REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
01-06-2005

2. REPORT TYPE
Final Report

3. DATES COVERED *(From - To)*
04/01/01-12/31/02

4. TITLE AND SUBTITLE
Instrumentation for the High Resolution Measurement of Ocean Surface Waves and Currents over km Square Areas

5a. CONTRACT NUMBER

5b. GRANT NUMBER
N00014-01-1-0467

5c. PROGRAM ELEMENT NUMBER

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

6. AUTHOR(S)
Smith, J., Pinkel, R.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Marine Physical Laboratory
Scripps Institution of Oceanography
291 Rosecrans Street
San Diego, CA 92106

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Office of Naval Research
Ballston Centre Tower One
800 N. Quincy Street, 322 Modeling
Arlington, VA 22217
Terri Paluszkiewicz

10. SPONSOR/MONITOR'S ACRONYM(S)
ONR

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

DISTRIBUTION STATEMENT A
Approved for Public Release
Distribution Unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The objective of this project funded by ONR (grant # N00014-01-1-0467) was to develop imaging sonar with increasingly higher resolution. With modern advancements in digital electronics, it is now feasible to digitize incoming sonar data at the carrier frequency, in this case, of ~3 x 50 kHz. Subsequent homodying and data compression can be done "in software." This sonar technology was tested on two occasions on R/V FLIP, once at a depth of 200m and the other off the Hawaiian Island of Oahu, observing large amplitude internal waves generated by tidal flow over the Keana Ridge. The next development task is to create a real-time analysis and display capabilities to match the speed of this sonar, which digitally recorded at a rate of 100 Gigabytes/day.

15. SUBJECT TERMS
DURIP, phased array Doppler sonar, high resolution imaging sonar, ocean surface waves, Langmuir cells

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
unclassified	unclassified	unclassified	None	4	Erika Wilson
					19b. TELEPHONE NUMBER *(Include area code)* 858-534-1802

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

20050705 032

Marine Physical Laboratory of the Scripps Institution of Oceanography University of California, San Diego

Instrumentation for the High Resolution Measurement of Ocean Surface Waves and Currents over km Square Areas

Jerome Smith
Robert Pinkel

Marine Physical Laboratory
Scripps Institution of Oceanography
291 Rosecrans Street
San Diego, CA 92106

June 1, 2005

Final Report

DISTRIBUTION STATEMENT A
Approved for Public Release
Distribution Unlimited

Contract N00014-01-1-0467

For the Period
1 April 2001 – 30 March 2003

Instrumentation for the high-resolution measurement of ocean surface waves and currents. ONR Grant N00014-01-1-0467. April 1, 2001 – December 31, 2002.

It has been a long-standing Navy and basic science goal to image the surface of the sea and to subsequently gain information about ocean current structures lying below. To do so one needs quantitative measurements of the signatures of the deep structures at the surface and corresponding measurements of the natural background motion associate with Langmuir cells and surface waves.

Our group has been developing multi-beam phased array Doppler sonars (PADs) for use in examining sea surface current structures. The early devices operated in the 200 kHz band and had useful maximum ranges of 250-500 m depending on scattering conditions. With a range resolution of 5 cm, the early PADs were used in studies of Arctic leads, in the equatorial undercurrent and in the coastal ocean. The maximum range was insufficient to measure the surface signature of internal waves, which have horizontal scales of hundreds of meters to kilometers.

In late 2000, we received support from ONR to develop a 16 beam 50 kHz PADs system. The objective of the program was to image the sea surface to ranges of 1.5 km or more, with sufficient detail that internal wave signals could be resolved. Ideal, a 3-d (ν,σ,t) map of the vertical displacement of the theromcline could be formed.

The program only had sufficient funding to develop a 1-channel receiver. With each of the corresponding 16-channel receive beams roughly 3° wide, the azimuthal resolution of the system would be marginal. At 1.5 km range each beam would be approximately 75 m wide.

In an effort to augment the program to produce a truly high resolution imaging sonar, the present DURIP proposal was prepared. Approximately $275 k was requested to augment the 50 kHz PADs, so that 64 beams could be formed over the 45° sector being imaged. The primary tasks were to increase the number of receive channels from 16 to 64 and to develop a recording 1 processing system capable of handling the increased data note. Ultimately the DURIP was funded at the ~25% level, and the Scripps Directors Office contributed matching funds of $60 k to the effort. At the reduced level of funding it was decided to proceed with the creation of a compromise 32-beam system, and to focus attention on the collection of quality data as apposed to the development of the real-time processing and display capability.

In the development of the sonar itself there were two principal challenges. The first was to create an efficient 50 kHz transducer. We had two previous experiences working in this frequency band, with custom transducers developed by channel Industries and by APL, Penn State. Both efforts proved to be very disappointing. At the same time, both SIMRAD (Norway) and Reson (Denmark) were marketing 50 kHz utility transducers with impressive specifications. Unfortunately, these devices were dimensionally inappropriate for our application. On inquiry, we found that the commercial transducers were in fact constructed as a matrix of smaller individual Tonpilz transducer elements. These smaller elements would be nearly ideal for use in Doppler applications.

Following discussions, Reson agreed to provide the "base" tonpilz elements at a cost less than that of in house development and manufacture. In the end, a 1.5 m x 2 m receive array with over 300 individual elements was constructed; along with two smaller transmit arrays.

The second technical effort was directed at a new generation of sonar receiver. Large numbers of these (32 here) are needed for a multi-channel phased array. High sensitivity, large (~100 db) dynamic range and a robust immunity to external noises are required in these devices. They must also be very small so that they can be packaged immediately adjacent to the individual receive transducers.

With modern development in digital electronics, it is now feasible to digitize incoming sonar data at the carrier frequency, ~3 x 50 kHz in the present case. Subsequent homodying and data compression can be done "in software". This approach eliminates virtually all of the sources of analog distortion in the signals. An enormous amount of hardware is also eliminated, including the heterodyne/homodyne currents with matched in phase and quatrature signal tracks.

A next generation sonar receiver should consist of a tuning element that matches the transducer to the receiver, a band filter that accepts signals only in the transmit band, a single pre-amplifier and the digitizer. Development Engineer Mike Goldin, developed a prototype design for 50 kHz operation, subsequently 32 more were constructed.

The sonar was first tested in the summer 2002 Passive Synthetic Aperture Sonar (PaSaSS) experiment. It was mounted on the Research Platform FLIP at a depth of 20 m and operated over a 20-day period with FLIP moored in 200 m deep water. In these summer experiments the mixed layer depth was very thin. The sonar was positioned in the upper thermocline, where sound is strongly downward refracted. Thus, the sonar scattered primarily from the sea surface for the first 800 m range, and subsequently recorded a mix of surface and bottom echoes to ranges greater than 2.5 km.

A second data collection opportunity occurred in September-October 2002, when FLIP was moored off the Hawaiian Island of Oahu, observing large amplitude internal waves generated by tidal flow over the Keana Ridge. Here the depth of the mixed layer was 25 m and breaking waves, which provide sub-surface bubbles as scattering targets, were common. The sonar was operated continuously for about 20 days, achieving ranges of 1.5 km from pure surface scattering. The dominant signal seen was the surface wavefield, which was quite energetic during trade wind conditions. When these signals were low-pass filtered in time, images of underlying Langmuir Cells emerged. Further filtering has begun to reveal the internal wave signature. Several examples of high frequency wave (20 min period) packets have been detected. The packets are seen to propagate northward, normal to the underlying topography and in general opposition to the prevailing swell. Further analysis (with support continuing from the ONR PaSaSS program) will allow us to establish proper methods for imaging and quantifying these waves.

DURIP funding was used specifically for the purchase of model TC2120 hydrophone transducers from Reson, numerous components of the new-generation sonar receivers, a new controller to coordinate transmit, receive, and data sampling functions, and numerous aspects of the mechanical packaging of the sonar system. Funds were also expended to construct a rotational mount for the sonar, such that the "sampling plane" of the sonar could be oriented at various angles relative to the sea surface. The sonar will next be deployed for performance tests at the end of the SIO Pier in La Jolla, CA, in 5 m water depth. We wish to quantify the capabilities of the system in extremely shallow water. If successful, we will also collect measurements of wave propagation across the head of the Scripps submarine Canyon, in support of the ONR NSEX Canyon Experiment.

The next development task is to create a real-time data analysis and display capability. At present, the raw data is digitally recorded, at a rate of 100 G-byte/day. The subsequent post processing of the date is extremely laborious. Also, many scientific opportunities are being missed in the absence of real-time data displays. Further development work on the system is presently unfounded. However, even in its present state, we anticipate a long and useful life for the instrument.

DISTRIBUTION OF TECHNICAL REPORTS AND FINAL REPORTS

N00014-01-1-0467

(1) Program Officer
Dr. Terri Paluszkiewicz
Office of Naval Research
Code 322 Modeling
800 N. Quincy Street
Arlington, VA 22217

(1) Administrative Contracting Officer
Mr. Lee Washington
ONR, San Diego Regional Office
4520 Executive Drive, Suite 300
San Diego, California 92121-3019

(1) Director, Naval Research Laboratory
ATTN: Code 5227
Washington, D. C. 20375

(1) Defense Technical Information Center
8725 John J. Kingman Road
STE 0944
Ft. Belvoir, VA 22060-6218