Once a red tide of *G. breve* is formed, after DON supplied from nitrogen-fixers of our one-dimensional model, its simulated trajectory over 16 vertical levels during December 1979 (**Figure 5A**) matches repeated shipboard and helicopter observations (**Figure 5B**) of this dinoflagellate bloom at the surface of the West Florida shelf, if one samples the model at sunrise after nocturnal convective mixing: at noon, the simulated red tide instead aggregates in a subsurface maximum, as observed during additional time-series studies.

Under the predominantly upwelling-favorable winds of fall/winter, the circulation model yields a positive w of $\sim 0.5\text{–}1.0\,\mathrm{m\,d^{-1}}$ within the red tide patch and of $1.0\text{–}2.0\,\mathrm{m\,d^{-1}}$ at the coast. In another model case, without the vertical downward migration of *G. breve* at a speed of $\sim 1\,\mathrm{m\,h^{-1}}$ to avoid bright light, the model's surface populations then did not replicate the data; they were instead advected farther offshore than the *in situ* populations. It appears that in the 'real world' *G. breve* spent most of their time in the lower layers of the water column, before ascending to be sampled by ship and helicopters during daylight at the sea surface.

Furthermore, within the bottom Ekman layer, the simulated red tide is advected onshore, mimicking observations of shellfish bed closures on the barrier islands. Thus, the coupled models suggest that, upon maturation of a red tide from successful competition among functional groups of the phytoplankton community (**Figure 1**), vertical migration of *G. breve* in relation to seasonal changes of summer downwelling and fall/winter upwelling flow fields then determines the duration and intensity of red tide landfalls along the beaches of the west coast of Florida.

Prospectus

Other regional models of varying ecological and physical realism have been constructed for numerous shelf regions. They are mainly classic *N–P–Z* formulations, however, such that they may be improved with inclusion of a larger number of ecological state variables. Simply adding biochemical and physical variables for the next generation of coupled regional models is not sufficient, because the initial and boundary conditions will always be poorly known. Like models of the weather on land, such predictive models must be continually validated with data to correct for the poor knowledge of these conditions.

Given the expense of shipboard monitoring programs, a few bio-optical moorings (e.g., fluorometers or remote sensors (**Figure 1**)), are the most likely sources of such updates for the ecological models. Furthermore, the veracity of the underlying circulation models must be maintained with a complete suite of buoyancy flux measurements at the same moorings, to derive the baroclinic contributions important to the regional flow fields. For example, the barotropic calculations of the West Florida shelf case did not match current meter observations during summer on the outer shelf. The bio-optical implications of regional physical/ecological models driven by time-dependent density fields must be included in future simulation analyses.

See also

Elemental Distribution: Overview. El Niño Southern Oscillation (ENSO) Models. Forward Problem in Numerical Models. Inverse Models. Lagrangian Biological Models. Population Dynamics Models.

Further Reading

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REMOTELY OPERATED VEHICLES (ROVs)

K. Shepherd, Institute of Ocean Sciences, British Colombia, Canada

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Introduction

Remotely operated vehicles (ROVs) are vehicles that are operated underwater and remotely controlled from the surface. All types of this vehicle are connected to the surface platform by a cable that provides power and control communication to the vehicle. There are three basic types of vehicle: free-swimming tethered vehicles; bottom-crawling tethered vehicles; and towed vehicles. The free-swimming vehicle is the most common. It has thrusters that allow maneuvering in three axes, and provides visual feedback through onboard video cameras. It is often used for mid-water or bottom observation or intervention. Bottom-crawling vehicles move with wheels or tracks and can only maneuver on the bottom. Visual feedback is provided by onboard video cameras. Bottom crawlers are usually used for cable or pipeline work, such as inspection and burial. Towed vehicles are carried forward by the surface ship's motion, and are maneuvered up and down by the surface-mounted winch. Towed vehicles usually carry sonar, cameras, and sometimes sample equipment.

Remotely operated vehicles were first introduced to the offshore community in 1953. Over the next 22 years, several more vehicles were built to fulfill military and other government research requirements. In 1975, the first commercial vehicle was built for the offshore oil industry. Since 1975, over 90% of the ROVs produced have been developed for commercial offshore work that includes oil and gas drilling support, as well as pipeline and telecommunications cable inspection, burial, and repair. As the depths for oil exploration and production have increased, the commercial ROV industry has been pressed to keep pace. Current exploration depths are now reaching 3000 m. The remaining vehicles are used to support military and scientific research and intervention. Military applications include submarine rescue, mapping, reconnaissance, recovery, and mine countermeasures. Scientific applications are far-ranging and cover many different fields including biology, physics, geology, and chemistry. Depths for this work range from a few metres to 10 000 m.

Basic Design Characteristics

ROV systems are built in many different configurations and sizes. However, there are many common design characteristics that consist of some or all of the components described in the sections below.

Vehicle

Vehicles range in size from 20 cm in length and a mass of a few kilograms, to several metres in length and masses of thousands of kilograms. The vehicle itself can be broken down into several subsystems.

Frame The vehicle frame is typically an open frame constructed of aluminum. Components are bolted to the frame. The frame provides structural support and protection, and provides a method of connecting the buoyancy, propulsion, and other vehicle systems.

Buoyancy Buoyancy control is critical to the proper performance of the vehicle. ROVs typically have fixed buoyancy provided by syntactic foam, or some other type of noncompressible foam. This flotation counteracts the weight of the vehicle frame and mechanical components. Smaller variations in buoyancy are provided by vertical thrusters. This type of vehicle is usually ballasted so that it will float to the surface if the tether is accidentally severed. This also improves operations, as the vertical thrusters are usually forcing the vehicle down, with the thruster wash moving upward away from the bottom. If the thrust is directed toward the seabed, the silt is easily stirred up, destroying visibility.

Propulsion The propulsion system consists of thrusters that control the vehicle motion in three axes. A minimum of two fore/aft thrusters control forward and reverse motion and speed and, by the direction of thrust, the vehicle heading. Vertical thrusters control the vertical motion of the vehicle. Lateral thrusters may be used to allow the vehicle to maneuver sideways while maintaining a constant heading.

Vision Video cameras contained in pressure-proof housings with acrylic or glass faceplates are the primary source of vision. Multiple cameras are used on larger vehicles to give a wider field of view, or a different perspective. High-resolution, state-of-the-art television broadcast-quality cameras are now being integrated to provide high-quality images that some clients require. In some cases, stereo vision is implemented to help improve spatial awareness and operator efficiency.

Control Control of the vehicle is most often implemented with computer control. A computer on the surface communicates with a computer mounted on the vehicle. Control input, from human or computer, is fed into the surface control computer. The vehicle computer then issues the control commands and provides feedback to the operator. This system is referred to as a telemetry system. A second type of control, most often found on small, less sophisticated vehicles, is hardwire control. In this

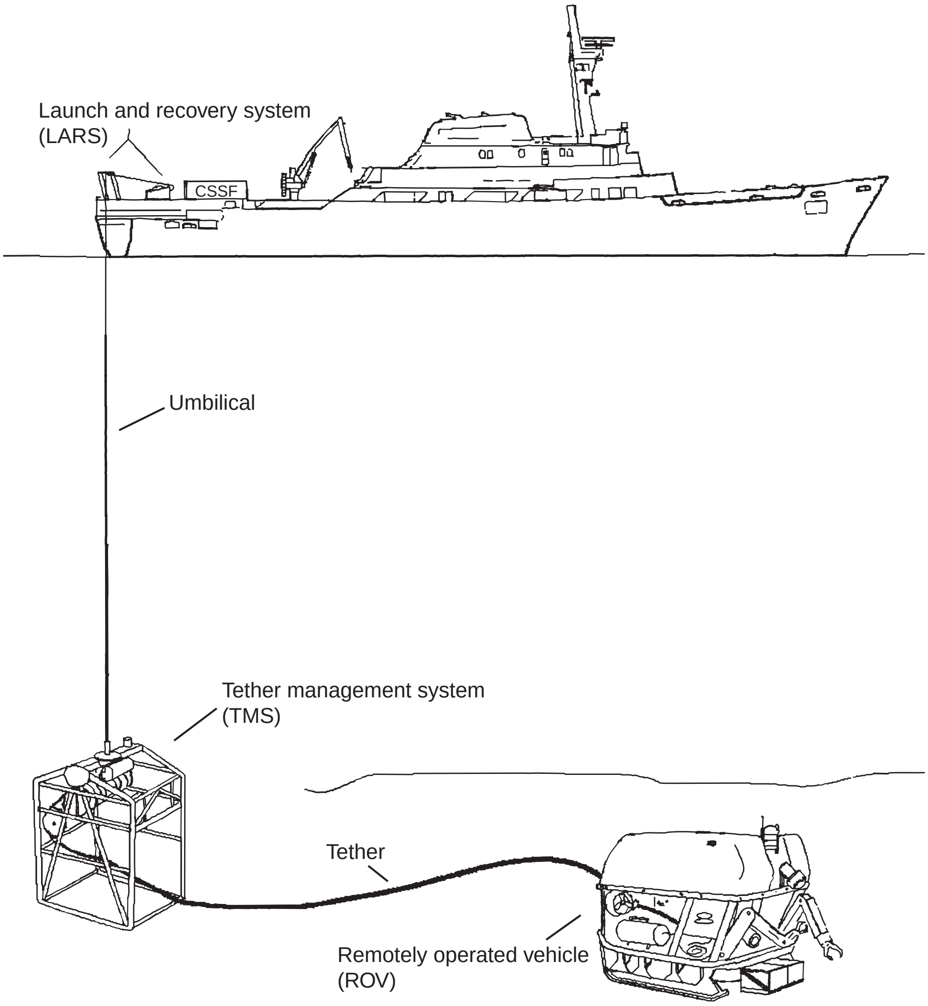

Figure 1 Use of the tether management system for larger vehicles.

case the vehicle thrusters, lights, etc., are wired directly to surface controls. This eliminates the requirement for control computers but restricts the amount of control that can be implemented, and can also limit the tether length.

Manipulators ROVs are usually fitted with some type of manipulator. Smaller vehicles, if fitted with a manipulator, will often carry a small arm with one or two functions. Large vehicles will be fitted with two powerful manipulators. These will range from simple five-function, rate (the function direction is either on or off) control arms to complex seven or eight-function arms with force feedback and spatially correspondent control. Manipulator technology has evolved steadily during the history of the ROV. Reliability and efficiency have improved as a result.

Other sensors ROVs are usually fitted with additional sensors. Scanning sonars are common and give an acoustic image of the area surrounding the vehicle. The range of the sonar will vary depending upon the system used, but generally it will reach past 100 m – well beyond the visual range of the cameras. Altimeters are similar to echo sounders and give vehicle height above the bottom. Depth sensors are implemented on nearly every vehicle. They range from precision sensors to hand-held units strapped to the vehicle frame in front of the camera.

Tether Management System (TMS)

Some ROVs operate with a neutrally buoyant tether cable connecting them directly to the ship or work platform. The buoyancy of this cable can be modified by adding floats and weights. A common alternative approach for larger vehicles is to use a tether management system (see **Figure 1**). The TMS can be designed in several different configurations.

- One approach is to use a ‘cage’, which houses the vehicle for launch and recovery, and has a winch that pays out or retracts tether as needed. The vehicle is clamped into the cage and is launched from the support vessel. The main winch, mounted on the support vessel, lowers the complete package to the working depth and then suspends it several meters above the worksite. The vehicle is released, tether is paid out by the TMS, and the ROV flies out to perform its work. Upon completion of the work, the vehicle returns to the cage and is clamped in place, and the complete package is recovered.

- The 'top hat' configuration has a smaller TMS with an integral winch that sits on top of the vehicle. Once at operating depth the ROV unlatches from the TMS and descends to the worksite. Upon completion of the work, the ROV latches to the bottom of the TMS and the complete package is recovered.

Tether Cable

The term tether is usually used to refer to the cable directly connected to the vehicle. The vehicle tether is the greatest advantage that an ROV has over other types of systems, such as autonomous underwater vehicles (AUVs) and manned submersibles. It delivers power continuously to the vehicle as well as delivering control data. It also allows a tremendous volume of data to be transmitted in real time from the vehicle to the surface. This includes many channels of high-resolution video, acoustic sonar data, vehicle feedback information, and other data. The tether is also the greatest liability of the ROV: it is adversely affected by currents, it has high drag, and it can easily be damaged during operations. It is most often neutrally buoyant by design, or is made neutral by adding floats.

Umbilical Cable

The term umbilical usually refers to the cable, commonly steel armored, that connects the support vessel to the TMS. This cable will have a fiberoptic bundle, or coaxial cable for command, control, and data transmission. This core will be surrounded by power conductors, used to provide the vehicle with power. Finally, it will have a protective jacket and steel or synthetic strength member. This cable will be paid in and out from a deck mounted winch, to control the depth of the TMS or vehicle.

Launch and Recovery System (LARS) and Winch

Most ROV systems come complete with an integrated LARS. Small vehicles can be deployed and recovered by hand, while medium to large vehicles employ either a crane or an A-frame. Large systems typically have a purpose-built LARS that is integrated with the umbilical winch. With a self-contained system the vehicle can be installed upon many different platforms that are not equipped with launch and recovery gear.

Surface Control Station(s)

Surface control stations usually contain at a minimum a video monitor, videocassette recorder, and joystick for vehicle control. As systems become larger and more complex, the amount of surface equipment grows to include electrical distribution systems, surface control computers, and consoles for copilots and navigators.

Control System

Control systems cover as wide a range of design as there are vehicles. The control systems can be broken down into two basic types.

- Hardwired control. In this configuration each individual ROV component is connected directly to the surface, through the tether, with its own set of dedicated wires. This approach is simple, robust, and inexpensive. It does limit tether length and increases the wire count in the tether and the amount of control that can be implemented.
- Computer telemetry system. Computer control allows a tremendous increase in the control available for the vehicle. Wiring for the vehicle can be reduced to power and one pair of control wires, or fiberoptic cable. Video and sonar data are still typically brought back discretely on their own fiber or signal wires.

Portable Design

Almost all ROV systems are designed to be portable. This allows them to be installed on ships or platforms of opportunity in various ports around the world. When an operation is complete, they can be demobilized and returned to a shore-based work area for maintenance and storage. The term 'portability' is stretched when referring to the large systems that weigh tens of tonnes, but with proper port facilities these systems can be removed and installed on a variety of vessels.

Challenges and Solutions

Remotely operated vehicles work in an extreme environment. While working at depth they are subject to high external pressure, particularly as depths increase. Sea water is also corrosive and electrically conductive. Ships also present a high-motion and high-vibration environment. ROV manufacturers and operators have dealt with these challenges in several ways, as described below.

Some components must be protected from the pressure and water by being mounted in a pressure-proof housing. Pressure-proof housings are typically made of a corrosion-resistant material such as stainless steel or anodized aluminum. As greater pressures are encountered, the strength of these two materials is no longer adequate and housings are made from more exotic materials, such as titanium, composites, or ceramics.

Electrical components such as cameras, lights and sonars are mounted outside the main pressure housings. They must be connected to the main telemetry pressure housing by an electrical cable. The cable penetrations, where the wires enter the pressure proof housings, must be carefully designed. Improper design can result in cables being extruded into the housing or, worse, failure of the seal and flooding of the housing.

Pressure-compensated housings are often used for components that can withstand the pressure but require protection from the water. In this case, components such as transformers or hydraulic components are mounted either in plastic or in thin-wall aluminum housings. The housings are then oil filled and connected to a soft bladder. As the external pressure increases, it presses onto the soft bladder. The oil in the bladder compresses somewhat, thus equalizing the internal and external pressures. The advantages of this type of housing are reduced weight and cost, both significant design constraints.

Vehicles must be built with corrosion-resistant materials. Aluminum is commonly used owing to its light weight, but it will eventually corrode. Titanium, stainless steel, and plastics are much more corrosion-resistant, but may have problems in specific applications.

The system components that remain at the surface also must perform reliably in an extreme environment. The high-vibration and corrosive, wet atmosphere of the exposed deck has led to the design of many components rated for marine duty. While expensive, these components will operate reliably under such conditions.

The human operators of ROVs must also withstand these harsh conditions. ROV personnel must work long hours in a continually moving environment, often in wet and cold conditions. The systems use high voltages, harsh oils, lubricants, and other dangerous substances. The pressure to perform well is high because often ROV work is carried out upon expensive installations that cannot afford downtime for repairs and maintenance. The complete ROV spread, including the support vessel, is expensive to hire and there is no tolerance for unreliable people or vehicles.

Scientific Research Vehicles

Remotely operated vehicles have been supporting scientific operations since the mid-1980s. Some ROVs were originally funded to complement manned submersible work, but a few were developed as replacements for existing submersibles, or as stand-alone vehicles for smaller institutions. The strengths and weaknesses of ROVs do not allow them to be direct replacements for manned submersibles.

Manned submersibles (*see* **Manned Submersibles, Deep Water** and **Manned Submersibles, Shallow Water**). refer to manned vehicle article) were the dominant technology for ocean floor scientific research for decades. ROVs have entered the field, and have gained acceptance because of their distinct advantages in many areas. They have unlimited power and can therefore remain on the bottom for extended periods, efficiently performing large surveys, extended time series experiments, and multidisciplinary operations. A tremendous volume of data is transmitted to the surface, with many channels of real time video, sonar, CTD (conductivity–temperature–depth) data, and other information. In fact, properly managing the data can be a challenge. Many scientists can participate in the operations, which is an advantage. Operations often cover many disciplines, often with unexpected results. Key people can always be on hand to discuss and decide upon modifications to the operational plan as the operation unfolds. Some of the advantages that manned submersibles have will be difficult to replace with the ROV. It is difficult to replace the human eye with remote telepresence. The surface ship motion and control will always influence the ROV operations.

The current (as at 2000) high-profile science ROVs are briefly described in **Table 1**. Each of these vehicles is unique. Some have been developed with a specific focus, and are therefore better at some tasks than others. Every vehicle design is a compromise between the many elements that can be incorporated into an ROV.

Conclusion

The efficiency of ROVs will continue to improve in two major ways. (i) The efficiency of the work will improve with better integration of ROV capabilities into offshore component design. (ii) The efficiency of the ROV itself will also improve with advances in hydraulic components and design, control system components and design, and higher-voltage cables and motors. Electric vehicles that do not have large hydraulic systems are beginning to enter the market.

Table 1 Summary of some scientific ROVs and their characteristics

Propulsion	*TMS*	*Operator*[a]	*Power*	*Manipulators*	*Depth*
Jason/Medea http://www.marine.whoi.edu/ships/rovs/jason_med.htm					
Electric	Depressor weight; 50 m fixed tether length	WHOI	9 kW	Single electric manipulator	6000 m; significant vehicle upgrades planned for 2002
ROPOS http://www.ropos.com					
Hydraulic	Cage; 250 m tether	CSSF	22 kW	Two hydraulic manipulators	5000 m
Tiburon http://www.mbari.org/dmo/vessels/tiburon.html					
Electric	None	MBARI	15 kW	Two hydraulic manipulators	4000 m
Ventanna http://www.mbari.org/dmo/ventanna/ventanna.html					
Hydraulic	None	MBARI	30 kW	Two hydraulic manipulators	2000 m
Victor http://www.ifremer.fr/victor/victor_uk.html					
Electric	Depressor weight	IFREMER	20 kW	Two	6000 m
Dolphin 3K http://www.jamstec.go.jp/jamstec-e/rov/3k.html					
Hydraulic	None	JAMSTEC	?	Two	3300 m
HYPER-DOLPHIN http://www.jamstec.go.jp/jamstec-e/rov/hyper.html					
Hydraulic	None	JAMSTEC	56 kW	Two	3000 m
KAIKO http://www.jamstec.go.jp/jamstec-e/rov/kaiko.html					
Hydraulic	None	JAMSTEC	?	Two	11 000 m

[a] WHOI, Woods Hole Oceanographic Institution; CSSF, Canadian Scientific Submersible Facility; MBARI, Monterey Bay Aquarium Research Institute; IFREMER, l'Institut Francais de Recherche pour l'Exploitation de la Mer; JAMSTEC, Japan Marine Science and Technology Center

Altogether, this will result in smaller, lighter cables, which will reduce systems size and cost and will have less effect upon the vehicle as it is operating in currents, or traveling at speed. The multidisciplinary vehicle will remain as the dominant vehicle type, but specialized vehicles will also become more widespread as more and more tasks are assigned to ROVs and the scope of work increases. Designers of offshore equipment are more commonly incorporating ROV intervention technology into the original equipment. This has great benefits in improving ROV efficiency. For many years, ROVs have been challenged with attempting to work with components designed for human hands or for dry land manipulation. Once thought and design are applied to ROV intervention techniques, all parties benefit from the increased efficiency. ROVs have evolved, and are still evolving, to fill a requirement for reliable, efficient vehicles in an environment that is inaccessible to humans. As these vehicles develop, and the engineering progresses on the vehicles as well as on their worksites, they will continue to fulfill a unique and expanding role in the underwater world.

See also

Autonomous Underwater Vehicles (AUVs). Bottom Landers. Manned Submersibles, Deep Water. Manned Submersibles, Shallow Water. Towed Vehicles.

Further Reading

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