Expendable Benthic Lander (XBL)

A.J. Williams 3rd
Woods Hole Oceanographic Institution
98 Water St., MS#12
Woods Hole, MA 02543 USA

Abstract- **Observatories on the sea floor are about to permit long term observations of physical and chemical processes. Most of these observatories will deliver their measurements ashore in real time or near real time and many will derive power from a cable that connects them to shore. The cable is both empowering and limiting insofar as it permits long deployments and real time data return but restricts observations to regions where the cable has been laid. There remains a need for observatory type arrays of sensors where cables have not been emplaced. The expendable benthic lander is an instrument that can be deployed in such an array. The requirements for such an instrument are that it be inexpensive so that large numbers can be deployed in an array, easily deployed so that costs of laying the array are modest, capable so that physical and chemical properties can be resolved at the speed and sensitivity required to understand processes of importance, and recoverable so that the data may be analyzed in detail. Physical instrument recovery is a desirable attribute but not as important as data recovery. Since data may be recovered even if the instrument is lost, the term expendable is applied to this benthic lander although this is not the primary mode of use.**

I. INTRODUCTION

While the Expendable Benthic Lander has not yet been deployed, its predecessors have been used extensively and the XBL, as the target instrument is designated, has been designed and its cost computed and its use planned. The most difficult measurement is the vector measurement of current so this is the basis of the XBL. Additional scalar sensors are included for pressure, temperature, conductivity, and optical backscatter. Chemical sensors can be added as required for pH and oxygen. Experience with these measurements from an inexpensive instrument has been acquired from the Modular Acoustic Velocity Sensor, MAVS [1-3]. MAVS in turn is descended from the Benthic Acoustic Stress Sensor, BASS [4], a standard of deep-sea velocity and turbulence observations in the experiments HEBBLE [5], CODE, STRESS [6,7], and CMO [8]. The conversion of BASS into MAVS and its pending transformation into XBL is an instructive story for both instrumentation engineers and for scientists hoping to extend observatory coverage.

Operation of the XBL

The XBL will be free-fall delivered to the sea floor from a moving ship where it will remain a meter above the bottom for a preset time, measuring velocity and scalar properties at intervals of seconds to minutes for durations of one month to a year. Statistical measures such as Reynolds stress and heat flux will be computed in real time and stored for satellite transmission upon release from the bottom. Such data will be recovered by radio transmission through its glass buoyancy housing upon surfacing after anchor release. Simultaneously the GPS location of the floating XBL will be transmitted by VHF radio for relocation if a recovery ship is on site to collect the instruments of the array. Physical recovery will not only save the replacement cost of the instrument but allow more high frequency analysis of the measurements to be made.

II. OBSERVATORY WITHOUT CABLE

Continuous observations over some region of space and time imply a facility for acquiring these observations and this facility is now termed an observatory. While installations of observatories near shore and somewhat offshore have begun, these are cable connected to shore for power supply and for data delivery. Current measuring moorings have long been placed far from shore without cable connections. These might well be called observatories by today's terminology since they record events over extended periods of time. When these are placed in arrays, they also cover regions of space, typically a section such as the RAPID array along 26°N in the Atlantic Ocean [9]. These arrays share some of the cost and logistic constraints of cabled observatories and the alternative described here avoids some of these.

Rapid Deployment Array

Event-driven observatories must be deployed quickly; much more rapidly than can be done with capital and ship intensive cabled arrays or even moored arrays with heavy anchors, buoyancy, and mooring line. An example of such a short lead time need would be a submarine slump occurring alongside a seamount or at a shelf edge or slope. The short relaxation period (about a week) that the turbidity event of such a slump creates may require rapid deployment of a benthic observatory array. Turbidity relaxation after passage of a hurricane or tsunami similarly requires rapid deployment of an observatory array. Deep convection events such as are known to occur in the Gulf of Lyons in the Mediterranean Sea or in the Labrador Sea in winter might also need such a rapid observatory array to be deployed when they develop since the location is not known in advance. In shallow water the transport of sand in response to northeast storms along the New Jersey, US coast has been proposed as an event needing a regional array on short notice. Northeaster landfalls are not predictable more than 36 hours in advance.

1) Deployment: Rapid deployment means that the instruments in the array must be deployable from a moving ship, preferably by hand without slowing the vessel. The ship must be readily available on short notice such as a coastal fishing vessel if the event is near shore or a mud boat or offshore fishing vessel if it is offshore. No cranes or winches should be required. Ideally the instruments should be deployable by a person or two persons from the rail of the vessel. The instrument should then free fall to the bottom where it stabilizes itself and commences to observe and log measurements.

2) Array Size: Elements of the array should be spaced as far apart as possible to reduce the numbers required but closely enough to resolve the spatial structure that is required to understand the process at work. The area that is covered should be large enough to capture the event that is targeted and this may require a greater array diameter than absolutely minimum because of uncertainty in position and size. Non-uniform spatial sampling should be considered to reduce the number of instruments and still resolve most of the characteristics of the array; for example, an extension along several radii with sparsely spaced deployments may confine the scale of the event without densely sampling it at considerable reduction in the number of instruments. Yet when done, the number of instruments may total scores or even up to one hundred and there must be room enough on the vessel of opportunity to carry such a number. The obvious need in the design then is that the instrument should be small and compact, at least before it is prepared for deployment.

3) Cost: The number of instruments that will be deployed in the array will be great enough that the cost of each will have significant impact on the cost of the deployment of the array. Economies of scale should help and the manufacturing techniques of automatic assembly, testing, and common firmware coupled with commercial off the shelf hardware where available are necessary

Remote Deployment Array

Regions of the seafloor remote from existing observatories or planned cabled observatories may be interesting, essential to observe in order to understand some global phenomena, or recently identified as a critical area for observation. Some regions are just too far from possible shore side support to be cable connected. Such regions may benefit from deployment of an array of expendable benthic landers.

1) Deployment: Remote sites for deployment of a benthic array do not necessarily require rapid emplacement of stockpiled instruments as event-driven array deployment might. But cost of both instruments and ship time may be an issue. The cost issue is the same as the constraint for rapid deployments that are event driven and also drives deployment choices for ship time. Dropping instruments over the side of a ship running at full or near full speed saves ship time when deploying a numerous array of instruments. In a one-week cruise to and from the deployment site, one hundred instruments deployed 10 miles apart will add four days of ship time to this week contrasted with an additional eight days of ship time if the ship must stop for each deployment, assuming one hour per deployment.

2) Recovery: For truly remote regions, it may be uneconomical or even logistically impossible to recover the array at the end of the deployment. In such cases, data recovery alone is acceptable. This is possible by satellite relay of data stored in the instrument. Bandwidth limits on such transmissions dictate that compressed data only is sent in this way but these compressed or compact data sets are commonly what full data sets are reduced to after recovery. In the case of fluid velocities for example, mean current speed and direction every hour (vector averaged from more frequent observations) along with turbulent kinetic energy or Reynolds stress for deep water or directional wave spectra for shallow water will suffice. These are compact and discard some data that are inevitably valuable occasionally for discoveries of unsuspected processes (internal wave breaking, tsunami passage, deep convection being processes that may be missed by such compact data representations). Thus, there is value beyond simply the capital cost of the instrument in recovering the instrument with its entire data set.

If it is possible to physically recover the instruments or most of the instruments in the array, an efficient way to locate them without waiting for them to be released upon acoustic command and tracked to the surface may be required. The time required to acoustically release and track and recover an instrument in 5000 meters depth is typically three hours and may be as much as five hours if there are uncertainties in location. For the XBL the plan is to release the anchor on a timer in advance of the expected recovery ship's arrival so that it is already at the surface when the ship arrives at the launch site. Upon reaching the surface, or more practically upon release of the anchor, the instrument commences transmitting by VHF radio the GPS position received from satellite. Of course, these data are of no value until a GPS position is received but then there will be no VHF transmission until the instrument reaches the surface. A ship within recovery range of the instrument can steam to the position transmitted via VHF and pick it up. This range is limited to several miles so the ship must have a reasonable location to start with, generally the deployment location amended by estimates of surface current drift.

In an array of instruments, it is not unreasonable to release a cluster of instruments at dawn each day and sweep them out of the water in an optimum path with the recovery ship, deriving enhanced estimates of surface drift from the instruments recovered to aid in recovering the remainder. Time for each recovery is probably two hours added to one hour of steaming time between instruments. For safety, no more than five instruments a day should be so released to permit them to be located during daylight. This means a total time for recovery of an array of one hundred instruments would be 20 days added to the transit time of the ship to the array site. Some instruments would inevitably be lost from the array and compact data relayed by satellite would have to suffice for these. With GPS positions added to the compact data there is even a possibility of recovering some of these after the bulk of the array has been recovered.

III. INSTRUMENTATION

BASS

The Benthic Acoustic Stress Sensor (BASS) serves as an example of a benthic lander, though neither expendable nor inexpensive. This instrument consists of a tower of six vector velocity sensors in a 5-m tall tripod with internal logging of correlations of velocity components averaged over 30 minutes. The sample rate for each vector determination is 2 Hz, resolving the turbulent eddies in the 15-cm diameter of the velocity sensor for velocities less than 30 cm/s without aliasing. BASS has four acoustic axes, each inclined 45° to the horizontal and distributed 90° in azimuth. As each measurement is made, the four vector velocity components are accumulated, the count of accumulated measurements is incremented, the products of the four velocities with themselves and each other are accumulated, and the count of each accumulated product is incremented. This continues for 3600 samples and then the accumulated velocity components and products are divided by the count of each accumulated result to obtain an average, which is stored. With six velocity sensors and four axes in each sensor, a compact sample consists of 6x14=84 data words plus a time stamp, data quality based upon the number of accumulated values used in the averages, and a number of scalar measurements such as temperature, optical turbidity, pressure, and tripod orientation. A data word is 16 bits or 2 bytes and this added up to 2 Mbytes, in a 7-month deployment. Fig. 1 is a plot from such a BASS deployment showing current direction and speed, optical turbidity, temperature, and turbulent kinetic energy for 6 months at the HEBBLE site in 4800-m depth. It is difficult to see the details in this plot because it is so rich and this doesn't even compare the records from the other five levels of the profile. The point is that this is a 2-Mbyte record and contains ample information to analyze and understand benthic processes.

There remained an interest in high frequency data as well from the HEBBLE area and subsequent deployments added a second logger that recorded uncompressed data upon event trigger for detailed analysis. These too were stored in 2 Mbytes allowing only 4 event records, hopefully chosen by the event-trigger algorithm with wisdom. The trigger was variously based upon optical turbidity, turbulent kinetic energy, and current speed with an adaptive threshold that considered how much logging capacity was left, and how much time was left. In practice, the compact data were the most valuable and their lessons led to the need that the XBL attempts to fill. Some of the observations about benthic storms and advective processes in the deep sea are indicated by the notes in blue and red on the plot.

One valuable benefit of the event-triggered data records was that they could be analyzed to determine the average current, average turbulent kinetic energy, and Reynolds stress for comparison to the *in-situ* computed value for that burst of samples. It was convincing to skeptics to show that the results matched.

MAVS

BASS is a fine benthic lander, capable, accurate, and well validated. But it is expensive to build and to deploy. MAVS was developed to reduce these costs and move toward making an XBL instrument. The sensor in MAVS is a four-acoustic-axis array similar to that in BASS with each axis inclined 45° to the horizontal and distributed 90° in azimuth. The path length is reduced to 10 cm and the paths do not cross in the center as they do in BASS. This makes the sensing volume only 10 cm in diameter vs. 15 cm in diameter in BASS. MAVS has faired rings supporting the transducers with no exposed wires, unlike BASS where the support cage was flat rings and struts, creating less turbulence for strictly horizontal flow but causing some velocity defect near 45° elevation in flow direction. Support for the sensor in MAVS comes from a central tube containing the wires and this raises the turbulent intensity fourfold over that in BASS but this is still below the Reynolds stress found in a boundary layer flow so that the ability of MAVS to detect and record boundary layer turbulence is not compromised [10].

Ancillary Sensors

Velocity may be the most demanding measurement for a benthic lander but studies of sediment transport, benthic biology, bottom disturbances by waves or earthquake, and anoxia require additional sensors. Temperature is simple with an internal thermistor but for more rapid response, the thermistor may need to be placed in a sealed needle extending from the instrument housing. Response time can be improved from minutes to about 1 second with such a sensor. Pressure is valuable for shallow deployments where surface waves may be felt on the bottom and this sensor is also moderately easy to include as an internally-mounted pressure gauge vented to the outside through a pressure port. For deep-sea pressure sensing, such as that used in the DART tsunami detecting instruments [11], an expensive, ultra stable and sensitive pressure sensor is required and this is not what the XBL will employ. For deep-sea deployments, only tidal signals will be detectable with a low cost pressure sensor in the XBL. This will, however, sense surface elevation changes due to hurricane passage or down-slope movement of the XBL during a benthic slump [12].

Conductivity is the next most difficult measurement and this can be accommodated with a pressure exposed inductive cell mounted on the XBL endcap. The cell and electronics to support the conductivity measurement is moderately expensive so it too may be optional and only installed for deployments requiring close monitoring of salinity. Oxygen sensing is needed for observing anoxia events but no suitable sensor has been found yet so this remains a development or research task. Several promising candidates are being watched.

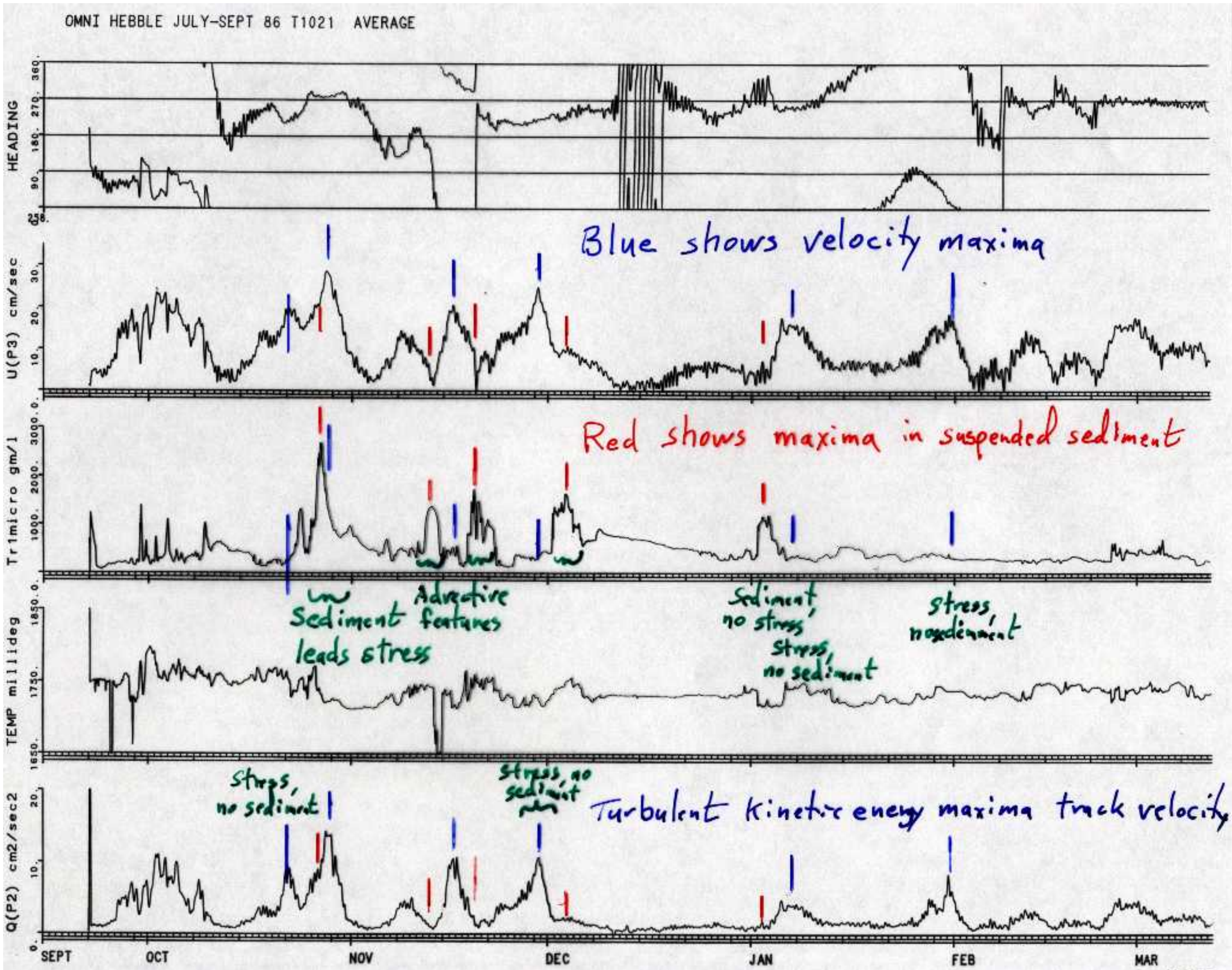

Fig. 1. BASS logged compact data show bottom current and speed, optical turbidity, temperature, and turbulent kinetic energy from 30-minute averages of 2-Hz samples. This display is derived from a single sensor of a six-sensor array over a 6-month deployment all stored in 2 Mbytes of memory.

Turbidity measurements are necessary for many targeted deployments, particularly sediment transport studies and the optical backscatter sensor provides qualitative measurements of turbidity to distinguish onset of benthic storms. The optical backscatter sensor is moderately expensive to purchase but it also is moderately expensive in power to operate so must be used intermittently and, more seriously, the optical sensor is sensitive to marine fouling, both due to colonization by organisms and particle settling. An additional turbidity measure has become recently available, acoustic transmission [13] in which the forward scattering and attenuation of acoustic signal is used to estimate the mass of suspended particles along the acoustic path. This is easily added to a standard MAVS instrument and only costs power during a burst of measurements, which like the optical backscatter sensor can be intermittent.

Compass and tilt are built into the MAVS but are separately logged for additional information such as disruption of the bottom by a seismic event or slump.

IV. Configuration

Deep-Sea Lander

Deployment of an array of XBL instruments in the deep sea by hand dropping them from a moving ship is facilitated by configuring each instrument as a short mooring. The buoyancy of the XBL is provided by a lightweight glass housing containing the electronics. Other components include:

lower endcap with MAVS velocity sensor, ancillary sensors, and burn wire release; battery; antennas to receive GPS and transmit VHF and satellite radio; an anchor; and a short mooring connecting the anchor to the burn-wire release. Fig. 2 shows the Sensor-Down XBL or the deep-sea version of the XBL.

Buoyancy in both the Deep-Sea Lander and the Shelf Lander described in the next section is provided by glass housings as employed in RAFOS floats [14]. Glass is inexpensive, free from corrosion (thus requiring no surface treatment), and radio transparent for communications when back on the surface. Deployment of RAFOS floats in large numbers demonstrates the utility of this package, even being deployed successfully on volunteer ships of opportunity by motivated but inexperienced crew.

As shown in Fig. 2, the electronics, including the data logger and batteries, are mounted on the endcap. An expanded view of this package is provided on the right since it is a short portion of the glass housing. The burn-wire release attaches to the end of the velocity sensor tube, beyond the sensor rings. Voltage applied, when release is wanted, to a short section of bare nichrome wire relative to the sensor tube causes a galvanic current to flow that dissolves away the wire, disconnecting it from the lanyard to the anchor plate. The anchor plate is a simple steel weight, initially tied to the sensor with soluble polyvinyl alcohol tape so that it can be thrown over the side of a moving ship without damage to the instrument but that disconnects and hangs beneath the instrument during its descent to the sea floor. When it reaches the bottom, the sensor tube may bump the anchor plate before rising to its deployed position 3/4 m above the bed. Because the XBL does not invert when released, a sediment trap can be attached to the glass housing (although in this configuration the ship must stop and the XBL lowered over the side and released with a slip line since the sediment trap has great drag). Such a trap will collect particulate matter that settles out of the turbid nepheloid layer for subsequent analysis.

Shelf Lander

Where surface wave action may be important for benthic processes, as on the shelf, a rigid mounting with the sensor up is preferred. This is shown in Fig. 3. A sand anchor, which stows flat on board ship, is connected to a launch tube of PVC containing the XBL in an inverted position. This is dropped from a slowly moving ship to implant itself on the bottom with the steel arms of the sand anchor slightly buried in the sediment. The buoyant XBL in its glass housing is tied into the launch tube with a burn wire. The velocity sensor for the Sensor-Up XBL is positioned 2¾ m above the bottom, giving a significant vertical velocity due to surface waves in depths less than 90 meters [15]. As in Fig. 2 the details of the electronics and sensors can be seen in the quadruple expanded drawing on the left.

At recovery time, voltage is applied between the burn wire and the sensor tube and the connection from the endcap to the launch tube is dissolved. The glass housing floats out of the launch tube, inverts due to the distribution of weight, and floats to the surface where its glass end projects out of the water for radio communications. The determination of position by GPS, retransmission of that position by VHF radio, and the slow trickling back of compressed data by satellite telemetry, here indicated as Argos, provides the possibility of physical recovery and the back up of data recovery only, just as in the Deep-Sea or Sensor-Down XBL.

MAVS in the Deep-Sea

Fig. 4 illustrates how such a deployment will look in the deep sea. This is a MAVS instrument that was emplaced by the Alvin submersible at the Juan de Fuca hydrothermal vent field and photographed before recovery after 2½ months [16]. The MAVS was anchored by a steel plate as the XBL will be. However, the housing, not quite buoyant as it is aluminum, was held upright by a block of syntactic foam out of sight above the picture. Data recovery required instrument recovery.

V. Weights and Costs

Weights

Table I gives the weights of each component in the XBL in column 2. The weights are those determined from actual weighing of components in the author's laboratory except for the glass pressure housing, the buoyancy of which has been taken from specifications. Total buoyancy is greater than 5 Kg, ensuring sufficient exposure of the antennas for correct functioning. A 12-Kg anchor easily overcomes the buoyancy to keep the Sensor-Down XBL on the bottom. The Sensor-Up XBL with its sand anchor resists overturning in currents and waves up to 100 cm/s.

Costs

Column 3 of Table I gives costs in US 2003 dollars. These costs have increased in the intervening five years and are likely to accelerate with the present (2008) weakness of the US dollars. However, comparison with other costs in 2003 would put the cost of an XBL about equal to that of the cost of a MAVS current meter, not surprising since it is largely, at heart, a MAVS instrument. The 2008 price for a MAVS current meter without ancillary sensors is US $9k. There is a difference between cost and price due to the need for a manufacturer to cover assembly costs, fixed costs, profit, and risk. These are typically 100% of parts costs so that a cost for an XBL in 2008 can be estimated at $4,500 without optional sensors and $7,515 with optional sensors. Commercially produced, the price in US 2008 dollars can be expected to be $9,000 without optional sensors and $15,000 with optional sensors.

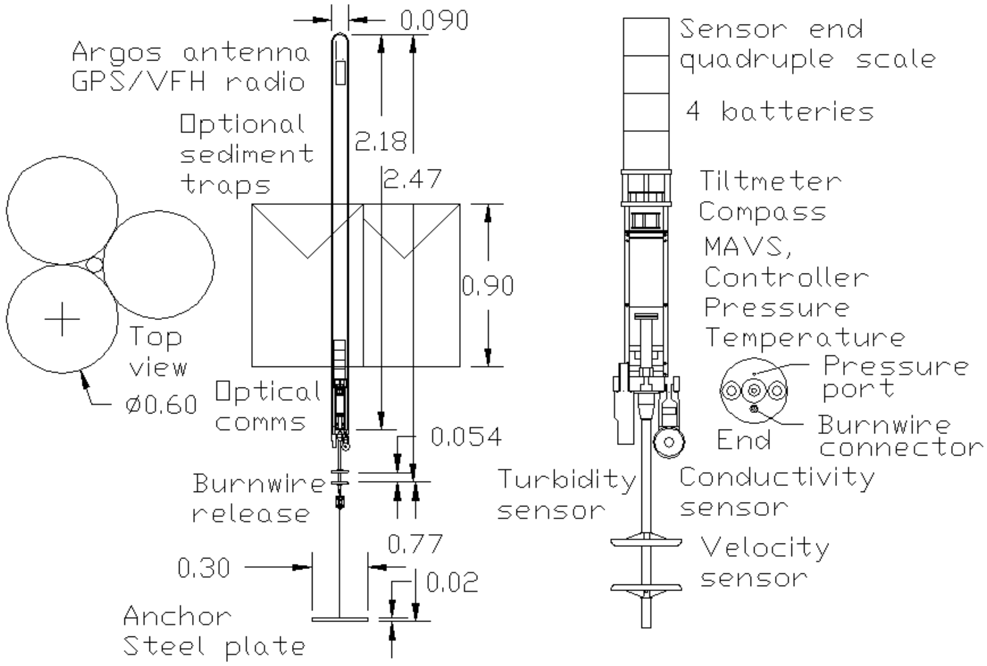

Fig. 2. Down configuration for the XBL with steel plate anchor. The sensor volumes are ¾ meter above the bed. As illustrated, all the sensors possible are included. Optional sediment traps can be clamped around the housing since the XBL does not invert when released.

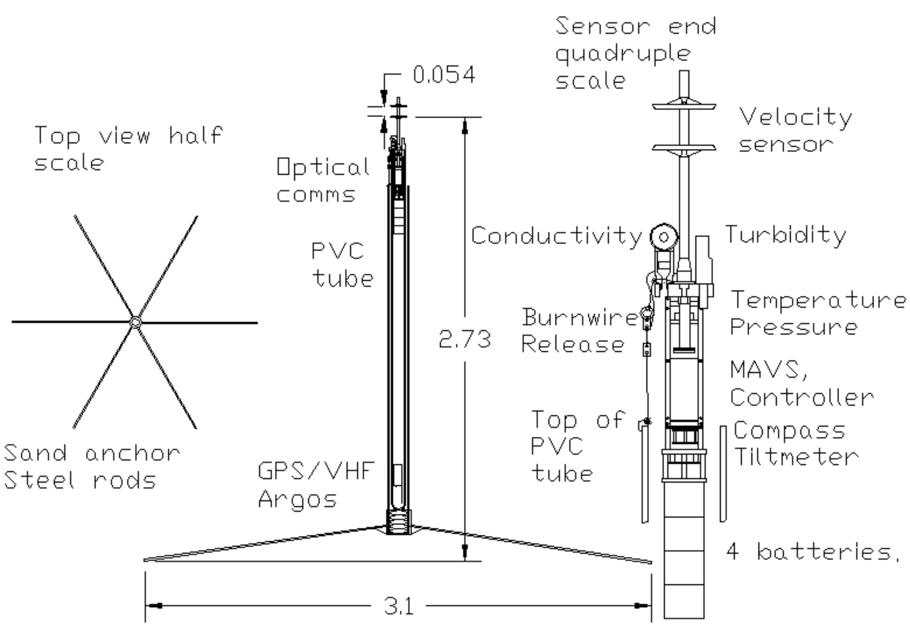

Fig. 3. Up configuration of the XBL with sand anchor. The sensor volumes are 2¾ meters above the bed. As illustrated, all the sensors possible are included although in use some or all of the optional sensors may be replaced with dummy plugs. A burn wire keeps the XBL in the launch tube until a preset time. The XBL inverts when it is clear of the tube and extends its antenna end above the surface for radio transmission.

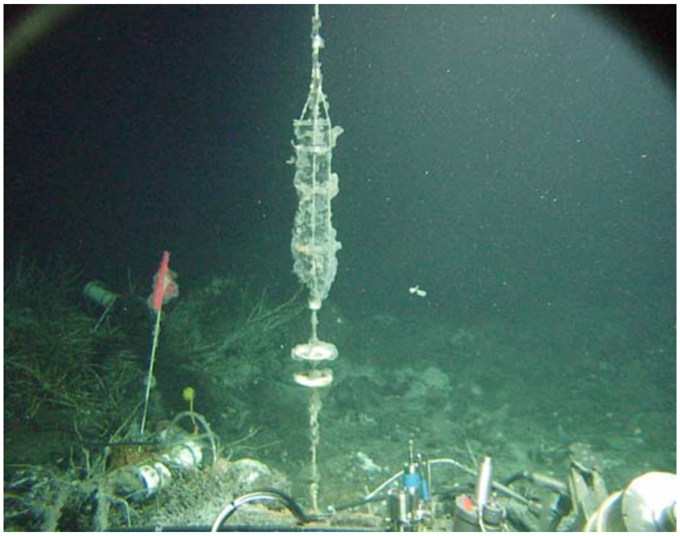

Fig. 4. MAVS at 2300 meters at the Endeavour Field of the Juan de Fuca hydrothermal vents. Organisms growing on the sensor after 2½ months did not impede the measurement of the flow to any noticeable extent.

VI. Deployment Schedules

Deployment Types

Table II indicates four classes of deployment with the optional sensors needed, the deployment duration, sample rate, burst length, burst interval, super interval (third-order interval between samples), record length, and condensed data record length. The four classes are Deep-sea, Outer-shelf, Estuary, and Inner-shelf. Each of these classes has a typical study target so that Deep-sea target is Benthic Weather (episodic turbidity events), Outer-shelf target is Shelf Response to Storms, Estuary target is tidal mixing, and Inner-shelf is Waves and NE Storms.

Condensed Data

In the Deep-sea classes of deployment where durations are 3 months or 12 months, depending how remote the site is, total condensed data can be kept below 12 Kbytes per deployment. This is done for the 3-month deployment by taking a 20-minute burst of 2-Hz data every 4 hours. For the 12-month deployment, data are only taken on this schedule, one day in four, so a super interval of four days is applied. However, for either case, every burst generates 48 Kbytes of data, which is condensed to a single record of 60 bytes. This condensed data is what was shown in Fig. 1 indicating that condensed data are sufficient for scientific purposes. Twelve Kbytes of data can be transmitted by Argos satellite in two weeks.

The Outer-shelf classes of deployment are of one-month, three-month or six-month duration, each collecting less than 12 Kbytes of data for transmission by Argos satellite in two weeks. Sampling is for 20 minutes at 2 Hz with a burst interval of 2 hours, 4 hours, and 6 hours, respectively, every day for the one-month deployment and every other day for the three-month and six-month deployments.

Table I. XBL Weights and Costs

Component	Weight (gm)	Cost	Specification
MAVS board assembly	374	$40	Chassis with circuit boards and micro computer
TT8	part of	$400	Onset controller, A/D, in situ processor, scheduler
CF 40 MB	board	$400	Persistor with compact flash memory
MAVS electronics	assembly	$236	Four axis differential travel time circuit and power
GPS/VHF radio	200	$200	Receives GPS, transmits fix on VHF
Argos transmitter	300	$150	Position and data @ 1kB/day, $11/day ∗ 14 days
Batteries	1000	$160	4 ea. Li thionyl chloride battery @ 12v, 10 Ah
Sensors			
Vector velocity	200	$720	Acoustic differential travel time ± 0.1 cm/s
Compass	10	$40	Three axis magneto-resistive circuit ± 2 °
Tilt	20	$50	Analog Devices three-axis accelerometer ± 0.2 °
Temperature	0	$10	Thermistor on endcap ± 0.03°C
Optional sensors			One or more may be included as required
Pressure	76	$260	Omega strain gauge ± 0.1% f.s.
Turbidity	50	$990	Seapoint backscatter 25 to 2500 FTU f.s.
Conductivity	76	$1200	Aanderaa inductive cell ± 0.2 mS/cm
Pressure housing	-7730	$580	90 mm glass housing 215 mm long rating 4000 m
Connectors	10	$20	Burn wire, communications through glass
Total	-5424	$5296	Reusable part less batteries, all optional sensors
less optional sensors	-5626	$2846	Reusable part less batteries, no optional sensors
Anchor	12000	$600	Cast iron shoe with spear for mud or spider for sand
Release	50	$50	Burn wire on timer from controller
Total	6636	$6106	Cost of deployable XBL, all optional sensors
less optional sensors	6434	$3656	Cost of deployable XBL, no optional sensors

The Estuary classes of deployments are four months or eight months but the sample rate is 0.1 Hz with a burst length of 240 minutes every day or every other day. Condensed data also remain below 12 Kbytes per deployment.

The Inner-shelf classes of deployments are one, three, and six month durations with 4 Hz sample rate and 30, 15, and 15-minute burst length. Condensed data again are less than 12 Kbytes per deployment.

For each class of XBL deployment, sufficient data can be recovered by Argos satellite to permit scientific analysis of the region covered by the array. If the instruments themselves are recovered, additional analyses of the complete data set may reveal other processes not anticipated in advance. But any process that is suspected can be analyzed *in-situ* and put into condensed form for transmission by satellite [17].

Table II. XBL Sampling

Environment	Deep-sea		Outer-shelf		
Optional sensor(s)	Turbidity		Pressure & turbidity		
Study	Benthic weather		Shelf response to storms		
Duration (months)	3.0	12.0	1.0	3.0	6.0
Sample rate (Hz)	2.0	2.0	2.0	2.0	2.0
Burst length (minutes)	20.0	20.0	20.0	20.0	20.0
Burst interval (hours)	4.0	4.0	2.0	4.0	6.0
Super interval (days)	1.0	4.0	1.0	2.0	2.0
Record length (Bytes)	20.0	20.0	22.0	22.0	22.0
KiloBytes/burst	48.0	48.0	52.8	52.8	52.8
KiloBytes/day	288.0	72.0	633.6	158.4	105.6
MBytes/deployment	26.8	26.8	19.6	14.7	19.6
Condensed data					
Record length	60.0	60.0	62.0	62.0	62.0
Rec. averaged	3.0	3.0	2.0	2.0	2.0
Bytes/day	120.0	30.0	372.0	93.0	62.0
KB/deployment	11.2	11.2	11.5	8.6	11.5
Environment	Estuary		Inner-shelf		
Optional sensor(s)	Turbidity, pres. & cond.		Pressure		
Study	Tidal mixing		Waves in NE storms		
Duration (months)	4.0	8.0	1.0	3.0	6.0
Sample rate (Hz)	0.1	0.1	4.0	4.0	4.0
Burst length (minutes)	240.0	240.0	30.0	15.0	15.0
Burst interval (hours)	4.0	4.0	4.0	6.0	12.0
Super interval (days)	1.0	2.0	1.0	1.0	1.0
Record length (Bytes)	24.0	24.0	20.0	20.0	20.0
KiloBytes/burst	34.6	34.6	144.0	72.0	72.0
KiloBytes/day	207.4	103.7	864.0	288.0	144.0
MBytes/deployment	25.7	25.7	26.8	26.8	26.8
Condensed data					
Record length	24.0	24.0	60.0	60.0	60.0
Rec. averaged	1.0	1.0	1.0	3.0	3.0
Bytes/day	144.0	72.0	360.0	80.0	40.0
KB/deployment	17.9	17.9	11.2	7.4	7.4

VII. Conclusion

The Expendable Benthic Lander presents a new observatory asset for sudden events or remote location deployments where cabling is impracticable or impossible. One might hope this new instrument is produced soon to join the sensors now being installed in cabled observatories.

Acknowledgment

Development of MAVS and generation of an XBL proposal from which this paper was taken was supported by NSF Grant OCE-9314357 and Nobska Development, Inc. Woods Hole Oceanographic Institution supported the author's participation in Baltic 08.

References

[1] Williams, A.J. 3rd, 1994. Design of a Modular Acoustic Velocity Sensor, *Oceans 94*, pp. I 658- I 659.

[2] Thwaites, F.T. and A.J. Williams 3rd, 1996. Development of a Modular Acoustic Velocity Sensor, *Oceans 96*, pp. 607-612.

[3] Williams, A.J. 3rd and F.T. Thwaites, 1998. Earth coordinate 3-D currents from a Modular Acoustic Velocity Sensor, *Oceans 98*, pp. 244-247.

[4] Williams, A.J., 3rd, J.S. Tochko, R.L. Koehler, W.D. Grant, T.E. Gross, and C.V.R. Dunn, 1987. Measurement of turbulence in the oceanic bottom boundary layer with an acoustic current meter array, *J. Atmos. and Oceanic Tech., 4(2)*, pp. 312-327.

[5] Grant, W.D., A.J. Williams 3rd, and T.F. Gross, 1985. A description of the bottom boundary layer at the HEBBLE site: low frequency forcing, bottom stress and temperature structure, *Marine Geology, 66*: pp. 219-241.

[6] Lentz, S.J., B. Butman, and A.J. Williams 3rd, 1995. Comparison of BASS and VACM current measurements during STRESS, *J. Atmos. and Oceanic Tech.., 12*, pp. 1328-1337.

[7] Sherwood, C.R., B. Butman, D.A. Cacchione, D.E. Drake, T.F. Gross, R. W. Sternberg, P.L. Wiberg, A.J. Williams 3rd, 1994. Sediment-transport events on the northern California continental shelf during the 1990-1991 STRESS experiment, *Continental Shelf Research, 14 (10/11),* pp. 1063-1099.

[8] Chang, G.C., T.D. Dickey, and A.J. Williams 3rd, 2001. Sediment resuspension over a continental shelf during hurricanes Edouard and Hortense, J. *Geophys. Res. 106(C5),* pp. 517-9531.

[9] Bryden, H.L., H.R. Longworth, and S.A. Cunningham, 2005. Slowing of the Atlantic meridional overturning circulation at 25N, *Nature, 438*, pp. 655-657.

[10] Williams, A.J.3rd and C. Beckford, 1999. Reynolds stress resolution from a Modular Acoustic Velocity Sensor, *Oceans 99,* ISBN: 0-933957-24-6, pp. 386-390.

[11] Milburn, H.B., A.I. Nakamura, and F.I. González, 1996. Real-time tsunami reporting from the deep ocean, *Oceans 96 MTS/IEEE Conference*, 23-26 September 1996, Fort Lauderdale, FL, pp. 390-394.

[12] Normark, W.R. and C.E. Gutmacher, 1988. Sur submarine slide, Monterey Fan, central California, *Sedimentology*, **35,** pp. 629-647.

[13] Williams, A.J.3rd, 2008. AT, an acoustic transmissometer, *Proceedings of IEEE/OES Current Measurement Technology workshop,* Charleston, SC, March 17-19, 2008.

[14] Rossby, T., D. Dorson, and J. Fontaine, 1986. The RAFOS system, *J. Atmos. and Oceanic Tech., 3*, pp. 672-679.

[15] Williams, A.J. 3rd, 2006. Bottom boundary layer wave measurements for particle studies, *Oceans 2006 Singapore*, May 17-19, 2006.

[16] Williams, A.J. 3rd and M.K. Tivey, 2001. Tidal currents at hydrothermal vents, Juan de Fuca Ridge, *Sea Technology, June 2001*, pp. 62-64.

[17] Williams, A.J., 3rd and T. Gross, 1991. In situ processing of boundary layer flow measurements for data compression, *IEEE Oceans '91 Conf. Proc., 2,* pp. 973-976.