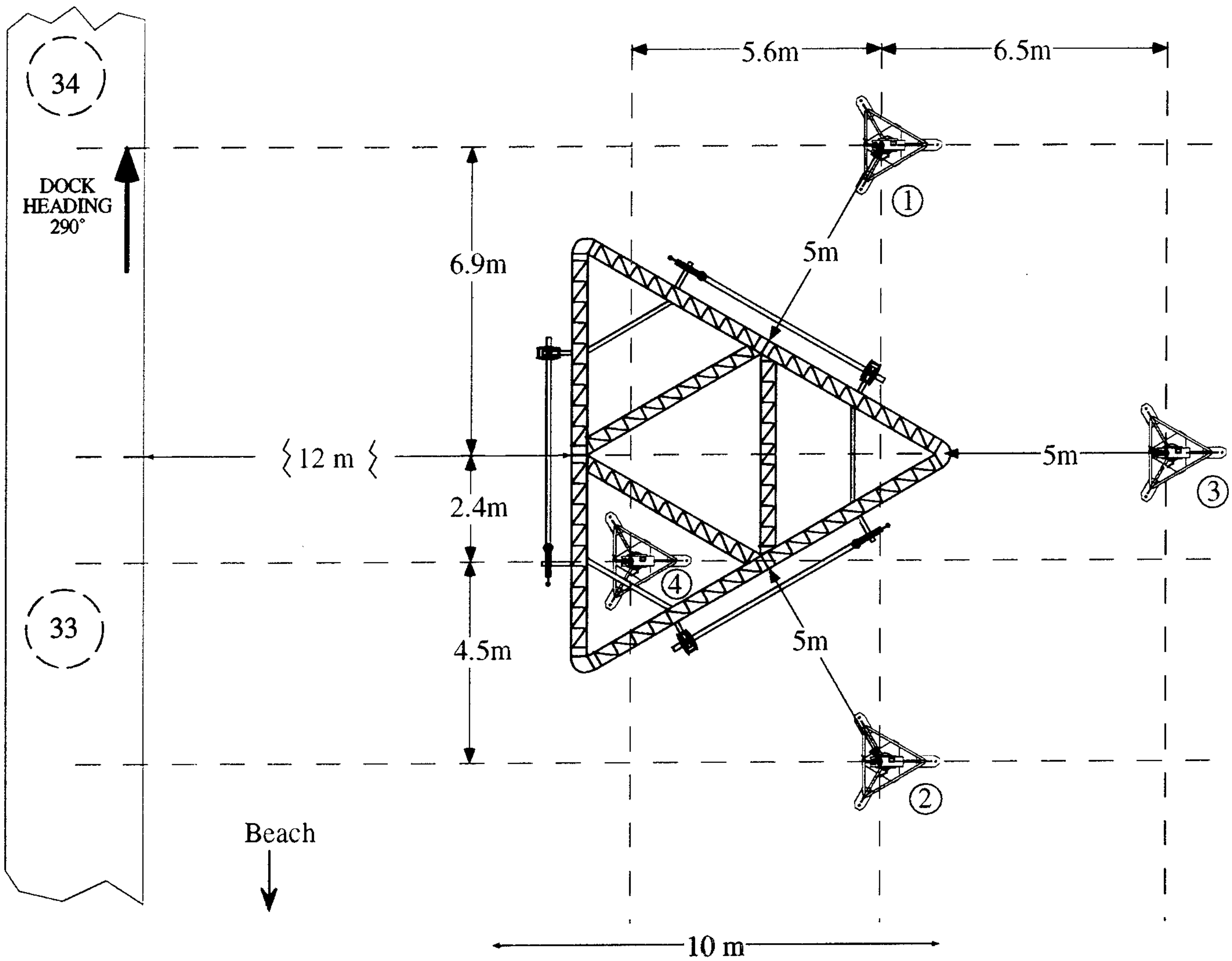

Figure 3. Plan view and grid of the experimental area showing NRL-SSC Delta Frame and locations of the four transducers.

There were 10 synchronized runs, each lasting between 90 and 120 min. The start times, defined here as the start of the first transmit pulse sent out simultaneously by the four transducers, are given below for each run.

Synchronized Run No.	Date and Start Time
1	5 March 08:28:24
2	5 March 15:44:42
3	6 March 10:15:00
4	7 March 09:20:57
5	7 March 14:01:06
6	8 March 09:14:18
7	8 March 14:26:09
8	10 March 08:44:00
9	10 March 15:54:04
10	12 March 16:00:31

Of the ten runs, the most notable were Runs 5 and 7, during which several rip-current events were observed both visually (as a seaward flow on the surface) and with the various bubble-measurement instruments, as these currents transported bubbles into the measurement area. The wind speed was highest (approximately 8 m/s)[1] during Run 10, with some small-scale wave breaking preferentially on the rear face of the swell being observed. More gentle conditions prevailed during the other seven runs. Between Runs 6 and 7 two legs on the Delta Frame gave way, settling the frame onto unit 4, which was located within the frame structure. This caused unit 4 to be tilted 9° during the remainder of the experiment, but no contact was made with the transducer face, and the data from this unit appear normal.

3. FIRST RESULTS AND SCHEDULED ANALYSIS

The transport of bubbles via rip currents is a prominent feature of the bubble environment within the vicinity of a surf zone. The extent to which this environment can change over a very brief period is demonstrated in Figs. 4 and 5, each of which shows a 10-min display of acoustic backscattering vs depth and time (ping number) obtained during Run 7. Data obtained between +30 and +40 min into the run are shown in Fig. 4, and data between +50 and +60 min in Fig. 5. The acoustic data

[1]More precise estimates of wind speed are to be made available.

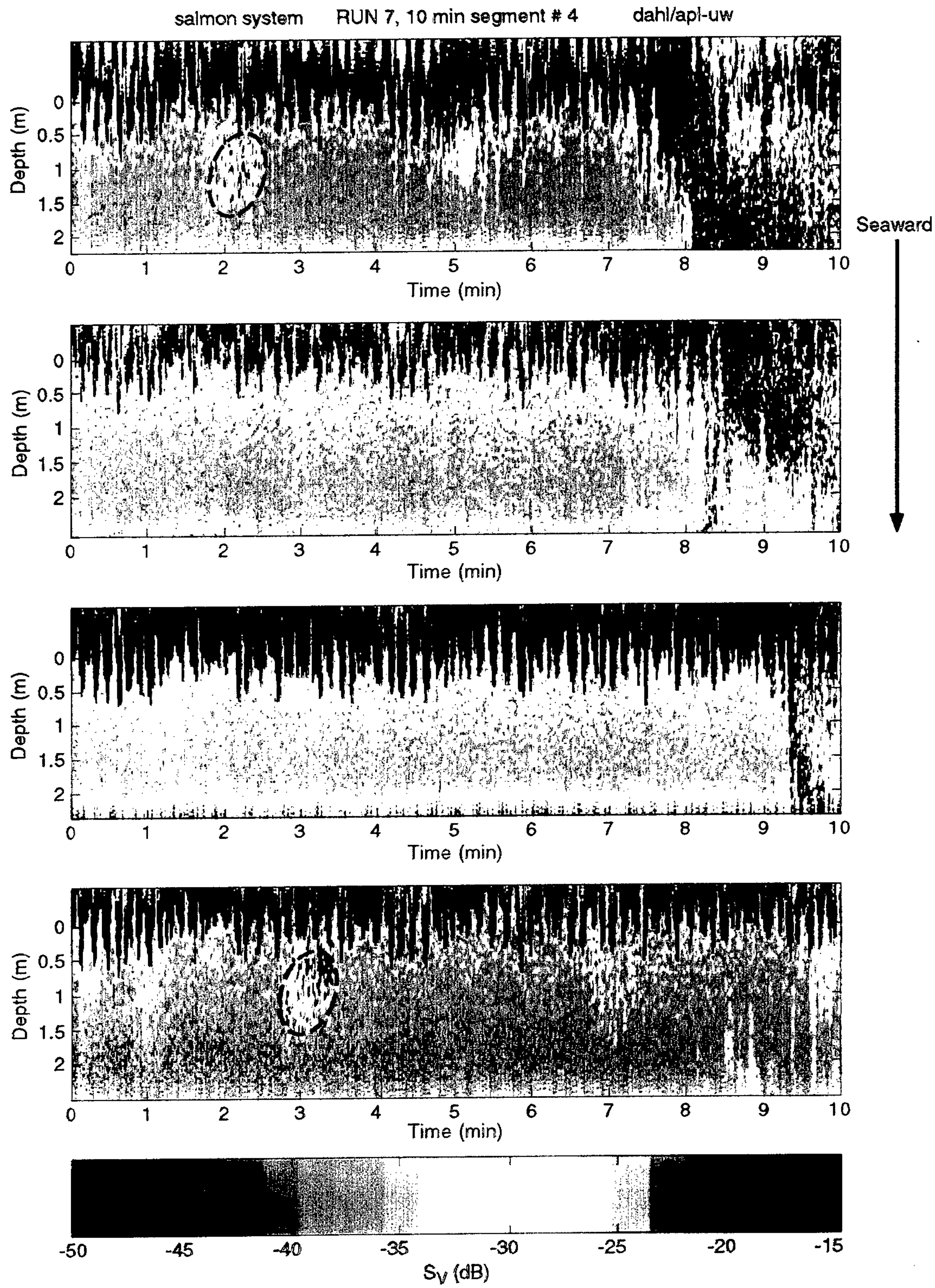

Figure 4. Depth vs time display of S_V (in decibels) as measured at 240 kHz during Run 7, between minutes 30 and 40. The plots are arranged such that their order, from top to bottom, represents the seaward direction, or increasing distance from shore. The feature circumscribed by the black circle in the top and bottom plots is interpreted as a bubble cloud that has advected in the seaward direction along a line connecting transducers number 1 and 2.

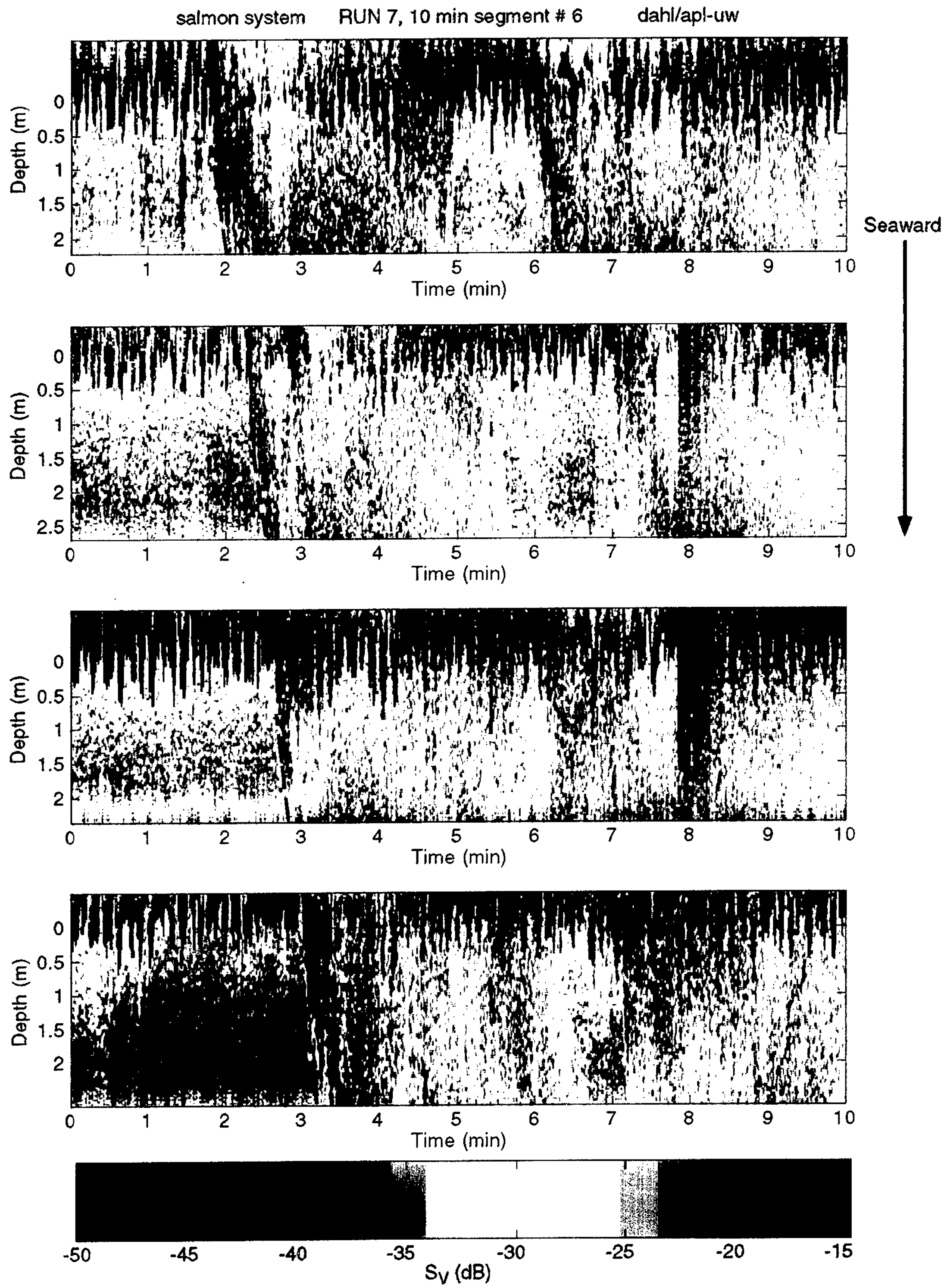

Figure 5. Depth vs time display of S_V (in decibels) as measured at 240 kHz during Run 7, between minutes 50 and 60. The plots are arranged such that their order, from top to bottom, represents the seaward direction, or increasing distance from shore. The abrupt increase in scattering level at minute 2 in the top plot is interpreted as a bubble cloud that subsequently spans the area delimited by the four transducer locations.

have been converted via the sonar equation to backscattering cross section per unit volume per unit solid angle, or s_V, and plotted in decibel form (S_V). The air/sea interface can be seen on the top of each image as the dark brown color[2] with a peak-to-peak waveheight variation on the order of 1 m. The depth axes for each subplot are referenced to the approximate mean-still-water level (this level will be made be more precise later by incorporating the pressure data to recover more exact instantaneous waveheights.)

The plots in each figure are arranged such that their order, from top to bottom, represents the seaward direction, or increasing distance from shore. Thus the advection of bubble clouds via rip currents, for example, will be first observed in the upper plot representing data from unit 2 (see Fig. 3). Figure 4 shows increased scattering from a bubble cloud in the upper plot at about 2 min (circumscribed by black circle), and we assume that this same assemblage of bubbles is the one seen in the lower plot about 60 s later. The 60-s lag suggests an average current speed of about 0.23 m/s, as the inshore and offshore transducers are separated by 13.6 m. The scattering level persists for approximately 30 s in each case; if we invoke Taylor's frozen-turbulence hypothesis, this suggests that the characteristic extent of the bubble cloud in the offshore direction (parallel to the pier) is $\sim$7 m. Furthermore, scattering from this cloud is *not* seen in the data from units 3 and 4 (middle plots), which bounds the cloud's along-shore extent (perpendicular to the pier) to $\leq$10 m. In other words, we interpret this scattering feature as being from a bubble cloud with a horizontal aspect ratio of order unity and a vertical thickness of approximately 1 m, which advects seaward traversing a line connecting transducers number 1 and 2. A much larger scattering feature becomes visible in the upper plot at about 7.5 min, with the onset of enhanced scattering seen in the 2nd and 3rd plots being also consistent with a seaward flow of bubbles.

In Figure 5, each sonar system shows a very abrupt increase in scattering level, as seen, for example, at about 2 min in the top plot. The lag between plots in this case is consistent with an average current speed of about 0.20 m/s. The increased scattering level persists this time on all four units for at least 3 min, suggesting the offshore extent of this cloud feature is about 36 m. Note that the bubble concentration over the inshore transducer is sufficient to temporarily extinguish the sound entirely, as seen by the disappearance of the surface return (at 2.75 min) in the upper plot. There is even a hint of vertical shear in the current, as evidenced by the slight vertical dependence in the onset of scattering. The fact that similar enhanced scattering levels are seen on all four units simultaneously means that the along-shore extent of this

[2]The exact sea-surface scattering level, as shown in this display, cannot be compared with the level of volume scattering from bubbles originating from the water column. Separate estimates of sea-surface scattering strength will be computed in future analysis.

cloud feature is ≥12 m. It may be useful to refer to this cloud feature as a *coherent structure*, i.e., a structure that is spatially organized on a large scale. Shortly after the scattering level dies downs, it increases again, but this time there is less similarity, or coherency, across all four units.

The space-time images of bubble cloud structure, as exemplified in Figs. 4 and 5, provide a framework with which to interpret the measurements made within the Delta Frame. The cloud feature outlined in Fig. 4, for example, was likely detected only by instrumentation located in the vicinity of the right-hand apex of the Delta Frame, provided the cloud did not actually *pass over* the frame. On the other hand, the cloud feature depicted in Fig. 5 was likely detected at some time by all of the frame-based instrumentation. The data in Fig. 5, for example, suggest that the cloud feature spans the entire frame and, near minute 3.5, roughly the entire water column.

We emphasize that Figs. 4 and 5 are really only a first look at the data. Nevertheless, these data show how bubble populations associated with surf-zone processes are clearly different from their counterparts produced in deep water by breaking waves. A more detailed data analysis is planned in FY98. In addition to coordination with the other participants, the analysis plans include the following:

- Determine a pattern (if any) in the spectrum of fluctuations in bubble scattering brought on by rip currents. The approximately 4 hours of data from Runs 5 and 7 taken at a 2-Hz rate will be used for this purpose.

- Describe differences in shallow-water bubble populations associated with small-scale breaking (e.g., Run 10) vs those whose presence depends on transport via rip currents (e.g., Runs 5 and 7).

- Identify and characterize coherent structures in the shallow-water bubble field.

- Place bounds on the bubble field's horizontal scales in the manner demonstrated in Figs. 4 and 5, combined with more detailed analysis of inter-unit correlations.

- Identify and characterize patterns in vertical scales and vertical transport of the bubble field.

- Compare direct measures of S_V and attenuation made at 240 kHz with theoretical estimates, where inputs to the theoretical calculations are the bubble size distribution and void fraction estimated from the Delta Frame.

All of the above will need to be interpreted within the context of the local oceanography, as governed in this case by current fields, surface wave fields, and tides.

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13. ABSTRACT *(Maximum 200 words)*
Measurements of acoustic volume scattering from bubbles made during the Scripps Pier Bubble Experiment (24 February – 14 March 1997) are discussed. The measurements were made with APL-UW's SALMON (Shallow water Acoustic Light-weight MONitor) system consisting of an array of four upward-looking transducers which operate at 240 kHz. Measurements from this system were coordinated with measurements made by NRL-SSC, IOS, APL-UW, SIO, NCPA, and NRL-DC for the purpose of studying bubble populations in a near-shore environment. Data from this and future experiments will be interpreted vis á vis the coastal oceanography and used to model the effect of bubbly environments on sonar system performance.

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