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Workshop Proceedings

TOWED VEHICLES: UNDULATING PLATFORMS AS TOOLS FOR MAPPING COASTAL PROCESSES AND WATER QUALITY ASSESSMENT

Seaside, California
5-7 February, 2007

Funded by NOAA's Coastal Services Center through the Alliance for Coastal Technologies (ACT)

An ACT Workshop Report

A Workshop of Developers, Deliverers, and Users of Technologies for

Monitoring Coastal Environments:

Towed Vehicles: Undulating Platforms As Tools for Mapping Coastal Processes and Water Quality Assessment

Seaside, California
5-7 February, 2007

Sponsored by the Alliance for Coastal Technologies (ACT) and NOAA's Center for Coastal Ocean Research in the National Ocean Service.

Hosted by ACT Partner organizations Moss Landing Marine Laboratories (MLML) and the Monterey Bay Aquarium Research Institute (MBARI).

ACT is committed to develop an active partnership of technology developers, deliverers, and users within regional, state, and federal environmental management communities to establish a testbed for demonstrating, evaluating, and verifying innovative technologies in monitoring sensor, platforms, and software for use in coastal habitats.

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Executive Summary

The Alliance for Coastal Technologies (ACT) Workshop on **Towed Vehicles: Undulating Platforms As Tools for Mapping Coastal Processes and Water Quality Assessment** was convened February 5-7, 2007 at The Embassy Suites Hotel, Seaside, California and sponsored by the ACT-Pacific Coast partnership at the Moss Landing Marine Laboratories (MLML). The TUV workshop was co-chaired by Richard Burt (Chelsea Technology Group) and Stewart Lamerdin (MLML Marine Operations). Invited participants were selected to provide a uniform representation of the academic researchers, private sector product developers, and existing and potential data product users from the resource management community to enable development of broad consensus opinions on the application of TUV platforms in coastal resource assessment and management.

The workshop was organized to address recognized limitations of point-based monitoring programs, which, while providing valuable data, are incapable of describing the spatial heterogeneity and the extent of features distributed in the bulk solution. This is particularly true as surveys approach the coastal zone where tidal and estuarine influences result in spatially and temporally heterogeneous water masses and entrained biological components. Aerial or satellite based remote sensing can provide an assessment of the aerial extent of plumes and blooms, yet provide no information regarding the third dimension of these features. Towed vehicles offer a cost-effective solution to this problem by providing platforms, which can sample in the horizontal, vertical, and time-based domains. Towed undulating vehicles (henceforth TUVs) represent useful platforms for event-response characterization. This workshop reviewed the current status of towed vehicle technology focusing on limitations of depth, data telemetry, instrument power demands, and ship requirements in an attempt to identify means to incorporate such technology more routinely in monitoring and event-response programs. Specifically, the participants were charged to address the following: (1) Summarize the state of the art in TUV technologies; (2) Identify how TUV platforms are used and how they can assist coastal managers in fulfilling their regulatory and management responsibilities; (3) Identify barriers and challenges to the application of TUV technologies in management and research activities, and (4) Recommend a series of community actions to overcome identified barriers and challenges.

A series of plenary presentation were provided to enhance subsequent breakout discussions by the participants. Dave Nelson (University of Rhode Island) provided extensive summaries and real-world assessment of the operational features of a variety of TUV platforms available in the UNOLs scientific fleet. Dr. Burke Hales (Oregon State University) described the modification of TUV to provide a novel sampling platform for high resolution mapping of chemical distributions in near real time. Dr. Sonia Batten (Sir Alister Hardy Foundation for Ocean Sciences) provided an overview on the deployment of specialized towed vehicles equipped with rugged continuous plankton recorders on ships of opportunity to obtain long-term, basin wide surveys of zooplankton community structure, enhancing our understanding of trends in secondary production in the upper ocean. Dr. Allan Otta (US EPA Region 9) described the common challenges facing coastal zone nagers by describing the selection and monitoring requirements for ocean dumping sites permitted under the Ocean Dumping Act. Combined, these presentations demonstrated the broad utility of TUV platforms for routine and rapid response applications in coastal monitoring programs.

Alliance for Coastal Technologies

The Alliance for Coastal Technologies is a NOAA-funded partnership of research institutions, resource managers, and private sector companies dedicated to fostering the development and adoption of effective and reliable sensors and platforms. ACT is committed to providing the information required to select the most appropriate tools for studying and monitoring coastal environments. Program priorities include transitioning emerging technologies to operational use rapidly and effectively; maintaining a dialogue among technology users, developers, and providers; identifying technology needs and novel technologies; documenting technology performance and potential; and providing the Integrated Ocean Observing System (IOOS) with information required for the deployment of reliable and cost-effective networks.

To accomplish these goals, ACT provides these services to the community:

- Third-party testbed for quantitatively evaluating the performance of new and existing coastal technologies in the laboratory and under diverse environmental conditions.
- Capacity building through technology-specific workshops that review the current state of instrumentation, build consensus on future directions, and enhance communications between users and developers.
- Information clearinghouse through a searchable online database of environmental technologies and community discussion boards.

The ACT workshops are designed to aid resource managers, coastal scientists, and private sector companies by identifying and discussing the current status, standardization, potential advancements, and obstacles in the development and use of new sensors and sensor platforms for monitoring, studying, and predicting the state of coastal waters. The workshop's goal is to help build consensus on the steps needed to develop and adopt useful tools, while facilitating critical communication among the various groups of technology developers, manufacturers, and users.

> ACT is organized to ensure geographic and sector involvement:
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> - Headquarters is located at the UMCES Chesapeake Biological Laboratory, Solomons, MD.
>
> - Board of Directors includes Partner Institutions, a Stakeholders Council, and NOAA/CSC representatives to establish ACT foci and program vision.
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> - There are currently eight ACT Partner Institutions around the country with coastal technology expertise that represent a broad range of environmental conditions for testing.
>
> - The ACT Stakeholder Council is comprised of resource managers and industry representatives who ensure that ACT focuses on service-oriented activities.

ACT Workshop Reports are summaries of the discussions that take place between participants during the workshops. The reports also emphasize advantages and limitations of current technologies while making recommendations for both ACT and the broader community on the steps needed for technology advancement in the particular topic area. Workshop organizers draft the individual reports with input from workshop participants.

ACT is committed to exploring the application of new technologies for monitoring coastal ecosystem and studying environmental stressors that are increasingly prevalent worldwide. For more information, please visit www.act-us.info.

Goals for the Workshop

- Summarize state-of-the-art Towed Undulating Vehicle (TUV) technologies
- Identify how TUVs are used and how they can assist coastal managers in fulfilling their regulatory and management responsibilities
- Identify barriers and challenges to the application of TUV technologies in management and research activities
- Recommend a series of community actions to overcome these barriers and challenges

Workshop Structure

The Alliance for Coastal Technologies (ACT) Workshop on Towed Vehicles: Undulating Platforms as Tools for Mapping Coastal Features and Processes was convened February 5-7, 2007 at the Embassy Suites in Seaside, California. The workshop was sponsored by ACT's West Coast Regional Partner headquartered at MLML, which maintains a collaborative partnership with MBARI. Invited participants were selected to include equal representation from three population segments concerned with water resource quality and included individuals from academic research institutes, private sector companies, and local, state, and federal resource managers.

An opening reception was held for participants the first evening, and G. Jason Smith (Technical Coordinator for ACT-Pacific Coast Chapter) provided an introduction to the workshop and programmatic overview of the national ACT program.

The following morning, during the opening plenary session, Co-Chairs, Dr. Richard Burt (Chelsea Technologies) and Stewart Lamerdin (Moss Landing Marine Laboratories), provided an overview of the workshop goals. This introduction was followed by four plenary talks (Appendix A) to set the stage for subsequent breakout session discussions. Dave Nelson (University of Rhode Island) provided a brief introduction to several of the commercially available TUVs. Dr. Burke Hales (Oregon State University) provided examples of how high-resolution chemical measurements collected with TUV technology improves our understanding of marine chemistry and gives researchers the ability to visualize large scale phenomena (like carbon export and coastal productivity). Dr. Sonia Batten (Sir Alister Hardy Foundation for Ocean Sciences; SAHFOS) provided a description of the Continuous Plankton Recorder (CPR), the data it collects, and how data are used to monitor plankton communities throughout the world's oceans. Allan Ota (US Environmental Protection Agency, Region 9) provided an overview of the EPA's Ocean Dumping Program and described how he thought TUV technology could be utilized to monitor and identify dumping sites in the program.

The remainder of the day was comprised of two breakout working group discussions and summary sessions. After the working sessions, a tour and dinner was hosted at MLML. Workshop participants provided photographs of TUVs in action, as well as other work-related experiences for a slide show that ran throughout the evening. The crew of the R/V Pt Sur, a UNOLs vessel berthed at MLML, provided a DVD of deep water recovery operations for their Triaxus TUV lost due to submerged object collision during normal operations off the coast of Santa Barbara, CA. The visualization of the difficulty of this ROV aided recovery generated additional discussion of the needs for improved altimetry/object avoidance control as an integral component of TUV operational systems. The following morning was spent in open discussion of consensus recommendations derived from the working group discussions.

Background on TUV Technologies

In natural waters the scale of ecosystem features reflects the physico-chemical characteristics of interacting water masses, geomorphology, and regional weather conditions constrain dependent biological processes, which can further modify water quality characteristics. These water quality features encompass a broad range of spatial and temporal scales, generally becoming more dynamic in coastal and estuarine environments where tidal cycles and watershed inputs can seasonally predominate. Identifying the nature and impacts of these features places great demands on the design of monitoring programs. While point-based core water quality monitoring stations (e.g., conductivity, temperature, chlorophyll fluorescence, turbidity/beam attenuation, dissolved oxygen, and currents from moorings or pier based instrument platforms) provide critical time series information at fixed depths, the point-based sampling design inherently limits their capacity to resolve evolution and connectivity of processes between monitoring station to fortuitous positioning of these limited monitoring resources. While such data sets are invaluable, the limited spatial sampling can lead to biases in model predictions derived from these datasets, especially in dynamic coastal environments. Accurate resolution and monitoring of mesoscale physical or biological features (e.g., fronts and blooms) generally requires synoptic observations, such as those derived from airborne or satellite based remote sensing data products (see ACT Optical Remote Sensing Workshop Report 06-02). Yet even the accuracy of these data products is dependent on the quality and coverage of ground control points in the field of view. Clearly, there is a defined need for the routine implementation of mobile observing assets (AUVs, gliders, drifters, integrated ferrybox systems, see ACT Workshop Reports: 04-05, 04-07, 05-07 and 06-06) to provide high density maps of near surface and subsurface oceanographic features.

Towed vehicles constitute another important class of observational platforms that can provide complimentary data sets to point-based observing networks, by providing rapid high resolution descriptions and tracking of near surface water features, which can guide adaptive sampling strategies for identification of unique features and processes (e.g., thin layer dynamics). While hydrocast surveys have traditionally been used to describe the three dimensional structure of physical, chemical, and biological properties of both marine and freshwater systems, these labor and ship-time intensive surveys necessarily sacrifice resolution of small spatial scale features. In contrast, towed systems provide higher sampling horizontal sampling efficiency and, with the advent of undulating sampling platforms, have provided insights into small spatial and temporal scale features characteristic of aquatic biogeochemical features and fluxes (Fig. 1).

Development of Towed Observational Platforms

The towing capacity of motorized vessels has long been recognized and exploited as a means to isolate a variety of oceanographic observations away from a ship's noise, roll and pitch, while leveraging the advantages of the vessels speed for enhanced survey coverage. A variety of fixed depth tow body designs have been developed and now are an integral platform for the variety of hydroacoustic transducers employed in high resolution bathymetric surveys routinely being conducted from vessels large and small (see ACT Acoustic Remote Sensing Workshop Report 04-06). These efforts have also yielded the added benefits of improving the design and testing cycle processes for improving hydrodynamic efficiencies for given tow body, payload, and cable configurations.

Towed deployment has also been integral in the development of our knowledge base of biological distributions and dynamics in the ocean (phytoplankton, zooplankton, invertebrate and fish larvae, and pelagic fisheries in general), initially through discrete, fixed depth net sampling and post cruise processing. Invention of simple mechanical conveyor systems powered by water motion and development of robust low cost tow bodies led to the deployment of continuous plankton recorders. These relatively simple capture devices have served as towed sampling platforms compatible with deployment by non-technical staff from ships of opportunity (SOOPs) providing an incredible historical record of trans-basin zooplankton distributions since the 1930s. Such towed surveys enabled description of the generally patchy spatial and temporal distribution of biological communities in the sea that were being determined in part by the physics of interacting water masses. While these long distance continuous surveys revealed near surface feature scales not previously described, they also pointed to their limitations in terms of the depth and hence volume resolution of oceanographic features.

Hydrodynamic bodies initially developed for rapid profiling of vertical temperature and salinity structure of water masses (e.g., batho-thermograph / salinograph) have been leveraged as efficient tow body designs to support continuous underway sampling of water chemistry. These tow bodies provide a relatively stable fixed-depth platform for deployment of water sampling inlets and flow lines away from potential contamination from a ship's surfaces and wash and have facilitated accurate high resolution mapping of near surface chemistry of trace metals (e.g., Vink et. al 2000) .

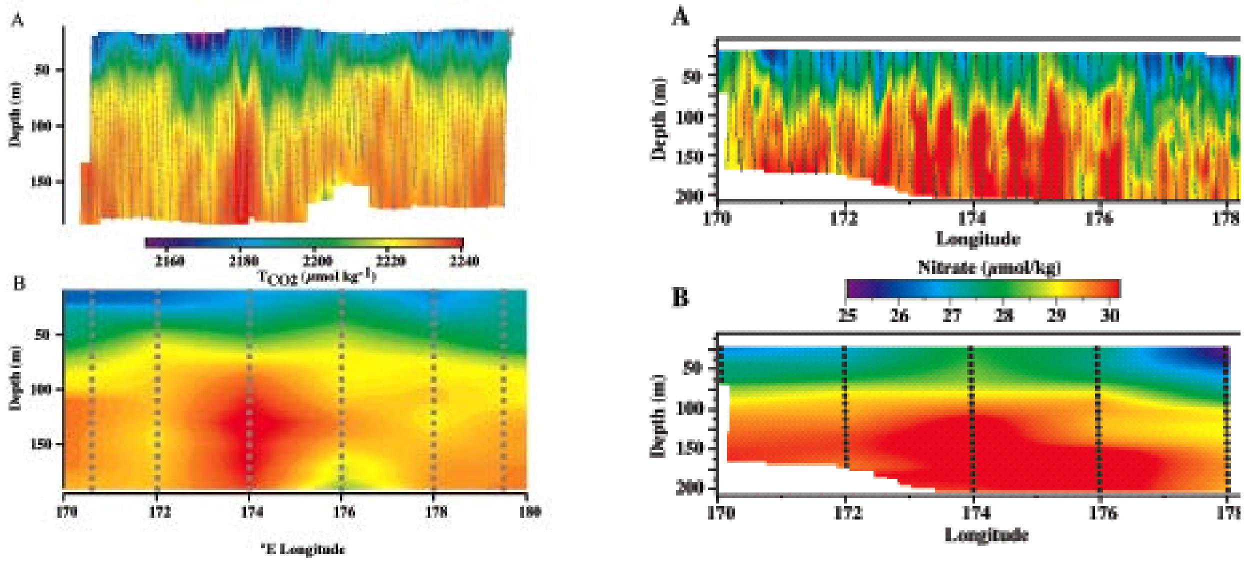


Figure 1. High resolution water sampling enabled by deployment of towed undulating vehicle reveals fine horizontal and vertical scales of variation characterizing biologically important chemicals in the coastal ocean. A panels represent distributions of total CO2 (left) and NO3 derived from underway chemical analysis of water sampled at depth from a TUV. B panels represent the corresponding distribution maps derived from high resolution hydrocast sampling. Courtesey: Burke Hales, OSU.

A critical limitation of the tow system applications described above is that only fixed depth sampling is possible and controlled by length of deployed cable and vessel speed. As physical drag on the cable will increase with tow speed and length, attainable underway sampling depths were limited in absence of increased payload weights or depressor surfaces to counteract the buoyant effects of cable drag. In the late 1970s advances in hydrodynamic design and control systems enabled development of solutions to the problem of fixed depth sampling from tow bodies by incorporation of active control surfaces (wings) onto a variety of tow body platforms (Aiken 1981; Hermann and Dauphinee 1980). The advent of this new class of oceanographic platforms, towed undulating vehicles (or Undulating Oceanographic Recorders, UORs), was not a trivial achievement as to permit reliable water underway water column sampling patterns, an undulating vehicle with desired instrumentation payload must be able to generate sufficient hydrodynamic forces to overcome tow cable and vehicle drag while diving and combined tow cable, vehicle with payload weight and drag when climbing within targeted depth ranges at a given vessel speed (Packwood 1988). Achievement of reliable undulation performance and stable vehicle flight was also dependent upon concurrent development of depth responsive control algorithms and power systems for precision orientation drive flight surfaces. Such systems have evolved from on board independent servo-hydraulic systems (e.g., CTG SeaSoar) to shipboard control computers enabling vertical and lateral flight adjustments in realtime (e.g., MacArtney A/S Triaxis). Again as cable drag is a component of flight performance (Williams 2006) TUV control systems must also provide dedicated winch control for optimal undulation performance.

Alternate engineering solutions enable underway-high frequency acquisition of vertical profile data sets. As an alternative method of profiling, a recoverable free-fall fish (ODIM Brooke Ocean Moving Vessel Profiler) transits near vertically at speeds ranging from 2-7 m/s with the mother ship underway at up to 18 knots. By free-falling the payload during deployment, only tangential drag forces act on the cable and the fish is capable of reaching significant depths compared to a towed system (100 m @ 18 knots, 800 m @ 12 knots, 1,850 m @ 6 knots). Again the wavelength of the profiles will be dependent on ship speed and profile depth.

TUV systems have been proven as an effective ocean observing platform, with existing vehicle designs being adapted to carry the full range of oceanographic instrumentation, including standard CTD packages, fluorometers, transmissometers, spectral attenuation meters, optical particle counters, optical zooplankton recorders, optical nitrate sensors to high speed pumping systems providing flow streams for ship board analyses of the full range of chemical nutrients un-impinged by ship wash (Burt 2000). The rapid movement of the undulating platform (dive/rise speeds 0.1 – 3 m/sec and tow speeds 0.25 – 10 m/s) places a requirement for high sampling rates (≥1Hz) instrumentation to avoid aliased sampling of physical and biological features. This requirement places increased demands on robust internal memory capacity, as well as efficient multiplexed data transmission via the tow cable, such that real time parameter display, along with platform flight attitude (pitch, roll, depth, speed, position), can be used operationally to identify water masses of interest for adaptive re-sampling or control point sampling by traditional hydrocast methods. While the desire is to increase instrument payload capacity, enabling acquisition of more comprehensive data sets per deployment, continued evolution of TUV systems will always be constrained by the coupled system comprised of not only payload capacity but also desired depth maxima, undulation range, ship speed (spatial coverage potential), tow cable design, fairing, and winch requirements (system portability). Larger payload capacity generally necessitates larger tow body size or a sacrifice of vehicle hydrodynamics placing greater demands on winch requirements and reduction in platform portability. None-the-less, a variety of TUV systems have become part of the routine scientific package on UNOLs and oceanographic operations worldwide, as well as been proven as integral components of coastal monitoring programs (Berman and Sherman 2001, Dunning and Hutchings 2005). Manufacturers have also recognized a significant market design for increased portability of TUV systems, and several light weight systems capable of deployment from simple manual or small electronic winches have appeared in the last decade (e.g., Sea Sciences Acrobat, EIVA A/S Mini Scanfish) and incorporating sophisticated flight control systems well suited to work in shallow topologically complex coastal environments. A parallel trend of miniaturization of water quality sensor packages made possible by robust solid state optics, improved memory, battery design, and data integration schema have also facilitated incorporation and integration of diverse sensor packages without sacrificing payload capacity or vehicle hydrodynamics.

Descriptions of Commercially Available Undulating Systems

A majority of workshop participants felt that a compilation of commercially available TUV systems would provide a valuable resource to encourage more routine utilization of these monitoring platforms in ocean observing activities. This is compiled in the following sections, but the reader is urged to check for updated specification provided in the ACT Technology database at http://www.act-us.info/tech_db.php or through the manufacturer's website.

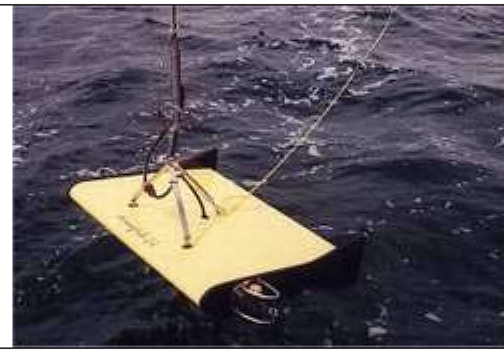
The following summary pages are meant to provide a quick view of specifications and applications of commercial TUV systems. The term "standard WQ packages" refers to instruments for measurement of IOOS designated core water quality parameters of conductivity, temperature, depth (CTD) coupled with chlorophyll, a fluorescence, along with nephelometry/turbidity measures and/or dissolved oxygen measures. CTD packages often provide data integration capabilities as well. "Base Costs" are intended to represent the minimal pricing for a deployment-ready TUV platform sans custom instrumentation and encompassing a system configuration, including vehicle, cabling, winch, and deck control box with flight software.

System:	**ACROBAT**
Manufacturer:	Sea Sciences, Inc.
Website:	www.seasciences.com
Specifications:	
Dimensions (lwh) -	0.8m x 0.73m x 0.4m
Materials -	Welded stainless steel frame and towing yolk PVC Tail, Composite wings
Weight -	15 kg air, 9 kg water
Payload Capacity -	
Tow Speed -	1-12 knots
Max Depth -	100 m
Dive/Rise Rate -	Adjustable
Power -	120V/220V AC input, 30V DC output, max 0.1A
Cable -	Vectran with 8 conductors, 50 – 150 m length
Winch -	Portable winch with slip ring assembly for full flight control. Can be operated from small boast using cable rope clutch and hand control unit.
Control -	Manual and/or computer with real-time communication
Instrumentation Deployed:	Standard WQ sensor packages, optical plankton counter, optical nitrate sensors, in situ chemical sensors, marine optics packages, video cameras. Flexible instrument configuration on open frame.
Current Applications:	Estuary, coastal zone and fresh water data surveys from very small boats. Ecosystem health monitoring, real-time three dimensional data gathering in support of modeling efforts. Pollution monitoring, dye tracking studies, ground truth surveys for satellite remote sensing scenes. Event driven local area site assessments.
Base Cost:	$74,600

System:	**AquaShuttle III**
Manufacturer:	Chelsea Technologies Group
Website:	www.chelsea.co.uk
Specifications:	
Dimensions (lwh) -	1.39m x 0.5m x 0.38m
Materials -	316 stainless steel frame and towing yolk Strengthened glass fibre reinforced plastic body
Weight -	66 kg air, 45 kg water
Payload Capacity -	Two payload areas – forward and aft
Tow Speed -	8 - 25 knots
Max Depth -	85 m (>120 m with faired cable)
Dive/Rise Rate -	Up to 1 m/s
Power -	Impellor driven alternator powering digital servo above 5 knots; via cable
Cable -	Rochester 7-H-314A or equivalent for real-time deployments. Indal Flexnose® fairing or equivalent used for increased depth and undulation performance
Winch -	Dedicated winch with slip ring assembly required for real time flight control and data assessments via communication to surface deck unit. Unattended bare cable towing possible via ship's capstan
Control -	On board processor control of elevator servo from pre-programmed profile or via real-time communication with deck control unit.
Instrumentation Deployed:	Standard WQ sensor packages, optical plankton counter, optical nitrate sensors, in situ chemical sensors, marine optics packages, versatile payload configuration
Current Applications:	Oceanographic data collection from ships of opportunity. Estuary, coastal zone and open ocean surveys, ecosystem health assessments, pollution and dye tracing studies, satellite remote sensing sea truth
Base Cost:	$190,000

System:	**NvShuttle**	
Manufacturer:	Chelsea Technologies Group	
Website:	www.chelsea.co.uk	
Specifications:		
Dimensions (lwh) -	1.3m x 0.58m x 0.5m	
Materials -	Welded stainless steel frame with affixed polyethylene panels Stainless towing yolk	
Weight -	72 kg air, 45 kg water	
Payload Capacity -	One large enclosed payload area	
Tow Speed -	5-15 knots	
Max Depth -	80 m (>150m with faired cable)	
Dive/Rise Rate -	Up to 2 m/s	
Power -	Impellor driven alternator powering digital servo above 5 knots; via cable	
Cable -	Rochester 7-H-314A or equivalent for real-time deployments. Indal Flexnose® fairing or equivalent used for increased depth and undulation performance	
Winch -	Dedicated winch with slip ring assembly required for real time flight control and data assessments via communication to surface deck unit. Unattended bare cable towing possible via ship's capstan	
Control -	On board processor control of elevator servo from pre-programmed profile or via real-time communication with deck control unit.	
Instrumentation Deployed:	Standard WQ sensor packages, optical plankton counter, optical nitrate sensors, in situ chemical sensors, marine optics packages, protected payload configuration in tow housing	
Current Applications:	Oceanographic data collection from ships of opportunity. Estuary, coastal zone and open ocean surveys, ecosystem health assessments, pollution and dye tracing studies, satellite remote sensing sea truth sampling	
Base Cost:	$170,000	

System:	**SeaSoar II**
Manufacturer:	Chelsea Technologies Group
Website:	www.chelsea.co.uk
Specifications:	
Dimensions (lwh) -	1.5m x 0.98m x 1.6m
Materials -	Stainless steel frame and towing yoke Strengthened glass fibre reinforced body covering frame
Weight -	150 kg air
Payload Capacity -	
Tow Speed -	6.5-12 knots
Max Depth -	100 m (to 500m with faired cable)
Dive/Rise Rate -	1m / s (3m / s with faired cable)
Power -	Impellor driven alternator powering digital servo above 5 knots; via cable
Cable -	Rochester 7-H-314XX, high strength armor or equivalent. Indal Flexnose® fairing or equivalent used for increased depth and undulation performance
Winch -	Dedicated slip ring winch and cable system required to meet user specifications
Control -	Surface deck control unit for flight control, manual override and real time data, altimetry visualization. Pre-program flight compatible
Instrumentation Deployed:	Standard WQ sensor packages, optical plankton counter, optical nitrate sensors, in situ chemical sensors, subsurface water sampling, bioluminescence detectors, marine optics packages
Current Applications:	Coastal zone and open ocean surveys, Large marine ecosystem health assessments, satellite remote sensing sea truthing, upper ocean dynamics, Military oceanography, fisheries research
Base Cost:	$260,000

System:	**ScanFish MK I**	
Manufacturer:	EIVA a/s	
Website:	www.eiva.dk	
Specifications:		
Dimensions (lwh) -	0.6m x 1.0m x 0.14m	
Materials -	Stainless steel towing yolk and frame encased by molded PVC wing. Wing structure forms instrument payload and control system housing	
Weight -	20 kg air	
Payload Capacity -	20 kg	
Tow Speed -	10 knots	
Max Depth -	100 m	
Dive/Rise Rate -	2m / s	
Power -	Via tow cable	
Cable -	Rochester A301301 or similar	
Winch -	Winch or capstan	
Control -	Preprogrammed undulation or fixed depth/altitude tows	
Instrumentation Deployed:	Standard WQ sensor packages, optical plankton counter, optical nitrate sensors, video cameras. Custom integration of sensor suites.	
Current Applications:	High speed fixed depth or undulating oceanographic surveys. Well suited for applications requiring low magnetic or acoustic signatures.	
Base Cost:	$????	

System:	**ScanFish MK II**	
Manufacturer:	EIVA a/s	
Website:	www.eiva.dk	
Specifications:		
Dimensions (lwh) -	0.8m x 1.6m x 0.14m	
Materials -	Stainless steel towing yolk and frame encased by molded PVC wing. Wing structure forms instrument payload and control system housing	
Weight -	50 kg air	
Payload Capacity -	20 kg	
Tow Speed -	10 knots	
Max Depth -	400 m	
Dive/Rise Rate -	1m / s	
Power -	Via tow cable, internal battery backup	
Cable -	Rochester A301301 or similar, no fairings, customizable with system	
Winch -	Dedicated winch with slip ring configuration, customized with system	
Control -	Deck control box and data acquisition, individual wing flap control, with on board feedback, pitch & roll sensors, selfrighting, acoustic altimeter for depth and bottom avoidance control, automatic winch control	
Instrumentation Deployed:	Standard WQ sensor packages, optical plankton counter, optical nitrate sensors, video cameras, ADCP, marine optic packages. Custom integration of sensor suites.	
Current Applications:	3D oceanographic and hydrographic surveys, ecosystem health assessments, mulibeam and sidescan sonar calibration surveys, pollution tracking, suited for shallow water operations	
Base Cost:	$ 188,000	

System:	**ScanFish Mini**
Manufacturer:	EIVA a/s
Website:	www.eiva.dk
Specifications:	
Dimensions (lwh) -	0.57m x 0.97m x 0.22m
Materials -	Stainless steel towing yolk and frame encased by molded PVC wing. Wing structure forms instrument payload and control system housing
Weight -	35 kg air
Payload Capacity -	20 kg
Tow Speed -	10 knots
Max Depth -	400 m
Dive/Rise Rate -	1m / s
Power -	Via tow cable, internal battery backup
Cable -	Rochester A301301 or similar, no fairings, customizable with system
Winch -	Dedicated winch with slip ring configuration, customized with system
Control -	Deck control box and data acquisition, individual wing flap control, with on board feedback, pitch & roll sensors, selfrighting, acoustic altimeter for depth and bottom avoidance control, automatic winch control
Instrumentation Deployed:	Standard WQ sensor packages, optical plankton counter, optical nitrate sensors, video cameras, ADCP, marine optic packages. Custom integration of sensor suites.
Current Applications:	3D oceanographic and hydrographic surveys, ecosystem health assessments, mulibeam and sidescan sonar calibration surveys, pollution tracking, suited for shallow water operations
Base Cost:	$ 100,000

System:	**TRIAXUS E**
Manufacturer:	MacArtney a/s
Website:	www.macartney.com
Specifications:	
Dimensions (lwh) -	1.85m x 1.95m x 1.25m
Materials -	Carbon fibre, syntactic foam
Weight -	130 kg air unloaded
Payload Capacity -	50 kg (E)
Tow Speed -	1-10 knots
Max Depth -	350m, +/- 80 m lateral from tow axis
Dive/Rise Rate -	1m / s
Power -	120V/220V AC via cable
Cable -	Rochester 05382 2 fibre optic 2 conductor
Winch -	Dedicated winch system with slip ring assemble
Control -	Top side programmable control and data integration unit, programmed or manual flight after deployment, vertical and lateral positional control, including pitch, roll yaw feedback. Altimetry sensors and bottom avoidance, high speed fibre optic communications
Instrumentation Deployed:	Standard WQ sensor packages, optical plankton counter, optical nitrate sensors, in situ chemical sensors, marine optics packages, ADCP, video cameras, 4 internal payload bays
Current Applications:	High speed 3D oceanographic and hydrographic surveys, bloom and plume monitoring, fisheries research
Base Cost:	$365,000

System:	**Moving Vessel Profiler**
Manufacturer:	ODIM Brooke Ocean
Website:	www.brooke-ocean.com
Specifications:	
Dimensions (lwh)	Fish sizes range from 0.8 m to 2.1 m in length
Materials -	Aluminum or brass free-fall fish with internal payload bay
Weight -	Family of systems ranging from 12 kg to 100 kg
Payload Capacity	Can accommodate 5 or more sensors
Tow Speed -	Up to 18 knots
Max Depth -	1,850 m @ 6 knots, 800 m @ 12 knots, 100 m @ 18 knots
Dive/Rise Rate -	Up to 7 m/sec during free-fall; 1.5 m/s retrieval speed
Power -	Via tow cable, internal battery backup
Cable -	E-M cable with synthetic strength member, no fairings
Winch -	Slip ring winch with integral overboarding boom
Control -	Automated system with built-in bottom avoidance
Instrumentation Deployed:	CTD, sound velocity, Laser Optical Plankton Counter, fluorometer, dissolved oxygen, turbidity, radiance/irradiance, Free-Fall Cone Penetrometer.
Current Applications:	Calibration of multibeam sonars for hydrographic surveys, oceanographic surveys, mine countermeasures, rapid environmental assessment, satellite ground truthing.
Base Cost:	$ 150,000 for smallest system

Summary of Breakout Group Discussions

First Breakout Session

This breakout session sought to develop sector-specific viewpoints on the following aspects of towed underwater vehicle technologies:

1. What TUV technologies are currently available?
   a. What are the main markets?
   b. What instrumentation do they support?
   c. In what environments are they used?
   d. What type of ship support is required for successful operations?
2. Do you use TUVs? Would access to such platforms aid your monitoring efforts? How? If not, why not?

Management Sector Viewpoint:

Group Chair: Ann Jochens; Rapporteur: Greg McFall

Representatives from the management sector had limited experience with TUV technologies and felt that TUV data could easily be used in their projects and programs, but access to information and operational data from TUVs was the limiting factor. They focused much of their discussion on how they wanted to use TUVs, the instruments they would need, and the advantages and disadvantages to using TUVs. Management felt they could use TUVs for most survey tasks including: ecological sampling, routine environmental monitoring, trend analysis, locating archaeological sites, surveying and locating seafloor features, looking at impacts (both current and historical) on the seafloor, examining benthic habitat (who and what), habitat mapping, biological characterization, tracking plumes, and hazard mapping. Instrumentation for some of these applications would include CTD, chemical and biological sensors (i.e., nutrients, harmful algae, pathogens), side scan sonar, sub-bottom profilers, optical imaging (video and still images), and passive acoustic listening.

Management sector representatives felt that the advantages to TUVs were that they were (a) cheaper to buy but had to overcome the underlying perception that they are more expensive to operate, and (b) as observational platforms, they were more flexible, could be used over a longer duration, potentially have higher data resolution, can quickly survey a large area, and more likely to be found if lost (compared to AUV). The disadvantages were perceived as (a) defining precise platform position astern of the towing vessel (time and space), (b) surface, bottom, and submerged obstacle avoidance limitations, (c) mechanical / maintenance needs and costs (e.g., for cable breaks, re-termination), (d) capacity for realtime, precision flight control need to maneuver in topographically complex habitats, (e) need for expert operators increase operational costs but may be necessary for data quality control, and (f) purchase and operational costs may be prohibitive for many management agencies, and regionally shared resources would be needed.

Industry Sector Viewpoint:

Group Chair: Christian Casagrande

Representatives from the industry sector felt that most markets were utilizing TUVs because they are more flexible and provide greater data coverage than permanent moorings. TUVs have been used in habitat association studies, geological surveys, dye diffusion/transport studies, homeland security, and military research. Representatives stated that there were very few instrument packages that a TUV body could not accommodate; it is important for potential users to identify the in water characteristics they want to measure and the depths they require with optionals constrained within the limitations of undulating vehicle size and ship support requirements. TUVs can be used in any environment, freshwater or coastal, but are constrained by the size of the vehicle and the depth of the water. Industry representatives emphasized the need for customer education both during the proposal stage and post delivery. Hands-on-training is important – users should be properly instructed on vehicle flying and maintenance to avoid damage to the TUV and instrument payloads.

Research Sector Viewpoint:

Group Chair: John Morrison

Representatives from the research sector focused most of their discussion on suggestions and improvements for current TUVs. They strongly believed that the cable, winch, and body need to be packaged as one system. A mismatch of these major components can lead to inefficient flying of the vehicle and potentially cause damage and endanger personnel. Researchers felt that TUVs are under-utilized given the amount of potential and believe that they would be used more in research if they were "more user friendly." TUVs should be easier to maintain, especially while out at sea, and they need better lost vehicle recovery options. Calibration standards for both the deployed instrument packages and the vehicle itself need to be provided in user-friendly configurations. Vehicle diagnostic packages need to be further developed to help identify when problems arise during sea deployment. Improved modularity of vehicle design would increase TUV research use, as currently it is difficult to add or remove instruments for different research groups while at sea. Research representatives thought that problems with macro-fouling needed be addressed. The research sector also segued into the topic of cables and fairings. They felt that currently they have to sacrifice optimal flight control of the vehicle for practical or safety issues because of the difficulty of fairing a ship's standard cable. A strong call was made for improved fairing design, including cable attachment/release functionality; this point also echoed the desire to have TUVs packaged as matched systems (vehicle, cable, fairing, and winch) to promote ease of use and safety in deployment from a range of research vessels.

Second Breakout Session

Cross-sector groupings of the participants were formed to address the questions:

1. What improvements are needed or are on the horizon to increase the utility of these platforms in coastal ocean monitoring programs?

2. What would be your ideal instrumentation package for a TUV system? What limits attaining that ideal?

Group Chairs: Bungy Williams, Margo Edwards, Doug Weaver

The workshop participants generally agreed that TUVs need to be less expensive and easier to use and maintain. Their suggestions for improvement fell into three main categories: Vehicle, Vehicle Flying, and Handling System (winch and wire).

Vehicle – Body and vehicle suggestions included having a smaller more compact body with increased flexibility of modulation. Participants wanted the ability to easily integrate new instruments, to expand the payload around the unit, and have access to the inside of the vehicle to add on and fix problems with instruments. They also felt it was important to have the vehicles fitted with forward sonar (or another instrument) to assess bottom topography for collision avoidance and have some sort of geo-reference locator in case the vehicle is lost.

Vehicle Flying – The participants also felt improvements needed to be made in relation to actually using the TUVs. They wanted a user friendly software package with a simple visual screen, standardized data output, and, more importantly, a diagnostic program to troubleshoot problems with the vehicle itself and communications with the vehicle and its instruments. The participants also felt that developing a standard operating procedure (SOP) made up from the technical manuals to help with daily use and troubleshooting would be very useful. Users also wanted the ability to deploy TUVs from smaller vessels and have better recovery options, such as auto-triggered acoustic pingers, tethered buoys, or fluorescent dye markers.

Winch and Wire – Participants strongly agreed that there needed to be improvements with the winch and wire systems on the vessels and acknowledged that this would require increased communications with winch and cable companies. The participants felt that TUVs should be designed to use winch and wire systems that are compatible with UNOLS ships. They suggested that winches be controlled electrically (vs. hydraulic), drum driven, have auto controls, and be designed to tow more than one body. Participants wanted tow cables to be stronger, more flexible, and smaller with increased bandwidth and data rate. The group felt that, when needed, fairings must be easier to use, with snap on capability highly desirable to increase the life expectancy of the wire, as permanent fairings provide ample hidden environments for metal cable corrosion and premature failure.

An ideal TUV would have the flexibility to make all geological, archaeological, and oceanographic observations tailored to the user's needs. It would also be relatively inexpensive to purchase and operate and easy to use and maintain. Ideally, the winch, wire, and body would be one unit, eliminating a lot of the winch and wire problems operators encounter. It could also increase the portability of the unit, thereby increasing its usage among users. This ideal TUV would also have underwater connectors and anti-fouling devices for both the wire and the body.

Most importantly, the participants specified a need for increased training in an effort to increase safety and decrease vehicle damage, but also recognized that this is logistically difficult in terms of cost and personnel. One solution was finding someone who offered a training course where users pay to learn about the systems (similar to the multi-beam training offered by Ocean Mapping Group, University of New Brunswick). Ideally, there would be training for the system as a whole, instrument training, and safety training for the launch, recovery, and maintenance of the TUVs. Training could also include incorporating a "flight simulator" to familiarize operators with controls and the vehicle without actually being in the water and have experienced support on board during the first deployment. The TUV vendors said they could realistically train for flight and payload, but training for instrumentation becomes difficult because the instruments come from different vendors.

Workshop Recommendations

The enthusiastic and vigorous discussions among workshop participants led to their development of the following prioritized list of recommendations that the group felt were needed to facilitate the further development and use of TUVs for mapping coastal features and processes.

1. Make information about the accessibility of TUV platforms readily available to end users. This includes:
    a. Developing mechanisms for facilitating user interactions and information exchange (e.g., ACT Discussion Forum), and link this report to those specific user forums.
    b. Encouraging the development of dynamic inventories of TUV platforms, user supported regional OOS efforts, and local monitoring efforts.
2. Industry needs to be encouraged to be actively involved in IOOS and Regional Association development.
3. Increase communication between end-users and manufacturers. Specific user groups need to clearly identify their sampling needs and potential management applications to TUV manufacturers (e.g., plume tracking, habitat mapping, harmful algae blooms).
4. Increase communications with related business manufacturers, including fairing design, cable and winch technology, and hybrid control systems.
5. ACT should sponsor a workshop on emerging trends in these areas and create an opportunity for user input on needs for cable and connector technology.
6. ACT can help pursue broader public relations efforts on TUV and other workshop findings (e.g., publish summaries in SeaTechnology, MTS, ORION, etc., as well as broadcast an executive summary to regional agencies and societies).
7. TUV application training workshops and TUV demonstrations should be supported by ACT and other similar programs.

Concluding Remarks

This workshop provided a unique opportunity for experienced users, represented by regional oceanographic research vessel technicians, to join meetings with TUV manufacturers, principal scientists, and resource managers to describe their hands-on experiences with deployment, flight, maintenance, and instrument integration experiences with a variety of TUV platforms. Relaying of this real-world experience was enlightening to all attendees.

The utility of these systems is without question and rugged vehicle designs are well suited for the range of aquatic environments. The group came to the realization that, while the goal is there to make use of TUV platforms systems for adaptive or event-driven regional ecosystem surveys of coastal and estuarine as well as open ocean environments, it is a technology that requires dedicated and experienced personnel for generation of high quality survey data. To open up TUV survey to broader user groups, continual improvements in flight control software and onboard altimetry systems (for improved bottom avoidance, specifically in shallow waters) is needed. Concurrent improvements in cable, fairing, and winch design with the goal of increasing system portability, along with flight control and payload capacity, are also needed to help expand TUV deployments and applications as regional resource management aids and permit reliable deployment from ships of opportunity. Not-withstanding these tractable problems, TUV platforms were viewed by the group as operationally ready platforms, uniquely capable of conducting high resolution, rapid, integrated physical-chemical-biological area assessments of regional aquatic ecosystems and are viewed as an essential, potentially rapid-response asset in regional observing programs.

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Towed Undulating Vehicle Applications Workshop Participants Gathered for the Final Plenary Session

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APPENDIX A. PLENARY SESSION TALKS

Speaker	Topic
Dave Nelson (URI, GSO)	**TUV's or Not TUV's …. Data Is The Question. A Brief Introduction To The Technologies**
Burke Hales (Oregon State University)	**New Insights From TUV-based Chemical Measurements**
Sonia Batten (SAHFOS, Fisheries & Oceans Canada)	**The Continuous Plankton Recorder Programme and Some Recent Results**
Allan Otta (US EPA Region 9)	**Site Selection and Monitoring Requirements of the Ocean Dumping Act – Potential Applications for TUV Technology**

Copies of the PowerPoint™ presentation files are available upon request from jsmith@mlml.calstate.edu .

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