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14. ABSTRACT

Continually improving acoustics measurements in the ocean is a sine qua non for the advancement of the field of ocean acoustics, a national naval responsibility. Acoustic sensors on mobile, autonomous platforms will enable basic research topics on temporal and spatial coherence and the description of ambient noise, with direct impact on the applicability of coherent processing with its associated gain to the ASW detection problem and acoustic navigation and communications within the context of distributed autonomous persistent undersea surveillance sensor networks. Acoustic Seagliders with integrated acoustic receiving and communication capability are one necessary tool to address these research topics and applications.

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Final Technical Report: Acoustic Seaglider

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LONG-TERM GOALS

Continually improving acoustics measurements in the ocean is a sine qua non for the advancement of the field of ocean acoustics, a national naval responsibility. Acoustic sensors on mobile, autonomous platforms will enable basic research topics on temporal and spatial coherence and the description of ambient noise, with direct impact on the applicability of coherent processing with its associated gain to the ASW detection problem and acoustic navigation and communications within the context of distributed autonomous persistent undersea surveillance sensor networks. Acoustic Seagliders with integrated acoustic receiving and communication capability are one necessary tool to address these research topics and applications.

OBJECTIVES

General objectives of the work (in close collaboration with other Undersea Persistent Surveillance team members) were:

1. Investigate as a function of range and depth the effective communication data rates that are possible to support both short-range (<1 km) connectivity within mobile array clusters and long-range (10–50 km) connectivity between clusters.
2. Use acoustic Seagliders as communications gateways between underwater sensor platforms and shore.
3. Use acoustic Seagliders to evaluate adaptive sampling techniques developed under the ONR Uncertainty and ASAP MURI programs.
4. Determine the optimum strategy to exploit observed environmental variability for surveillance, maximizing probability of detection and minimizing probability of false alarm.
5. Devise metrics to test this strategy with in-situ glider-based measurements.
6. Acoustically navigate Seagliders within fixed/mobile long baseline (LBL) networks to demonstrate this capability and to determine the accuracy.
7. Obtain acoustic fluctuation data to better understand limits to coherent processing using slowly moving platforms (assume constant Doppler).
8. Demonstrate on this wide range of spatial scales precision acoustic navigation and communications, independent of the surface.
9. Demonstrate the capability to use gliders to acquire acoustic tomography signals for mapping ocean temperature/sound speed by showing resolution and stability of acoustic arrival peaks (over space/time) and ray identification along the vertical slice.
10. Advance our understanding of the ocean ambient sound budget that includes seismics, ships, whales, wind, rain, sonars, and oceanographic instrumentation.

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The short-term objective of the work was to integrate, demonstrate, and use acoustic communications and receiving capability in a Seaglider.

APPROACH

Acoustic Seagliders (ASGs) were equipped with a broadband hydrophone (5 Hz–30 kHz) acoustic receiver system (ARS) and a WHOI micromodem to demonstrate basic capability and to addresses the above objectives. Key to the integration of the hydrophone and modem was software engineer Geoff Schilling working with Jason Gobat. Russ Light and Peter Sabin implemented the hardware aspects of the hydrophone system. Rex Andrew provided the power spectrum routine for real-time processing, and a scheduling routine for receiving signals on a prescribed time schedule. Keith van Thiel and Keith Magness handled logistics and mechanical aspects. Tim McGinnis was project engineer. Mike Boyd, Robert Miyamoto, Marc Stewart and Jim Luby were pilots. Lee Freitag and Matt Grund provided the micromodem from WHOI. Andrew White, a beginning graduate student, assisted in Puget Sound testing.

WORK COMPLETED

The project funding period was FY2006 – FY2007, with work completed mid-FY2007.

An initial version of the hydrophone system was integrated into two existing Seagliders from the NPAL project (SG022 and SG023). This system has a bandwidth of 5–1200 Hz with two fixed gain channels. This was done to ensure a basic working system, and to satisfy the low-frequency applications. The next hydrophone system had one channel with this same bandwidth, and one with a 5–30,000-Hz bandwidth; this was integrated into SG106 (Marc Stewart's DURIP) that had been recently delivered from the UW Seaglider Fabrication Center (SFC). The ARS uses a CF2 processor with flash memory and a 60-GB disc. Besides storing raw data on disc, the processor computed power spectra for near-real time telemetry via Iridium. Much work went into the ARS software and the interfacing of the unit to the glider. The ARS is synched to GPS when at the surface, with better than 1-ms accuracy maintained during a dive.

A 25-kHz WHOI micromodem was integrated into SG106 with a Gumstix processor between the modem and the glider TT8 processor to facilitate integration and control. The lack of additional modems and timely delivery of additional new gliders purchased on this grant precluded fielding more than these three gliders in the summer 2006 field work.

The gliders were used in three experiments:

- *LWAD-06* (deployed 29–30 July 2006, SG022, 14 dives) – measure signal transmission loss as a function of range, as well as make ambient sound and temperature/salinity measurements in the Philippine Sea (an important precursor to the upcoming OA Deep Water 2009 experiment).
- *MB06* [deployed 12–25 August 2006, 3 gliders (# of dives), SG022 (61), SG023 (83), SG106 (131)] – As part of this major multi-project experiment in Monterey Bay, the primary objective for the acoustic Seaglider was to demonstrate the capability of a glider to serve as a communications gateway for subsea assets "talking" with shore via acoustic modem and satellite links. This is an important demonstration for the concept of undersea persistent surveillance. Secondary objectives include the acquisition of ambient sound data (wind, rain, ships, whales, modem signals, etc.) and

temperature/salinity data, and the use of the modem signals to acoustically navigate the gliders (working towards the ultimate goal of constructing large aperture coherent arrays and implementing moving receiver tomography).

- *Kauai* (deployed 31 August – 8 October 2006, SG023, 143 dives) – listen to the NPAL 75-Hz source as a function of range and depth to study signal coherence, demonstrate long range communication capability, and collect ambient sound data.

In FY2007, after the summer 2006 field work, the data were analyzed (results below) and work proceeded on completing the balance of the acoustic Seagliders. The last of the three new Seagliders purchased from the SFC on this grant was delivered in late CY2006. Acoustic modems and acoustic receiving systems (ARS-B) were installed in the remaining new Seagliders; ARS-B replaced the earlier version in the two older gliders. In summary, at the end of the project our "squadron" consisted of seven gliders total, two older ones with only a hydrophone (SG022 and SG023) and five built by the SFC and modifed with a modem and hydrophone (SG106 and SG107, originally purchased on Marc Stewart's DURIP; and SG116, 117, and 118 purchased on this grant). These acoustic Seagliders are now being used by the follow-on grant, Acoustic Seaglider2: PLUS.

RESULTS

LWAD-06 – A typhoon during this cruise shorten the glider deployment to just 1 day, with ranges up to 15 n mi from the ship. Signals transmitted from the ship, along with reverberation, and other man-made signals were very clearly received.

MB06 – SG106 successfully relayed commands from shore to the bottom-mounted University of Texas/ARL array (turn on/off). It successfully relayed associated status messages from the UT array back to shore. These demonstrated the capability for the acoustic Seaglider to serve as a communications gateway for subsea assets "talking" with shore via acoustic modem and satellite links. Acoustic communications were successful up to 4 km (Figure 1). The modem on the glider was used as a long baseline tracking transponder, talking with kayaks on the surface with GPS; the kayaks (Joe Curcio, MIT) successfully tracked the glider in real time and adapted their tracks to follow the glider (a step towards constructing large aperture coherent arrays and implementing moving receiver tomography). The passive hydrophones on the all three gliders clearly heard many signals including whales, the Lubell acoustic source being towed by the R/V *New Horizon*, acoustic modem activity at 25 kHz, and ship noise (Figure 2). Ambient sound spectra were calculated; one is shown in Figure 3 with the signature of the acoustic modem. The temperature/salinity data were assimilated into the Harvard and JPL models in near-real time. In one case a glider was left to drift on the surface; agreement with models of the surface current was mixed.

A total of 401 dives were completed and over 107 hours of acoustic data recorded (Figure 4). Blue whale calls were detected on all but two of the 76 dives where acoustic data were analyzed in detail, while humpback and sperm whale calls were detected on roughly 20% of those dives. Various whistles, clicks and burst calls, similar to those produced by dolphins and small whales were also detected, suggesting that the capability of ASGs can be expanded to sample a broad range of marine mammal species. Finally, sea lion barks and seabird calls were noted on 15 and 9 occasions, respectively, on SG022; and on one occasion each on SG023. These detections occurred at the beginnings and ends of dives, when the gliders were close to the surface.

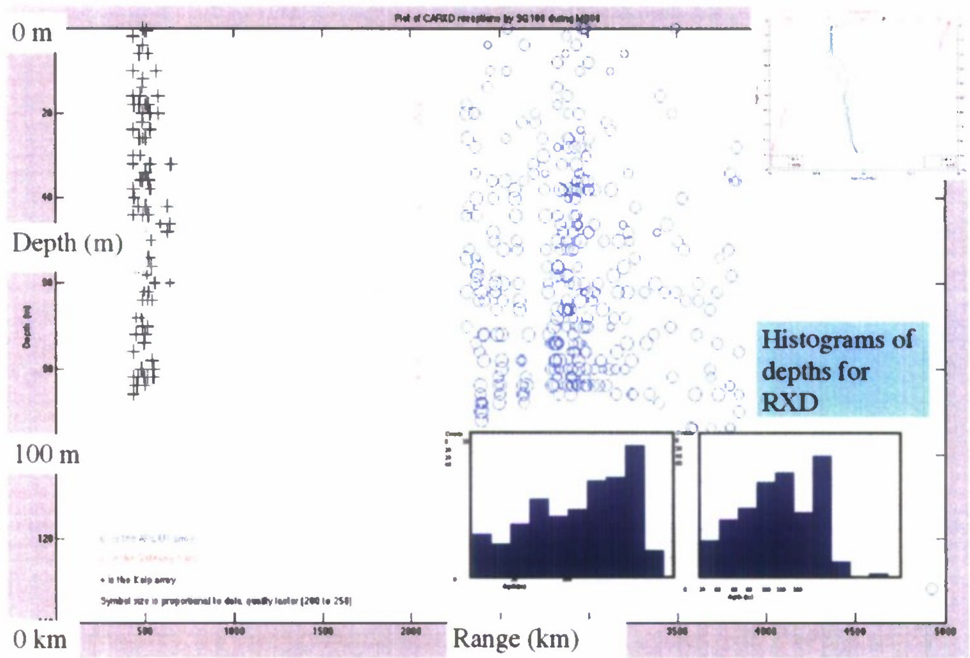

Figure 1: Location (range and depth) of the glider when acoustic communications signals were sent or receiverd by ASG106. Symbol size is a measure of signal quality. This shows a maximum range of 5 km, though less than 4 km is more common. Gaps in the plot are due to particular acoustic source/receiver geometry. There appears to be a slight performance improvement with depth of the glider, possibly due to the downward refracting sound speed profile (top right inset shows temperature and salinity versus depth, with a sharp mixed layer at 20 m).

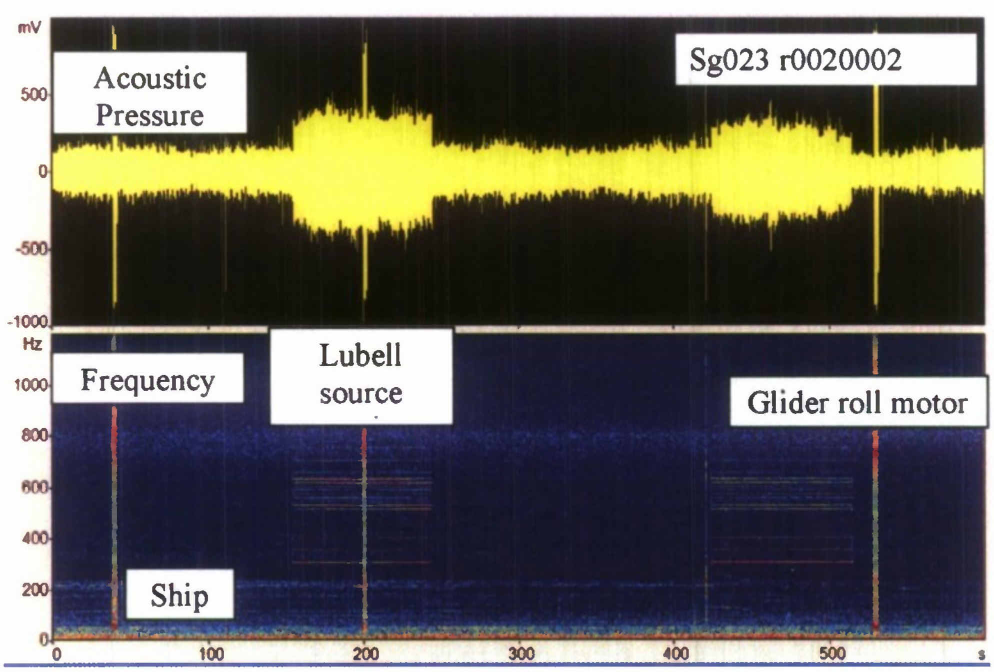

Figure 2: Pressure and spectrum versus time, showing the repeating Lubell source signal, the intermittent glider roll motor, and continuous low-frequency ship noise.

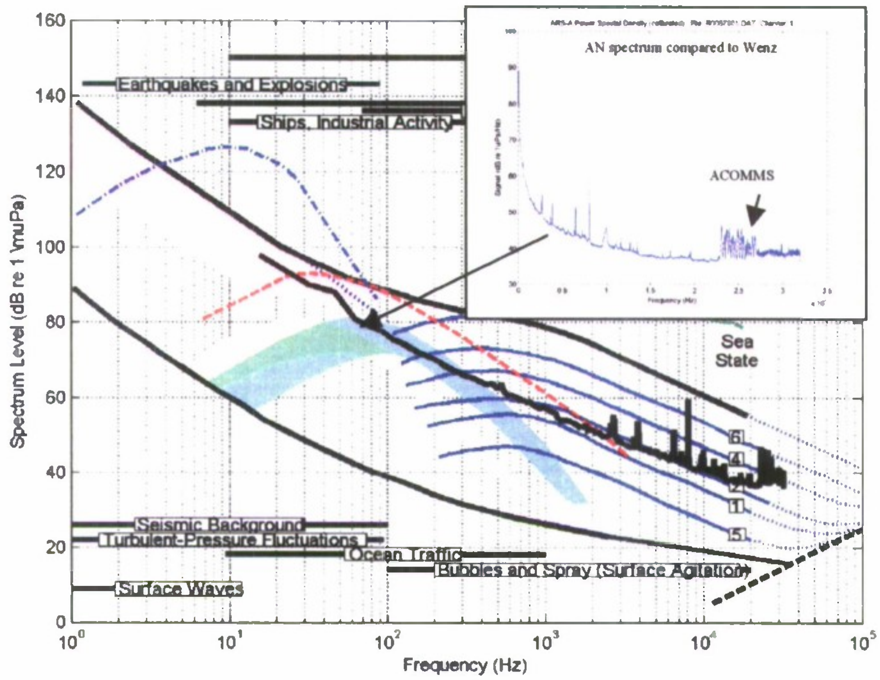

Figure 3: An MB06 ambient sound spectrum measured with an acoustic Seaglider plotted on the Wenz curves, showing the acoustic modem signals around 25 kHz.

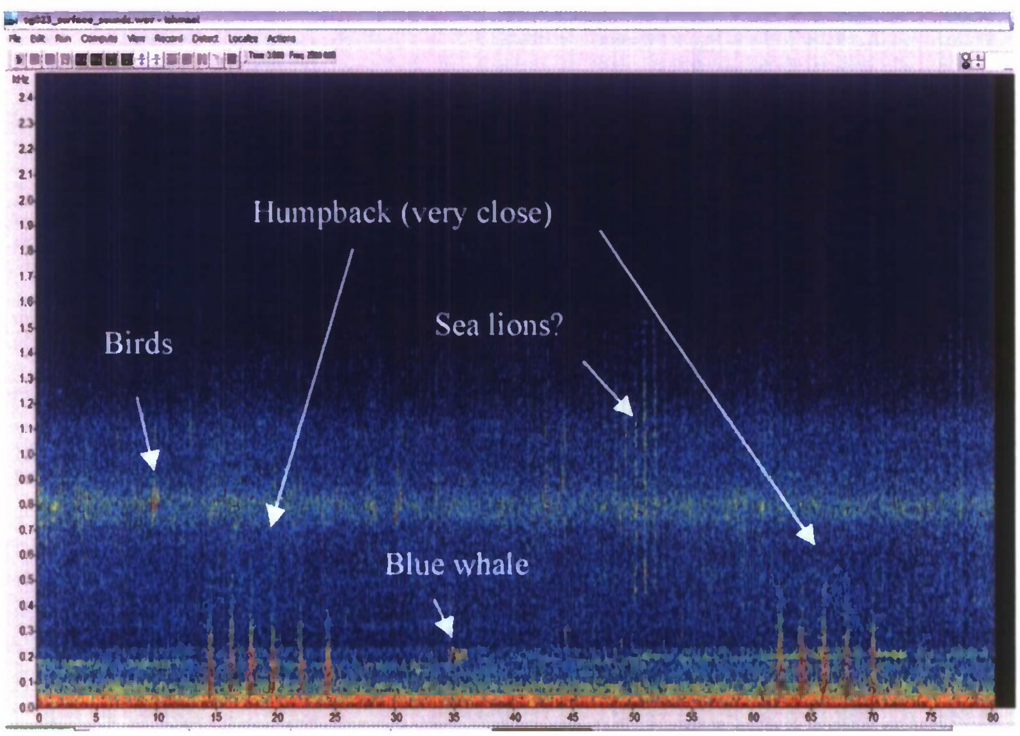

Figure 4: Spectrum versus time (frequency scale from 0 to 2.5 kHz, time over 80 s) showing the sound of birds, humpback whale(s), a blue whale, and possibly a sea lion.

To demonstrate the capability of ASGs to integrate whale call detections with conventional oceanographic measures, blue whale calls were matched to ASG locations (Figure 5, inset track) and a composite temperature and salinity record derived to show the real-time hydrography associated with the whale locations. Not surprisingly, there was a clear temperature and salinity cline at roughly 130-200 m in the area where the blue whales were detected (Figure 5, inset hydrography). These results complement data from a long-term study of blue whales within Monterey Bay, wherein whales have been shown to forage on dense euphausiid aggregations that occur between 150–200 m along the edge of Monterey Bay Submarine Canyon (Croll et al., 2005). (Kate Stafford and Sue Moore assisted with this analysis.)

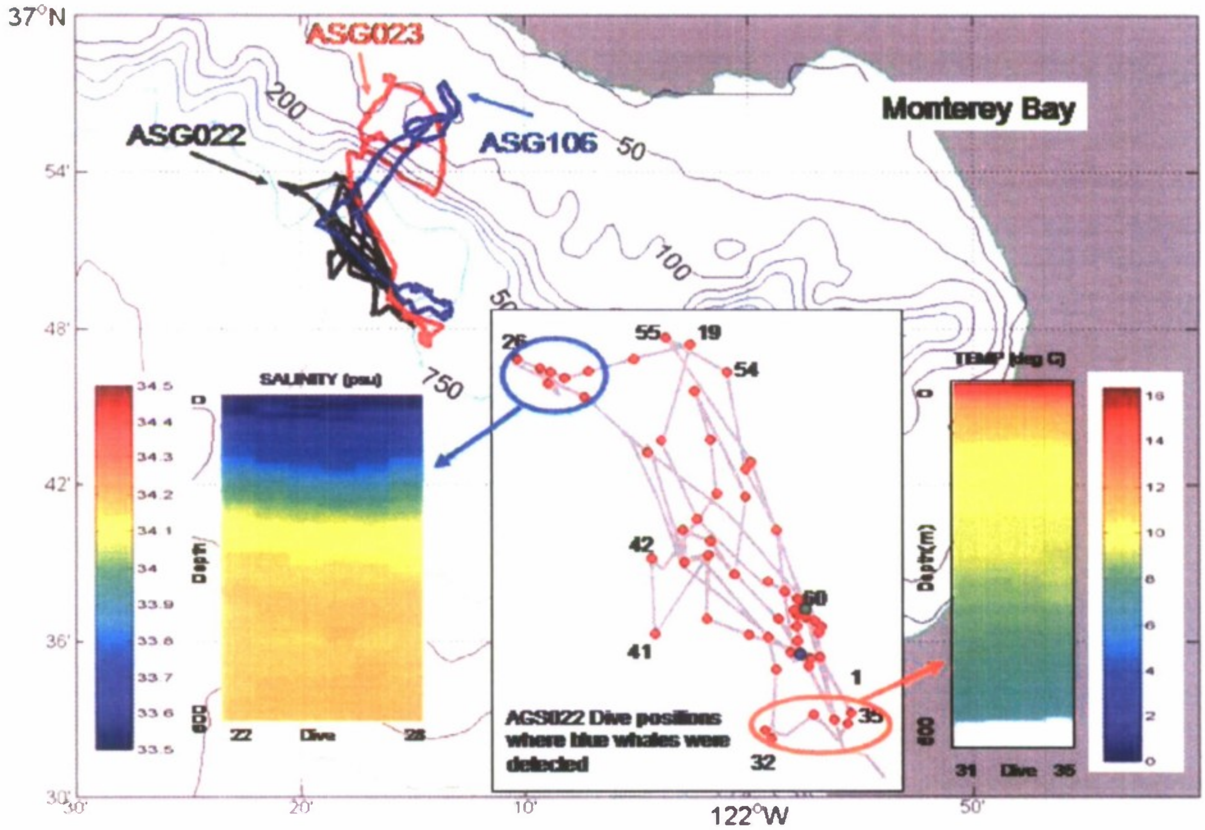

Figure 5. Glider paths in Monterey Bay and relation to temperature and salinity clines and whale calls.

Kauai – Off Kauai, the NPAL/ATOC transmissions at 75 Hz were received at ranges up to 200 km (limited only by the fact that the source turned off due to the expiration of the operating permit). In the example presented in Figure 6, coherent processing was possible (with 10 dB of gain) with the glider moving 136 m horizontally, 33 m vertically, and 12 minutes. The figure shows relative travel time increasing by 3.8 ms (5.5 m) / 27.28 s block, equivalent to 0.204 m/s, consistent with measured Doppler shift.

This work has been presented at the 2006 Fall Meetings of the Acoustical Society of America and the American Geophysical Union, the ONR Workshop on Scientific Use of Submarine Cables & Related

Technologies 2007, and the NASA Science Technology Conference (NSTC2007). A paper has been submitted to the *Marine Technology Society Journal.*

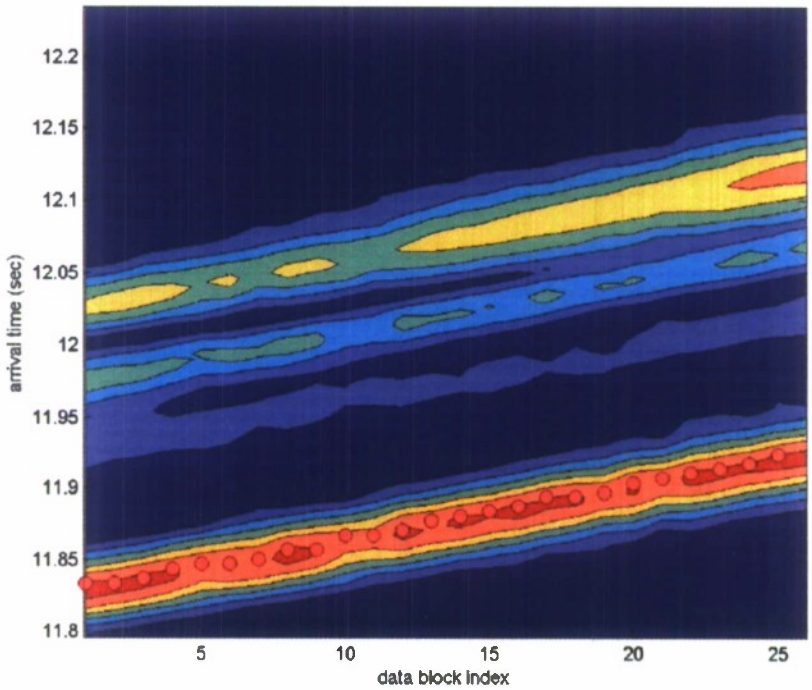

Figure 6: The NPAL/ATOC arrival received on the acoustic Seaglider as a function of travel time (on y-axis) and data block number (on x-axis; 1 block is 27.28 s). The change in travel time is consistent with the measured Doppler shift as well as the motion estimated by glider kinematics.

IMPACT/APPLICATIONS

Two very important technical developments were demonstrated:

1. The acoustic Seaglider was used as a communications gateway (acoustic in the water, satellite above). Albeit relatively slow, the Seaglider can be a persistent sensor platform that can adjust to the changing ocean. The acoustic Seaglider can be used as a two-way "data truck" connecting shore and other distant, sub-sea, long-lived sensor platforms.

2. The collection of raw acoustic data with near-real time satellite transmission of processed results provided the capability to use raw data after the fact for in-depth analysis, as well as to use processed results for real-time adaptive purposes.

In future work we expect to fully integrate the glider, modem, and "tactical sensor" systems/processors, using the full integrated functionality of the modem for precise time transfer, navigation, and communications. A "nexgen" glider will be developed with more payload (e.g., vector sensors), higher glide speed, and high frequency ground wave radio for local communications. Algorithms will be adapted/developed to simplify and optimize the field operations. With these capabilities we expect to demonstrate truly long-term, sustained, persistent surveillance capability as part of the PLUS program.

RELATED PROJECTS

ONR – Acoustic Seagliders as described here are expected to be one component in the 2009 QPE experiment in the East China Sea and the 2010 Ocean Acoustics Deep Water Acoustic Propagation experiment in the Philippine Sea. The acoustic Seaglider will be used to measure transmission loss from ship/fixed sources and in a tomography context, with data assimilation an integral part. Further, acoustic Seagliders are expected to play a role in U.S. Navy marine mammal monitoring and mitigation efforts.

NASA – funded project to address acoustic communications network protocols – flying several gliders around a cabled mooring system in Monterey Bay in summer 2008 (P. Arabshahi at APL-UW is PI, Howe a co-PI).

NSF – Gliders using RAFOS navigation under the ice in Davis Strait and Arctic Ocean (C. Lee at APL-UW is PI). Gliders, including acoustic gliders, are relevant in the context of the ORION program and ocean observatories.

NOPP/Ocean.US/IOOS – both the communications capability and the hydrophone receiving capability can be used in the operational observing systems being planned.

PUBLICATIONS

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