Critical opportunities for technologically advanced shipboard oceanography in the next 3-5 years

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Introduction

On August 19-20, 2014, Schmidt Ocean Institute convened an interdisciplinary focus group of 25 international experts in ocean sciences, technologies, and scientific marine operations. Participants from Australia, Canada, China, and United States discussed and articulated critical directions and opportunities for technologically advanced shipboard oceanography in the next 3-5 years.

The workshop objectives were to generate new insights into the sources and nature of the societal needs that ocean sciences and marine technologies will be addressing in the next decade. The discussions included topics such as research infrastructure, innovative technological capabilities that will continue to accelerate the pace of ocean sciences, and critical research directions and opportunities for advanced exploratory shipboard oceanography.

Throughout the two day workshop, a series of keynote addresses and breakout discussions centered around three discussion areas, which were:

1. What new and emerging societal needs will shipboard oceanography be addressing in the next 3-10 years?
2. What major changes will ocean science be experiencing in the next 3-5 years due to continued technological innovation?
3. What critical research and exploration will technologically innovative ship-based oceanography enable in the next 3-5 years?

Each discussion area was led by keynote addresses, followed by breakout discussions centered around interdisciplinary topics associated with each of the discussion topics, and finally, contained a chance for each breakout session to “report” back on their discussion.

New and emerging societal needs that shipboard oceanography will be addressing in the next decade

This session focused on the societal needs that could be addressed by shipboard oceanography. While a broad range of needs could have been addressed, the session focused on three key themes, Climate and Environmental Change, Marine Pollution with an emphasis on the emerging theme of marine plastics, and Polar Oceanography. All three themes presented a range of opportunities for shipboard oceanography. Schmidt Ocean Institute is well equipped to tackle some of these issues, and it was recognized that there is also opportunity for Schmidt Ocean Institute to build capability in other areas (e.g Polar Oceanography), if desired.

Oceans and Global Climate Change - Prof. Malcolm McCulloch, The University of Western Australia

Professor Malcolm McCulloch presented the challenges associated with understanding the ocean and its global challenges. Key points from the presentation were:

- The ocean plays a key role in serving as a sink for heat and CO_2 on Earth, which comes at a cost in the form of increased sea level, higher temperatures, and ocean acidification.
- There is an urgent need to understand the causes of the hiatus in global warming and better predict future warming, including:
    - the interactions between the El Nino Southern Oscillation (La Nina and El Nino) and the Interdecadal Pacific Oscillation (Pacific Decadal Oscillation), and
    - the role of deep ocean interactions on centennial and millennial timescales
- The Antarctic plays a critical role in climate, particularly with respect to:
    - instability of grounded ice-sheets and rapid (catastrophic) rise in sea levels,
    - deep-water formation, and
    - global impacts
- Another challenge to understanding global climate change is addressing the role of the deep-ocean circulation of the Southern Ocean
- The response of marine biota (especially shallow water corals) to global climate change and ocean acidification is a key component of how the ocean helps regulate rising temperatures and CO_2.
    - What is the inherent resilience versus finite ability to adapt to rapid change in shallow water corals?

Marine Pollution with a focus on Plastics - Julia Reisser, University of Western Australia

Ms. Julia Reisser presented on the topic of marine pollution, focusing on plastics and ideas for how shipboard oceanography can help advance the understanding of marine plastic sources, distribution, and impact. Key points from the presentation were:

- One of the big unknowns related to marine plastic research is the amount of plastic currently located at the sea surface, throughout the water column, and seafloor, and how it impacts the marine food chain. Conducting an efficient 3D survey could yield a greater understanding of the spatial distribution of plastic debris and its pollutant loads.
- Polymers , such as marine plastics, have unique infrared signatures and the development of a sensor capable of detecting ocean plastic is something worth exploring.
- A 3D survey would also provide the opportunity to study plastic inhabitants. Data suggest that marine hydrocarbon-degrading microorganisms are abundant in some pieces of ocean plastics. Perhaps, by using metagenomics researchers could screen for hydrocarbon-degrading genes in biofilms of polymers collected at different marine regions. This type of research could lead to biotechnological solutions for better waste management practices on land (polymer biodegradation).
- There is no drifter data in the Indonesian Throughflow area. Deploying shallow-water drifters in SE Asia (e.g Indonesia) could enhance the understanding of ocean connectivity, improving the ability to pinpoint plastic pollution sources.
- At-sea feeding experiments could be an interesting and a more realistic method to better understand the feeding relationships between zooplankton and plastic debris. This could also provide a powerful tool for better visualizing such interactions (e.g. high quality films of these feeding activities).

Polar Oceanography - Dr. Phil McGillivary, United States Coast Guard

Dr. Phil McGillivary presented on the challenges and opportunities for polar oceanography in a warming world and the technologies that will enable future polar research. Key points from the presentation were:

- An increased use of Unmanned Aircraft Systems (UAS) from ships and Autonomous Surface Vessels (ASVs) with persistent re-powering by either laser or microwave systems should be encouraged. For example, laser systems are already available using commercial-off-the-shelf parts (http://www.lasermotive.com) and there is also a microwave system test planned for fall 2014 (http://www.escapedynamics.com).
- The use of small, low cost, low energy meta-material LEDs for underwater high bandwidth communications (600-700 MB/sec) should also be incorporated. Demonstrations are planned for late 2014/early 2015, which will enable high bandwidth data collection and data transfer from Autonomous Underwater Vehicles (AUVs) to ASVs and also to UASs.

- Construction of new research vessels based around cloud computer systems (also known as Software Defined Networking systems) will enable multi-ship, and multi-autonomous component control and ready reconfiguration.
- There is a need for an AUV "pickup truck" to go considerable distances under the ice to deploy and recover sensor systems.

Breakout Session 1: Climate Change - Summary of Discussion:

- There is a need for higher resolution observations both vertically (deep ocean), horizontally (particularly in remote areas), and temporally.
- Observations of any kind in the deep ocean will be helpful, as data collection is lacking.
- In the coastal ocean, higher density of observations would lead to higher resolution models that could be of immediate use to (coastal) communities.
- A higher temporal and spatial resolution of ocean data could be achieved with the development of lower cost sensors that can make measurements regularly as part of an ongoing science program. In addition, R/V Falkor could make a major contribution to extant ocean observing programs by committing to deploying existing instrumentation such as drifters, ARGO floats, BIO ARGO floats, etc. on a regular basis.
- There is a need for dedicated funding for mining data that already exists and making the data available, so that researchers have the opportunity to detect change from data that was collected in the past.
- Oceanography research should also focus on specific locations that are under stress, such as the poles, Oxygen Minimum Zones, and the East Australian Current region (western boundary current warming).
- There is a need to establish baseline monitoring of undisturbed regions, in real-time. It is difficult for scientists to receive funding for monitoring regions that are not already threatened. There may be opportunities for Schmidt Ocean Institute to contribute, but real-time monitoring needs to occur in more than locations that are in distress. Studies of pristine locations that are not yet in distress, should be used to establish baselines for the more distressed regions.
- R/V Falkor could make routine calibration measurements in the vicinity of previously deployed autonomous sensors, (e.g Bio-argo floats) to calibrate the less robust data. If the vessel is used as a mobile platform, less robust sensors (and the resulting data) can be made valuable. Scientists need help with outreach tools to increase public confidence in the scientific knowledge on climate change.

Breakout Session 2: Fisheries/Sustenance - Summary of Discussion:

- Because there are a number of existing fisheries programs, Schmidt Ocean Institute can facilitate other programs through connections and/or partnerships instead of starting a new initiative. This will reduce the complexity for scientists by creating a bridge and augmenting some of the government research with Non-Governmental Organization (NGO) research.
- Examples of sensors that need to be further developed are sensors for studying the climatic effect of parasites and tracking fish moving into new habitats.

- Technologies also need to be improved for studying Harmful Algal Blooms and their effect on fisheries, including ciguatera poisoning and its relation to ocean warming.
- Although recent effort has been put into investigating, monitoring, and developing measurement systems and sampling with autonomous systems for marine pollution and radiation, background data for comparison is still lacking.
- Sensor technology could also be developed to better understand the 3D structure of plastics in the ocean.
- Overall, fishery research needs more adaptive sampling because of the movement of living marine resources; researchers and technology developers need to be adaptive and flexible.

Breakout Session 3: Ocean Acidification / Ocean Health - Summary of Discussion:

- A long time series of Ocean Acidification data doesn't exist, particularly in deep water. While a Remotely Operated Vehicle (ROV) could be helpful in collecting a longer dataset, Schmidt Ocean Institute could serve as a coordinator for leveraging a larger data collection program, in efforts to maintain continuity. The organization should also recognize the need to make repetitive measurements of high value information and maintain the data collection capability of the vessel, whether on a research cruise or transiting.
- There is a need for new sensors to be developed that can more holistically measure Ocean Acidification properties, such as Total Alkalinity, and/or pCO_2.
- Schmidt Ocean Institute could serve as a coordinator between other groups by connecting countries and organizations to create a larger Ocean Acidification research/monitoring program. The European Project on Ocean Acidification, is an expired example of such coordination (http://www.epoca-project.eu, the project ended in 2012).
- The ability to have internal science support and to be flexible (in order to respond to environmental events, disasters, etc.) are key aspects to any support/coordination model. As an example of this flexibility, transit voyages could be used to facilitate event-driven research. By allocating a bit of research sea time to Falkor transits, more opportunistic research could occur. Such agreements could be flexible enough to change research plans if something unexpected, worth investigating, happens close to Falkor's location.
- Transit voyages could also be an opportunist time to allocate research space to early career scientists; a successful example is the Commonwealth Scientific and Industrial Research Organisation (CSIRO)'s Next Wave program, which allows early career researchers to submit sea time proposals to conduct research while the R/V is underway.

What major changes will occur in ocean sciences in the next 3-5 years due to continued technology innovation?

This session focused on three unique ways to collect data in the ocean, via close range sensing (remote sensing) to collect fishery data, the use of robotic platforms such as AUVs and ROVs, and through the use of cabled network observatories. Although some challenges still exist, such as advancing the development of instruments and collecting data non-destructively, these platforms and future innovations have great potential for complementing shipboard data collection.

Remote Sensing - Dr. Euan Harvey, Curtin University

Dr. Euan Harvey discussed remote sensing from the perspective of using close range sensing to measure fish ecology. Key points from the presentation were:

- Many challenges exist for collecting fishery data remotely, such as:
    - Collecting data in a non-destructive, fishery independent way
    - Sampling in the deep ocean (shelf and slope)
    - Collecting data in the pelagic
    - The large cost associated with analysis inhibits uptake of data
- There are several opportunities for technological innovation, which would improve the way fishery data is collected, such as:
    - Improving Fine scale optical sampling
    - Increasing sample scale and resolution
    - Using multiple delivery tools (AUVS, ROVS, Baited cameras/Landers) to increase sampling depth
    - Using deployed equipment to collect multiple types of data
    - Investing in automated image analysis to decrease time of analysis

Instrument Robotic Platforms: Measurements in a Changing Environment - Dr. Luc Rainville, University of Washington

Dr. Luc Rainville discussed the challenges for sampling in remote areas, monitoring climate change and developing biogeochemical sensors for studying the integrated physical and ecological system. Key points from the presentation were:

- Autonomous vehicles can successfully sample across the broad range of space and time scales needed to resolve physical and biogeochemical processes.
- Technology development can be directly tied to science interests. Identification of important science questions where the lack of availability of observations impedes understanding, can yield development of new observing technologies and approaches.
- Calibration of sensors is critical. The community needs in-situ cross-calibration of biogeochemical sensors, but there is still a need for vessels; as lab calibration of sensors is insufficient.

- One challenge is that technology development requires integrated teams of interdisciplinary scientists and engineers with diverse skills and a tie to science interests to drive advances in complex problems. Cross-discipline collaboration, risk-taking and novel ideas should be encouraged and promoted.
- Another challenge is that many new expensive, 'proven' platforms have been developed, but access for use and sensor development and integration needs to be provided.
- Additionally, no single instrument resolves everything, so learning and teaching integrated science need to occur. What is the best way to learn and teach how to use the technology?
- Multi-platform programs and data synthesized from autonomous platforms, remote sensing, ship assets, etc. needs to be coordinated properly.

Cabled Ocean Observatories - Dr. Kate Moran, Ocean Networks Canada

Dr. Kate Moran discussed the underwater cabled ocean observatories already established and future plans for new systems. Key points from the presentation were:

- Cabled ocean observatories offer complementary observing in the deep sea, with sensors in the water column, on the ocean floor, cameras and hydrophone arrays constantly operating. These observatories create a data management system that can capture complex data in real-time and deliver it over the internet, which is then freely available and used around the world.
- Schmidt Ocean Institute partnered with Ocean Networks Canada to conduct a study of the marine dead zone off the coast of British Columbia, Canada. It was a cruise designed to specifically study water masses and map their characteristics. The newly collected data complemented the long term records of shipboard observations.
- The cabled ocean observatories that are established around the world promote various synergies by building upon sustained observations, enhancing scientific output, providing surveys at fixed sites, and leveraging scientific capacity by bringing together scientists across disciplines.

Breakout Session 1: Robotic Platforms - Summary of Discussion:

- There is a need to continue to ensure that robotic platforms are meeting user needs when considering system design. Articulating the requirements to help select/design platforms and multi-asset systems is important. For example, sometimes capabilities are designed that are beyond what the end users might expect/need. Expectations should also be managed with respect to the use of autonomous systems; i.e. vehicle capabilities should be clearly articulated.
- Demonstrating the scientific outcomes is often as, or more, important than technical validation of a platform. Nereus, for example, saw a large increase in proposals following its successful use as a scientific vehicle aboard R/V Falkor (shortly before loss of vehicle).
- Platform and System Capabilities to consider:

- Requirements for automation in data stream processing and the need for high computing power on board the R/V to allow for more adaptive sampling.
- Capabilities that are ideal for autonomous platforms routine monitoring and event response.
- Autonomous systems change the dynamics of vessel-usage, allowing scientists to maximize ship efficiency and time at sea. Power at sea, endurance, fast delivery to sites of interest, servicing at sea, and communications infrastructure are key characteristics that could change how users interact with platforms. There is potential for long-range, persistent systems.
- Sampling of biological processes requires innovation in sensing capabilities. Spatial and temporal variability is also high.
- Can models help to drive observing regimes? Can modellers and observationalists work more closely together to facilitate this?
- Researching the deep sea is a big challenge. Shallow water is also identified as a need – high energy, rugose terrain.

Breakout Session 2: Innovation in Sensing - Summary of Discussion:

- The adoption of advanced sensing capabilities has been somewhat disappointing (Secchi disks are still in use). Some institutions are focused on high-end needs while the practice is still languishing behind the 'Jetsons'.
- Challenges to advancing sensor development:
  - Platforms (AUVs and ROVs) for delivering sensors have more appeal than the sensors themselves. There are also differing views on the length of time to develop new sensors and see them through to maturity.
  - Breaking out of the lab and into the field is still a challenge. There are significant risks associated with field testing and the funding environment is problematic.
  - Linking science questions with the right engineering/technical people is also a concern. Cross-disciplinary groupings to foster innovation need to be encouraged.
  - The community and/or developers must decide on what needs to be sensed beyond simple physical parameters (temperature, salinity, etc.).
  - Educating a wider public and technical developers on the requirements necessary to support ocean sciences
- Ways that Schmidt Ocean Institute could contribute:
  - Provide a pool of platforms for testing sensors
  - Provide a pool of costly sensors that can be tested by the community
  - Provide an example of best-practices of combining multiple sensors and platforms in real-time to achieve true multidisciplinary ocean research outcomes
  - Focus Expressions of Interest on one theme and the evaluate all the types of technologies that could be brought to bear in an integrated fashion to advance the specific topic.

Breakout Session 3: Observation Networks - Summary of Discussion:

- What role could a research vessel, such as R/V Falkor play in deploying, maintaining, and recovering cabled observatories?
- Finding synergies between shipboard observations and other platforms is a role that Schmidt Ocean Institute could fill. However, these connections need to be nurtured and developed over time.
- Bio-acoustics may be an area of exploitation for cabled observatories.
- Citizen scientists may be able to assist with some analysis – however will this yield data suitable for scientifically relevant questions? How much of this could be automated?
- One challenge is providing data from sensor networks in a way that empowers a community to use data.

Critical research and exploration that technologically innovative ship-based oceanography will enable in the next 3-5 years

The overarching theme of the talks in this discussion group is that there is a need for technology to expand current spatial and temporal scales and the suite of measurements available. One of the most important roles that Schmidt Ocean Institute can play is as a facilitator in technology development to fill this need. As a NGO it is uniquely suited to work with industry and to coordinate internationally.

Biological Oceanography - Dr. David Karl, University of Hawaii

Dr. David Karl presented on the critical opportunities for biological oceanography from a scientific and sustainable perspective. Key points from the presentation were:

- The ocean as a changing habitat: marine life in the anthropocene
  - The ocean is in a state of rapid change including warming and enhanced stratification, changes in circulation and productivity, increased acidification and loss of oxygen, loss of biodiversity, increases in the number of invasions, and increased coastal erosion and pollution.
- Time space variability: controls and consequences
  - Without time series records, we are lost in the invisible present - a lack of a long-term perspective and context of the current observations or events.
  - Leading indicators of ecosystem change include wider swings in dynamics of key variables, slower return rates following perturbations, and shifts of variance towards lower frequencies.
- Ocean-omics: challenges and opportunities
  - Genomics, transcriptomics and proteomics, etc., are incredibly powerful new tools that can tell us who is out there, what they are doing and what they are genetically capable of doing.

Chemical Oceanography - Dr. Lyndon Llewellyn, Australian Institute of Marine Science

Dr. Lyndon Llewellyn presented his "wish list" of innovative technology to advance researching in the field of chemical and biogeochemical oceanography. Key points from the presentation were:

- Mother duck and ducklings analogy: R/V Falkor can serve as a central facility surrounded by other measurement or observational platforms that could extend their spatial reach.
- Ocean science needs to capitalize on innovation in consumer electronics to enable science. Examples of inexpensive measurement devices based off a mobile phone include a hand held microscope, hand held spectroscopy, USB powered sequencer and PCR machines, and cheap seawater pH sensors. These instruments can produce high quality data that could be adapted for use in flow through systems that would be great on a ship.

Geological Oceanography - Prof. Mike Coffin, University of Tasmania

Professor Mike Coffin presented on the Critical Research and Exploration that should continue to take place in the field of Geological Oceanography. Key points from the presentation were:

- A survey of geological oceanography yields active processes (tectonics/magmatism, hydrothermalism, and seismic oceanography) and paleoprocesses (environmental changes, cryosphere changes, sea level changes).
- R/V Falkor has a small subset of technology typically employed for geological oceanography studies. Considerably more geological oceanography research could be undertaken if R/V Falkor had a full suite of appropriate technology.
- Two highly promising areas for oceanographic research over the next decade are the International Quiet Ocean Experiment (http://phe.rockefeller.edu/docs/IQOE%20Oceanography.pdf), which will address ocean soundscapes and the effects of sound on marine life, and seismic oceanography, which enables structural studies of water masses over large geographic areas.
- New and developing technologies that would be useful for addressing outstanding geological oceanography questions include AUVs, drones (equipped with LIDAR, magnetometers, etc), gliders, geotags, and sensors (acoustic, biological, chemical, physical).

Physical Oceanography - Dr. Richard Brinkman, Australian Institute for Marine Science

Dr. Richard Brinkman presented on the role of localized turbulence and mixing in the global ocean and the sub-mesoscale processes and shelf ecosystem response. Key points from the presentation were:

- Small scale features in the ocean have the ability to have a large effect, i.e. ocean circulation is primarily forced at the large (basin) scales but is dampened and dissipated at much smaller scales.
- A high priority research question is to find the cause of the missing heat and the mechanisms for trapping and releasing heat from the deep ocean.
- Leveraging ocean observations through integration with numerical simulation models, anchoring process studies to long term observational sites, and designing/evaluating the impact of observation systems are needs in physical oceanography.

Breakout session 1: High-resolution data collection - Summary of Discussion:

- Monitoring the whole ecosystem is important, i.e. increasing the spatial extent and increasing the number of platforms. Cross-disciplinary and interdisciplinary research is also an important aspect, which often requires a 'question driven' rather than 'PI driven' approach.
- Power supply is the ultimate limitation for most platforms.

Breakout session 2: Multi-scale data collection - Summary of Discussion:

- Calibration and validation when collecting data across multiple scales is important. It would be great to have the ability to assimilate and analyze the large datasets generated in the field while still on board a research vessel.
- If multiple platforms worked in sequence the study of time and space could be extended.
- Pressing needs are:
    - the ability to resolve multi-trophic scales simultaneously,
    - a jelly or salp camera (because we are sliding towards a gelatinous ocean), and
    - novel sensors to understand light and sound in the ocean.
    - a better understanding of where ocean plastic is stored in the ocean. Sediment cores taken below one of the major accumulation zones (e.g. North Pacific Garbage Patch) may show where ocean plastic's ultimate sink is. For example, plastic particles may get to the deep ocean with marine snow.

Breakout session 3: Deep Ocean Exploration - Summary of Discussion:

- Areas that are currently under-studied are the South Pacific Basin, seamounts, ecosystems under ice, Antarctica, abyssal plains, and convergence zones.
- One way to get a lot of data fairly quickly is to do video transects. These must be archived and have accurate GPS locations so that they are repeatable.
- Instrumentation development needs:
    - Long range technology that can cover a lot of space and enter hostile territories

  - Investigation into the potential to use bioluminescence as a sensor for biomass
  - Quiet, red light instruments to mitigate animal avoidance in the mesoplagic zone
- Monitoring around perturbed sites, deep sea mining sites (pre-, syn-, and post-mining of massive sulfide deposits and manganese nodules), and methane hydrate (clathrate) fields are important (both extent of these sites and the potential for rapid changes of methane hydrate fields due to climate change).
- When developing new techniques "don't let the perfect be the enemy of the good."

Workshop Recommendations

The following recommendations formulated during the workshop appear to resonate especially well with the technological focus of Schmidt Ocean Institute's oceanographic research program interests:

- A concept of "Mother Duck and Ducklings" emerged whereby R/V Falkor could provide a facility for oceanographic research, including a range of sensors and diverse vehicles deployed from R/V Falkor, that might include AUVs, ASVs, UAVs, etc. for data collection and assimilation, along with the capabilities for sensor calibration and vehicle support.

- Provide the oceanographic research and technology development community with access to Schmidt Ocean Institute-owned vehicles for prototyping and testing of sensors and other technologies.

- Provide broader support for the development of new sensors, vehicles, and research technologies that will help to increase the spatiotemporal resolution and intelligence of ocean process characterization.

- Accommodate diverse persistent sensing capabilities onboard R/V Falkor for continuous data collection and its open sharing.

- Develop a shipboard high performance computing capability for near real-time ingestion and assimilation of multi-scale, multi-modal data for low latency ocean process modeling, analysis, and prediction to support planning and situational awareness for the science party during research cruises as well as other ocean research and technology development applications.

- Facilitate interactions and collaborations among scientists of different countries, governments, NGOs, commercial sectors, operators, technology developers, makers, and the Do-It-Yourself entrepreneurial community to better coordinate ocean research and technology development efforts.

- Focus exploratory research on the remote, understudied areas of the world's ocean, such as South-East Asia, polar regions, South Pacific basin, seamounts and convergence zones.

- "Make people care": Instill interest among all audiences around the world in learning more about the value and significance of the ocean by providing them with diverse media including original imagery and video from under the sea. Also, making data available to scientists in a more interactive manner - visually-appealing and user-friendly could lead to a better understanding of the ocean. Good video and imagery of ocean processes is a way to educate and instigate curiosity.

- Continue to support early career ocean researchers and technology developers.