Ocean Observatories Initiative Facilities Needs from UNOLS

Report of the UNOLS Working Group on Ocean Observatory Facility Needs

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Executive Summary

Since the 1800's, oceanographers have explored and sampled across two-thirds of Earth using ships as observational platforms. Measurements and models from this exploratory, mapping and sampling, phase of oceanography have resulted in growing recognition of the diversity and complexity of processes that operate above, within and beneath the oceans. The questions posed from these efforts increasingly cannot be answered using only the tools of the present, in large part because of a limited ability to resolve episodicity and temporal change. For this and other reasons, the ocean sciences are beginning a new phase in which scientists will enter the ocean environment and establish interactive networks for adaptive observation of the earth-ocean system. The growing move to establish ocean observatories reflects this trend.

It is reasonable to expect that the construction of substantial new ocean sciences observing systems will carry new requirements that may impact on existing ocean sciences facilities, and especially oceanographic research ships and deep submergence vehicles. As a consequence, the University-National Oceanographic Laboratory System (UNOLS) Council constituted a Working Group on Ocean Observatory Facility Needs in February 2003 to assess compatibility of current and planned UNOLS assets with requirements generated by the Ocean Observing Initiative (OOI) and related programs. The following findings and recommendations are based on a detailed consideration of these issues, and are discussed in greater detail in Sections 3 and 4.

General Issue

Finding

The UNOLS committee structure and makeup does not adequately incorporate ocean observatory expertise.

Recommendation

UNOLS should establish a standing committee on ocean observatories that is cross-cutting with existing UNOLS committees, or ensure that existing committees include members with expertise on ocean observatories.

Ship Usage and Scheduling

Findings

The ship time requirements for deep water OOI installation will be about 480 days of Global Class shiptime and an additional 375 days of contracted commercial shiptime. About 3/4 of the UNOLS ship days will require a deep ROV. For the coastal component, the requirement is for 150 days of Regional to Intermediate class shiptime and an additional 7 days of contracted cableship time.

The ship time requirements for annual Operations and Maintenance (O&M) of the OOI global buoy systems using UNOLS Global Class vessels will approach two ship-years per year, about

3/4 of which will require a deep ROV. However, some of the high latitude O&M may be better carried out under commercial charter, somewhat mitigating the impact on UNOLS facilities.

The ship time requirements for annual O&M of the OOI regional cabled observatory using UNOLS Global Class vessels will be about 1/4 that of the global buoyed systems. O&M of the backbone cable and systems is best handled by a commercial cableship through membership in a cable industry consortium.

The impact of OOI Global Class ship demand will dramatically increase with the retirement of two of four general purpose vessels in the next decade.

The ship time requirements for annual O&M of the OOI coastal observatories will require one virtual ship per year, although this estimate is more uncertain than for the deep water components.

The ship time requirement estimates for O&M of all OOI components are sensitive to the reliability of the ocean observatory infrastructure.

The ship time requirements for O&M of all OOI components will be higher during the initial commissioning (i.e., 1-2 years post-installation) phase.

OOI global buoy O&M has limited schedule flexibility due to finite battery and/or fuel resources, while regional cabled observatory O&M is constrained by a spring to fall weather window for UNOLS vessel operations.

Ocean observatory operations are not as predictable as more traditional mapping and sampling activities, and hence will require increased ship scheduling contingency allowance and improved contingency handling.

Recommendation

The UNOLS ship schedulers and operators should consider ways of increasing scheduling flexibility to support future ocean observatory operations and report to UNOLS on the issues and requirements.

Mapping

Findings

The suite of deep water mapping tools available within the UNOLS and academic communities is adequate to fulfill near term ocean observatory regional context mapping requirements.

The UNOLS fleet has limited mapping assets for shallow to intermediate depths at state-of-the-art resolution.

Cable route and burial assessment surveys are best contracted out to industry when required.

Deep water observatory site selection will require much higher spatial resolution than is current commercial practice, and must be carried out using near bottom sensors from deep vehicles.

Recommendation

UNOLS and NSF should consider ways of enhancing the shallow to mid-depth, high resolution mapping capability.

Deep Water Vessel Operations

Findings

The large global buoys will require the development of an at-sea refueling capability for the Global Class UNOLS vessels.

The Global Class UNOLS vessels are optimized for fuel economy, cruise duration, large shipboard parties, extensive lab space, and limited over-the-fantail operations. These characteristics are often the opposite to what will be required for ocean observatory operations.

Fitting the AGOR-23 class vessels with a second bow thruster at mid-life refit could open the working seastate to SS5 or more, and would significantly enhance their utility for ocean observatory operations.

Fitting all of the Global Class vessels with redundant DP systems will improve their usefulness for ocean observatory operations.

Shrouding the z-drives on the AGOR-23 class vessels will improve DP efficiency and reduce the risk of cable entanglement during over-the-side operations.

A substantial increase in deckspace for the AGOR-23 class is required for many deep water ocean observatory operations, and could most easily be facilitated by lengthening the vessels by about 50’ at mid-life refit.

Doubling the A-frame capacity with concomitant increases in winch, cable, and crane capacity for the Global Class vessels would improve their lift capability and facilitate many ocean observatory operations.

A below-deck fiber optic traction winch would simplify ROV operations on Global Class vessels.

Heavy lift operations from UNOLS vessels will require specially trained and qualified crew members to handle most deck evolutions.

A long-term contract with the globally-distributed submarine cable servicing industry for heavy lift installation and maintenance of the OOI global buoy systems could significantly reduce the scheduling and demand impact on the UNOLS Global Class ships and enhance the scientific output from the buoy systems.

As an alternative, one or more heavy lift vessels could be acquired into the UNOLS fleet to carry out OOI global buoy and some submarine cable operations at sea.

Recommendations

The vessel and licensing requirements for at-sea buoy refueling should be investigated before the large DEOS buoy design process is initiated.

Mid-life refit of the AGOR-23 class should explicitly consider ocean observatory needs, including enhanced seakeeping through bow thruster improvement, z-drive shrouding, and vessel lengthening.

Upgrading of all Global Class vessels to redundant DP should be considered.

Doubling of the heavy lift capability of the UNOLS Global Class vessels through A-frame, winch, wire, and crane enhancements should be evaluated.

All Global Class vessels should be equipped with a below-deck fiber optic traction winch.

UNOLS should consider the training and qualification requirements, including legal issues, associated with heavy lift deck operations carried out by ship's crew members rather than the scientific party.

The feasibility and cost of contracting with a submarine cable maintenance company for global buoy installation and maintenance should be further investigated.

The feasibility of acquiring one or more heavy lift vessels into the UNOLS fleet to support future ocean observatory operations should be further evaluated.

Deep Submergence

Findings

ROVs will usually be preferred over manned submersibles for ocean observatory operations due to their enhanced bottom time and human safety concerns.

AUVs are not presently part of any UNOLS facility, but will be an important standard tool at ocean observatories.

Commercial ROVs capable of operation below 3000 m are very limited in number, and this situation is unlikely to change in the near future.

The capabilities of current generation academic ROVs such as Jason II are highly compatible with ocean observatory operations.

Some infrastructure and community instrument servicing tasks could be carried out under industrial contract if this proves cost effective.

New instrument development and installation at ocean observatories will continue to require close interaction between the scientist/engineer and the operators of academic ROV facilities.

Three additional academic ROVs will be required by 2010 to support ocean observatory operations and sustain or enhance traditional ocean science vehicle demand.

Recommendation]

UNOLS and NSF need to consider ways to increase the academic deep ROV fleet by three vehicles over the next 5-7 years to support ocean observatories and traditional ocean science.

Coastal Observatories

Findings

The increasing presence of coastal observatories will increase rather than decrease the demand for ship-time.

A rapid response capability needs to be developed to enable reaction to coastal events.

ROVs will be needed for outer continental shelf coastal observatories, but shallower installations will continue to be supported by dive teams.

Aircraft will be an important auxiliary, coordinated observing platform for coastal observatory science.

Recommendation

Ten additional small Regional to large Local Class vessels are needed to provide support both for coastal observatory and traditional coastal science.

Fleet Renewal

Findings

The proposed Ocean Class vessels and the ARRV do not fulfill deep water ocean observatory needs due to their size and concomitant limitations in seakeeping, deckspace, and lift capability.

The Fleet Renewal process needs to consider the construction or acquisition of vessels larger than the current Global Class size.

Future ship planning is not adequately coupled to ROV operations as a standard ship mission.

The proposed Regional Class vessels are well-suited for coastal observatory operations.

Recommendations

The UNOLS Fleet Renewal process should develop a Science Mission Requirement for a class of vessel larger than the present Global Class to support ocean observatory and other heavy lift needs.

All UNOLS Fleet Renewal planning should explicitly include ROVs as a standard shipboard tool and incorporate space to support them in ship designs.

1. Introduction and Scope

Since the 1800's, oceanographers have explored and sampled across two-thirds of Earth using ships as observational platforms. This has provided a series of snapshot views of the oceans, and has limited resolution in time. Measurements and models from this exploratory, mapping and sampling, phase of oceanography have resulted in growing recognition of the diversity and complexity of processes that operate above, within and beneath the oceans. The questions posed from these efforts increasingly cannot be answered using only the tools of the present, in large part because of a limited ability to resolve episodicity and temporal change. For this and other reasons, the ocean sciences are beginning a new phase in which scientists will enter the ocean environment and establish interactive networks for adaptive observation of the earth-ocean system. The growing move to establish ocean observatories reflects this trend. Ocean observatories are defined to be fixed facilities which provide power and real-time, two-way communications infrastructure capable of supporting many instruments located on the seafloor, within the water column, or at the ocean's surface, and enable scientists located anywhere in the world to carry out interactive oceanic experiments. This definition does not include other key ocean observing system technologies such as satellite remote sensing or surface and subsurface floats, gliders, and drifters which will not be extensively considered in this report.

Many of the fundamental scientific questions that can be addressed using ocean observatories have been identified in four National Science Foundation (NSF) Ocean Sciences Division long range "futures" reports [Jumars and Hay, 1999; Baker and McNutt, 1998; Royer and Young, 1999; Mayer and Druffel, 1999], in the report *Ocean Sciences at the New Millenium* [National Science Foundation, 2001], in the NRC report *Illuminating the Hidden Planet: The Future of Seafloor Observatory Science* [National Research Council, 2000], and in numerous community planning documents over the past decade. A number of coastal [e.g., LEO-15; Schofield et al., 2002] and a few deep [e.g., the Hawaii-2 Observatory or H2O; Chave et al., 2002; Petitt et al., 2002] ocean observatories have already been constructed, and are archetypes for future designs. A substantial increase in ocean observatory installation will ensue from a Major Research Equipment (MRE) request for ~$200M to fund the Ocean Observatories Initiative (OOI) which is in the National Science Foundation budget plan for FY2006. The NRC report *Enabling Ocean Research in the 21st Century: Implementation of a Network of Ocean Observatories* [National Research Council, 2003] discusses implementation and management of the OOI. All of these documents provide relevant background information for the present report.

The OOI as presently envisioned will have three principal components: a global network of deep ocean moored buoy observatories, a regional scale cabled observatory, and an expanded network of coastal observatories. The global observatory component is a set of 15-20 moored buoys linked to shore via satellite that supply power and communications to sensors located on the surface, in the water column, and on the seafloor. The regional scale cabled observatory (e.g., NEPTUNE; http://www.neptune.washington.edu) will provide a comprehensive set of long-term measurements of ocean processes on an intermediate scale such as that of a tectonic plate. This type of observatory will utilize submarine fiber optic cable to provide unprecedented levels of power and bandwidth to large numbers of volumetrically-distributed sensors. The coastal component of the OOI encompasses a diverse set of components, and will be implemented using both buoy and cable technologies.

It is reasonable to expect that the construction of substantial new ocean sciences observing systems will carry new requirements that may impact on related, existing ocean sciences facilities, and especially oceanographic research ships and deep submergence vehicles. As a consequence, the University-National Oceanographic Laboratory System (UNOLS) Council constituted a Working Group on Ocean Observatory Facility Needs in February 2003 to assess compatibility of current and planned UNOLS assets with requirements generated by the OOI and related programs and suggest possible augmentation where appropriate. The Working Group was tasked with the following issues:

1. Identify major observatory-related ship and submergence needs and describe the process that will be used to address these issues

2. Identify the requirements for facility support of ocean observatory systems. This should include requirements for both ships and submergence vehicles encompassing:
    - a) Pre-installation needs (i.e., mapping)
    - b) Installation
        - Mooring deployment
        - Cable lay
        - Node set-up
        - Compatibility issues related to observatory infrastructure
    - c) Maintenance and servicing
    - d) Operation support
        - Submergence vehicles for instrument support
        - Event response
        - Improved navigational capability

3. What requirements can be met with currently available academic assets (vessels and submergence vehicles), and what modifications or augmentation may be suggested including efficiencies that may be gained through contracts to industry?

4. What are the changes in demand for facilities resulting from observatory initiatives?

5. Identify the specific observatory needs that cannot be met by currently available academic facilities

6. For those observatory facility needs that cannot be met by currently available facilities, the working group should:
    - a) Identify what facilities should be added to the available suite of academic assets
    - b) Identify commercially available assets that could be used to meet observatory needs
    - c) Address the effectiveness, both in terms of cost and practicality, of adding academic assets, using commercial assets, or a combination of both

7. When are the facilities needed for installation, operation, and maintenance of the observatories? Establish a timeline.

8. Provide suggestions for the management, scheduling and operations of facilities related to observatory infrastructure. The ships will likely fall under the UNOLS system, but coordination of vehicles such as autonomous underwater vehicles (AUVs) and remotely operated vehicles (ROVs) will need to be considered. It is assumed that the operation of the actual observing system will be managed by the organization that established the system.

This report constitutes the Working Group response to the UNOLS charge, although preliminary comments from the Working Group are summarized in National Research Council [2003]. It is divided into four parts, including this introduction. Section 2 describes a series of mission scenarios for both the installation and operations and maintenance (O&M) phases of ocean observatory implementation from which specific requirements flow. Section 3 summarizes these requirements, covering ship time and ship scheduling aspects, mapping, deep water operations, submergence asset operations, and coastal operations. Section 4 summarizes the findings and recommendations of the working group, and suggests further work where appropriate.

2. Use Scenarios

This section presents a series of use scenarios for ship and deep submergence activities at ocean observatories. Ship and submergence vehicle use can be broadly divided into two phases: 1) installation, and 2) operations and maintenance. The purpose is to construct a picture of typical ocean observatory operations from which the detailed requirements may be derived in Section 3.

2.1 Mapping

Three types of mapping use scenarios at increasingly finely nested scales are envisioned for ocean observatory applications: regional context surveying, cable route surveys, and observatory site selection. Regional context surveying is nearly identical to traditional mapping science, and has the principal goal of placing observatory sites (which may be extended areas rather than points, depending on the infrastructure design) into a larger scale, morphological or geological, framework. Regional context mapping is done in exactly the way that traditional surveys are carried out using a multibeam swath mapping sonar on a precisely navigated surface vessel.

Cable route surveys are typically carried out by specialized companies (for example, Seafloor Surveys International located in Seattle, WA) early in the planning and permitting phase for a new submarine telecommunications system, and will be necessary for any new scientific cable system. An overview of the cable route survey process is given by Horne [2002]. There are three main steps in a cable route survey: desktop study, cable route mapping, and burial assessment survey. The desktop study consists of a detailed background investigation into geological, meteorological, and man-made (e.g., fishing) hazards to cables, shared seabed use (i.e., pipeline and cable crossing), environmental and permitting issues, and shore station infrastructure. It serves as a planning document for the remaining components of a cable route survey leading to permitting. An example of a desktop study is the NEPTUNE one which may be found at http://www.neptune.washington.edu/pub/documents/documents.html. Due to specificity and legal concerns and because new scientific cable installations will be infrequent, desktop studies are best carried out by experienced commercial companies. In any case, desktop studies do not carry any major UNOLS facility issues.

Cable route mapping is similar to regional context mapping in deep (>2000 m) water, although the accuracy requirements are more stringent, a single swath rather than a large scale map is usually sufficient, and real-time processing for near real-time decision making is often necessary. UNOLS vessels equipped for multibeam mapping could be used for deep water cable route mapping in a similar manner to traditional surveys. However, current commercial practice is to bury submarine cable to a depth of 1-3 m in water shallower than 2000 m to protect it from external aggression hazards. Cable route mapping in shallow water requires both multibeam swath and sidescan surface information and sub-bottom profiling. A primary goal is detection of hazards to the cable installation process. Cable route mapping is typically carried out with a deep towed vehicle or an AUV. Many aspects of shallow water cable route mapping could be carried out with academic tools such as the towed vehicle sonar DSL-120A or an AUV like the Autonomous Benthic Explorer (ABE) from UNOLS vessels using current protocols. Cable route mapping carries legal liability issues that can impact the permitting process, and commercial companies are probably better equipped to handle these requirements than academic organizations. Commercial cable route mapping concerns are well-equipped to conduct the necessary surveys from vessels of opportunity, including UNOLS ships. This does not pose any special gear handling or towing issues, as the self-contained commercial survey systems are very similar to current academic ones. Because of the relative infrequency of new scientific cable installations, the impact on ship demand and scheduling will not be large.

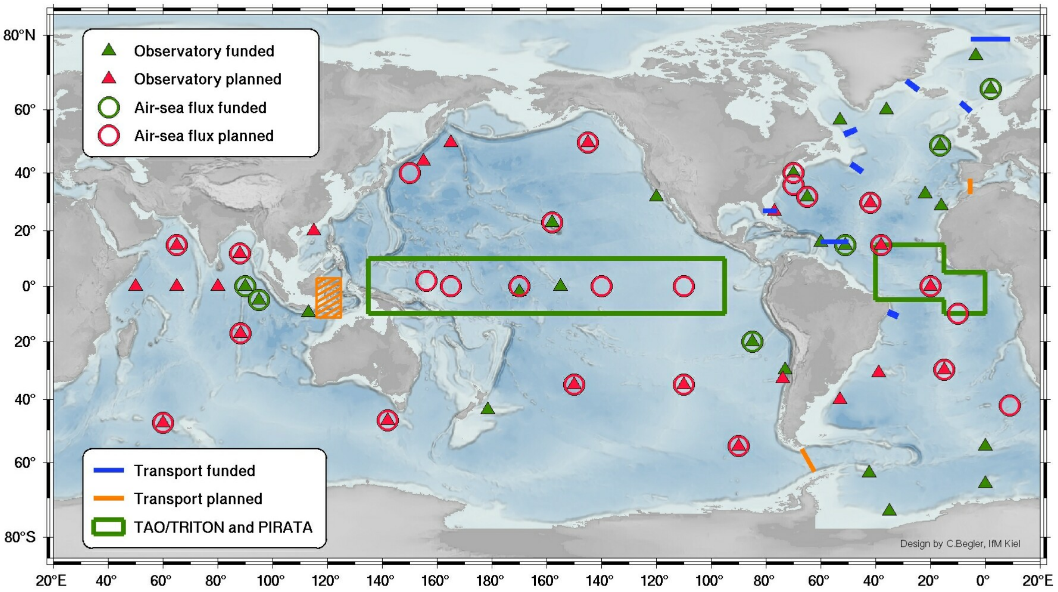

Figure 1. Planned locations of OOI global buoys. Green symbols denote sites that are currently funded, while red symbols denote sites that are planned.

A burial assessment survey is primarily a geotechnical study of bottom conditions to aid in choosing a route over which a cable can be reliably and economically buried using specialized plows or ROVs equipped with hydraulic jetting tools. It consists of a detailed sub-bottom profile and cone penetrometer analysis of sediment conditions, and is often augmented by a DC resistivity survey. Because of the specialized nature of the tools and due to legal issues, burial assessment surveys are best carried out by specialized commercial entities. Except possibly for infrequent use of UNOLS vessels as ships of opportunity, burial assessment surveys carry no major implications for UNOLS facilities.

Observatory site selection surveys are carried out on a much finer scale than regional context mapping. Near bottom mapping will be a standard requirement. In deep water, this can be carried out using ROVs like Jason II, AUVs like ABE, and deep towed survey systems like DSL-120A using existing ships and practices.

2.2 Buoy Installation

Figure 1 shows the planned locations for the OOI global buoy network, along with those for present and related programs. It is apparent that the OOI installations will be dominantly at high latitudes, although some are planned for low- to mid-latitudes.

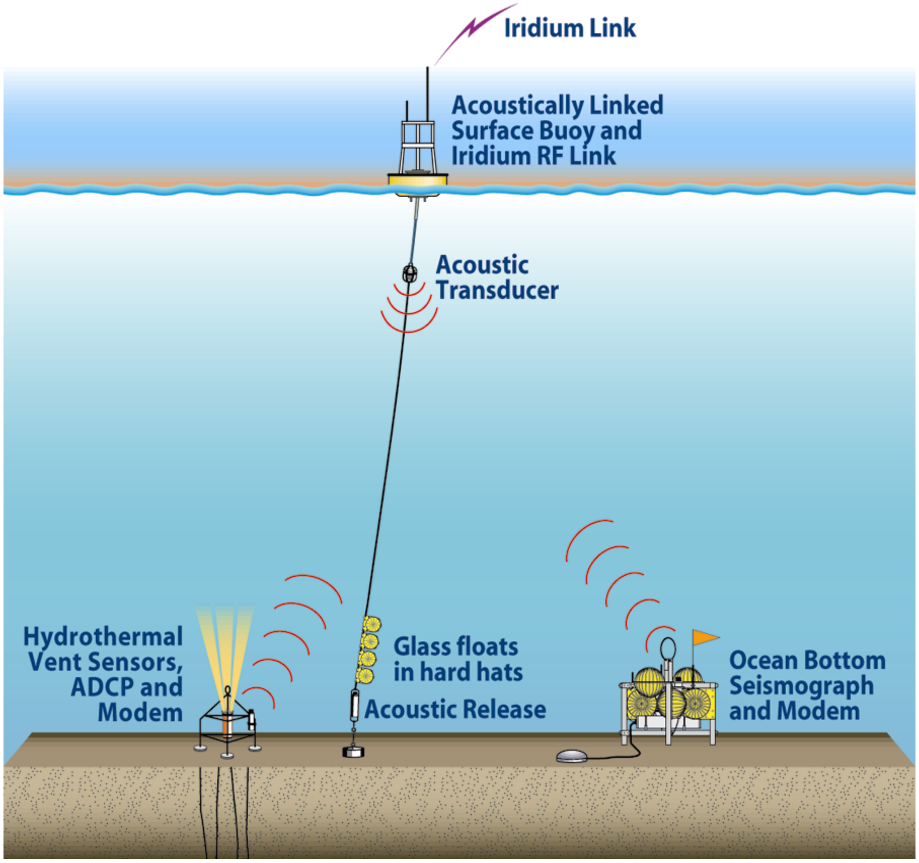

Figure 2. Acoustically-linked surface buoy on a single point mooring planned for the OOI global network. A surface buoy is linked to shore by satellite and to autonomous (battery powered) instruments using acoustic modem technology.

Some of the sites in the OOI global network (primarily those at low- to mid-latitudes) will utilize buoys and moorings that are similar to present surface and sub-surface moorings. As a result, both the hardware and deployment methodology are comparable to those in present use. Such buoys can be installed by a general purpose Global Class UNOLS vessel which has the deckload, cranes, sea-keeping ability, and endurance necessary to deploy the buoys worldwide. Two types of conventional buoys are planned in the OOI: those that are acoustically-linked to seafloor instruments (Figure 2) and those which are linked to the seafloor by an electro-optical mechanical cable (Figure 3). Buoy installation for these two buoy types is conventional and based on rigging, handling gear, and deployment methods that are familiar to the oceanographic community and UNOLS ship crews. However, instrument installation methods differ. Acoustically-linked instruments may either be free-falled to the seafloor or installed precisely on a wire in an acoustic network. The cable-linked buoys utilize a seafloor junction box to which instruments may be attached at wet-mateable electrical or electro-optical connectors using an ROV equipped with suitable manipulators.

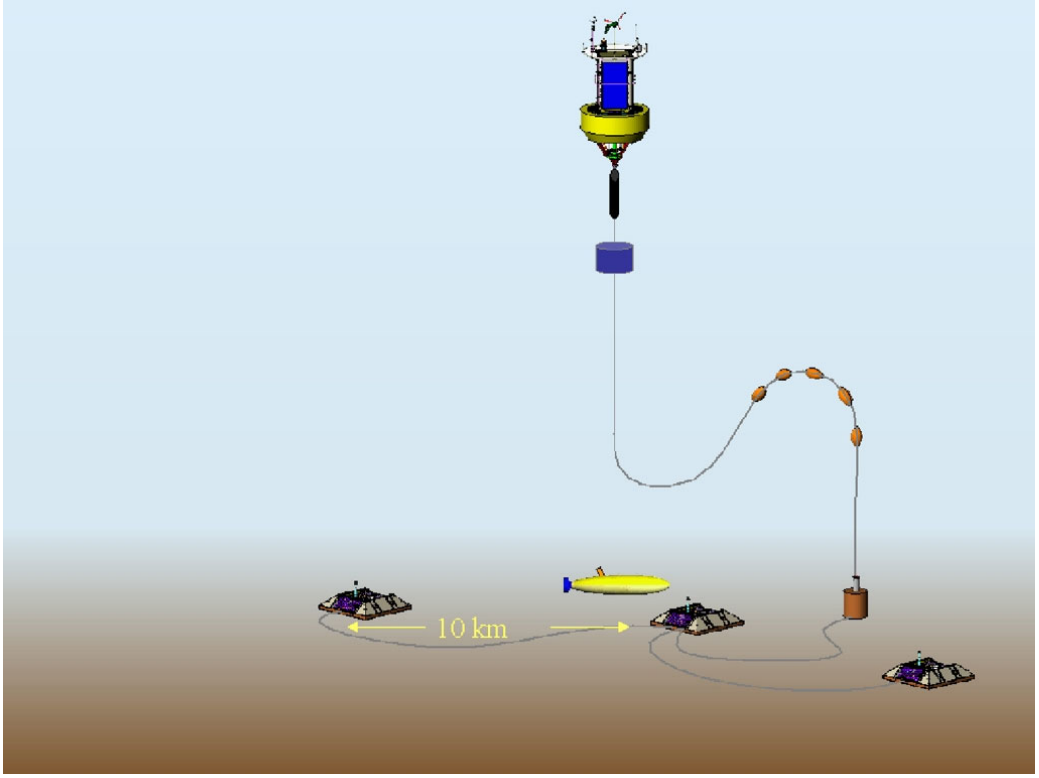

Figure 3. Electro-optical mechanical cable tethered surface buoy planned for the OOI global network. The buoy is a 2.4 m discus type on a single point mooring with S-link to protect the cable from fiber breakage. One or more seafloor junction boxes are linked to the buoy, which provides limited power and satellite communications for seafloor instruments.

High latitude sites in the OOI global network and those where high bandwidth is desired will require substantially larger buoys that are stable in extreme sea states, capable of supporting significant on-board power generation using diesel generators, and able to house a large radome for high bandwidth satellite communications. A candidate 40 m surface spar buoy design is described in DEOS Moored Buoy Observatory Design Study [2000] and shown in Figure 4. In addition to the three-point moor, there is an electro-optical mechanical S-link to seafloor junction boxes as in

Figure 3. Both the buoy and tether size exceed the handling capabilities of the largest UNOLS vessel, primarily due to deckspace and A-frame/crane capacity limitations. Either a special purpose vessel will have to be acquired into the UNOLS fleet to handle this sort of load, or commercial charters for offshore supply boats, cable repair vessels, or ocean-going tugboats will have to be used. In the last case, the charter tugboat will tow the buoy into place, and is required only for installation of the spar and mooring. A large UNOLS vessel could be subsequently used to install some of the topside modules in the buoy, seafloor junction boxes, and instrumentation, while suitably equipped offshore supply or cable repair vessels could handle the entire operation, and have the additional advantage of carrying the buoy on deck where it is better protected from damage during transit. As for the electro-optical mechanical tethered buoy in Figure 3, an ROV will be required for installation of the seafloor components.

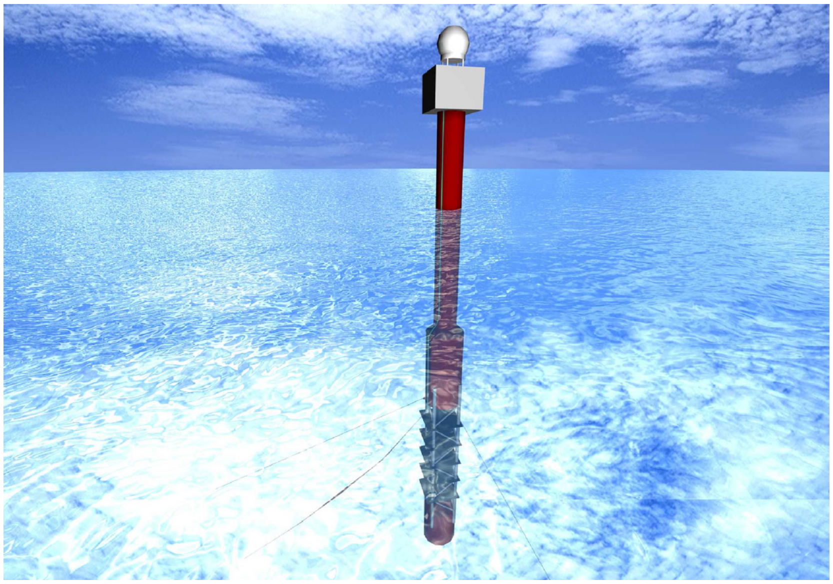

Figure 4. Conceptual 40 m spar buoy design on a three-point moor proposed for the OOI global buoy network.

2.3 Buoyed Observatory Maintenance

Periodic (approximately annual) maintenance will be required for surface moorings due to corrosion, bio-fouling, and general mechanical issues, as well as the requirement for sensor recalibration, battery replacement or diesel generator servicing. Routine maintenance of all OOI mooring types can be handled by a large Global Class UNOLS vessel. Any operations which involve seafloor junction boxes will require a dynamically-positioned (DP) vessel and a deep water ROV using procedures described in Section 2.5. Some maintenance operations (e.g., replacement of satellite communications electronics) may require transfer of people from a vessel to the buoy by small boat, which will be weather/sea state dependent and presents safety issues. This can be somewhat mitigated using boat deployment/recovery systems which do not require the use of cranes or over-the-side ladders, such as the davit system on *Thomas G. Thompson* which enables deployment and recovery of a workboat to the O2 level of the vessel. It can also be simplified by modular design of the buoy systems so that people time on the buoys is minimized. Some maintenance operations on large buoys present special challenges. For example, replacement of a diesel generator in a spar buoy would require over-the-side crane operations from a research vessel to the buoy and will be high risk even if the system is modularized. Probably a better approach is to provide redundant generators on the buoy to avoid replacement altogether. Refueling of a buoy at sea is feasible using standard maritime practices, although these are not in present use on UNOLS vessels.

Fatigue and mechanical wear dictates periodic replacement of the buoy and/or tether, especially for buoys located in severe environments or at high latitudes. While current practice for surface buoys is to replace them at approximately two year intervals, the OOI goal is to extend this to three to five years, which is technologically ambitious. Buoy or tether replacement can be accomplished from a large, Global Class UNOLS vessel for the acoustically and electro-optical mechanical cable linked types. Replacement of a large spar buoy will require the use of a UNOLS heavy lift ship or commercial charter of a suitable vessel.

With a few exceptions (e.g., at sea replacement of large items on spar buoys, refueling at sea), the operations required for maintenance of OOI buoys are routine for UNOLS vessels.

2.4 Cabled Observatory Installation

Installation of submarine cable requires specialized cable laying vessels and equipment, and is not compatible with the UNOLS fleet in most respects. The exceptions to this include the installation of short (~100 km) cable segments which can be accomplished using vessels of opportunity (including UNOLS vessels) equipped with cable handling equipment, and attachment of science nodes to a backbone cable previously installed using a cableship.

The key design features required in modern cable installation ships are given by Brown [2001], and include:

- LOA of at least 100 m
- 100 tons of bollard pull
- Redundant dynamic positioning capability up to SS7
- Cable capacity of 4-8000 tons (2500-5000 m^3) in multiple tanks
- Clean room space for cable splicing
- 40 ton linear cable engine
- 40 ton, 3 m diameter cable drum
- A-frame capable of handling 30 ton static weight (SW) burial plow
- ROV handling ability

Smaller and less capable cable repair ships are also in service, and can be used for short to intermediate installation jobs. Cable lay procedures are discussed in Horne [2002]. It should be apparent that these requirements cannot be met by any UNOLS vessel, as even the large Global Class vessels have substantially less power and carrying capacity than cableships of comparable LOA and tonnage. Cableships are operated by several major cable suppliers or installers (e.g., Global Marine Systems in the UK, Alcatel in France, Tycom in the US) and a number of smaller operators. Due to the infrequency of major scientific cable installations, the use of commercial charters for this purpose will prove to be economical, and developing a cable lay capability in the academic community is not recommended.

Short (~100 km) cable lays are sometimes handled using vessels of opportunity such as offshore supply vessels. Linear cable engines or drums and cable tanks must be installed on the vessel, usually on a large open aft deck. In most instances, short lays will be shore ends and hence will require plow burial, which in turn requires sufficient bollard pull and A-frame capacity to handle the necessary equipment. The Global Class UNOLS vessels are marginally capable of use for short lays, although they are underpowered and have very limited deckspace and deckload capacity compared to the usual vessels of opportunity.

At some of the OOI global sites, it may prove feasible and cost effective to re-use retired submarine telecommunication cables to provide power and communications rather than a surface buoy. The Hawaii-2 Observatory was installed in deep water (5000 m) using a large UNOLS vessel (*Thomas G. Thompson*) and an ROV for all operations. This taxed the capabilities of the vessel to or beyond the limit of safe operation; in particular, picking up the cable using a conventional research vessel trawl winch and A-frame required 24 hours with a nearly continuous load of over 20,000 lb. Unless UNOLS vessels are retrofitted with heavier lifting tackle, it is unlikely that this operation would be repeated, and most cable re-use installation operations will require the use of a heavy lift vessel or cableship.

Large DP UNOLS vessels can be used to install major parts of the infrastructure for a cabled observatory once the backbone cable is laid by a cableship. One generic consideration for any cabled observatory is that the science node infrastructure (i.e., power and communications systems) will be complex and correspondingly likely to require repair despite placing emphasis on reliability engineering during design. This mitigates against the use of submarine telecommunications-standard in-line splicing of nodes which would require a cableship for any repair and in favor of a design which is inherently maintainable using lower cost (e.g., UNOLS) vessels. This problem has been considered extensively by the NEPTUNE consortium, and two possible approaches have been identified. In both instances, the cableship installs a backbone containing branching units to break out the nodes, but not the nodes themselves. Subsequent installation of a node is nearly identical to maintenance, and is discussed in the next sub-section.

2.5 Cabled Observatory Maintenance

There are two kinds of maintenance operations that will be required for a cabled observatory covering the backbone cable and the nodes, respectively. Presuming careful route engineering (especially with respect to the choice of armor packaging) and high quality installation practices (especially with respect to burial) have been followed, the backbone itself should be virtually maintenance free. The only exception to this is rare cable faults caused by external aggression (e.g., fishing activity), chafe faults if the cable is laid in rocky terrain, and rare geological events such as submarine landslides. Any of these can cause failures ranging from shunt faults to cable breakage, and will have to be repaired with industry-standard practices using a cableship. For this purpose, it will be possible for scientific cable operators to join industry repair consortia which share the fixed costs of keeping a repair ship on hot stand-by. In fact, it may be possible for scientific cable operators to realize lower membership costs by accepting a reduced priority for repair. In any case, deep water backbone cable repairs cannot be done from UNOLS vessels both because specialized equipment and personnel are involved and because the carrying capacity of these ships is not adequate. An exception to this might ensue if UNOLS acquires a heavy lift vessel as described in the next section, although the need for specialized equipment and personnel remains.

Node maintenance requirements have to be carefully considered during the ocean engineering design process for the backbone cable. The NEPTUNE consortium has proposed two geometries for the science nodes which are maintainable using a UNOLS vessel. In the more conservative one, each node is connected to the backbone at a standard submarine telecommunications industry branching unit via a short (1.5 water depth) spur cable to which the node is attached (Figure 5). Node repair requires raising the node and attached spur cable to the surface. After repair or replacement of the node, the entire unit is replaced on the seafloor. This evolution requires an ROV and a DP ship with a lifting capacity of up to 8000 lb SWL, depending on water depth (presuming the node weighs ~1500 lb in water, as for the H2O junction box, and the spur cable is telecommunications-standard unarmored fiber optic cable). Recovery of the node is accomplished using an ROV to disconnect attached science instruments and then hook the j-box to a lifting line attached to the main ROV cable (e.g., at the depressor weight Medea for Jason II). The ROV and attached node are then raised to the surface and secured on deck through a series of standard load transfers. Alternately, a separate lift line contained in a basket dropped to the seafloor on an elevator could be attached to the junction box, released acoustically once the ROV is recovered, and used to raise the node and attached cable to the surface with a traction winch and storage drum. Either of these evolutions is only a slight extension of current academic ROV practice.

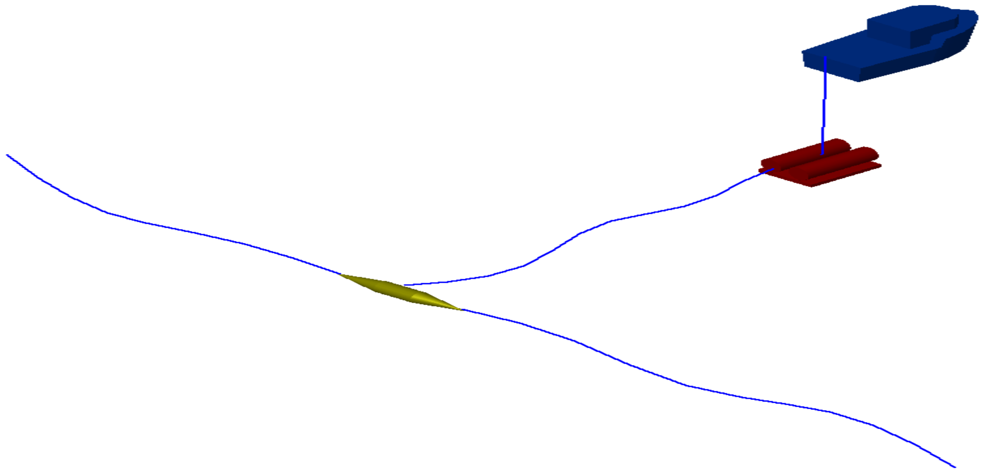

Figure 5. Cabled observatory node layout utilizing a branching unit (yellow) connected to the node (red) by a 1.5 water depth spur cable. Repair of the node requires lifting it plus the attached spur to the surface.

The second node geometry (Figure 6) requires the use of wet-mateable fiber optic connectors to attach the node to the backbone via a short (~30 m) umbilical cable. The umbilical is housed in a branching unit assembly which also is connected to the backbone cable by two gimbals. Maintenance of the node is easily accomplished by unplugging from the backbone, attaching a lift line from the ROV main cable (e.g., from the depressor weight Medea for Jason II) to the node, and recovering the ROV and node to the surface ship. This is identical to the procedure currently used to recover the junction box at the H2O in 5000 m of water. Re-deployment is accomplished by lowering the node on the end of a standard trawl wire equipped with acoustic releases, a transponder, and a pinger, placing the package on the seafloor after precise location in an acoustic net, and firing the acoustic releases. This is also identical to the procedure used at H2O. In addition, installation of the branching unit plus attached segments of backbone cable in a vee as depicted in Figure 6 allows it to be lifted to the surface in the event of failure of the fiber optic connector. This operation can also be accomplished from a UNOLS vessel, although the static load can easily reach 12,000 lb, and hence sea state considerations become paramount.

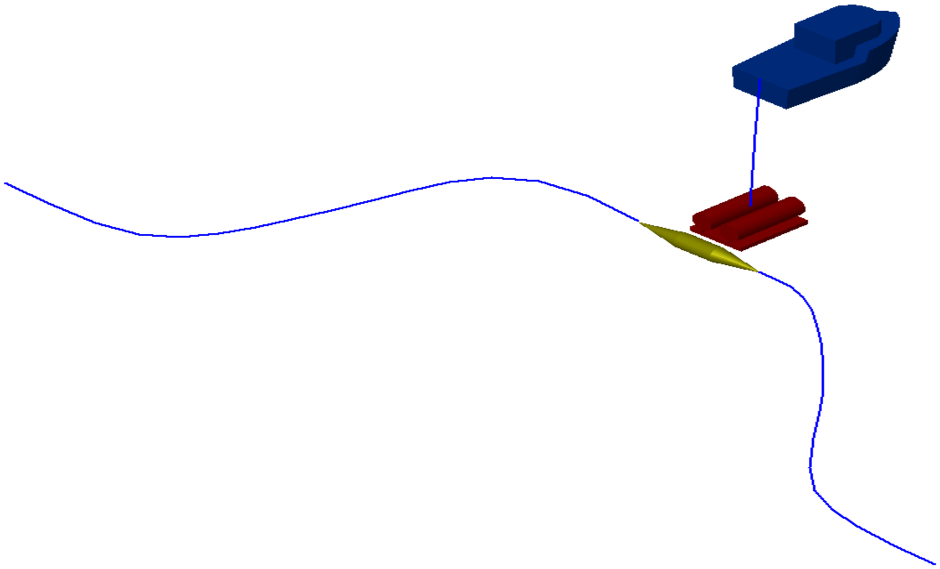

Figure 6. Cabled observatory node layout utilizing a branching unit (yellow) housing a short umbilical and wet-mateable fiber optic connector to connect to the node (red). Repair of the node requires unplugging it from the branching unit and lifting it to the surface.

2.6 Science Instrument Servicing

For all save the acoustically-linked buoy observatory shown in Figure 2, science instrument installation will require the use of an ROV from a DP ship. In most instances, the instrument will be dropped to the seafloor on an elevator using standard procedures. The ROV is needed to position the elevator where it is needed, plug it into the science node, and carry out any other operations that are specific to a given instrument, including placing the instrument in a borehole. All of these operations can be carried out from a Global Class UNOLS vessel.

2.7 Coastal Observatories

All of the operations described for deep water buoyed and cabled observatories carry over into the coastal environment, although in many instances the scale will be reduced with the water depth so that smaller regional to intermediate vessels can execute operations which do not require dynamic positioning, such as mooring installation. In water shallower than ~30 m, many of the node maintenance and instrument servicing activities will be handled by human divers rather than ROVs, simplifying the ship requirements.

Coastal cabled observatories will inevitably require the use of single and double armored cables (depending on water depth) to facilitate burial at all points. Cable burial requires specialized plows or jetting ROVs, and is best left to the cable industry.

3. Requirements

3.1 Ship Time

The ship time required to implement the ocean observatory paradigm can be divided between the installation and operations and maintenance (O&M) phases, respectively. The former is a one-time cost, although it must be recognized that ocean observatories will be in a continuous state of evolution, and hence some level of ongoing installation should be anticipated beyond the 2006-2011 OOI. O&M is an ongoing requirement throughout the life of an ocean observatory. The ship time requirements also differ substantially between the buoyed and cabled types of observatories, especially for O&M, where buoyed observatory ship demand will be very high.

Table 1: OOI Installation Ship Requirements

Observatory Type	Ship Type	Ship Days	Comments
Global low BW	UNOLS global	300 (30 per site)	Half will require ROV
Global high BW	Commercial	300 (30 per site)	ROV required
Regional cabled backbone	Commercial	75	45 d for deep water lay and 30 d for shallow water burial
Regional cabled node installation	UNOLS global	182 (7 per site)	ROV required
Coastal buoyed	UNOLS regional	150 (2 per buoy)	ROV not required
Coastal cabled	Commercial	7	ROV not required

Table 1 gives ship time requirement estimates for installation of the OOI buoyed, regional cabled, and coastal phases, respectively. This does not consider future, additional installations after the OOI or those which might be funded under the Integrated Ocean Observing System (IOOS), and hence should be considered a lower rather than an upper limit. The assumption for the global buoyed component is for 20 buoys, with 10 each of the low bandwidth (either acoustically-linked or cable-linked) and 10 each of the high bandwidth, cable-linked moorings. Some of the high bandwidth moorings might be replaced with re-used submarine telecommunications cables, but either solution will require commercial charters and the ship time needed is comparable, hence this option has not been broken out separately. The regional cabled observatory ship time estimate is that required for NEPTUNE, with 26 science nodes and 3200 km of backbone fiber optic cable, of which 500 km is buried. Cable burial at 0.5 knot and main cable lay at 4 knots with an additional one day per branching unit installation is assumed. UNOLS ship time will be needed for node installation as shown. Additional time for post lay inspection and burial by an ROV will probably be required by permitting authorities. This might be carried out on a UNOLS vessel using a commercial burial ROV. The coastal component includes two each 30 node Pioneer arrays and 15 moored long term time series sites, as well as a single cabled observatory.

The information in Table 1 differs significantly from that given in National Research Council [2003] only in the estimate for installation of the backbone component of a regional cabled and a coastal cabled observatory, which were extremely high in that report. This has very little bearing on UNOLS ship needs since either type of installation will be carried out using commercial vessels.

Table 2: OOI Annual O&M Ship Requirements

Observatory Type	Ship Type	Ship Days	Comments
Global low/mid latitude	UNOLS global	300 (30 per site)	Half will require ROV
Global high BW	UNOLS global or commercial	300 (30 per site)	ROV required
Regional cabled backbone	Commercial	Consortium membership	Standby contract with industry
Regional cabled node	UNOLS global	150	ROV required
Coastal mooring	UNOLS intermediate/regional	300 (4 per site)	ROV not required
Coastal cabled	UNOLS regional/local	30	ROV not required

Table 2 gives estimated ship time requirements for O&M (both infrastructure and instrument) for all three OOI observatory types. The ship time need for the global buoyed observatories is very large, amounting to about one ship-month on a Global Class vessel per year per mooring, including transit. This amounts to 20 ship-months per year, or about 1/3 of the available time (allowing for maintenance downtime) on the six existing Global Class UNOLS vessels. Once the specialized natures of *Atlantis* and *Ewing* are factored in, which probably precludes their use for buoy maintenance, the impact is greater, amounting to nearly 1/2 of the available general purpose Global Class shiptime. In addition, the global scatter of the OOI buoys (Figure 1) and sea state considerations at high latitudes will introduce scheduling challenges, as further discussed in Section 3.2. Node and instrument O&M ship time requirements for the regional cabled (NEPTUNE) observatory are more modest, reflecting both weather window considerations and the impact of short transit time from the US west coast. Approximately 1/4 of the ship time budget is for node maintenance, with the remainder applied to instrument installation and recovery. Maintenance of the regional cabled observatory backbone infrastructure should be covered through membership in an existing industry consortium which pools the fixed costs of keeping a cable repair ship on hot standby. For this purpose, Global Marine Systems and Alcatel both have cableships in Victoria, BC, and Tyco has a cableship in Portland, OR, to maintain existing commercial systems in the Pacific Northwest. It may be possible to negotiate a low cost maintenance contract by accepting a lower priority for repair than would be acceptable for commercial cables. Coastal moorings will also require servicing at approximately quarterly intervals by a regional or intermediate UNOLS vessel. This could be handled by commercial vessels where appropriate. About four days per mooring per year (or one day per visit) is a conservative estimate of the coastal mooring ship time requirement.

O&M ship time estimates for node and instrument maintenance are very sensitive to the reliability of node and instrument systems. In the event that nodes and instruments are not constructed to meet a high reliability design requirement, substantially greater amounts of ship time might be needed for repair. If failures do occur in remote places, the result will be either substantial downtime for some of the global observatories or a large element of chaos in the ship scheduling process as the operators attempt to react to frequent failures, along with a concomitant rise in ship time demand for O&M. At present, the regional cabled (NEPTUNE) observatory has reliability as a principal design driver, and the remaining OOI elements must do the same. Failure to build reliable ocean observatory systems will have a major impact on UNOLS facilities.

It is very likely that ship time requirements for O&M for all three observatory types will be substantially higher during the initial commissioning phase (i.e, 1-2 y after installation) than in the later, operations phase. This can be somewhat mitigated through attention to reliability during the design phase, but some residual problems are inevitable in systems as complex and pioneering as ocean observatories.

It must be recognized that the demands of ocean observatory operations (and especially the global buoy component) could easily swamp the available Global Class resources unless alternative solutions are found. This situation will be exacerbated when the Global Class decreases to four ships (of which only two are general purpose) within the next decade or so as *Melville* and *Knorr* reach end of useful life status. Further, the suitability of the largest (Ocean Class) vessel being considered under UNOLS Fleet Renewal for deep water ocean observatory operations is quite limited, as is further discussed in Section 3.7. Thus, new approaches need to be considered, as is further described in Section 3.4.

3.2 Ship Scheduling

In addition to ship time demand, ocean observatory operations will place strong requirements on the ship scheduling process. This is especially true for the global component because of its worldwide reach and the need for frequent (nominally, annual) visits to each buoy.

The impact of the OOI on ship schedules will be manifest in the area of flexibility in addition to demand. For global buoy maintenance, flexibility is limited because battery life and/or fuel in the spar buoys are finite resources. For the regional cabled observatory (NEPTUNE), sea state constraints limit ROV operations to a roughly five month window centered on July using large UNOLS vessels. Because of the scientific requirement for continuous time series at each site, it is important to replenish the global buoys in sufficient time to avoid data gaps; yet, visits that are too frequent will substantially raise O&M ship costs. The margin of uncertainty on annual visits may be as small as two weeks. When combined with the remote location of many of the global buoy sites (Figure 1) and the operational weather window at high latitude locations, the result is a strong constraint on the UNOLS scheduling process for the Global Class ships if these are the operational platforms.

At the same time, the OOI will require greater scheduling flexibility to handle observatory failures which require emergency repair. With the current process in which ship schedules are fixed as much as fifteen months in advance of operations and in the face of strong demand for limited ROV resources, it is generally not possible for the system to react quickly to problems. Experience with H2O in 1998 is a case in point. About two months after initial installation, the ULF seismometer at H2O failed. With special efforts from NSF program managers, a repair cruise was scheduled nine months later; using the normal scheduling process, this would not have happened until the subsequent year. However, improving scheduling flexibility to handle repairs of this sort requires more than a better scheduling process, and cannot be achieved in the face of very high demand for large UNOLS vessels and ROV time without increasing the size of these UNOLS facilities. Flexible scheduling for repairs at remote, high latitude sites presents even greater challenges which in many instances cannot be met with any reasonable level of UNOLS resources. International coordination to make effective use of non-US vessels for some repairs will help alleviate the problem. High reliability design procedures to minimize downtime are also essential. Improving UNOLS vessel sea keeping ability to widen the working window, either by modification of existing vessels or acquisition of new ones, is a third mitigating step. However, this will inevitably mean larger, more powerful vessels in addition to or instead of the smaller ones that are under consideration in the fleet renewal process.

3.3 Mapping Operations

Regional Context Mapping

Mapping in support of establishing the regional context of an ocean observatory is most in line with the traditional mapping capabilities of the UNOLS fleet. For this purpose, there is a requirement for large areal coverage with the best possible resolution and the collection of both bathymetry and backscatter. There are typical tradeoffs between resolution, coverage and operating depth, with higher-frequency systems operating in shallower waters and low-frequency systems operating in deeper waters.

The vertical resolution of a multibeam sonar system will be a function of the pulse length of the system (bandwidth) and the digitizing rate and bottom detection algorithm used, and is typically on the order of about 1 - .1 % of water depth. The horizontal or lateral resolution of a multibeam sonar system is a function of the beam width (array size) of the system, the geometry of the sonars, and the bottom detection and beam forming algorithms that are used. Typical values are on the order of ~ 5 - 1% of water depth, though new developments in dynamic focusing are beginning to improve lateral resolution capabilities. The depth to which a sonar will operate will be a function of the source level (limited by the transducer characteristics) and most importantly, the attenuation of sound in the water column which increases as frequency rises. Thus, high frequency (high resolution) sonars operating at frequencies of 300 kHz and above can be used for ranges of 100 m or less while low-frequency (lower resolution, e.g. 12 kHz) sonars can operate over ranges of 10 – 15 km. The tradeoffs between operating frequency, range, array size and resolution for some typical multibeam sonar configurations are summarized in Table 3.

Table 3: Tradeoffs Between Attenuation, Range, and Transducer Size for Sonar Systems

Frequency	12 kHz	30 kHz	100 kHz	300 kHz	455 kHz
Attenuation (dB/km)	1	5	30	65	100
Typical range (km)	11	5	1	0.2	0.1
0.5° beamwidth (m)	18	7.2	2.2	0.6	0.5
1° beamwidth (m)	9	3.6	1.1	0.3	0.2
2° beamwidth (m)	4.5	1.8	0.6	0.2	0.1
5° beamwidth (m)	1.8	0.7	0.2	0.1	0.05
10° beamwidth (m)	0.9	0.36	0.1	0.03	0.02

With respect to the ability of the UNOLS fleet to provide regional mapping information in support of ocean observatories, a brief review of the existing mapping systems immediately available on the UNOLS fleet reveals:

- *Roger Revelle* - EM120 (12 kHz) 1x2 degree
- *Atlantis* - SB2100 (12kHz) 2x2 degree
- *Thomas G. Thompson* - EM300 (30 kHz) + Hydrosweep DS (12kHz)
- *Maurice Ewing* - Hydrosweep DS-2 (12 kHz)
- *Melville* - SB2000 (12 kHz) 2x2 degree
- *Knorr* - SB2100 (12 kHz) 2x2 degree
- *Kilo Moana* - EM120 (12 kHz) and EM1002 (95 kHz)
- New Delaware vessel – Reson 8101 (240 kHz)

Thus, seven UNOLS vessels have full-ocean depth multibeam systems and one vessel (*Thompson*) has what can be considered an intermediate depth system (good to approximately 3000 m). *Kilo Moana* also has a mid-range capable system (EM1002) which should be good to about 800 m and the University of Delaware recently took delivery of a 240 kHz system (Reson 8101) that should work to depths of approximately 200 m. Of the deep water systems, the EM120 and EM300 have higher lateral resolution (1 degree as opposed to 2 degree beam widths) than the other systems. All systems can provide backscatter along with bathymetry but only the EM1002, EM120 and the EM300 offer quantitative full-time series backscatter for each beam.

Non-UNOLS vessels available to academic users with deep water multibeam systems on them include:

- *Nathaniel B. Palmer* - EM120 (12 kHz)
- *USCGC Healy* - SB2112 (12 kHz)
- *Ronald H. Brown* - SB2112 (12 kHz)

Several universities (Stony Brook, USF, etc.) have very high-frequency (300 kHz) EM3000 systems for small vessel, shallow water work.

Other mapping assets available to the UNOLS community to varying degrees include:

- Odyssey AUVs
- ABE w/ Simrad SM2000 - 200 kHz, Mesotech and Imagenix 675 KHz sector scanner
- MBARI AUV w/ Reson 7000 series multibeam (not delivered yet)
- NDSF JASON II - SM2000 (200 kHz) sector scanning sonar for very fine bathymetry near bottom
- MR-1 – phase comparison bathymetry and sidescan, with the newer MR-2 nearly on-line
- DSL-120A - phase comparison bathymetry and sidescan
- Argo II – 200 kHz sidescan sonar, cameras, 100 kHz forward look sonar
- Deep-Tow – sidescan sonar, single beam bathymetry, and sub-bottom high-resolution seismic

Looking at these assets, we can conclude that for deep water regional surface ship mapping studies with relatively low resolution (50-100 m pixels), the UNOLS fleet is well equipped. For shallower or intermediate depth areas where finer resolution should be possible even from surface ships (40 – 3000 m) the UNOLS fleet has limited assets (only the EM300 on the *Thompson* and the EM1002 on the *Kilo Moana*). Thus, if there is a great demand for mid to shallow water mapping in support of observatory work, there may be a need to either lease commercial systems (with vessels as these systems are too large to mount temporarily) or acquire additional systems into the UNOLS fleet.

Cable Route Surveys

Pre-lay and post-lay cable route surveys will place the most stringent mapping demands on the community. Typical requirements for a pre-lay cable route survey include:

- very high resolution over relatively narrow swath
- 100% bathymetry over 800 m swath
- sidescan (backscatter) - 1200 m swath overlapping bathymetry
- sub-bottom, coring and CPT if cable is to be buried (2.5 m sub-bottom)
- detect obstacles to 1 m lateral dimension
- detect hazards, including surface faulting, tectonic deformation, turbidity flows, unstable slopes, potential liquefaction, gas charged sediment, rocky outcrops, hard bottom (if ploughed), steep slopes, pinnacles, boulders, seismic activity, high currents, trawl marks, anchor marks, proximity to cables, pipelines, etc., man-made debris or hazardous materials, signs of oil or oil exploration
- real-time processing for near real-time decision making

The high resolution needed for cable route surveys in deep water requires the use of deep-towed, ROV or AUV-deployed sonars that survey close to the bottom. This is an expensive and complex process that has been done by the commercial sector in the past. Some UNOLS organizations have experience with commercial cable surveys (e.g., Hawaii Institute of Geophysics) but given the liability issues associated with those who lay the cables, it may make most sense to keep this component within the commercial sector.

Observatory Site Selection

Final selection of node sites will probably require much higher resolution surveys than those provided by the regional context surveys. Depending on the water depths involved, it may be necessary to bring the sensor near the bottom (AUV, ROV or other towed system) in order to obtain the necessary resolution. These surveys represent more traditional geological surveys and do not have the same stringent requirements (and associated liability) as cable lay surveys. Thus for deep water survey work, the ROVs, AUVs and towed systems available to UNOLS institutions (see above) should be appropriate for this task. For high-resolution site-selection surveys in mid to shallow water depths, there are few appropriate systems available to the UNOLS community (100 kHz or greater) and thus new systems may need to be acquired or leased.

3.4 Deep Water Vessel Operations

The use scenarios presented in Section 2 indicate that virtually all deep water ocean observatory operations will require a large DP vessel like the UNOLS Global Class. The single exception to this would be installation or O&M on the low bandwidth, acoustically-linked buoys which do not require an ROV, for which a UNOLS intermediate vessel (e.g., *Oceanus* class) would be sufficient. Specialized operations like cable lay and repair require expertise (e.g., fiber optic cable splicing) and equipment (e.g., linear cable engines) that are not available at UNOLS institutions, and that situation is unlikely to change in the future. Deep water cable installation and repair is best contracted to the submarine telecommunications industry which has the requisite tools and personnel. However, this leaves a range of operations which might be feasible using UNOLS facilities or which could be contracted to industry. All of these share the common characteristic of requiring a heavy lift capability that exceeds that on UNOLS vessels at present. Two possible solution paths within UNOLS are modification of Global Class vessels to enhance their utility or addition of new vessels to the fleet with expanded capabilities.

In addition, a new mission requirement for the Global Class ocean observatory operations will be refueling of large spar buoys at sea. Underway refueling has been practiced by navies for many years, and is also widely used in the commercial fishing industry. Commercially-available refueling hose technology for this purpose is normally placed on the receiving vessel (i.e., the buoy), and the tanker vessel will have to be equipped with a compatible fueling manifold. Refueling operations will be limited to light sea state conditions to minimize any opportunity for oil to enter the marine environment, especially in sensitive areas. Depending on environmental considerations where refueling is to take place, containment systems might be needed. A reliable means of sounding the tank on the buoy will also be required to avoid fuel spillage; on ships this is ordinarily done by manual means which is probably not feasible on a buoy. An attractive alternative would be a dual hose arrangement so that any overflow from the buoy is returned to the tanker ship. Any long range planning for these operations must take into account the concerns of ship's officers, as they are ultimately responsible if oil enters the sea. UNOLS should understand the liability concerns of ship's officers and perhaps consider purchasing license insurance for the mates and engineers aboard the ships to cover refueling mishaps. It may also be necessary for one or more ship's officers to have a tankerman license endorsement. This is very common for officers with merchant experience, but less so for those who have served on research vessels for most of their careers. A Coast Guard ruling on this requirement is needed to facilitate planning.

Modification of Global Class Vessels

There are currently six Global Class vessels in the UNOLS fleet (*Melville, Knorr, Ewing, Thomas G. Thompson, Atlantis*, and *Roger Revelle*). While the NOAA ship *Ronald H. Brown* is sometimes available to UNOLS researchers, it is outside of the control of the academic community, and hence will not be further considered. Of the six UNOLS Global Class ships, two (*Melville* and *Knorr*) are at least 2/3 of the way through their life cycle, and hence their modification makes little economic sense. In addition, *Atlantis* is more or less dedicated to manned submersible operations which limits the ability to make changes to the vessel. Similarly, *Ewing* or its replacement is a special purpose vessel primarily dedicated to multichannel seismic operations whose deck layout and capabilities preclude most heavy lift ocean observatory operations. Neither *Atlantis* nor *Ewing* will be further considered in this report. The emphasis will be on the AGOR-23 class vessels, and primarily *Thompson* and *Revelle*.

The AGOR-23 class was designed, and the *Melville*/*Knorr* were modified at mid-life, for use in global geosciences programs of the late twentieth century like WOCE and JGOFS. The mission requirement for those programs emphasized cruise duration, large shipboard parties, extensive lab space needs, and limited fantail over-the-side operations. Little consideration was given to compatibility with ROV operations, as these vehicles were in their infancy during the respective design phases. In aggregate, these characteristics are almost the antithesis of ocean observatory requirements. It is useful to consider how these vessels can be made more compatible with future needs. It must be recognized that only some candidate changes are feasible in anything short of a major refit, and the needs of the conventional expeditionary science communities will have to be considered before any changes are made. In addition, given that *Thompson* is approaching the planning phase for mid-life refit, with *Atlantis* and *Revelle* shortly behind, this exercise is timely. The main areas to be considered are sea keeping ability, deckspace, A-frame strengthening, and improved lifting tackle. These issues often interact and will need to involve a naval architecture study to determine feasibility and assess economics.

The Global Class ships were optimized for fuel economy, and hence are underpowered relative to work vessels of the same size and displacement in commercial service. Concomitantly, their sea-keeping ability is limited; dynamic positioning above SS4 with the AGOR-23 class is a challenge, especially if the wind and sea are not coincident. This is largely due to bow thruster limitations. Comparable size commercial work vessels can operate up to SS7, typically using dual bow and stern thrusters in addition to the main propulsion. Retrofitting AGOR-23 vessels with this number of auxiliary thrusters is probably not feasible, as it would require enhancement of generator capacity and presents hull space problems. However, it is worth considering augmenting the bow thruster capability of the AGOR-23 class at mid-life refit. This could be done either by adding a second steerable bow thruster or with a tunnel thruster. Extending the sea state window to SS5 would significantly impact the utility of these vessels at ocean observatories. For example, it would open the weather window for NEPTUNE by as much as two months, and make occasional year round operations possible.

All of the Global Class vessels have only a single (i.e., non-redundant or DP1) DP system, which makes them vulnerable to failure of DP which can under some circumstances be catastrophic to over-the-side operations (for example, refueling of a spar buoy). Commercial DP vessels typically use doubly redundant DP (DP2), and those engaged in man-over-the-side operations have triply redundant systems. Redundant DP systems are routinely installed on ships at a cost about 50% higher than a single one, and should be retrofitted to all of the Global Class vessels. This is not a major refit item, and should be considered in the near future. In addition, DP systems which incorporate data on ship movement result in substantial improvement in the ability to hold position in the presence of wind or sea. Such an approach has been tried experimentally on *Knorr* with very promising results, and should be considered for all of the Global Class vessels.

A third change that would improve the DP capability of the Global Class vessels is shrouding the z-drives. On the AGOR-23 class, this would involve modifications to the void space above the thrusters and to the thrusters themselves. The downside to shrouded nozzles is a reduction in the efficiency of the ship as it moves through the water, resulting in slightly slower underway speeds and a possible slight increase in fuel consumption. The upside of shrouds would be better protection of the props from entanglement and better efficiency of the thrusters at slow speeds and while dynamic positioning. Protection in the AGOR-23 class is a particular issue since these ships were originally designed for conventional propulsion and changed to z-drives during construction. As a result, the z-drives are further aft than is desirable, making them particularly vulnerable to fouling during over-the-side operations. Shrouding is clearly a shipyard operation, but falls short of being a major refit issue, and should be considered in the near term.

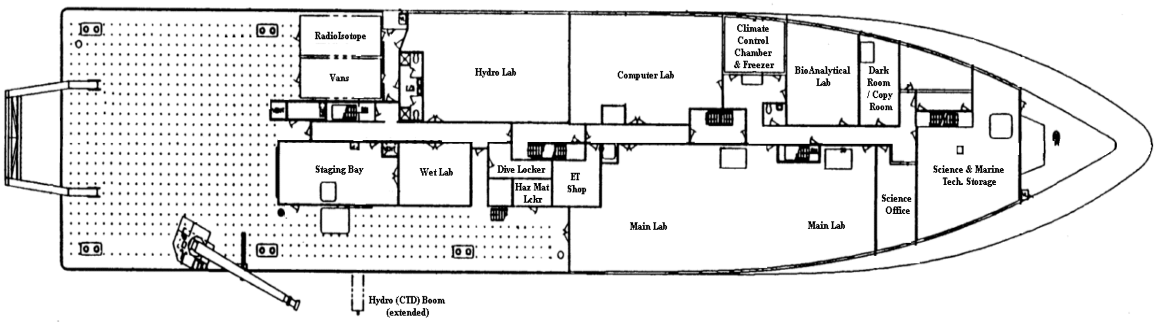

Figure 7. Main deck layout of *Thompson* showing open deckspace aft with tie-down bolt pattern on 2' centers. The staging hangar is on the starboard side immediately forward of the open deck.

A final improvement that could be made to the AGOR-23 class is the addition of a bulbous bow. This might improve sea keeping by reducing pitching and could also increase the efficiency of the vessel as it moves through the water. It may or may not reduce bubbles under the hull as well.The track record from retrofitting vessels with a bulbous bow is mixed. Naval architects should be consulted during planning for a major refit.

Figure 7 shows a main deck layout for *Thompson*. *Revelle* is very similar. The 3500 sq ft open main deck (including the 1200 sq ft starboard waist deck) has a 2’ tie-down bolt pattern, each of which is capable of supporting a 5000 lb load. The amount of usable deckspace on these ships is very small compared to work vessels of comparable size, where the open area would typically extend 1/2 to 2/3 of the available distance from the stern. The small working deck area of these ships is the result of tradeoffs made during their design for global geosciences missions. Unfortunately, options to increase the deckspace appear to be limited. It would be possible to remove the staging hangar, yielding a modest increase in open area. The simplest option (and the one least likely to effect CTD operations) would be to remove the starboard bulkhead and overhead of the hanger aft of frame 91 (just aft of the squirt boom), leaving in place the centerline bulkhead. This would add about 180 sq ft of outside deckspace and increase the available working deckspace on the starboard side. Another advantage of this would be increased visibility from the bridge. There would still be adequate space available for CTD operations.

There are other options, but they would cost considerably more and present a whole array of design challenges. Removing the center bulkhead of the hanger would involve reworking the fire main piping and electrical systems. There would also be strength issues regarding the location of the flag block for the trawl wire. Removing the entire superstructure aft of the hydro lab would present more difficulty, including relocation of the trawl winch operator’s room and the incinerator. Converting lab space into deck or hanger space would be almost impossible as modifications to these areas would involve spaces like the emergency and main generator rooms as well. All of these are major refit items which need input from a naval architect. In any case, they are probably not the most efficient way to improve deckspace on the AGOR-23 vessels.

Two additional ways to increase deckspace at mid-life refit are the addition of sponsons to the vessel and adding a hull section to increase the vessel’s length, as was done for *Knorr* and *Melville* during mid-life refit. The former is a relatively low cost option which increases the vessel beam without increasing length that is widely used in the fishing industry. However, it presents practical problems; for example, a wider *Thompson* would be unable to transit through the Ballard Locks to the University of Washington dock, and a wider *Revelle* may be unable to access the Nimitz Marine Facility dock in San Diego. Increasing the vessel length is much more viable. Adding a 50’ section to Thompson aft of the staging hangar would increase the working deckspace by about 2500 sq ft, more than doubling it from the present configuration, and greater extensions are probably feasible. This carries several added bonuses. First, it could yield a large scientific hold space, significantly increasing the carrying capacity of the vessel and enabling some types of operations that are not presently feasible (e.g., cable repair, with the hold serving as a cable tank). Second, the addition of ballast tanks aft would improve the trim and stability of the AGOR-23 class ships. At present, most ballast tanks are located forward of the midline, with the consequence that the large midships fuel tanks cannot be used without impacting stability. Third, adding a hull section would make it possible to address a persistent trim problem. At present on *Thompson*, the weight of the trawl winch combined with the weight of ROV vans and winches during Jason operations requires that the port trim tanks be empty and the starboard ones be full to maintain an even keel. Increasing the LOA of these ships from 280’ to 330’ will have only a slight impact on fuel consumption and top speed, and will not affect manning, so will have little impact on operating costs. Further, with a z-drive powered ship, there are no complex propulsion issues to deal with; extension can be accomplished by running longer power cables from the generator. This concept needs careful evaluation by a naval architect.

The current A-frame capacities of the UNOLS Global Class vessels can be stated as static weight limit (i.e., load capacity when locked at either end of its travel range) and moving capacity (i.e., load which can be swung in or outboard). For *Melville* and *Roger Revelle*, these ratings are 32,500 and 18,000 lb, respectively. For *Thomas G. Thompson*, they are 30,000 and 12,000 lb, respectively. *Atlantis* is equipped with a man-rated, high capacity A-frame for launching and recovering DSV *Alvin* whose static weight is ~40,000 lb. It is not generally available for other purposes. *Knorr* carries no A-frame but utilizes the main crane to deploy its trawl wire. Its capacity is dependent on the limits of the crane slewing mechanism which is rated at 60,000 ft-lb, so that its capacity at 30' extension is 2000 lb.

For purposes of this report, we will investigate what modifications would be required to double the A-frame handling capacity of the Global Class vessels. A target static load of 60,000 lb will be assumed. Construction of new or modification of existing A-frames should allow the load to be carried at multiple locations on the structure. At any given time, depending on such factors as load location, wire angle, and ship roll, a large majority of the deck loading may be concentrated under one side of the A-frame. Design goals should probably be for a structure either side of which could support the total load. Deck load capacity for the Global Class ships is on the order of 1000 lb/sq ft. The design goal could be met by a structure which spreads the load over a large area of the fantail (e.g., at least 120 sq ft around each side using a factor of two safety margin), or by utilizing deck reinforcement under the A-frame, or by a combination of both. These issues should be submitted to a naval architect for evaluation, but it is likely that doubling the handling capacity of A-frames can be accomplished.

Two UNOLS vessels either have (*Atlantis*) or are being modified for (*Knorr*) enhanced handling capability. In the case of *Atlantis*, the large A-frame for lifting *Alvin* was accommodated by extensive reinforcement of the deck structure during the ship construction process. The WHOI port engineer indicates that such reinforcement would be a challenge to retrofit to an existing vessel. *Knorr* will shortly be modified to handle the recently funded UNOLS long coring system. A reinforcing system for the fantail deck which will allow handling of loads >100,000 lb is being designed, but the coring gear will be handled by a deck-mounted sheave rather than an A-frame, because of issues of ship stability.

Modifying the A-frames and associated supports during refit to double their capacity will allow moderate loads to be handled from Global Class vessels. In combination with an increase in deckspace, this will allow all but the largest buoy deployments and recoveries to be carried out, and will facilitate some types of cable handling, such as cable repair or the lay of short (up to 100 km) extension cables. At the same time, the trawl winch and wire will need to be upgraded. The UNOLS standard 9/16", 3x19 wire is adequate for traditional coring and dredging operations, but its 24,000 lb elastic limit is not compatible with an upgraded A-frame or ocean observatory missions. Concomitant improvement in crane capacity will also be required, which probably poses additional deck strengthening issues.

Concomitant with upgrading the lifting capability of UNOLS Global Class vessels, it is essential to change the deck operations when conducting heavy lift operations. The traditional UNOLS model in which the science party carries out most over-the-side operations with crew assistance is not viable as the load increases. Instead, specially trained and qualified crew members should be responsible for all aspects of over-the-side operations with static loads above a threshold value (to be determined, but a nominal goal is 10,000 lb). It is also important to utilize good safety practices, including pre-deployment or recovery briefings, for all heavy lift operations.

Finally, it is essential that a below deck fiber optic traction winch be available on all global ships from which ROV operations will be carried out. At present, only *Atlantis* and *Revelle* carry such a winch. Ocean observatory operations from *Thompson* which require an ROV are a challenge given the very large amount of fantail space required for a fiber optic traction winch. It would also be highly desirable to provide interior space which is dedicated to ROV operations so that external control vans do not have to occupy large amounts of valuable deckspace. As will be discussed in Section 3.5, provision of an ROV has to be routine for most deep water ocean observatory operations, and hence making its control an integral ship function is a reasonable goal.

Augmentation of the UNOLS Fleet to Enhance Heavy Lift Capability

From the preceding discussion, it should be clear that two major large ship issues are facing the oceanographic community as the OOI reaches fruition. First, the projected demand for Global Class ship time for ocean observatory operations will swamp the available resources, especially when the planetary scale reach that is required to service the global buoys is factored in and the near future retirement of two of the four general purpose Global Class ships is considered. There are currently no plans for the construction of new general purpose Global (or larger) Class UNOLS vessels in the Fleet Renewal process over the next two decades. Even if there were, experience indicates that it takes fifteen years to take a new ship class from concept to delivery, and hence the large ship issue for ocean observatory science is a serious one. Second, even if the ship resources were available, the capability of the Global Class vessels will be stretched to the limit for many ocean observatory operations, and especially those involving heavy lift. Further, the latter issue is unlikely to be addressable in other than an incremental way before the AGOR-23 class vessels reach mid-life refit in 5-10 years.

A possible way to alleviate these problems in a timely manner is direct or indirect augmentation of the UNOLS fleet to increase the availability of large, heavy lift vessels. There are two distinct ways that this might be accomplished, and a hybrid approach is also feasible. First, a long term contract could be entered into with an industrial firm to provide worldwide heavy lift vessel services for ocean observatory operations. Submarine telecommunications cable service firms are viable candidates to provide this capability, as they maintain heavy lift vessels on hot standby around the world to provide cable repair services, and do look for ancillary tasks to augment this work. Second, a heavy lift vessel (or vessels) designed for use in either the offshore service or submarine cable repair sectors could be acquired and operated by a UNOLS institution to increase the size of the Global (or larger) Class fleet. This is a timely and time-critical option, as such ships can be purchased at very attractive prices at present, but this situation is unlikely to continue for long.

A long term contract to provide heavy lift vessel services could be entered into using two approaches. First, a single heavy lift vessel and crew could be contracted on a continuous or near-continuous basis, analogous to the manner in which specialized vessels have been chartered for ocean drilling for the past several decades. This vessel would then roam the world as needed, carrying out installations and servicing on a schedule set by the OOI operator. Second, a contractual relationship could be entered with one or more companies to provide heavy lift services as needed on a worldwide basis using an available vessel in their fleet located near the OOI site of interest. The first option has two major disadvantages: 1) the expense of long transits will have to be borne by the OOI operator, and 2) scheduling flexibility to cover unforeseen contingencies and emergency repairs will be limited by the use of only one vessel. By contrast, the second approach is likely to offer cost advantages and a substantially better ability to handle contingencies. However, to make its implementation as simple as possible, the number of contractors must be minimized, and ideally would constitute only a single one having a global ship network in place. This substantially limits the suitability of some marine sectors, notably the offshore oil supply industry which tends to be focussed heavily in a few places where oil drilling and production are active rather than being dispersed globally.

One marine sector that has a global network of heavy lift vessels and a relevant expertise base is the submarine telecommunications cable installation and repair industry. This community has undergone significant downsizing and consolidation in the past two years due to substantial overbuilding during the telecommunications boom of the late 1990's. However, Global Marine Systems remains both the oldest (having started as Cable and Wireless in the nineteenth century era of telegraph cables) and largest (in terms of fleet size) of these companies, and hence exploratory discussions have been carried out with them to assess the concept.

Figure 8. Global Marine Systems cable lay/repair vessel *Maersk Recorde*r. The ship is 106 m LOA and has twin screw main propulsion, twin stern tunnel thrusters, a bow tunnel thruster, and a steerable bow thruster. The ship is equipped with a stern A-frame rated at 60 ton SWL, a 60 ton SWL tow winch, and a range of heavy lift tackle rated at 35-45 tons SWL.

The Global Marine fleet numbers 14 ships ranging between 105-145 m LOA (see http://www.globalmarinesystems.com/site/R_vessels.htm) dispersed approximately equally around the world. Eleven of the ships are stationed on maintenance activities, servicing specific contracts for cable owners on a 24 h call out basis, while the remaining three are large cable layers which operate where needed worldwide. Each repair ship services multiple cable owners, and the company is usually free to load the ships with significant numbers of contracts for cable repair or other activities, as this is the only way that the ships become economic to operate.

Figure 9. Typical cable repair vessel fantail showing a high capacity A-frame (in this case, 60 ton SWL), a linear cable engine at center, and a 3 m diameter cable drum on the port side. The large, open deck is adaptable to a wide range of heavy lift operations.

Figure 8 shows a typical Global Marine cable lay/repair vessel. Figure 9 shows a close-up view of the large, open fantail on this type of ship. Cable repair ships typically possess dual stern and bow thrusters in addition to twin screw main propulsion, and are capable of dynamic positioning and conducting over-the-side operations in SS7, including launch and recovery of ROVs. They have a large, open aft deck with heavy lift gear including cranes, cable handling drums and winches, and a large A-frame rated at 35 to 60 metric tons, depending on the ship (e.g., Figure 9) through which objects as large and unwieldy as deep sea plows are launched at maximum sea state. All Global Marine vessels are at least DP1 rated, with some being DP2. All maintenance vessels are equipped with ROVs varying in power from 200 to 1200 hp and capable of operating in water depths under 2000 m. All have specific buoy launching facilities, as this is core to cable repair activities, as well as significant on and below deck storage capability, capability to lower cabled objects to the sea floor in accurate locations, powerful winch systems and cable engines, modelling software for cable related marine dynamics, significant workshop facilities, electronics clean areas, accommodation for customer representatives, and all of the ship operation facilities you would expect from a state-of-the-art cable ship operator. In addition, they have experienced crews trained to safely carry out heavy lift operations, as virtually all cable repairs involve this sort of activity.

In addition to primary cable maintenance activities, Global Marine vessels carry out other long term contracts or short duration one-off tasks. For longer term contracts, tasks are typically executed on an interruptible basis, where should a fault occur on one of the contracted cables, the ship is normally obliged to halt the task, mobilize to fix the cable fault, and then return to the initial task when the cable fault is repaired. The terms and conditions for these contracts have to be agreed upon in advance and are very similar in nature to the contracts which exist on the ships for cable repair. The short term contracts normally operate as ‘outside work’. This position allows for any reasonable number of days of work with the ship, sometimes but not always within certain geographic limits, on any type of activity which is suitable to the ship’s and crew’s capabilities.

While a variety of contractual relationships might be considered, a starting point would be a global contract where all Global Marine ships would be made available to the OOI operator on a call-off basis. Global Marine ships could be available to install ocean observatory equipment world-wide, with the vessel choice dependent on geographic considerations, base port locations and specific task related ship requirements. There might be a small standing charge for this service, dependent on OOI requirements for response time and whether or not the operations would be interruptible, with the charge decreasing or vanishing as flexibility increases. In addition, Global Marine would charge a mobilization rate and a day rate for vessel operations which would be set and fixed during negotiations for a period of 3-5 years. The day rates would depend on the expected utilization for the vessels and would obviously be inversely proportional to total usage.

This exploratory inquiry shows that the concept has considerable merit, and further discussions to include costing and possibly expand beyond a single company are warranted as the OOI moves toward implementation. One issue that will have to be resolved is that of ROV capability. Commercial ROVs in the cable industry are used primarily for shallow water burial and repair activities, and hence do not operate to full ocean depth. Utilization of Global Marine or equivalent vessels will require the addition of a deep ROV for many operations. This does not pose any technological challenges, as Jason has operated in a fly-away mode for years, but does present some scheduling and logistical challenges.

An alternate approach to OOI-related heavy lift operations would be acquisition of a suitable vessel into the UNOLS fleet. This option presents similar limitations to contracting with industry for a single dedicated vessel, since large mobilization costs will have to be absorbed for long transits to reach remote sites (see Figure 1) and flexibility to address emergency repair situations with a single vessel will of necessity be limited. This can be alleviated by increasing the number of UNOLS heavy lift vessels at the obvious cost of higher initial capital and ongoing operating costs. Whether the global industrial contract approach or the vessel acquisition approach is more favorable economically is unclear, and will require further study.

However, it is certainly true that heavy lift vessels can be acquired at attractive prices at the present time. Exploratory discussions with a ship broker (Don Dean of DMM International) have shown that several relatively new cableships are currently available at prices under $10M as a result of significant overbuilding toward the end of the telecommunications boom. This is less than 1/6 of the cost of comparable new construction in foreign shipyards, and substantially lower than US shipyard construction. Other information suggests that a glut of cableships will continue to depress the marketplace for awhile, as new vessels are being delivered and immediately placed into lay-up status. This in turn will result in more relatively new vessels being put up for sale. The situation is unlikely to persist for more than a very few years, and represents an opportunity to the academic community. A mitigating factor is that most of the currently available vessels are large (8000-15,000 tons displacement) cable layers rather than the more attractive (for UNOLS purposes) cable repair vessels in the 3000-5000 ton range. A similar overbuilding situation exists in offshore supply vessels, and these could be adapted to UNOLS heavy lift needs. However, more substantial refitting will be required to adapt this class of vessel to oceanographic purposes, and this will likely reduce the cost advantage as compared to the cableship class.

Since virtually all available cable and most offshore supply vessels have been constructed in foreign shipyards, the issue of re-flagging has to be considered. This problem is timely, as it is also a concern for the option of acquiring a foreign-built seismic vessel into the UNOLS fleet. While final disposition of this issue requires a case-specific Coast Guard ruling, preliminary indications are that non-commercial users such as UNOLS institutions can avoid most of the complex documentation and re-flagging requirements needed to operate from US port to US port.

Providing that the UNOLS decision making and federal procurement processes can move rapidly enough to take advantage of a short term opportunity, the present ship market is sufficiently attractive that a more detailed assessment, including the assistance of a naval architect where appropriate, is recommended. This evaluation needs to move in parallel with further study of the global contract option so that their relative costs and advantages can be more completely understood.

3.5 Deep Submergence Operations at Ocean Observatories

As has already been noted, ocean observatory installation and operations will in many instances require the use of submergence assets, notably remotely operated vehicles. While in some cases manned submersibles may be able to carry out ocean observatory tasks, the limitations imposed by human rating are a significant problem. Virtually all ocean observatories will include an extensive network of cables on the bottom and moorings extending up into the water column. Entanglement risk is very real, and will in many cases require that significant operating constraints be placed on manned submersibles to avoid endangering human life. Further, experience gained at the deep H2O site indicates that many observatory tasks require significantly more time (e.g., days rather than hours) than a single manned submersible dive can deliver. For these and other reasons, it is expected that manned submersibles will play a lesser role in ocean observatory operations compared to ROVs, and hence the focus in this report will be on unmanned vehicles. However, if a new manned submersible will be constructed as called for in a recent report [National Research Council, 2004], use scenarios and the resulting design requirements should include ocean observatory-relevant missions.

At the present time, no autonomous underwater vehicles (AUVs) are contained in the National Deep Submergence Facility (NDSF), nor are AUVs carried on UNOLS vessels as shipboard equipment. Instead, AUVs like ABE operate on a project-specific basis through collaboration between the vehicle designers and interested scientists. Unless this situation changes, AUVs are not a UNOLS facility issue. However, it is expected that AUVs will constitute an important standard tool at ocean observatories. While an operating model has not been agreed on, it is probable that individual ocean observatory operators will be responsible for these vehicles.

ROV Capabilities

Table 4 summarizes the available unmanned deep submergence (ROV) assets presently in existence. With the exception of ATV, MARUM, and the commercial vehicles, all of these systems have engaged in various, early stage observatory tasks of one type or the other. In general, these are likely to play some role in the installation and maintenance of the OOI observatories. The MBARI and NDSF ROV have or are soon to accomplish many of the tasks likely to be required at a full scale observatory. However, it is important to note many of these systems are being utilized at or near full operational capacity carrying out traditional (i.e., non-observatory) projects. It is highly likely that additional assets will be required as ocean observatory installation and maintenance places increased pressure for deep submergence services.

Table 4: Available Deep Submergence Assets

Vehicle	Depth Limit (m)	Affiliation
Jason II	6500	WHOI/NDSF
ROPOS	5000	Canada
Tiburon	4500	MBARI
Ventana	1850	MBARI
ATV	6000	SIO
Isis	6500	SOC
German ROV	4000	MARUM
Victor	6000	IFREMER
Remora	6000	Commercial
Magellan	6000	Commercial

At present, there are numerous commercially available systems specifically designed for telecommunications cable maintenance or oil field service applications up to 2500 m water depth. Below about 3000 m, the number of commercial systems decreases dramatically, and there are only a small number of commercial systems capable of operating in up to 6000 m water depth. While only one unit has been built to date, Alstom Automation has delivered a 4000 m system to the German research concern MARUM. The Canadian company International Submarine Engineering has also supplied specialized systems with 5000 meter ratings (one of these is the ROPOS). Other systems built for 6000 meters have been the efforts of commercial operators such as Oceaneering and Phoenix International. It is quite possible that some of these deeper systems could be suitably modified to meet the requirements for observatory installation or maintenance operations. At the present time, none of the commercial systems in operation have any direct experience with the tasks required for observatory installation and maintenance.

Commercial ROV operations are unlikely to extend much beyond 3000 m in the near future. The current deepest oil field development projects are in the Campos Basin in Brazil, which has a maximum depth of 3400 meters. In the Gulf of Mexico, the US Mineral Management Service publishes all oil and gas discoveries (http://www.gomr.mms.gov/homepg/offshore/deepwatr/deeptbl2.html), the deepest of which is at 2400 m (Merganser Field). Similarly, there is little pressure to operate below 2500 m in the telecommunications sector, and in the face of the current massive industry downturn, this is unlikely to change in the near term. Taken together, this implies that little commercial pressure can be anticipated to work below ~3000 m for the immediate future, and hence academic assets will be required for most deep ocean observatory operations.

Commercial vessels specifically outfitted for ROV support are available in the offshore oil field service sector, and could be a very viable option for ocean observatory support if UNOLS vessel availability is an issue. As such a vessel would not need to be a general purpose oceanographic ship, some economies are possible. Service vessels typically carry a crew of around 10. Such a vessel would have full dynamic positioning, adequate deckspace, and a suitable winch. It would not require the scientific laboratory infrastructure of UNOLS Class 1 ships and would not need to support large science parties. From a cost point of view, these commercial vessels have undergone many iterations in recent years, which allows them to be operated efficiently when they are well-matched to the work.

ROV Operations for Installation and Maintenance

It will be assumed that mapping and cable route surveys for ocean observatories will be conducted in the traditional cable industry fashion using their submergence assets (notably, AUVs which are increasingly being applied to cable route survey activities). However, given that portions of a scientific cable may be laid in areas that normally would be avoided for a commercial cable, an additional level of survey might be needed in some instances. This would also apply to observatory site selection for global buoyed observatories. Near-bottom surveys with multibeam sonar could be required, either from an ROV, AUV, or towsled. This would be a one time requirement, and could probably be combined with scientific survey of the area near the cable. These contingencies could be handled using existing academic or commercial assets, with the former probably being required in deep (>2000 m) water.

Installation of the backbone for cabled observatories will require specialist services supplied by commercially cableships. It is assumed that these services will also include the specialized ROVs required for burial and post lay inspection on the shallower portions of the cable system. This has no implications for UNOLS facilities.

Most of the global buoyed and the regional cabled observatories will require an ROV for infrastructure and initial instrument installation as well as ongoing operations and maintenance. The associated vehicle requirements are essentially identical for installation and operations and maintenance. Much of this work is typified by what is already being accomplished by ROVs at the H2O site, and can include such tasks as emplacement of junction boxes, deployment of long term experiments and short haul installation of additional bottom cabling runs. Deployment and connection of various moored elements will also be required. While some of these operations could utilize commercial ROVs such as those carried on cableships, their depth limitation will preclude use at the majority of deep water observatory sites. In fact, deep water commercial ROVs are rare, and it should be expected that academic vehicles will have to shoulder much of the ocean observatory load. Evolution of scientific ROVs and building the strong experience base for their operators necessary to fulfill these requirements is presently underway, and there can be no doubt that such capabilities will play an increasingly important role for the OOI.

ROV Operations for Science Support

Much of the ongoing support of science instruments at ocean observatories will require ROVs that are capable of operation to full ocean depth. For example, sensors will require maintenance, replacement, or upgrades at regular intervals. Observatory instruments can be divided into two classes: community and PI experiments. Community experiments include standard sensors for which there is a broad user base, and hence will probably be administered as facilities. Considerable instrument standardization across ocean observatories will be possible, and hence servicing of these instruments should be routine after an initial learning period is completed. It may be possible to have community experiment servicing carried out under commercial contract. By contrast, PI experiments will incorporate custom instrumentation, and installation and servicing will require considerable interaction of the PI with an ROV operator that is experienced in handling one off, specialized tasks. This argues strongly for an operational model that is similar to the current NDSF one, with an ROV operator dedicated to science support.

ROV Requirements

Based on experience with early stage observatory efforts such as the MBARI Ocean Observing System (MOOS) and H2O, a summary of the required vehicle system capabilities includes:

- Twin manipulators with at least one being a highly dexterous master/slave design
- Ability to accommodate on-board payloads of no less than 250 pounds water weight
- Adequate dynamic thrust to lift and transport objects weighing up to 500 pounds in water
- Ability to accomplish a heavy lift of up to 2000 pounds as may be required to recover junction boxes and other associated equipment
- Ability to operate to SS5, and preferably higher, for both NEPTUNE and the global buoy observatories, which carries both support vessel and vehicle system requirements
- Ability to carry diagnostic tools as may be required to troubleshoot nodes and associated equipment in-situ, which is largely a communications and power interface flexibility issue
- High precision real-time acoustic navigation.
- Flexible power and data telemetry to accommodate a wide variety of sensors (e.g. Ethernet, high speed serial data, up to 4 kW of power).

- Ability to accommodate a cable payout reel system for short (up to 10 km) near-bottom lays such as is under development by MBARI and WHOI, which carries a requirement to compensate for the loss of mass as cable is laid.
- Fiber optic umbilical with dedicated spare fiber.
- Deployable from a variety of support vessels

Most of these requirements can be met by current generation academic ROVs like Jason II, with the exception of the ability to operate in higher sea states and the existence of a variable ballast or equivalent system.The former is both a support vessel and vehicle system (especially deployment and recovery methods) issue that requires significant attention. In addition, a significant increase in delivered power could be achieved if the present NDSF requirement to be able to carry out both towed vehicle (e.g., DSL120A) and ROV operations on the same 0.68 fiber optic cable was removed. This dual use requirement leads to a much longer wire (9000 m instead of ~6500 m) than is needed for ROV operations, with a concomitant reduction in the power that can be delivered to an ROV. Vehicle system designs which optimize ROV operations can lead to a considerable improvement in capability.

Required Number of ROVs

The UNOLS facility contains one ROV: Jason II. In recent years, Jason II has been fully utilized for traditional expeditionary ocean science, and this trend is expected to continue and probably accelerate as the user community gains familiarity with ROV capabilities. Indeed, some increase in traditional usage demand can be expected to ensue as a consequence of ocean observatories due to scientific synergism.

With the projected ship usage for ocean observatory operations (see Section 3.1), it is clear that demand for ROV time will rise substantially and swamp the available resources. A rough estimate of ROV requirements after the initial installation of ocean observatories from Table 2 would be 600 ROV-days per year for ocean observatory activities. This is equivalent to about 2.5 ROVs when maintenance time is factored in, and does not fully accommodate the geographic diversity of the global buoyed observatories which will require time for shipping of fly-away systems. With an additional ROV required for traditional ocean science and on the premise that some of the load could be taken up under contract (e.g., using ROPOS), this means that at least two additional ROVs will have to enter the UNOLS facility early in the evolution of the OOI (i.e., within no more than five years). Even then, ROV time will be very tight and growth in traditional usage will not be accommodated very much. Indeed, it would not be hard to make the case that three additional ROVs will be needed by ~2010.

One mitigating factor that would reduce the cost of this ROV fleet enhancement might be operation with a reduced ROV crew for some or all observatory operations. Current Jason practice is to operate on a 24 hour per day basis with three traditional watches, enabling the vehicle to carry out submerged science activities for days at a time. This operation mode is consistent with expeditionary science requirements, but in many instances ocean observatory operations will require briefer submergence times. This is especially true for routine infrastructure servicing, where the task to be carried out is recovery or deployment of a science node which (based on H2O experience) requires 12 h or so. Reduced manning carries vehicle maintenance and repair risks, and will require greater involvement by ship's crews in launch and recovery operations, but is worth further consideration.

For ocean observatory operations, it is essential to get past the current model where a deep submergence vehicle is a specialized tool that is an add-on to specific cruises, and change to a new paradigm in which an ROV is a standard tool carried by any large research vessel and available to science.

3.6 Coastal Observatory Operations

While there is some commonality between deep water and coastal observatory operations, the variety of platforms and tasks at coastal observatories is substantially more diverse. At present, coastal observatory operations utilize an eclectic mix of ocean- and land-based fixed sensors ranging from moorings to codars, autonomous vehicles such as gliders, and intensive ship- and aircraft-based surveys. In part, this reflects the shorter time scales that dominate in coastal as compared to deep water processes, which makes intensive but short term studies of phenomena more scientifically productive. It is also due in part to the relative ease and low cost with which ship-based measurement programs can be staged using small, often university-based or non-UNOLS, vessels.

At the same time, planning for the global buoyed and regional cabled observatory components of the OOI is more cohesive and more advanced than for the coastal components. This is due in part to the diversity of the coastal observatory user community, in part to the relatively low unit cost of coastal observatories which makes them easier for single institutions to get funded through existing peer reviewed programs, and in part to their limited geographic size, which makes them amenable to funding through non-peer reviewed avenues. The combination of the wide mix of current coastal observatory instruments and practices with the lack of clear priorities by the coastal science community makes estimating the UNOLS-specific requirements for coastal observatories commensurately difficult. In particular, the ship time requirements shown in Tables 1 and 2 are substantially more uncertain than for the global buoyed and regional cabled observatory components of the OOI. Vessel and submergence needs should also be viewed as preliminary rather than definitive.

Future Needs for Mid-size Vessels in Coastal Research.

US plans for the next decade call for development of a national network of coastal ocean observatories and observation systems that serve both scientific and applied users. Coastal observations will be acquired from multiple platforms that include an international constellation of satellite and aircraft remote sensing platforms, a national network of shore-based high frequency (HF) radar systems, a NOAA-based backbone of buoys and shore stations, both sentinel and relocatable mooring arrays, fixed cabled observatories, and AUVs of both the glider- and propeller-driven type. For the scientist, the coastal network will provide a well-sampled ocean in which to conduct multi-disciplinary campaign-type scientific experiments, a long-term context for short-term process studies, and an opportunity for event response. Rather than decrease the need for surface vessels, recent experience has demonstrated that the availability of real-time data from ocean observatories and observing systems actually increases the demand for surface research vessels.

Given real-time data-rich nowcasts and model-generated forecasts of ocean conditions, scientists are optimizing their time at sea, requiring faster response at specific times to go to specific places, thus increasing the overall need for ships.

Individual universities and research institutions are partially fulfilling this need for coastal oceanographers by operating larger fleets of small research vessels capable of day trips. The growing need is for a larger fleet of mid-size vessels capable of sustained operations ranging from overnight to a fortnight. Using the UNOLS classification, this means small Regional Class (130’-180’) or large Local Class (<130’) vessels. Recent examples of the desired mid-size research vessels include the planned replacement *Cape Henlopen* (138’), the new *Savannah* (92’) and the 3-year old *Connecticut* (76’).

Beyond the regular science missions already served by UNOLS vessels, new requirements to support the coastal observatories will include maintenance of relocatable mooring arrays (30-40 moorings) and the coastal nodes on regional cabled observatories. Coastal cabled observatory nodes deployed in water depths greater than are safely diver accessible will require servicing by ROVs. A diverse set of suitable ROVs are commercially available for either purchase or contract. The relocatable mooring arrays are intended to be serviced through mid-sized UNOLS vessels. To maintain long-term continuous scientific datasets, there is an increasing need for servicing missions, both for scheduled and emergency maintenance. Coastal moorings with standard physical sensors typically are deployed on six-month turn-around schedules. New bio-optical sensors envisioned for installation on the relocatable moorings require more frequent servicing, especially during the high bio-fouling summer season. Assuming 4 turn-arounds per year of 40 buoys gives 160 servicing missions. Assuming 4 buoys are turned around per trip gives 40 trips per year. Assuming each trip requires about a 5 day work week for loading and unloading, steaming to and from the sites, and deployments and recoveries, maintenance of the relocatable mooring arrays comes close to requiring a full time virtual support vessel. Emergency maintenance needs and support of new instrument packages could fill in the remaining uncommitted days of a full-time support vessel. Thus, this estimate, which is in agreement with the estimate in the recent NRC report on the implementation of a network of ocean observatories, can be considered a lower bound.

Scientists will also require UNOLS vessels to conduct research within the coastal observatories. A composite list of characteristics compiled by participants in several regional coastal observatory meetings would include:

- Shallow water operation to a depth of 10 m
- 24 hour operations staffed by marine technicians
- Sustained operations for several days
- Standard sensor suites on board for meteorology, ADCP, CTD, bio-optics, acoustic mapping
- Broad bandwidth communications to
    - a) access onshore computers for observatory datasets and websites
    - b) send data back to shore in real time
    - c) communicate with other ships in collaborative experiments
- Computer lab
- Electronics shop
- Wet lab with ability to pump in seawater

- Deckspace for portable lab van
- Towing capabilities (including outside the wake on both sides) for undulators, towbodies and nets.
- Ability to deploy and recover autonomous vehicles, including
    - a) short-term (several hours) propeller-driven AUVs
    - b) mission-duration (or longer) glider AUVs
    - c) small autonomous aircraft once away from the nearshore airspace
- Mooring servicing for
    - a) atmosphere/ocean physical/bio-optical moorings (at least four 2-m diameter moorings per trip)
    - b) HF radar transmitter buoys
- Near bottom operations facilitated by dynamic positioning, including
    - a) deployment and recovery of bottom tripods and landers
    - b) deployment and recovery of new instruments on cabled observatory nodes with ROVs
    - c) use of ROVs for bottom sampling
- Acoustically as quiet as possible
- Ice capable for Arctic coastal waters

It must be recognized that not every mid-size vessel will be able to meet all of these desired characteristics, and that some specialization will be inevitable.

How many midsize vessels will be required in the future depends on how, and therefore where, they will be used. It is widely recognized that coastal priorities differ by region. Since the list of requirements is quite long, it is fully expected that some specialization in vessel design will be required. Vessels built for one region may not have the desired scientific capabilities or operational characteristics of vessels built for another region. There also is a tradeoff between the multiple shorter duration missions expected in an observatory setting and the transit time between staging facilities. Typical mission durations are expected to be in the 2-14 day range, and effective use of the vessel will require total mission durations to exceed the total transit times. The availability of multiple on-shore staging areas for each vessel will help reduce transit times. Vessel mounted cranes fully capable of loading and unloading the ship will facilitate transfers at docks outside of the home port. Thus, during different legs of the same cruise, the scientific crew may change, while the boat crew remains the same.

As the number of coordinated interdisciplinary experiments within observatories increases, it can be expected that there will be multiple demands for vessels during peak periods. Examples include peak spring discharge from estuaries or summertime low dissolved oxygen episodes. Experiments will attract a diverse group of scientists and will require multiple vessels with different capabilities operating in a coordinated manner in the same region. The real-time datasets available from observatories will further the need for rapid response to events. The usual method of scheduling a UNOLS vessel about a year in advance virtually excludes the UNOLS fleet from rapid response activities. It has been recommended by members of the scientific community that new methods to address this need should be examined, as is also discussed in Section 3.2. It is well understood that having a UNOLS vessel tied up at the dock waiting for an event is an inefficient way to operate. One suggested alternative was that additional funds could be run through the UNOLS system to hire approved private vessels that would be available for rapid response activities.

With this background, the following is a first cut at 10 regions for deployment of a UNOLS fleet of mid-size vessels that would be a mix of small Regional Class and large Local Class ships:

Gulf of Maine
Middle Atlantic bight
South Atlantic bight
Gulf of Mexico
Southern California
Central California
Pacific Northwest
Gulf of Alaska
Bering & Arctic Seas
Hawaii
Great Lakes

The last of these may require placing a larger (small Regional Class) vessel in the Great Lakes than has been available in the past. This list can be expected to change in parallel with the still evolving plans for regional coastal observatories and observing systems.

Coastal AUV/ROV Needs

Long-duration glider-type AUVs will likely bear the brunt of the monitoring tasks required by the coastal networks. Glider designs are currently targeted at year or greater mission durations in deep water and month or greater durations in shallow. The cross-over point between designs occurs at depths between 70-100 m. The shallow water gliders use some of their power to improve maneuverability in shallow water, resulting in shorter deployments. The shorter coastal deployments, however, are consistent with the shorter bio-fouling time in coastal environments, which can often compromise unprotected sensors on time scales of about a month. Coastal gliders likely will be operated as regional fleets using satellite maps and HF radar current maps to maximize the effectiveness of their flight patterns. Quite likely, a national network of regional glider operators will evolve to match the national network of regional HF radar systems to which they are linked. The national HF radar network will likely be organized into about twelve regional groups each operating about six HF radars. Assuming the same structure for coastal gliders, about twelve regional groups will have about six gliders deployed at any given time. Experience has shown that to maintain year-round operations on a sensor platform with one month turnarounds, a total of three redundant systems are desired. One system is deployed and in use, a second on-deck system is being readied for deployment, and the third system is undergoing long-term maintenance including sensor manufacturer recalibrations or upgrades that often require over one month to complete. Coastal gliders are usually deployed and recovered nearshore from small, fast chase boats, so little impact by the operational glider fleet is expected on the UNOLS fleet of regional-class vessels. The greatest potential for interaction is for UNOLS vessels to be able to deploy and recover additional coastal gliders during scientific experiments to locally enhance the operational network. To accomplish this, a small, fast chase boat aboard the regional class vessels will be the main requirement. Overall, the impact of coastal gliders on UNOLS facilities is not large.

Propeller-driven AUVs are also expected to be part of the coastal observation network, but their shorter flight durations, typically measured in hours, currently limit their use for continuous year-round operations to the inner shelf. One already implemented scenario is that the propeller driven AUVs will be deployed from piers with easy access to the open ocean. Propeller-driven AUVs typically do not surface and therefore rely on underwater acoustic networks for precise navigation. The AUVs may conduct surveys within the navigation network, or upon leaving it for an extended range mission, dead reckon their way back to an insonified target region. It is envisioned that in the future, subsurface docking stations will be developed and deployed to extend the regions in which propeller-driven AUVs will be used for continuous subsurface monitoring. Until then, the most likely widespread use of propeller-driven AUVs is to extend spatial sampling coverage for campaign-based science programs. Some large AUVs will require cranes to deploy and recover, and are often operated with a standby ship following the AUV for their short-duration missions. While this does little to increase the horizontal spatial sampling capabilities of a UNOLS science vessel, it can provide a more stable subsurface platform or a better near bottom following capability. Fleets of smaller, less expensive AUVs will likely be more useful in extending the spatial sampling capability of a UNOLS vessel. Fleets of small AUVs are already regularly deployed from small coastal vessels during scientific experiments, and could be operated from UNOLS vessels similar to the fleets of glider-type AUVs. In addition to the small, fast chase vessel previously mentioned, augmenting the UNOLS regional-class ships with an acoustic navigation system that can be easily deployed or mounted on the vessel will provide a larger target region for the AUVs, facilitating their survey missions and recovery.

ROVs that are controlled from a surface ship and operated on a tether are rare but not absent from coastal applications. This is partly because in the nearshore, ROV capabilities often can be provided less expensively by dive teams. Thus, ROV needs that do develop are expected to be concentrated on outer shelf applications in waters beyond diver depths. Some of these outer shelf applications will support specific science experiments on traditional shipboard cruises. A more widespread application expected to develop is operations and maintenance for cabled observatory nodes deployed on the outer shelf. At present, all cabled observatories are either inner shelf systems serviced by divers or deepwater systems serviced by ROVs from large UNOLS vessels. Even though the MARS cabled observatory currently under development is deepwater, it is deployed in a nearshore canyon, thereby providing a typical estimate of servicing requirements for the deeper coastal cabled observatories. MBARI engineers estimate that the single MARS node will require about 25 ROV days per year for operations and maintenance. Coastal cabled observatory nodes deployed beyond diver depths will likely require similar levels of ROV support. At present, there is no definite number of proposed shelf cabled observatory nodes, but a rough estimate for the east coast is four outer shelf nodes, requiring about 100 ROV days per year for operations and maintenance. The planned NEPTUNE system has always included a coastal component, but the number of coastal nodes and their locations is not well defined. These coastal nodes will likely be beyond diver depth since the envisioned plan is to run spur cables from the main trunk line from deepwater up onto the shelf. Overall, ROV needs for coastal observatories will amount to about 0.5 ROV per year. This could be an academic deep water vehicle operating at lesser depths, but given the diversity of capable shallow water ROVs that are available in industry, there are alternative contracting avenues that should be explored.

Aircraft Needs

Research aircraft, both manned and autonomous, will contribute to the missions of the planned coastal observatories in several ways. Repeat flights can provide time-series mapping of properties of the coastal ocean, shoreline and atmosphere that are not easily measured from other platforms – past examples have included aerial surveys for shoreline evolution, beach topography, reef changes, kelp-forest monitoring and whale/bird mappings. Aerial mapping will also augment process studies conducted in association with observatories, providing rapid synoptic regional mapping of physical properties, including sea surface temperature and salinity, wind fields, and ocean optical properties at higher space and time resolution than is available by satellite. Air-deployable in situ mapping instruments, such as AXBTs and surface drifters, can be placed synoptically for more accurate nowcasts and for assimilation into ocean models. Finally, aircraft can be quickly mobilized to investigate rapidly evolving coastal events, such as harmful algal blooms, storm response, or coastal runoff events.

In recognition of the role that aircraft can play in ocean observation, UNOLS has formed the Scientific Committee on Oceanographic Airborne Research (SCOAR), a new standing committee to provide advice on aircraft use. Other agencies (e.g. NCAR, NOAA/Florida, Department of Energy) and universities (e.g. U.Wyoming, South Dakota School of Mines, U. Washington) which operate research aircraft might wish to benefit from participation in SCOAR.

UNOLS also has designated the Center for Interdisciplinary Remotely-Piloted Aircraft Studies (CIRPAS) at the Naval Postgraduate School in Monterey, CA. to be a national facility. CIRPAS operates a DeHavilland Twin Otter for offshore survey work and a long-endurance modified single-engine Cessna 337 Skymaster called Pelican. In addition, CIRPAS operates several remotely piloted aircraft or UAVs, including Pelican II, Predator, and Altus 1, but their high operating cost is an obstacle to wide research use. A second, comparable facility serving both the East and Gulf coast observing systems would be desirable. Significant East/Gulf coast aircraft research facilities are already located in Tampa, Florida associated with the East Coast Center for Environmental Research and Aircraft Studies, and in Raleigh-Durham International Airport associated with the University of North Carolina. Alaska would be a third candidate for a national aircraft facility to provide research aircraft for multiple coastal observatories.

Additional flexibility can be gained by using aircraft leased for specific campaigns, although FAA certification issues may restrict these to “public use” craft. Portable suites of measurement and data acquisition instrumentation should be developed for installation on such aircraft. International groups have also expressed interest in flying their sensors within US coastal observatories if a host aircraft could be identified. The national facilities should play a role in designing, testing and providing these roving packages.

3.7 Fleet Renewal and Ocean Observatories

At present, UNOLS fleet renewal planning is focussed on four types of ships for which information is publicly available on the UNOLS website (http://www.unols.org):

Ocean Class Vessel
Regional Class Vessel
Global Class Vessel with Seismic Capabilities
Alaska Regional Research Vessel (ARRV)

Science Mission Requirements (SMRs) have been released for all four of these vessel types, and the ARRV has progressed to preliminary design. For deep ocean observatories, the capabilities of the Ocean Class vessels and the ARRV will be compared with ocean observatory requirements, while the Regional Class vessel capabilities will be compared to coastal observatory needs. The seismic vessel is intended to be a purchase/conversion rather than new construction, and the associated SMR focusses heavily on the special purpose seismic application for which it is intended. This vessel will not be further considered.

In Section 3.4, deep water ocean observatory vessel needs were described. Critical issues that are common to both the global buoyed and regional cabled observatory requirements are for doubling the open deckspace that exists on the AGOR-23 vessels (5000-6000 sq ft as a goal), providing a heavier lift and deck handling capability than exists in the current oceanographic fleet, and improved sea keeping ability to at least SS5, and preferably to higher sea states. Provision of much larger, sea-accessible hold space to carry fiber optic cable for short (order 100 km) lays was also recommended. The proposed Ocean Class vessels do not fill any of these needs very well. The proposed aft deckspace is only 1500-2000 sq ft, which will preclude many of the operations described in Sections 2 and 3.4. This is especially true if ROV control and tool vans have to be carried on the fantail, as the residual deckspace would then be very limited to nonexistent. Both the cranes and winches specified for the Ocean Class vessels are similar to current oceanographic practice, and hence not suitable for heavier lift operations. The size of the Ocean Class vessels (nominal 200' LOA) is not commensurate with the hold space required for cable lay. Finally, although the Ocean Class SMR calls for sea keeping to SS5 and dynamic positioning in SS5 with 35 knots of wind and 2 knots of current, it is likely that these goals will have to be relaxed as the user requirements are translated into a concept design given the limited size of the vessels. Overall, the Ocean Class vessels will find only limited utility for deep water ocean observatory operations envisioned in the OOI. Presuming they have adequate DP capability, they will be useful for science instrument installation, servicing, and recovery operations at global buoyed or regional cabled observatories. They may be suitable for limited installation and servicing of the global buoys, although probably not for the large spar buoys which constitute up to half of the installations. They may be usable for regional cabled observatory O&M if the nodes are plugged into the backbone cable, but will lack the lift and handling capability (and deckspace) to recover a node hardwired to the backbone. The size class and characteristics of the ARRV are very similar to those of the Ocean Class, and hence suitability for ocean observatory operations is likely to be as limited.

It is strongly recommended that fleet renewal planning carefully examine the needs of deep water ocean observatories. While many short term needs can probably be met by the existing four general purpose Global Class vessels, perhaps augmented by commercial contracts, the near term retirement of two of these vessels will clearly lead to a major problem for the oceanographic community. Fleet renewal planning needs to consider requirements for vessels larger than the current Global Class with relatively more ship resources devoted to deck operations as compared to laboratory spaces, with enhanced heavy lift capability, and with substantially better sea keeping ability. An SMR for such a vessel should be written as a preliminary step in the near future.

The situation with respect to the Regional Class vessels is much more favorable for coastal observatories, which largely reflects the general purpose rather than specialized nature of the required operations. These vessels are very suitable for the purposes described in Section 3.6. However, it is recommended that review of the SMR by the coastal observatory community be actively sought so that requisite fine tuning of the requirements can be accomplished before the design cycle is continued.

4. Findings and Recommendations

4.1 Findings

General Issue

The UNOLS committee structure and makeup does not adequately incorporate ocean observatory expertise. This has resulted in lack of awareness of ocean observatory requirements in some planning activities, and could result in costly mistakes if not remedied.

Ship Usage and Scheduling

The ship time requirements for OOI installation on UNOLS Global Class vessels will be significant. For the deep water component, the requirement for one time installation of the global buoyed and regional cabled components amounts to about 480 days of Global Class shiptime, an additional 300 days of contracted heavy lift vessel time, and 75 days of cable lay vessel time. About 75% of the UNOLS ship days will include the use of a deep ROV. For the coastal component, the requirement is for 150 days of regional to intermediate class shiptime and an additional 7 days of contracted cableship time.

The ship time requirements for annual O&M of the OOI global buoy systems using UNOLS Global Class vessels will approach two ship-years per year. If all O&M operations could be carried out using UNOLS vessels, the requirement is for 600 ship-days per year, or about 1/2 of the available general purpose (i.e., excluding *Atlantis* and *Ewing*) Global Class shiptime. About 75% of the UNOLS ship days will include the use of a deep ROV. However, some of the high latitude O&M may be better carried out under commercial charter, somewhat mitigating the impact on UNOLS facilities.

The ship time requirements for annual O&M of the OOI regional cabled observatory using UNOLS Global Class vessels will be about 1/4 that of the global buoyed systems. About 150 ship-days per year with ROV will be required for infrastructure maintenance and instrument installation and recovery, with O&M of the backbone cable and systems handled by a commercial cableship through membership in a cable industry consortium. Significant cost savings may be achieved through accepting a reduced repair priority compared to commercial cable owners.

The impact of OOI Global Class ship demand will increase with the retirement of two of four general purpose vessels in the next decade. *Knorr* and *Melville* are approximately 2/3 of the way through their life cycle at present, and no replacement Global Class vessels are in the fleet renewal plan for the next two decades.

The ship time requirements for annual O&M of the OOI coastal observatories will require one virtual ship per year, although this estimate is more uncertain than for deep water operations. This is primarily for maintenance of buoys, and will be spread out among a comparatively large number of Regional to Intermediate Class vessels, so will not have a large impact on UNOLS facilities.

The ship time requirement estimates for O&M of all OOI components are sensitive to the reliability of the ocean observatory infrastructure. Initial investment in high reliability design and fabrication could have a long term payoff in reduced O&M costs.

The ship time requirements for O&M of all OOI components will be higher during the initial commissioning (i.e., 1-2 years post-installation) phase. Even with high reliability design practices, residual problems are inevitable with systems as complex as ocean observatories.

OOI global buoy O&M has limited schedule flexibility due to finite battery and/or fuel resources, while regional cabled observatory O&M is constrained by a spring to fall weather window for UNOLS vessel operations. These factors will impose a strong constraint on UNOLS Global Class ship scheduling.

Ocean observatory operations are not as predictable as more traditional mapping and sampling activities, and hence will require increased ship scheduling contingency allowance and improved contingency handling. For single cruises, in some instances activities may finish early with little to be gained by remaining on station, while in other cases extra shiptime may be required to complete operations due to unforeseen occurrences. Emergency repair requirements will also impose the need for more rapid response than is possible under existing UNOLS ship scheduling procedures to avoid large amounts of observatory downtime.

Mapping

The suite of deep water mapping tools available within the UNOLS and academic communities is adequate to fulfill near term ocean observatory regional context mapping requirements. Seven deep water UNOLS vessels are equipped with modern multibeam survey systems adequate for this purpose.

The UNOLS fleet has limited mapping assets for shallow to intermediate depths at fine resolution. Only two UNOLS deep water vessels and one UNOLS coastal vessel are equipped with state-of-the-art mapping systems for high resolution mapping.

Cable route and burial assessment surveys are best contracted out to industry when required. This specialized mapping and geotechnical survey work will occur relatively infrequently, requires a thorough understanding of cable installation practices, and carries legal liability issues, making commercial contracts especially attractive.

Deep water observatory site selection will require much higher spatial resolution than is current commercial practice, and must be carried out using near bottom sensors. Academic AUVs, ROVs, or deep towed sonar systems are suitable for this purpose.

Deep Water Vessel Operations

The large global buoys will require the development of an at-sea refueling capability for the Global Class UNOLS vessels. This carries buoy design and minor vessel modification issues along with ship's officer licensing requirements and potential oil spill liability concerns.

The Global Class UNOLS vessels are optimized for fuel economy, cruise duration, large shipboard parties, extensive lab space, and limited over-the-fantail operations. These characteristics are often the opposite to what will be required for ocean observatory operations. In particular, the deckspace and heavy lift capability of these ships are very limiting for the installation and maintenance of large buoys or submarine cable systems.

Fitting the AGOR-23 class vessels with a second bow thruster at mid-life refit could open the working sea state to SS5 or more, and would significantly enhance their utility for ocean observatory operations. At present, these ships DP with difficulty above SS4, especially if the sea and wind are not coincident. Enhancement could be achieved either with a tunnel thruster or a second steerable bow thruster.

Fitting all of the Global Class vessels with redundant DP systems will improve their usefulness for ocean observatory operations. This is especially important for some critical operations, such as buoy refueling, where DP failure could be catastrophic.

Shrouding the z-drives on the AGOR-23 class vessels will improve DP efficiency and reduce the risk of cable entanglement during over-the-side operations. The penalty is a slight reduction in underway speed and a small increase in fuel consumption.

A substantial increase in deckspace for the AGOR-23 class is required for many deep water ocean observatory operations, and could most easily be facilitated by lengthening the vessels at mid-life refit. The addition of 50' to the hull would double the open fantail area, and offers the possibility of increased scientific hold space and improvements to ballasting and trim.

Doubling the A-frame capacity with concomitant increases in winch, cable, and crane capacity for the Global Class vessels would improve their lift capability and facilitate many ocean observatory operations. This level of change appears to be consistent with deck load limits.

A below-deck fiber optic traction winch would simplify ROV operations on Global Class vessels. The use of a deck-mounted traction winch reduces available fantail deckspace considerably, making many ocean observatory operations difficult.

Heavy lift operations from UNOLS vessels will require specially trained and qualified crew members to handle most deck evolutions. The traditional UNOLS model in which the science party handles most over-the-side operations carries significant safety risks with heavy loads.

A long-term contract with the globally-distributed submarine cable servicing industry for heavy lift installation and maintenance of the OOI global buoy systems could signifi-

cantly reduce the scheduling and demand impact on the UNOLS Global Class ships and enhance the scientific output from the buoy systems. Global pre-positioning of heavy lift vessels will reduce mobilization/demobilization costs and improve response times to failures.

As an alternative, one or more heavy lift vessels could be acquired into the UNOLS fleet to carry out OOI global buoy and some submarine cable operations at sea. This option is especially favorable at present due to overbuilding in the offshore supply and submarine telecommunications sectors.

Deep Submergence

ROVs will usually be preferred over manned submersibles for ocean observatory operations due to their enhanced bottom time and human safety concerns. Experience with existing ocean observatories indicates that many operations require days, and the presence of extensive seafloor cables and water column moorings produces an entanglement risk.

AUVs are not presently part of any UNOLS facility, but will be an important standard tool at ocean observatories. It is likely that AUVs will be the responsibility of ocean observatory operators.

Commercial ROVs capable of operation below 3000 m are very limited in number, and this situation is unlikely to change in the near future. Most deep water ROV operations will continue to rely on academic vehicles.

The capabilities of current generation academic ROVs such as Jason II are highly compatible with ocean observatory operations. Their continuing development will naturally occur in tandem with evolving ocean observatory requirements.

Some infrastructure and community instrument servicing tasks could be carried out under industrial contract if this proves cost effective. Once procedures are developed, these tasks will become routine.

New instrument development and installation at ocean observatories will continue to require close interaction between the scientist/engineer and the operators of ROV facilities. This argues strongly for an operating model similar to the existing NDSF one.

Three additional academic ROVs will be required by 2010 to support ocean observatory operations and sustain or enhance traditional ocean science vehicle demand. ROVs must become a standard rather than a specialized tool for ocean observatory operations.

Coastal Observatories

The increasing presence of coastal observatories will enhance rather than decrease the demand for ship-time. Scientists will optimize and target their sampling strategies based on models and observations from coastal observatories. Most of this time can be met by existing and planned Local to Regional Class vessels.

A rapid response capability needs to be developed to enable reaction to coastal events. The present ship scheduling process does not meet this requirement.

ROVs will be needed for outer continental shelf coastal observatories, but shallower installations will continue to be supported by dive teams. Numerous commercial ROVs are available that are suitable for this purpose, although few are run by UNOLS institutions.

Aircraft will be an important auxiliary, coordinated observing platform for coastal observatory science. This is especially true for rapid response.

Fleet Renewal

The proposed Ocean Class vessels and the ARRV do not fulfill deep water ocean observatory needs. Their size (~200') limits the available deckspace, lifting capability, and sea keeping ability below that which will be required for many ocean observatory infrastructure operations. However, they may be suitable for instrument installation and servicing providing an ROV can be supported without occupying most of the fantail.

The Fleet Renewal process needs to consider the construction or acquisition of vessels larger than the current Global Class size. At present, there are no plans for vessel construction larger than the Ocean Class.

Future ship planning should explicitly consider ROV operations as a standard ship mission. Below-deck fiber optic traction winches and ROV control stations inside the ship will enhance operating ability and free up deckspace for over-the-side operations.

The proposed Regional Class vessels are well-suited for coastal observatory operations. Their size and capabilities mesh well with projected needs.

4.2 Recommendations

UNOLS should consider establishing a standing committee on ocean observatories that is cross-cutting with existing UNOLS committees, or ensure that existing committees include members with expertise on ocean observatories. The present planning process has not explicitly considered ocean observatory needs in many instances, and will lead to serious and growing future disconnects if not remedied.

The UNOLS ship schedulers and operators should consider ways of increasing scheduling flexibility to support future ocean observatory operations and report to UNOLS on the issues and requirements. This might include banking a number of days of contingency time at the start of a scheduling year and adding/extracting from the bank as the year evolves. Operational considerations also need to be evaluated.

UNOLS and NSF should consider ways of enhancing the fleet shallow to mid-depth, high resolution mapping capability. Present capabilities are projected to be inadequate to meet ocean observatory demand.

The vessel and licensing requirements for at-sea buoy refueling should be investigated before the large DEOS buoy design process is initiated. This will require naval architect evaluation, a cost estimate, and Coast Guard review.

Mid-life refit of the AGOR-23 class should explicitly consider ocean observatory needs, including enhanced seakeeping through bow thruster improvement, z-drive shrouding, and vessel lengthening. All of these issues will require naval architect review for both engineering and economic feasibility.

Upgrading of all Global Class vessels to redundant DP should be considered. The cost impact is relatively small and there are no naval architecture issues.

Doubling of the heavy lift capability of the UNOLS Global Class vessels through A-frame, winch, wire, and crane enhancements should be evaluated. This will require naval architect review and a cost estimate.

All Global Class vessels should be equipped with a below-deck fiber optic traction winch so that ROV and other deck operations can be carried out efficiently. At present, only *Revelle* and *Atlantis* are fitted with this equipment.

UNOLS should consider the training and qualification requirements, including legal issues, associated with heavy lift deck operations carried out by ship's crew members rather than the scientific party. Science planning will need to incorporate a new way of operating on board ship.

The feasibility and cost of contracting with a submarine cable maintenance company for global buoy installation and maintenance should be further investigated. This mode of operation offers significant logistical advantages, but execution and economics are not evaluated sufficiently well to establish feasibility.

The feasibility of acquiring one or more heavy lift vessels into the UNOLS fleet to support future ocean observatory operations should be further evaluated. The current marketplace for these vessels is very favorable to buyers at present.

UNOLS and NSF need to increase the academic deep ROV fleet by three vehicles over the next 5-7 years to support ocean observatories and traditional ocean science. In particular, operating models (i.e., single centralized operator vs dispersed operators) will have to be evaluated for cost and efficiency.

Ten additional small Regional to large Local Class vessels are needed to provide support both for coastal observatory and traditional coastal science. These should be distributed along the east and west coasts, including Alaska.

The UNOLS Fleet Renewal process should develop a Science Mission Requirement for a class of vessel larger than the present Global Class to support ocean observatory and other

heavy lift needs. The present fleet renewal plan does not consider vessels that are suitable for many deep water ocean observatory operations.

All UNOLS Fleet Renewal planning should explicitly include ROVs as a standard shipboard tool and incorporate space to support them in ship designs. The present “fly-away” model will be increasingly difficult to operate under in the future, as it limits available deckspace.

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