STRATEGIC PLAN 2013–2018

OCEAN NETWORKS CANADA

DISCOVER THE OCEAN. UNDERSTAND THE PLANET.

oceannetworks.ca

AN INITIATIVE OF University of Victoria

oceannetworks.ca

OCEAN NETWORKS CANADA

DISCOVER THE OCEAN. UNDERSTAND THE PLANET.

Strategic Plan 2013–2018
June 2013

AN INITIATIVE OF University of Victoria

CONTENTS

ABOUT THE STRATEGIC PLAN 1

INTRODUCTION 2

OCEAN NETWORKS CANADA OBSERVATORIES 5

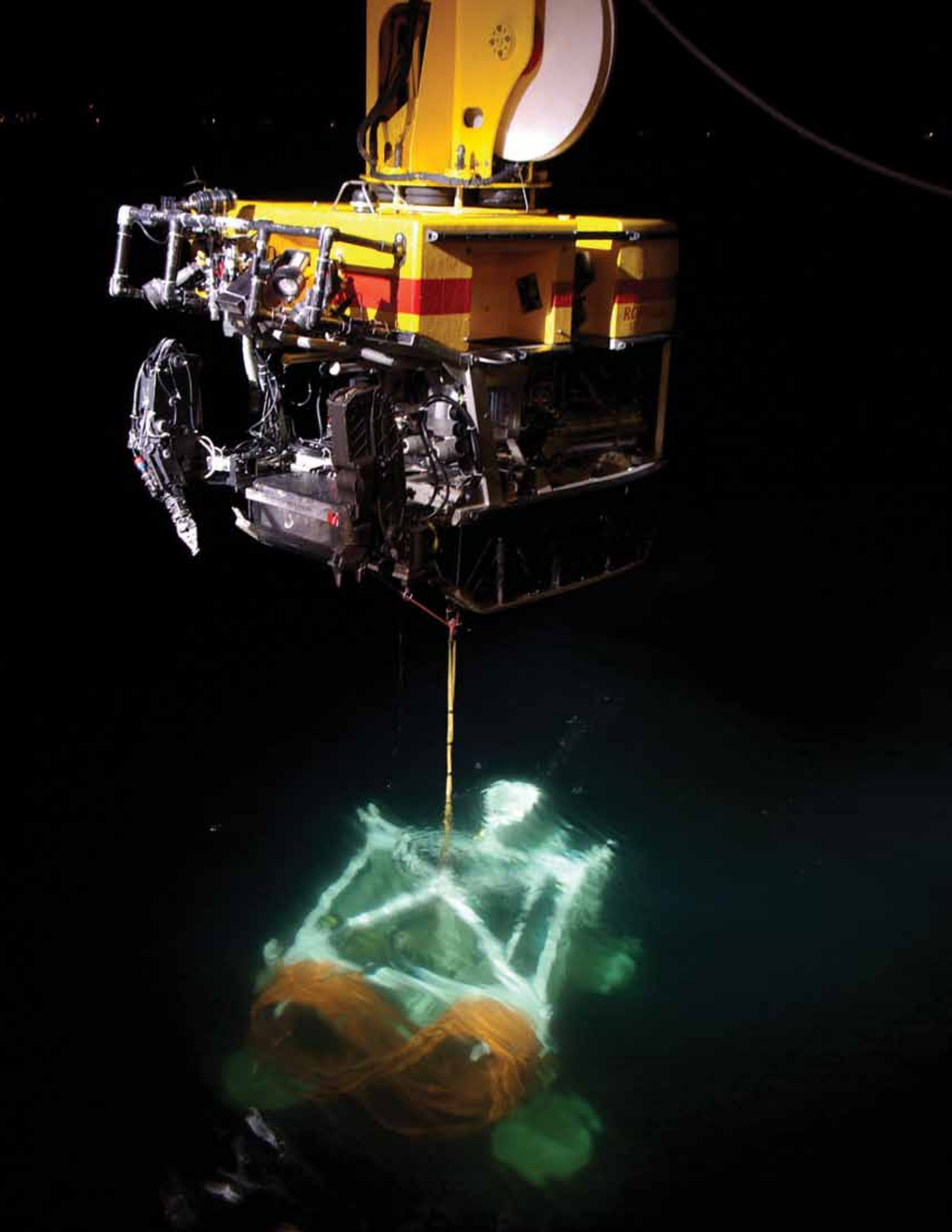
RESEARCH HIGHLIGHTS 8

SCIENCE PLAN 13

- Understanding Human-Induced Change in the Northeast Pacific Ocean 14
- Life in the Environments of the Northeast Pacific Ocean and Salish Sea 17
- Interconnections Among the Seafloor, Ocean, and Atmosphere 21
- Seafloor and Sediment in Motion 24

INNOVATION THROUGH COMMERCIALIZATION AND NEW TECHNOLOGY 27

GROWING RESEARCH AND DEVELOPMENT COMMUNITIES 31



ABOUT THE STRATEGIC PLAN

Established in 2007 as a major initiative of the University of Victoria, Ocean Networks Canada operates world-leading ocean observatories for the advancement of science and the benefit of Canada. The NEPTUNE and VENUS cabled observatories collect data on physical, chemical, biological, and geological aspects of the ocean over long time periods, supporting research on complex Earth processes in ways not previously possible.

The NEPTUNE regional observatory and VENUS coastal observatory provide unique scientific and technical capabilities that permit researchers to operate instruments remotely and receive data at their home laboratories anywhere on the globe in real time. These facilities extend and complement other research platforms and programs, whether currently operating or planned for future deployment.

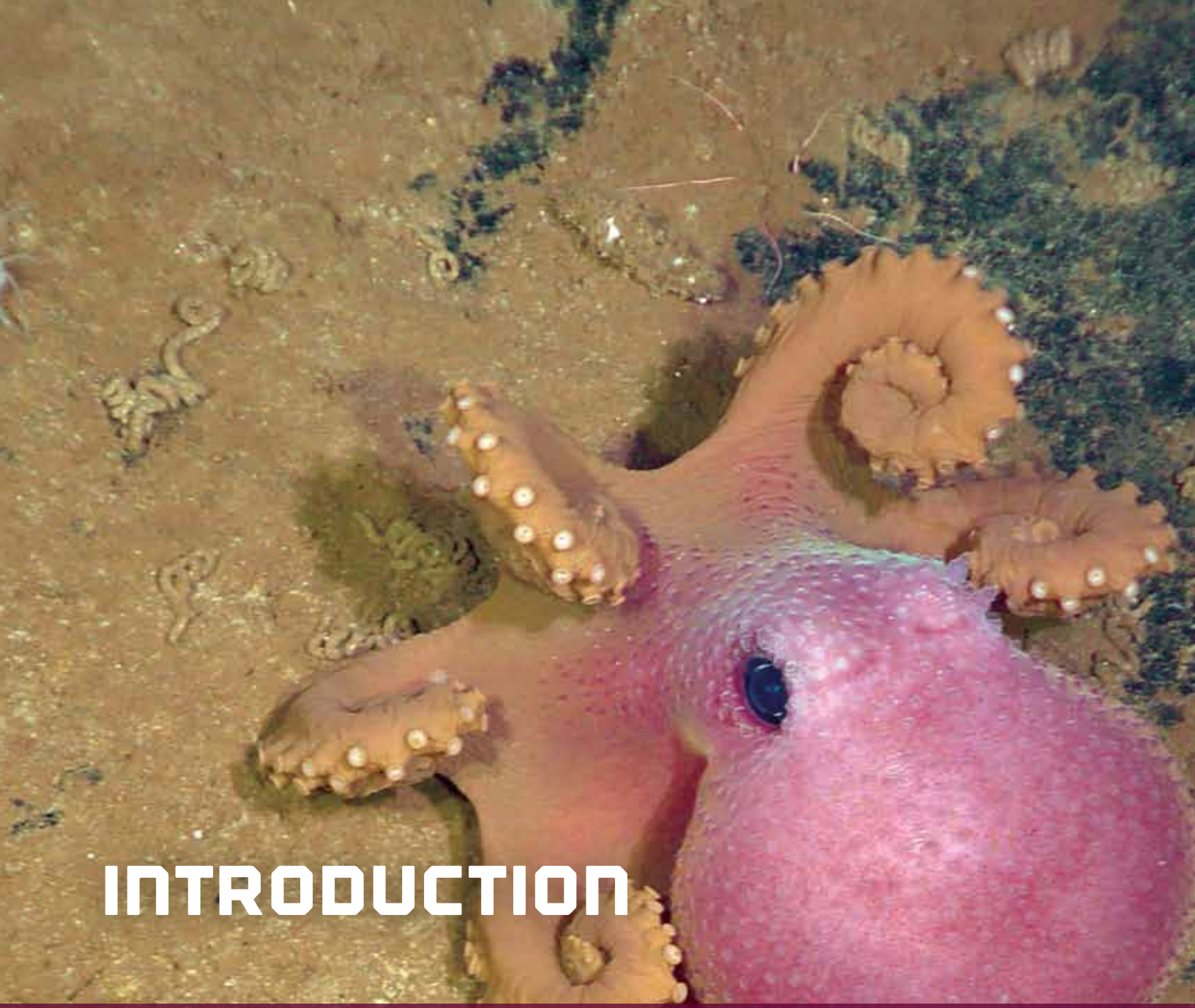
The Ocean Networks Canada Innovation Centre (previously called the ONC Centre for Enterprise and Engagement)—one of Canada's Centres of Excellence for Commercialization and Research—promotes the advanced technologies developed by NEPTUNE and VENUS.

The Canadian and international research, educational, and ocean industry communities are the primary drivers of Ocean Networks Canada's science and technology priorities described in this strategic plan. Proposals for observatory expansion, enhancement, and technological innovation come from this same global community.

This strategic plan sets out Ocean Networks Canada's goals and priorities over the next five years (2013–2018). Achieving these goals requires that operational funds are secured as a strategic priority.

While this strategic plan focuses on the NEPTUNE and VENUS observatories' research and commercial potential, Ocean Networks Canada's scientific and technology footprint will be expanded through collaborations with other programs and observatory efforts.

Andrew Bjerring
Chair, Ocean Networks Canada Board of Directors



INTRODUCTION

The ocean, covering approximately 70% of our planet, provides food and resources, moderates the climate, and supports most of the life on Earth. Much of our ocean is unexplored and poorly understood at the same time that it is being stressed and threatened by increasing temperatures and decreasing pH (acidification), nutrient and plastic pollution, and over-fishing. Arctic summer minimum sea ice is at its lowest recorded aerial coverage, rising sea levels are threatening coastal communities, and disasters such as oil spills and tsunamis are testing ocean and human resilience. Understanding the pace of climate change in the ocean, how the change is affecting ocean ecosystems and human society on small and large scales, and what steps might be taken to mitigate adverse effects of change is paramount and requires increasingly sophisticated ocean monitoring efforts.

VISION STATEMENT

To be a world leading organization that advances innovative science and technology

MISSION STATEMENT

To enable transformative ocean observatory research for the advancement of science and technology and for the benefit of Canada

STRATEGIC GOALS

- Serve and grow the user communities
- Deliver reliable infrastructure
- Expand innovation through commercialization and new technology

With an operational life of more than 25 years, the University of Victoria's Ocean Networks Canada provides essential data required to address these pressing scientific and policy issues. The innovative cabled infrastructure of the NEPTUNE and VENUS observatories supplies continuous power and Internet connectivity to a broad suite of subsea instruments from coastal to deep-ocean environments. The observatories are a crucial investment for Canada and unique on the global stage because the fixed infrastructure makes these data available, free and in real time, from hundreds of instruments distributed across the most diverse ocean environments found anywhere on Earth.

Ocean Networks Canada is leading the global community of cabled ocean observatories and contributes significantly to the international ocean research and observing enterprise by providing infrastructure below the seafloor, on the seafloor, and in the water in a wide range of ocean environments.

Ocean Networks Canada is especially well suited to support research that requires continuous data collection from a diverse array of ocean parameters over long time periods. These long-term data sets are a strategic priority for Ocean Networks Canada because of their pivotal role in understanding the impacts of climate change on the ocean. Such continuous data collection fills in gaps that are inevitable when sampling only sporadically by surface ships, enabling a more complete understanding of ocean and Earth processes. Real-time flow of data to on-shore laboratories and data centres permits rapid analysis of information on natural hazards such as earthquakes and tsunamis. Because the cabled infrastructure is fixed on the seafloor, observatory data collection is being complemented with ever more sophisticated mobile platforms such as gliders and unmanned undersea and aerial vehicles.

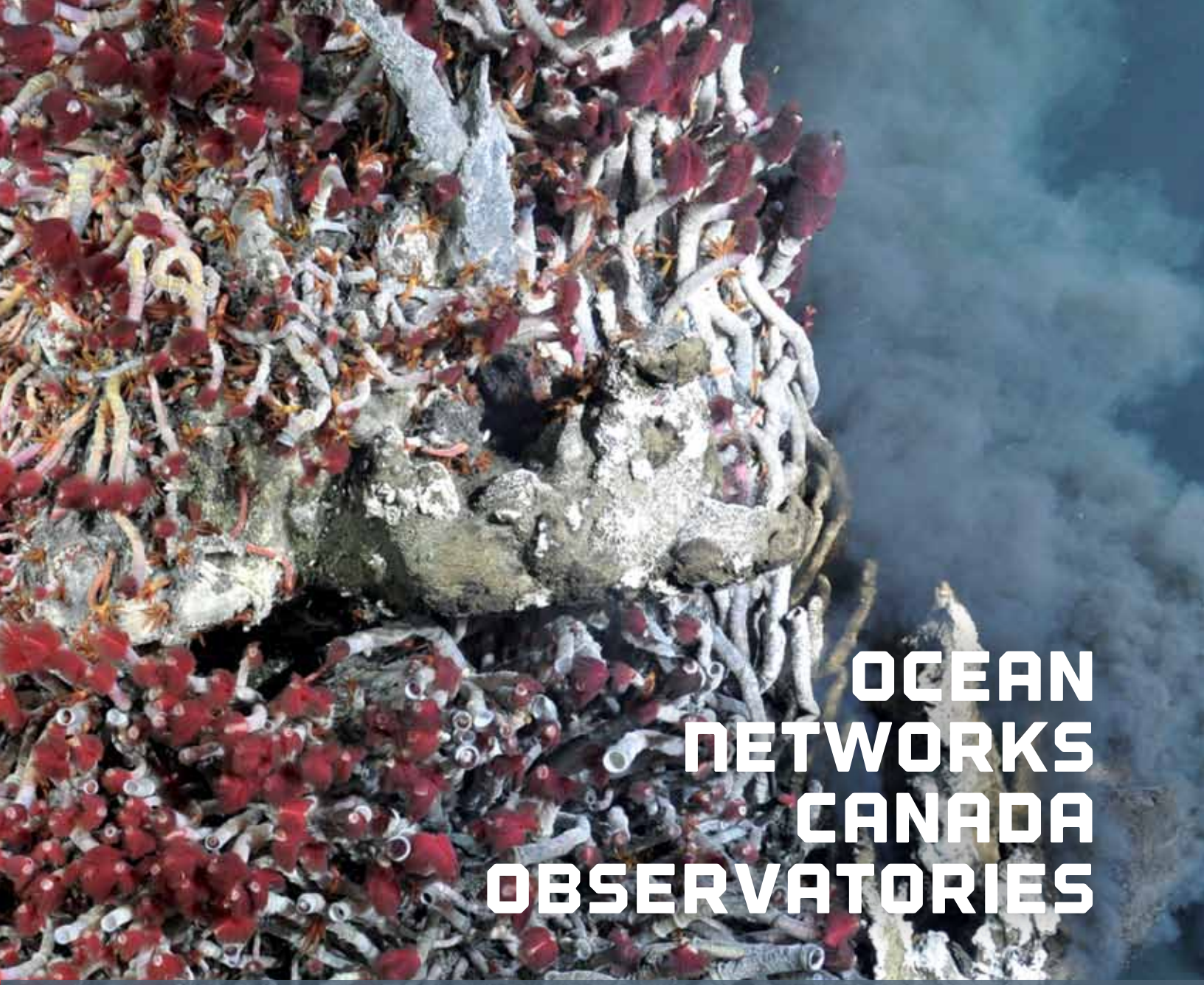
The Ocean Networks Canada observatories are all about enabling the community of users. Having an active group of committed ocean researchers in Canada and globally is key to that success. The reliability of the NEPTUNE and VENUS observatories and the ease with which scientists can plug their instruments into the cabled junction boxes to conduct their own experiments are major assets that encourage broadening of the user community. The three strategic goals, consolidated from the essential components of Ocean Networks Canada's 2011 plan, reflect our commitment to serve and expand the user community, deliver reliable infrastructure, and drive innovation through commercialization and new technology. The organization and staff are structured in three main groups that reflect these strategic goals.

This strategic plan for Ocean Networks Canada was led by the staff, with significant input by the user community through the NEPTUNE and VENUS science advisory committees and the International Science Advisory Board. The larger scientific community commented on drafts of this plan.

The first part of the strategic plan describes the observatories' backgrounds and infrastructures, as well as how scientific results will contribute to public policy issues. Another section provides scientific highlights from the first years of output from the observatories. A major part of this strategic plan lays out the main Ocean Networks Canada scientific themes and priority questions for the next four years. The four themes are:

- Understanding Human-Induced Change in the Northeast Pacific Ocean
- Life in the Northeast Pacific Ocean and Salish Sea
- Interconnections Among the Seafloor, Ocean, and Atmosphere
- Seafloor and Sediment in Motion

The last two sections of this plan describe Ocean Networks Canada's innovation efforts and strategies for growing its user community.



OCEAN NETWORKS CANADA OBSERVATORIES

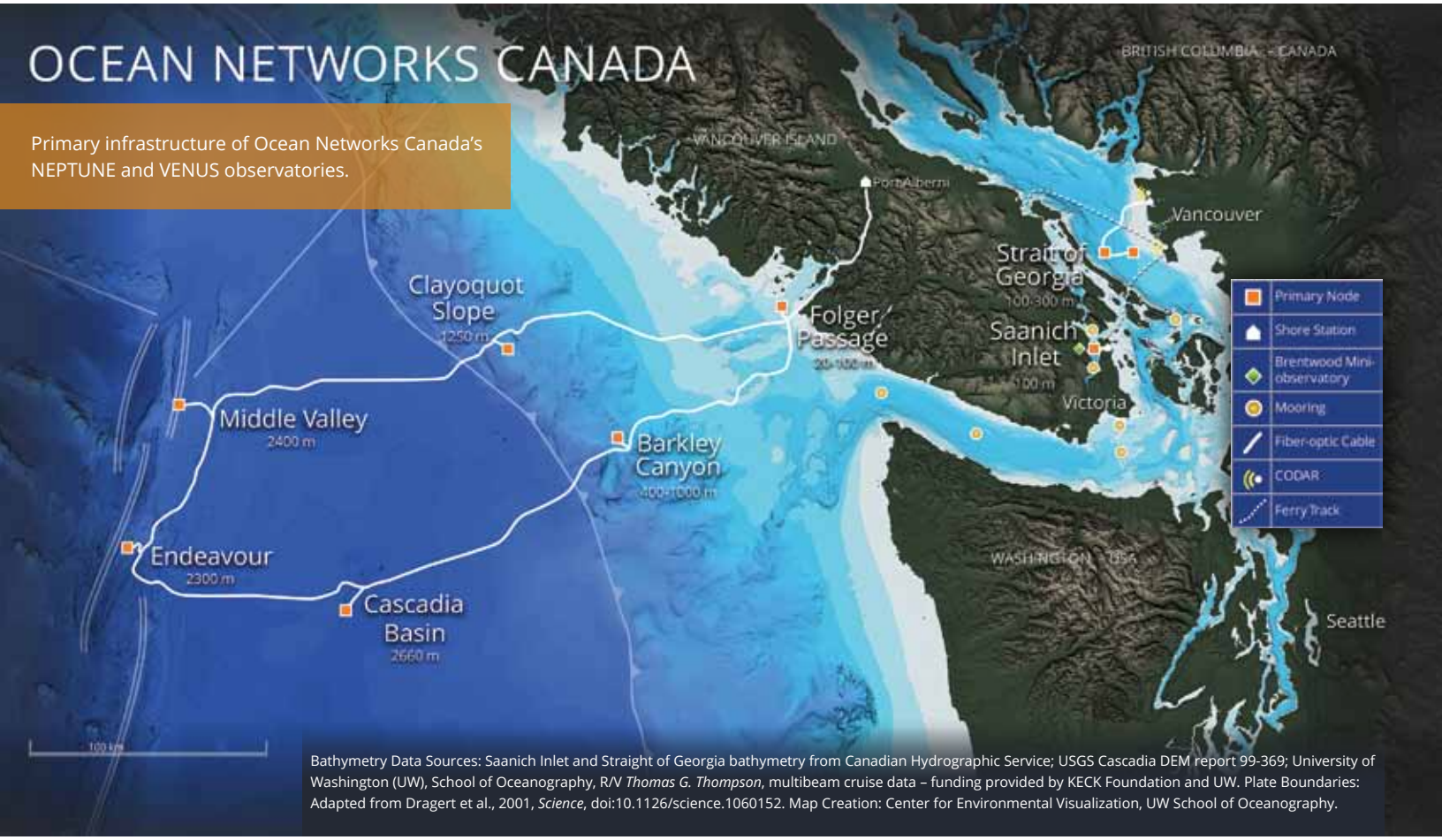
Ocean Networks Canada's **VENUS** was the world's first cabled seafloor observatory to enable researchers anywhere to connect in real time to undersea experiments and observations. Operations began in early 2006 with a short array in Vancouver Island's Saanich Inlet, a seasonally anoxic fjord. Saanich Inlet hosts a single node in 100 m water depth. VENUS expanded into the Strait of Georgia, which lies between the city of Vancouver on the mainland and Vancouver Island. It has nodes at 300 m and 170 m water depth and a special extension into the Fraser River delta. About 50 instruments are reporting seafloor and water column conditions on a 24/7 basis. Ocean Networks Canada is extending VENUS seafloor instrumentation and integrating roving and shore-based platforms, including gliders, ferries, and CODAR surface currents. These systems will transition to operations through 2014.

NEPTUNE, the largest cabled ocean observatory, followed VENUS after funding began in 2003. NEPTUNE developed deployment requirements spanning a wide range of ocean environments, from the wave-dominated coast, to gas-venting

seafloor areas, to deepwater hydrothermal vents. In 2007, an 840 km long seafloor cable was installed from Vancouver Island across the continental shelf into the deep sea. Observatory nodes were instrumented on the continental shelf at Folger Passage (at 20 m and 100 m water depth), the continental slope at Clayoquot Slope (previously called Ocean Drilling Program [ODP] Site 889) and Barkley Canyon, mid-plate at Cascadia Basin (previously called ODP Site 1027), and on the crest of the Endeavour Segment of the Juan de Fuca Ridge. A sixth site at Middle Valley is cabled for future development. A shore station at Port Alberni on Vancouver Island relays data via fibre optic cable to the University of Victoria. Operations began in 2009 and over 130 instruments on the NEPTUNE observatory are now providing real-time data over the Internet.

NEPTUNE and VENUS share the same data management and archive system called **OCEANS 2.0**. It provides users with open access to real-time and archived data and supports a collaborative work environment. The University of Saskatchewan hosts the observatories' data backup system, which collects ~50 terabytes per year.

In 2009, Ocean Networks Canada was awarded funds to establish a Federal Centre of Excellence for Commercialization and Research—the ONC Centre for Enterprise and Engagement—to develop the commercial and outreach opportunities created by the subsea networks. Now in its third year of operation, the Centre was recently renamed the



Primary infrastructure of Ocean Networks Canada's NEPTUNE and VENUS observatories.

Bathymetry Data Sources: Saanich Inlet and Straight of Georgia bathymetry from Canadian Hydrographic Service; USGS Cascadia DEM report 99-369; University of Washington (UW), School of Oceanography, R/V *Thomas G. Thompson*, multibeam cruise data – funding provided by KECK Foundation and UW. Plate Boundaries: Adapted from Dragert et al., 2001, *Science*, doi:10.1126/science.1060152. Map Creation: Center for Environmental Visualization, UW School of Oceanography.

ONC INNOVATION CENTRE, and it is creating national and international partnerships with industry and academia in all four of its main target areas—ocean sensor technologies, ocean observing system technologies, digital infrastructure, and public engagement—thereby developing opportunities to build upon Canada's leadership in ocean observing technologies. The Centre expanded ONC's reach in 2012 with the successful installation of a mini-observatory in Cambridge Bay, Nunavut. Further expansion to other areas of the Arctic is anticipated.

Ocean Networks Canada operates and manages the NEPTUNE and VENUS observatories on behalf of the University of Victoria, the lead institution for a national consortium of universities and partner organizations. The facility is a major national and provincial investment requiring substantial annual operating funding and support from government, university, and partner agencies to achieve its scientific goals and to generate benefits for British Columbia and all of Canada. Ocean Networks Canada's more than 80 staff members include scientists, engineers, technicians, and support staff who are focused on delivering ocean observatory data and products to the national and international community of researchers, educators, managers, and policy makers drawn from the academic, government, and private sectors. Given the highly specialized nature of the subsea and communications infrastructure, the combined expertise of this group is unique in Canada and the world.

ONC IMPACT ON PUBLIC POLICY

The Ocean Networks Canada observatories facilitate research that addresses important science questions. Ocean Networks Canada will disseminate results relevant to national and international policy priorities on topics such as hazard mitigation, climate change adaptation and mitigation, ocean health evaluation, renewable resource assessment, sovereignty and security issues, and socioeconomic development. Research outcomes that may be used for public policy purposes will be considered when evaluating large capital and operating fund expenditures.

Ocean Networks Canada's policy mandate has two primary and complementary objectives: (1) to expedite the translation of research results from Ocean Networks Canada programs to inform the development of ocean-related public policy at both the provincial and federal levels in Canada, while recognizing that many issues are global in scope, extend beyond national boundaries and (2) to create opportunities for government funding and support of our research programs to advance studies that mutually benefit science objectives and policy priorities.

To meet policy objectives, Ocean Networks Canada will establish strong partnerships with federal and provincial science-based departments and agencies (SBDAs). Ocean Networks Canada will carefully and critically assess the alignment of its scientific programs with the evidence-based policy needs of SBDAs. It is also important to conduct research in collaboration with social scientists to improve knowledge transfer from Ocean Networks Canada's community research results for the public good.

First and foremost, the Ocean Networks Canada observatories are enabling platforms for ocean monitoring and research conducted by the international scientific community. Ocean Networks Canada will develop close collaborations with this community to maximize the overall public benefits and policy impacts of the research as described in the Science Plan section.

RESEARCH HIGHLIGHTS

A diverse international scientific community defined Canada's NEPTUNE and VENUS observatories' research themes. Here we summarize some of the scientific accomplishments facilitated by this unique international facility.

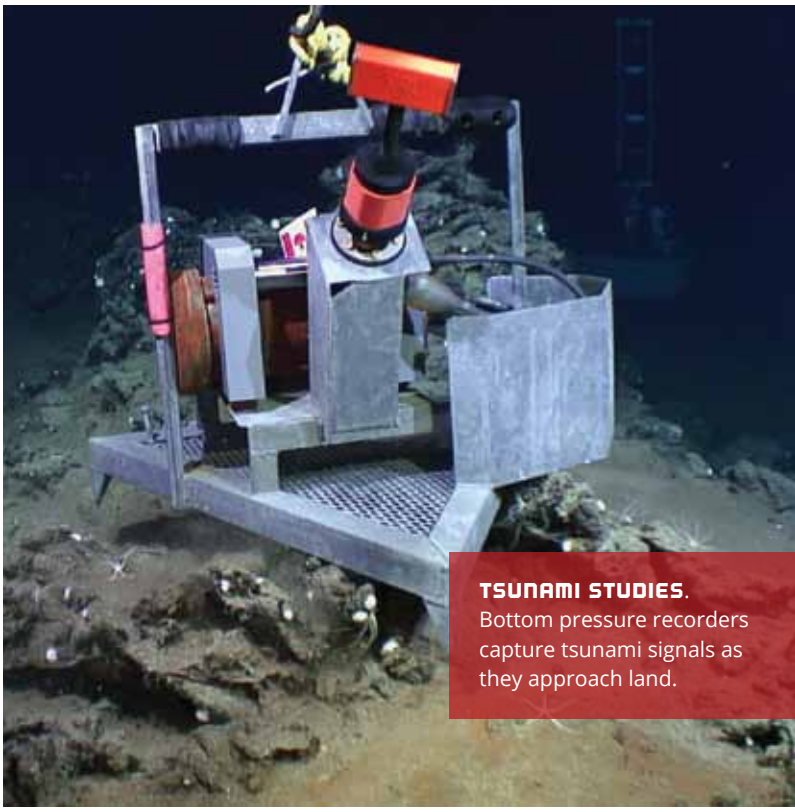
GAS HYDRATE OUTCROPS. *Wally*, an Internet-controlled seafloor crawler regularly surveys the seafloor where hydrates outcrop.

STUDIES OF GAS HYDRATE OUTCROPS WITH AN INTERNET-CONTROLLED BOTTOM CRAWLER

Changes in gas hydrates detected by instruments installed at an Ocean Networks Canada node in Barkley Canyon on the continental slope indicate high concentrations at and beneath the seafloor. If seawater temperatures warm, these hydrates will sublimate (transform from solid phase to gas), permitting methane—a potent greenhouse gas—to escape from the seafloor into the water column and potentially into the atmosphere. *Wally*, an Internet-controlled seafloor crawler connected to the Barkley Canyon node by a 70 m tether and equipped with cameras, microprofilers, and other sensors, regularly surveys the seafloor where hydrates outcrop. These data, combined with current meter measurements, indicate that methane release increases when bottom currents strengthen, such as during storms. Thus, submarine canyons that display high hydrodynamic activity can become key areas of enhanced seepage as a result of emerging weather patterns due to climate change.

TSUNAMI STUDIES

Highly sensitive bottom pressure recorders developed at the Natural Resources Canada Pacific Geoscience Centre are part of a tsunami array deployed on the NEPTUNE observatory that stretches from the deep ocean to the inner continental shelf. This real-time tsunami monitoring system captured signals from the September 2009 Samoan (M_w = 8.1), February 2010 Chilean (M_w = 8.8), and April 2011 Tōhoku (M_w = 9.0) earthquakes and tsunamis. Rapid, real-time calculations allowed precise determination of tsunami wave speed, direction, and amplitude. The ability to assimilate open-ocean data from the cabled observatory into an operational tsunami forecast model makes it possible to provide updated wave time and height information that could help mitigate the impact of future tsunamis approaching the west coast of British Columbia and northern Washington State.



TSUNAMI STUDIES. Bottom pressure recorders capture tsunami signals as they approach land.

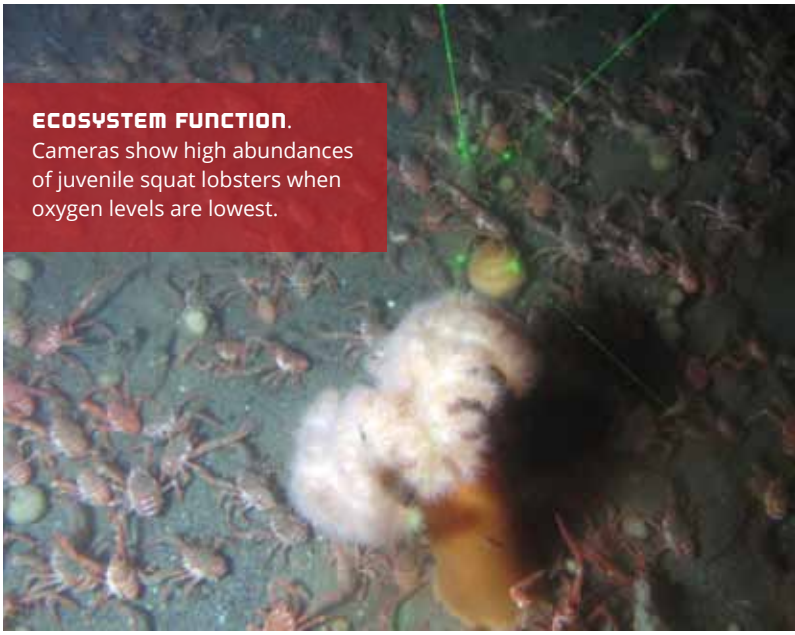
SEDIMENT AND BENTHIC DYNAMICS. Flatfish and other bottom sea creatures are important contributors to sediment mixing.

SEDIMENT AND BENTHIC DYNAMICS

Time series of sonar scans of bottom sediment at 400 m water depth in Barkley Canyon on the upper continental slope show depressions or pits that come and go over several months. Camera images of the same area collected over 10 months by Ocean Networks Canada suggest that benthic flatfish form these pits. These flatfish and other bottom sea creatures can churn up the surface sediment completely within about 100 days. These observations demonstrate that animals are important contributors to sediment mixing (bioturbation), which liberates nutrients back into the water column where they can support plankton growth. Continued long-term monitoring of bioturbation will help researchers understand the response of benthic and water column ecosystems to changes in currents and turbulence near the sediment.

ECOSYSTEM FUNCTION

Marine sediment ecosystems cover more of Earth than all other habitats combined, contributing significantly to global nutrient cycles, carbon and oxygen budgets, pollutant dynamics, and fisheries production (seafloor species comprise $2.5 billion of the $3 billion in total export value of Canadian fisheries). Ocean Networks Canada benthic ecology research combines camera observations and interactive sampling with sediment traps and data from multiple sensors collecting uninterrupted measurements of temperature, oxygen, and nitrate. Results from Saanich Inlet show that taxon richness (a measure of biodiversity) negatively correlates with low oxygen concentration—cameras show high abundances of juvenile squat lobsters when oxygen levels are lowest, possibly reflecting exclusion of larger predators by hypoxia. Adult crustaceans, in contrast, show increased biological activity within two hours after a high-oxygen intrusion. These findings indicate that as hypoxia increases, low diversity, hypoxia-tolerant species of low commercial significance will dominate benthic communities on the continental shelf.

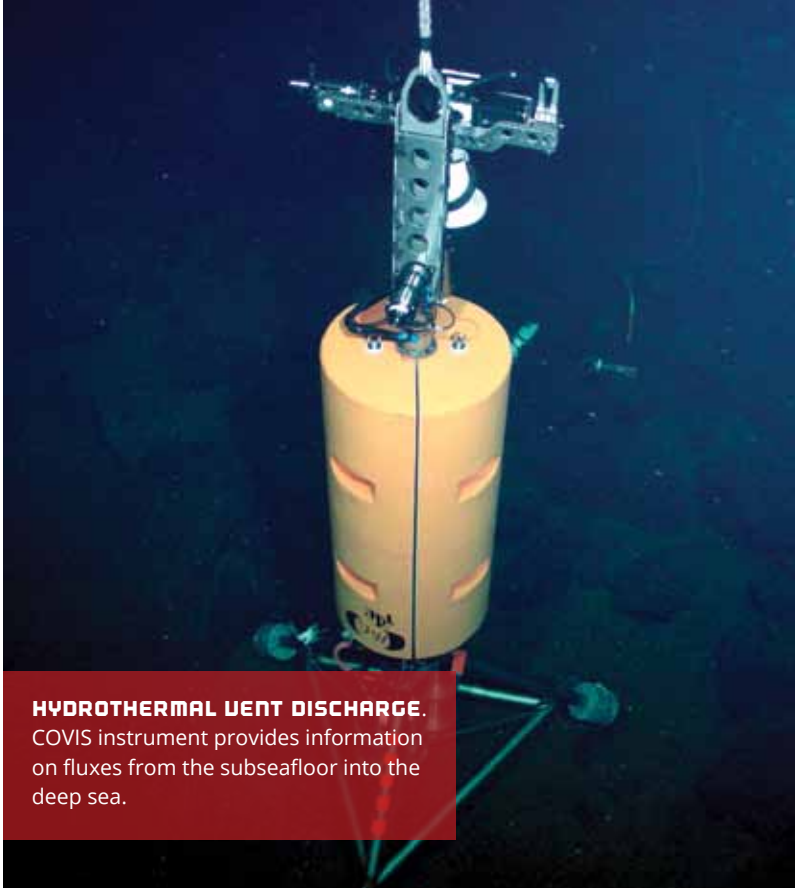


ECOSYSTEM FUNCTION. Cameras show high abundances of juvenile squat lobsters when oxygen levels are lowest.

MARINE MAMMALS

Underwater sound from human activities affects the physiology and behaviour of marine fauna. Ocean Networks Canada employs hydrophones to assess the large-scale acoustic ecology in the Strait of Georgia, near the mouth of the Fraser River. Every five minutes, VENUS processes the data to identify ships and marine mammals. Several whale species have been detected through recognition of their distinctive acoustic signals at locations on NEPTUNE and VENUS, including one interpreted to be an endangered North Pacific right whale, although there has been no visual confirmation. (Prior to a recent sighting in 2013, the last sighting of a right whale in these waters was in 1951.) Ocean Networks Canada is participating in an International Quiet Ocean Experiment (coordinated by the UNESCO Intergovernmental Oceanographic Commission). The aim of this project is to compare underwater noise levels in a variety of oceanic environments to learn what levels large mammals can tolerate and how adverse levels of underwater noise affect their behaviour.

MARINE MAMMALS. Ocean Networks Canada's seafloor hydrophones record marine mammal vocalizations.



HYDROTHERMAL VENT DISCHARGE. COVIS instrument provides information on fluxes from the subseafloor into the deep sea.

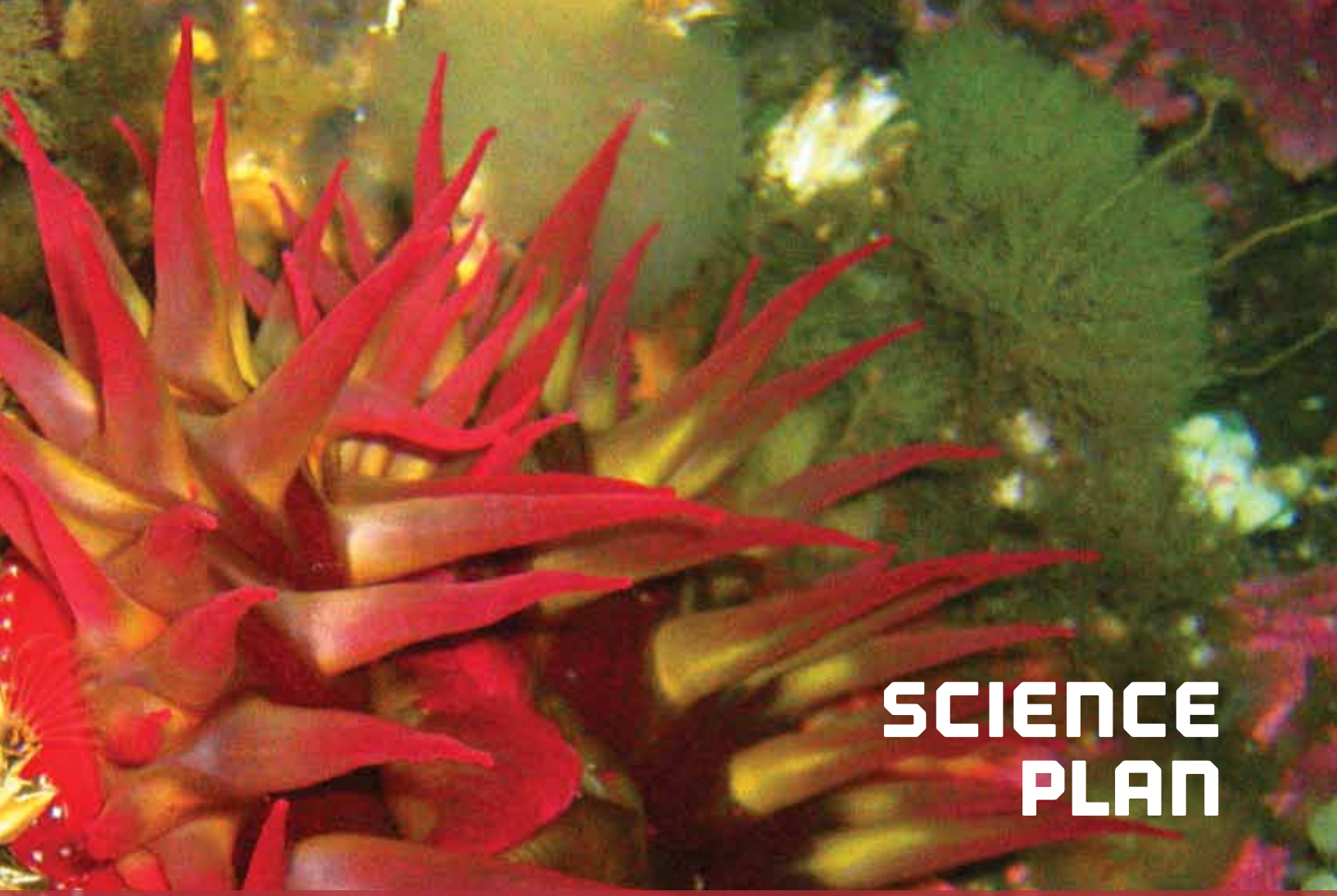
REAL-TIME VERTICAL PROFILING OF HYDROTHERMAL VENT DISCHARGE

Because flux studies require collection of long time series, little was known about heat, chemical, and biological fluxes from Earth's crust upward into the ocean via hydrothermal vents. The Cabled Observatory Vent Imaging Sonar (COVIS) installed at NEPTUNE's Endeavour field node on the Juan de Fuca Ridge continuously measures backscatter intensity of suspended particles in black smoker plumes in three dimensions and diffuse flow from the seafloor. These observations suggest that, at this location, the ratio of upward fluxes from black smokers compared with diffuse flow is about 20 times larger than previous estimates, underlining the important contribution of black smokers to heat and materials fluxes into the ocean at seafloor-spreading centres.

DEEP-SEA FORENSICS. Underwater cameras are being used to study the decomposition of pig carcasses.

DEEP-SEA FORENSIC INVESTIGATIONS

Time of death is an important piece of information in any human death investigation, but is of paramount value in a homicide, allowing the investigators to understand the victim's time line prior to death. Estimating elapsed time since death is difficult or even impossible after a body has been submerged for a long time. In addition, marks on remains recovered from the ocean can easily be misinterpreted as wounds inflicted before or at the time of death when the decay-related processes that cause damage to a carcass are not understood. VENUS underwater cameras are being used to study the decomposition of pig carcasses, lowered to the seafloor within a protective cage and unprotected in the Strait of Georgia. Pig carcasses are commonly used as proxy for human remains in forensic research. Results reveal strong effects of ocean chemistry and macrofaunal scavenging (e.g., feeding by swarms of benthic amphipods) on rates of carcass degradation. A recent deployment in 95 m deep water in Saanich Inlet resulted in much slower rates of carcass degradation during periods of very low oxygen concentrations, when benthic fauna were absent, despite other evidence of microbial activity. This work is continuing, with the analysis of bone remains by another forensic specialist.



SCIENCE PLAN

This Science Plan, which serves the broad scientific community, was developed by Ocean Networks Canada over the last two years, guided by strong interaction with the NEPTUNE Science Planning and User Committees, and with the VENUS Users Advisory Committee. The Science Plan is organized under four themes:

- Understanding Human-Induced Change in the Northeast Pacific Ocean
- Life in the Environments of the Northeast Pacific Ocean and Salish Sea
- Interconnections Among the Seafloor, Ocean, and Atmosphere
- Seafloor and Sediment in Motion

Each theme poses several key scientific questions, describes why each question is important, and explains how Ocean Networks Canada can contribute to answering the question. Collectively, addressing these questions is aimed at realizing the two goals in our Mission Statement: to advance innovative science and technology and to realise benefits to Canadians. Although the observatories are regional in scope, they have already attracted a number of committed international researchers, and we expect that number to continue to grow. Thus, the research conducted through Ocean Networks Canada's observatories, and collaboratively with other observatories as they come online in the next few years, is expected to contribute to the global effort to provide the scientific underpinning that will enable sustainable management of ocean resources, even as the human footprint on the ocean continues to increase.

UNDERSTANDING HUMAN-INDUCED CHANGE IN THE NORTHEAST PACIFIC OCEAN

The ocean is an integral part of Earth's climate system. By moving vast amounts of heat from tropical regions to the poles, ocean circulation moderates global temperature extremes. The ocean plays a major role in reducing the pace of global warming by absorbing some of the atmospheric carbon dioxide derived from human activities, leading to a subsequent increase in ocean acidification. In the Northeast Pacific, we have already observed impacts on fisheries resulting from ocean temperature changes, dissolved oxygen depletion, and increased acidification. We must collect information on the characteristics, magnitudes, rates, and consequences of change in physical, chemical, and biological aspects of the ocean so that decision makers have the information needed to secure a healthy ocean for future generations.

QUESTION 1: WHAT ARE THE MAGNITUDES AND RATES OF CHANGES OCCURRING IN THE NORTHEAST PACIFIC OCEAN?

The Pacific Ocean off southwestern Canada is dynamic. In winter, winds drive currents northward; in summer, winds blow equatorward, making the area the northern limit of one of the world's major eastern boundary currents—the California Current. Upwelling of deeper waters brings nutrients to the surface, supporting a rich and diverse ecosystem and important fisheries. In the Strait of Georgia, the annual cycle of freshwater input from the Fraser River dominates surface waters, while deep waters are dominated by subsurface inflows from offshore that propagate through Juan de Fuca Strait. Natural climate modes of the El Niño Southern Oscillation, Pacific Decadal Oscillation, and North Pacific Gyre Oscillation affect ecosystem function by influencing wind patterns, local currents, sea level changes, depth and strength of the thermocline, intensity of upwelling, and availability of nutrients.

In the Northeast Pacific Ocean, we are observing changes in the timing, intensity, and chemical properties of upwelled waters, nutrient availability, and primary production. It is anticipated that these changes will accelerate as the climate continues to warm, with cascading effects and implications for multiple facets of the ocean ecosystem. To quantify these changes, Ocean Networks Canada is committed to continuous, long-term recording of temperature, salinity, direction and intensity of water currents, dissolved oxygen distributions, pH, and pCO_2 using stationary seafloor sensors. Importantly, Ocean Networks Canada will continue to augment these seafloor measurements with mid-water and surface ocean data from mobile sensor platforms positioned to capture changes in stratification and water mass chemical and biological properties. This will require regular, repeat surveys with gliders and other autonomous underwater vehicles across the continental shelf and in the Strait of Georgia/Saanich Inlet basins that link to cable-supported measurements.

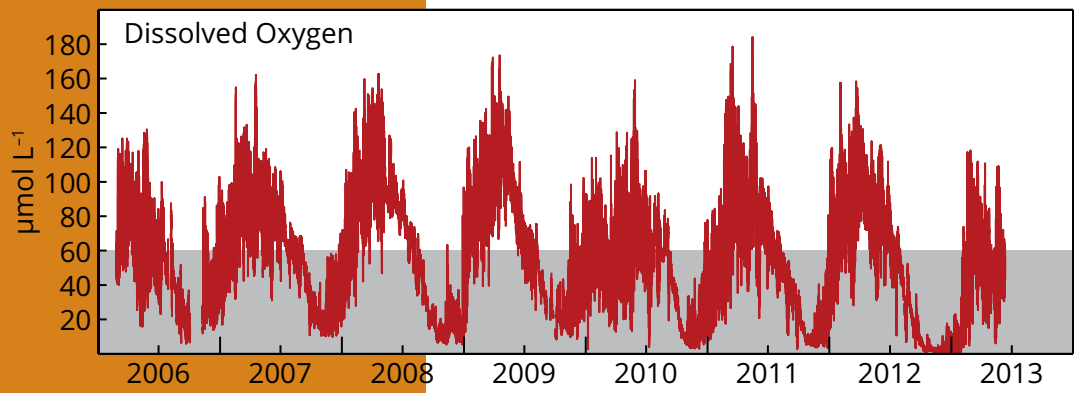
QUESTION 1. Stationary instrument platforms continuously record an array of ocean parameters.

QUESTION 2: HOW WILL NORTHEAST PACIFIC OCEAN MARINE ECOSYSTEMS RESPOND TO INCREASING OCEAN ACIDIFICATION?

Currently, the ocean is absorbing more than one-quarter of the carbon dioxide emitted by human activities, lowering its pH and affecting some organisms' ability to produce and maintain their calcium carbonate shells. Ocean acidification may be directly affecting the ability of oysters, clams, corals, and calcareous plankton, among other species, to build and maintain shells or skeletons and may be disrupting food webs. Ocean Networks Canada must develop and implement sensor technology that will accurately measure pH and pCO_2 over the long term to quantify their variability and the extent and spatial pattern of acidification in the Northeast Pacific. These data, together with studies of phytoplankton and zooplankton community structure and pattern that are currently carried out largely by Fisheries and Oceans Canada, are critical for evaluating whether and how acidification has affected these important planktonic organisms that are food for fish and other species. Ocean Networks Canada will enhance understanding of changes in species composition and distribution, trophic interactions, and, ultimately, ecosystem resilience and productivity by providing automated analyses of biological data from seafloor video cameras and other co-located sensors.

QUESTION 2. Understanding how ocean acidification affects shellfish is important to aquaculture and for studying impacts to the food web.

QUESTION 3. Seven years of dissolved oxygen near the bottom at 96 m in Saanich Inlet. Shading indicates hypoxic conditions stressful to animals.



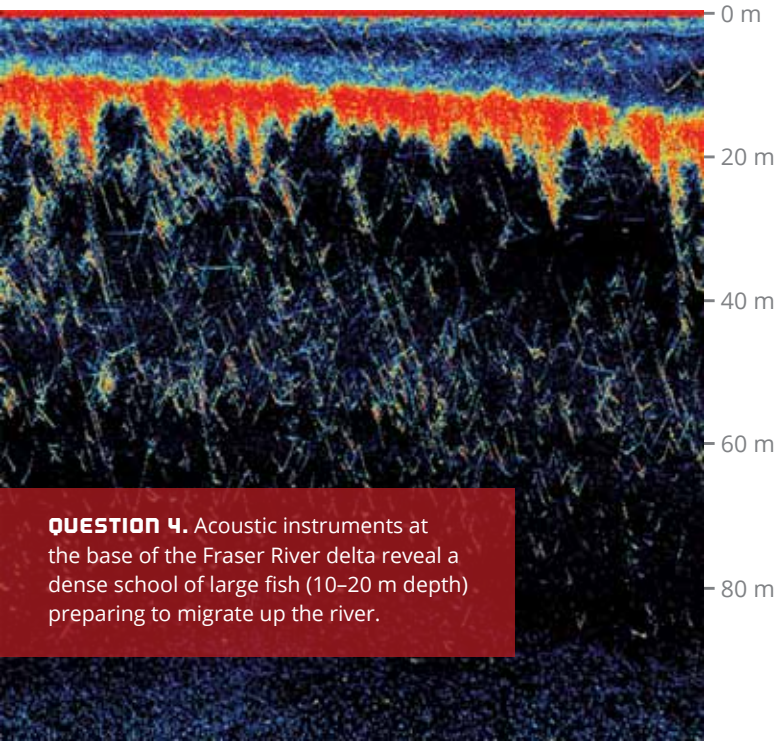
QUESTION 3: HOW DOES THE DEPLETION OF OXYGEN IN COASTAL WATERS AFFECT ECOSYSTEM SERVICES?

The number of oxygen-depleted zones and the severity and extent of hypoxic events are increasing. The Northeast Pacific Ocean has experienced increased regional upwelling events and sea surface temperatures that have led to reduced oxygen solubility and greater water column stratification. Continuous monitoring of benthic communities by Ocean Networks Canada will provide data to help evaluate how ecosystems respond to long-term changes in oxygen availability. Saanich Inlet, which is naturally anoxic at depth through much of the year, will continue to be a natural laboratory for studying impacts of variations in oxygen concentration on all parts of the ecosystem. Ocean Networks Canada can track potentially harmful intrusions of low-oxygen waters by deploying sensor-equipped gliders, measuring corrosive (low pH) deep-ocean waters by adding new sensors to the cabled observatories, conducting seafloor video surveys with autonomous and remotely operated vehicles, and collecting water-column profiles across oxic-hypoxic-anoxic boundaries. Vertical profilers can be controlled to measure salinity, temperature, currents, dissolved gases, nutrients, plankton, and fish concentrations and marine mammal occurrences several times per day. Benthic platform systems that include video and still cameras, sector scanning sonars, high-resolution current profilers, and sediment traps should be expanded beyond Barkley Canyon, Saanich Inlet, and the Strait of Georgia to capture benthic community changes in different environments.

Upwelled waters in the coastal Northeast Pacific Ocean are low in dissolved oxygen and high in pCO_2 (low in pH). There is recent evidence that both upwelling intensity and these deleterious water properties are increasing in magnitude. In addition, respiration of organic material and community metabolism remove oxygen from the water and introduce carbon dioxide, further enhancing these anomalies locally. Careful documentation of long-term environmental change by observatories will enable study of the response of ocean ecosystems to changes in multiple stressors (increasing temperature and carbon dioxide and decreasing oxygen and pH).

LIFE IN THE ENVIRONMENTS OF THE NORTHEAST PACIFIC OCEAN AND SALISH SEA

Effective ocean management requires knowledge of the diversity, distribution, and abundance of marine life in the ocean, from microbes, to zooplankton, to fish. This information, as well as knowledge about species interactions, improves our understanding of ocean health and ecosystems both in the water column and on the seafloor, and how the system responds to perturbations. Observations of marine life are needed across the broadest possible scales, from genes, to species, to ecosystems. Understanding the importance of biodiversity to ecosystem function requires knowledge about where species live, the characteristics of their habitats, their roles in the community, and how biodiversity changes over time at the community, species, and population levels. Studying deep-sea vent communities and the subseafloor biosphere also contributes to the fundamental understanding of the limits to life on Earth, its origins and its possible occurrence elsewhere in our solar system and beyond.



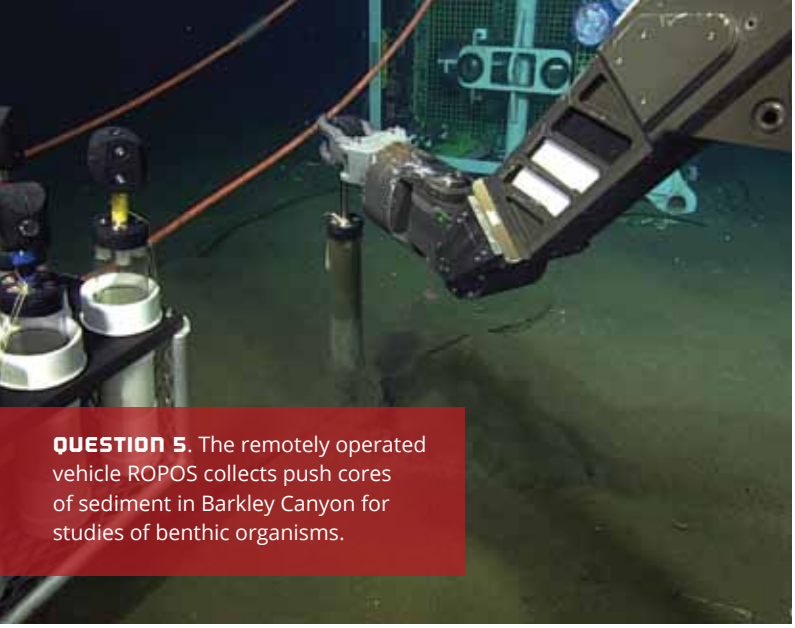
QUESTION 4. Acoustic instruments at the base of the Fraser River delta reveal a dense school of large fish (10–20 m depth) preparing to migrate up the river.

QUESTION 4. HOW ARE CHANGES IN THE NORTHEAST PACIFIC AFFECTING FISH AND MARINE MAMMALS?

Fisheries and Oceans Canada, the federal agency responsible for management of commercial fisheries and marine mammal populations is adopting an ecosystem-based management approach. In order to regulate individual fisheries and protect vulnerable populations, scientists and managers must be able to distinguish between changes in marine food webs resulting from human-induced environmental change and those resulting from fishing effort and techniques.

Existing Ocean Networks Canada infrastructure and new mobile platforms will provide data that contribute to understanding population dynamics of a number of marine species in the Strait of Georgia, including out-migrating juvenile salmon from the Fraser River. Satellite imagery, in conjunction with VENUS CODAR-derived currents, fish counts, and zooplankton abundances estimated acoustically, and photos from the Strait of Georgia, will permit mapping of surface and seafloor physical and chemical conditions in relation to fish and plankton concentrations and migrations. Gliders could provide observations of conditions in the mid-water column.

Ocean Networks Canada underwater hydrophones offer opportunities to use passive acoustics to study marine mammals in this region. The volume of data requires automated analytical techniques. Real-time analyses of these data are used to detect and identify cetacean vocalizations and guide sound propagation modelling, and can be expanded in the future.



QUESTION 5. The remotely operated vehicle ROPOS collects push cores of sediment in Barkley Canyon for studies of benthic organisms.

QUESTION 5: HOW DO BENTHIC MARINE POPULATIONS AND COMMUNITIES RESPOND TO AND RECOVER FROM PHYSICAL AND BIOLOGICAL DISTURBANCE?

The bottom boundary layer influences the distribution and stability of benthic biological communities. In shallow-water settings, tides and waves make the bottom boundary layer more energetic. Episodic, large-scale events such as turbidity flows impact both coastal and deep-sea benthos. Disturbances such as earthquakes, gas and liquid release, gas hydrate dissociation, bioturbation, and sinking plankton blooms also affect benthic communities. Ocean Networks Canada time-series data can record the thickness, shape, and timing of depositional events and other disturbances that influence epifauna, infauna, sediment structure, and recovery trajectories. With continuous observations, benthic communities can be studied as they respond to short-term (e.g., turbidity flows, tides, organic pulses, predator activity) and long-term changes (e.g., changes in gas and liquid release from active venting areas located along spreading ridges). Data from existing and future Ocean Networks Canada sensors and instruments, in concert with physical samples from ships of opportunity, will also be used to estimate larval supply and recruitment, two processes that are critical in the recovery of populations from disturbance.

QUESTION 6: WHAT ARE THE FUNCTIONS AND RATES OF SEAFLOOR AND SUBSEAFLOOR BIOGEOCHEMICAL PROCESSES?

Microbial activity such as sediment sulphate reduction and organic carbon oxidation contribute to the ocean's alkalinity and its dissolved inorganic carbon and oxygen concentrations. Simultaneously, seafloor species recycle organic matter and generate nutrients that help drive ocean production. Ocean crustal weathering reactions, enhanced through microbial activity, account for almost one-third of the silicate drawdown globally.

Ocean Networks Canada is well positioned to support studies of how seafloor species influence rates of carbon and nutrient cycling in coastal and deep-sea ecosystems and how subseafloor microbial processes influence oceanic and atmospheric chemistry through deep borehole investigations. Measurements recorded by a benthic crawler, in tandem with shipboard and manipulative experiments, offer mechanisms to link surface biodiversity at methane seeps to subseafloor microbial processes. NEPTUNE is connected to an Ocean Drilling Program borehole that is sealed with a CORK (Circulation Obviation Retrofit Kit), enabling prolonged deployment of borehole sensors and instruments that require power to extract subseafloor fluids. Collection of pristine fluids is central to the study of subseafloor environments and the microbes they host. NEPTUNE plans to connect to more CORKs in the future.

QUESTION 6. Instruments deployed in a sealed Ocean Drilling Program borehole and connected to the NEPTUNE observatory collect continuous data.

QUESTION 7: WHAT LIMITS LIFE IN THE SUBSEAFLOOR?

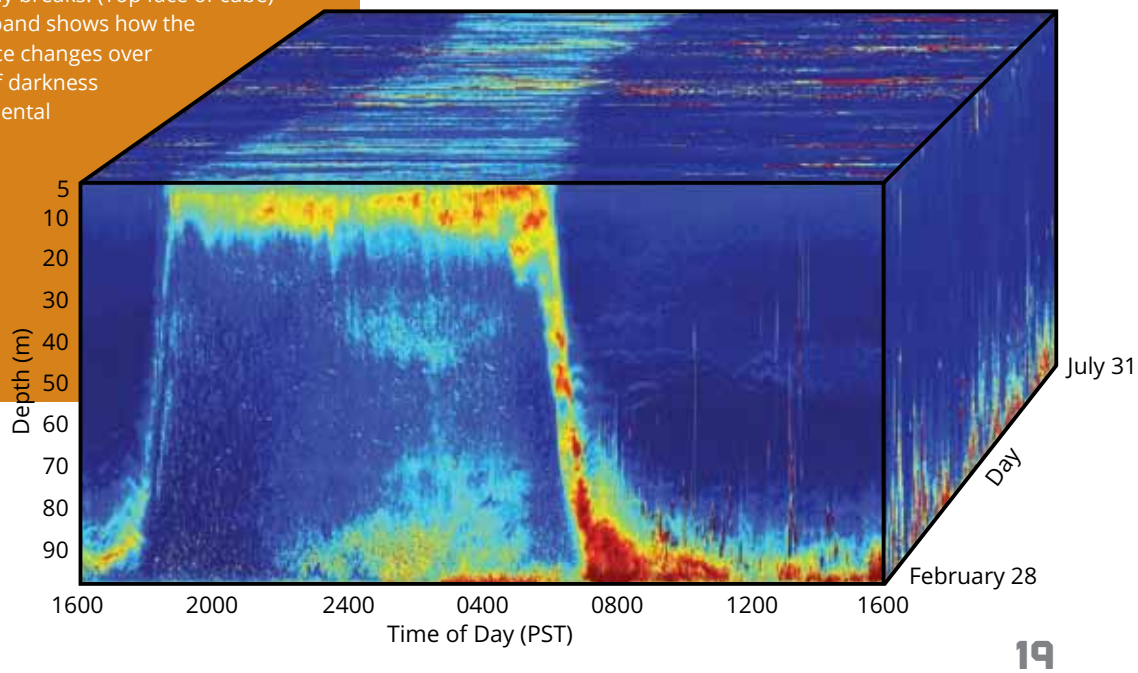
It is estimated that the subseafloor contains up to one-third of Earth's biomass. In subseafloor sediment, organic matter derived from surface photosynthesis is the main source of electron donors to microbes, and its availability limits their success. Water-rock reactions likely support primary carbon fixation within igneous oceanic crust where varying temperatures affect the distribution of life. There are currently opposing hypotheses about the ability of oceanic crust of various ages to support microbial life. Studies of both sediment-dominated and crustal microbial life can be conducted by installing long-term fluid sampling systems into boreholes connected to Ocean Networks Canada observatories. Automated, lab-on-a-chip technologies, such as the Environmental Sample Processor, soon to be deployed in Saanich Inlet, can provide continuous monitoring of microbial properties of borehole fluids.

QUESTION 8: HOW DO THE MICROBIAL COMMUNITIES REGULATE AND RESPOND TO TIMES WHEN OXYGEN IS LOW AND HOW DO THESE CHANGES AFFECT ANIMAL COMMUNITIES?

As dissolved oxygen concentrations decline, the habitat available to aerobically respiring organisms in benthic and pelagic ecosystems decreases, altering species composition and food web structure and dynamics. Although low-oxygen zones are inhospitable to aerobically respiring organisms, these environments support thriving microbial communities that mediate cycling of nutrients and radiatively active trace gases such as methane and nitrous oxide that can affect the climate.

In 2013, Ocean Networks Canada reached the seven-year mark of collecting long-term, continuous records of temperature, salinity, density, and dissolved oxygen in the oxygen-depleted zone in Saanich Inlet. This time series also includes imagery that records benthic community responses to periods of anoxia and acoustic records of changes in the daily vertical migration of zooplankton through the water column above the oxygen

QUESTION 8. Acoustic tracking of the daily migration of the zooplankton *Euphausia pacifica*. (Front face of cube) From the bottom near 95 m to the surface after sunset, spending the night feeding at the surface protected by darkness from visual predators, then descending to depth as day breaks. (Top face of cube) Width of bright coloured band shows how the time spent near the surface changes over the year with the length of darkness (courtesy of ASL Environmental Sciences).



minimum layer. The addition of a vertical profiler with an Environmental Sample Processor (currently capable of probing for specific genes) and sensors for nitrate, pH, and pCO_2 will enhance the sensing capability and continue to allow Saanich Inlet to be the ideal laboratory for study of oxygen-minimum zones in the open ocean, which are currently expanding in geographic extent.

QUESTION 9: HOW DO OCEAN TRANSPORT PROCESSES IMPACT PRIMARY PRODUCTIVITY IN THE NORTHEAST PACIFIC?

Ocean transport processes from molecular (diffusive/turbulent mixing) to large (wind, tides, currents) scales distribute heat, salt, and nutrients throughout the global ocean. Quantification of ocean mixing processes in areas of strong upwelling and productivity is needed to improve ocean circulation models that, in turn, improve our understanding of how ecosystems will be altered by climate change. An improved understanding of horizontal mixing at all scales, particularly at fronts and during storms, is also important for improving climate predictions. VENUS observations of currents, plankton, temperature, salinity, and oxygen are being used to validate ocean circulation models, which will improve our understanding of what factors regulate primary productivity.

NEPTUNE is positioned at the eastern edge of the North Pacific Current where it separates into the southward-flowing California Current and the northward-flowing Alaska Current. The California Current is one of the five major global upwelling systems. Moored water column instruments that measure currents, stratification, temperature, and nutrients (e.g., the existing vertical profiling system), combined with mobile assets (gliders) that delineate the extent of stable and mixing layers, could provide data to describe the temporal variability of mixing on a small scale, supplementing other upwelling area studies that collectively will advance our understanding of how mixing impacts nutrient supply and primary production and regulates benthic-pelagic coupling, leading to ecological variability.

INTERCONNECTIONS AMONG THE SEAFLOOR, OCEAN, AND ATMOSPHERE

Ocean Networks Canada observatories encompass a variety of oceanic environments. There are observatory nodes in active seafloor spreading regions that exhibit volcanic activity and hydrothermal venting and in continental slope environments that display active gas venting and where gas hydrates are exposed on the seafloor. The area covered by the observatories also contains an anoxic basin and swift-current-dominated straits with tidally driven turbidity events. Chemical and biological constituents are exchanged between these seafloor environments and the overlying water column. Some materials reach the ocean–atmosphere boundary where further complex interactions occur. For example, precipitation and evaporation modulate ocean salinity, waves heavily influence heat and gas exchange, particulates deposited onto the ocean from the atmosphere change surface ocean properties, and particulates injected into the atmosphere from the ocean aid in cloud formation.

QUESTION 10. A probe is inserted into a black smoker on Endeavour field to study chemical and heat exchanges.

QUESTION 10: WHAT ARE THE MECHANISMS AND MAGNITUDE OF CHEMICAL AND HEAT EXCHANGES BETWEEN THE OCEANIC CRUST AND SEAWATER?

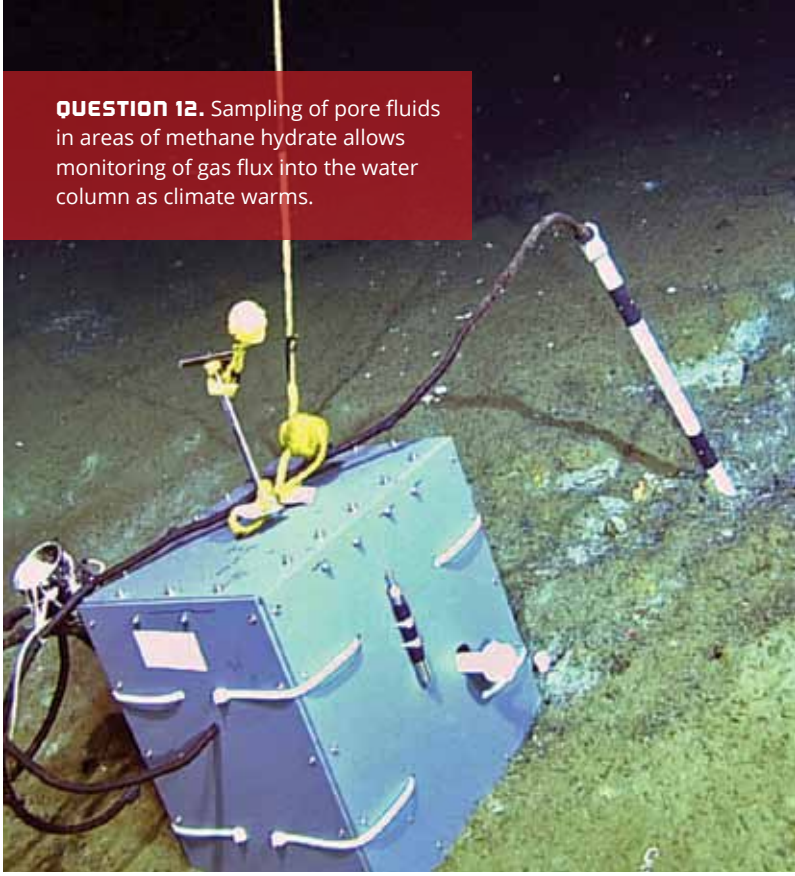
Void spaces and cracks in newly formed oceanic crust are filled with seawater. As seawater flows through this basaltic rock, driven by heat from subseafloor magma, it partially dissolves the rock, picking up chemical compounds. These heated, metal- and gas-rich fluids vent at the seafloor at mid-ocean ridges and on seamounts scattered throughout the ocean, contributing to the large chemical fluxes between oceanic crust and overlying seawater. Low-temperature vents are estimated to account for up to three orders of magnitude more fluid circulation than is exchanged at high-temperature black smoker vents.

Among mid-ocean ridge systems, Endeavour Segment of the Juan de Fuca Ridge is one of the best studied. The COVIS instrument, currently located at Endeavour Segment, measures fluxes from the seafloor into the water column using acoustic imagery. Sensors that determine fluid constituents and thermal fluxes should be expanded. On the eastern flank of the Juan de Fuca Ridge, Ocean Networks Canada monitors existing CORKed boreholes to understand complex subseafloor hydrology. New connections to existing CORKs would add to this long-term hydrologic observatory.

QUESTION 11: IN WHAT WAYS DO UPPER OCEAN PROCESSES INFLUENCE THE FORMATION OF AEROSOLS?

In situ measurements of surface ocean conditions are still rare, particularly during high-wind-speed events. Ocean-derived aerosols are some of the most important inputs to Earth's radiative budget, biogeochemical cycles, and ecosystems. Marine aerosol production from sea spray occurs at submicrometre particle scales and is affected by wind speed, sea surface temperature, and the biochemical composition of the source seawater. The source seawater is thought to be the surface ocean microlayer, which concentrates organic matter. There are almost no quantitative measurements of marine aerosol source components or processes involved in their production, despite the fact that this phenomenon may be a significant input to climate models. For example, bubbles and foam are known to play significant roles in aerosol formation. Key foam parameters that need to be quantified include their areal coverage and persistence.

VENUS's CODAR and ferry observations provide these data for the Strait of Georgia, but advancing knowledge of ocean-derived aerosols requires the addition of a radar system in the more open ocean. Photographic measurements can record the extent and persistence of foam. Hyperspectral remote sensing provides useful information on surface biology that is also related to surface chemistry. To complement the radar measurements and to augment the existing data on aerosols, NEPTUNE and VENUS could expand the mobile asset fleet, such as with unmanned aerial vehicles (UAVs) and surface gliders, each outfitted with a lightweight optical particle spectrometer that would record aerosol particle distributions over a wide range of sea states.



QUESTION 12. Sampling of pore fluids in areas of methane hydrate allows monitoring of gas flux into the water column as climate warms.

QUESTION 12: HOW LARGE IS THE FLUX OF METHANE FROM THE SEAFLOOR TO THE ATMOSPHERE?

Fluids expelled during subduction-driven sediment compaction drive an active hydrogeologic system on the Cascadia margin. The discharge of carbon-rich gases and fluids from the seafloor affects marine ecology, ocean chemistry, and atmospheric composition. Methane expelled at micro- and macro-seeps, mud volcanoes, and other seafloor features is now considered the second largest natural source of atmospheric methane after wetlands and is a potentially important contributor to global warming. Seafloor methane flux estimates range from 40 to 60 Tg/yr. Thus, changes in the flux of methane from geological sources must be determined and included in estimates of the global atmospheric methane budget.

Clayoquot Slope (ODP Site 889) and Barkley Canyon areas host buried and outcropping methane hydrate. Experiments to estimate

methane flux from the seafloor are already in place using *Wally*, but improved measurements using mass spectrometry would enable quantification of hydrate composition and fluxes. Sector scanning sonar and other in situ seafloor mapping systems are ideally suited for repeated measurements of the changing shape and size of carbonate-crusted hydrate mounds. Cameras and passive acoustics can be used to document bubble flux from the seafloor into the water column and active acoustic sensors can measure the fate of bubbles during buoyant ascent. Fluxes across the ocean-atmosphere boundary can be studied by adding surface gliders and regular, repeat UAV overflights at Barkley Canyon and Clayoquot Slope. UAVs are currently being tested in the NEPTUNE area.

QUESTION 13: WHAT ARE THE ADVANTAGES AND RISKS OF OCEAN GEOENGINEERING TO MITIGATE CLIMATE CHANGE?

Sequestration of excess CO_2 associated with fossil fuel emissions is viewed as one of the best approaches for mitigating climate change. Two of the mitigation mechanisms considered by the scientific and geoengineering communities are of interest to Ocean Networks Canada. First is to inject CO_2 into voids in young basalt because of its vast reservoir capacity. Oceanic crust has closed circulation pathways that stabilize CO_2 through chemical reactions, and there is low risk of post-injection leakage back into the ocean and ultimately into the atmosphere. A second mechanism proposed by the geoengineering research community is to increase the amount of solar radiation reflected back into space through increasing cloud cover generated by emitting sea spray into the marine boundary layer from wind-powered ships. It is hypothesized that these artificial aerosols would act as cloud condensation nuclei, increasing the density of marine stratocumulus clouds and albedo.

NEPTUNE has the potential to support ocean-related geoengineering research to assess approaches to carbon sequestration and aerosol generation and their environmental implications. For example, existing or new boreholes on the network could be used as test CO_2 injection wells, with associated seafloor and borehole sensors recording numerous variables pre- and post-injection over the long term. Surface artificial aerosol experiments could be conducted in an open sea area where long-term monitoring could document impacts on the ecosystem. This latter method does not necessarily reduce the invasion of excess atmospheric CO_2 into the ocean, which is currently reducing the ocean's pH.

SEAFLOOR AND SEDIMENT IN MOTION

QUESTION 14. Seismometers placed on the seafloor permit more accurate location of earthquakes, leading to a better understanding of the local tectonic regime.

Most of the world's largest earthquakes occur offshore in subduction zones, such as Cascadia. They directly impact society when the resulting ground shaking causes death, injury, and infrastructure damage. Vertical seafloor movement that occurs during subduction earthquakes and submarine landslides induced by earthquakes and storms are the most common cause of tsunamis. Scientists use geological data to help constrain recurrence intervals of these large earthquakes, but the uncertainty is too large to be used to predict future events. However, once a subduction fault starts to rupture, it is possible to analyze the initial earthquake P waves recorded on seismographs to give warnings of tens of seconds before the more destructive S waves reach our cities and to give warnings of half an hour to hours before destructive tsunami waves reach the shore. Combining information from our observatories with land instruments will make for the most effective warning systems and is an endeavour in which Ocean Networks Canada is actively engaged with operational agencies.

QUESTION 14: HOW IS THE PHYSICAL STATE OF THE SUBSEAFLOOR IN THE NORTHEAST PACIFIC RELATED TO EARTHQUAKE GENERATION?

The Northeast Pacific tectonic regime includes mid-ocean ridges, fracture zones, and a subduction zone capable of generating megathrust earthquakes. NEPTUNE seismometers record earthquake activity on the Juan de Fuca and North American plates at all nodes with the exception of Folger. Additional seismometers installed on the Juan de Fuca Ridge would permit more accurate location of local earthquakes, leading to a better understanding of the relationship between tectonics and ridge volcanism. NEPTUNE's Middle Valley node provides a stepping stone for the installation of a set of three seismometers and bottom pressure recorders, each located on a different tectonic plate (Juan de Fuca, Pacific, and Explorer). These future instruments would increase understanding of tectonic relationships among these plates, and would provide an offshore geodetic approach to earthquake research.

Japanese scientists identified slow slip along the earthquake-generating fault as a potential precursor to the 2011 Tōhoku megathrust event. Installation of strain gauges in boreholes on the NEPTUNE observatory would provide a direct measure of slow slip on Cascadia's major subduction zone fault. In addition, fluids under high pressure are thought to play a role in controlling slow slip. The NEPTUNE observatory is already recording long time series of temperature and pressure in boreholes, and integration of these data on fluid flow and fluid pressure changes with other tectonic measurements is continuing. All these measurements will complement the land-based networks that are being used to study slow slip along Cascadia, advancing research in this important area.

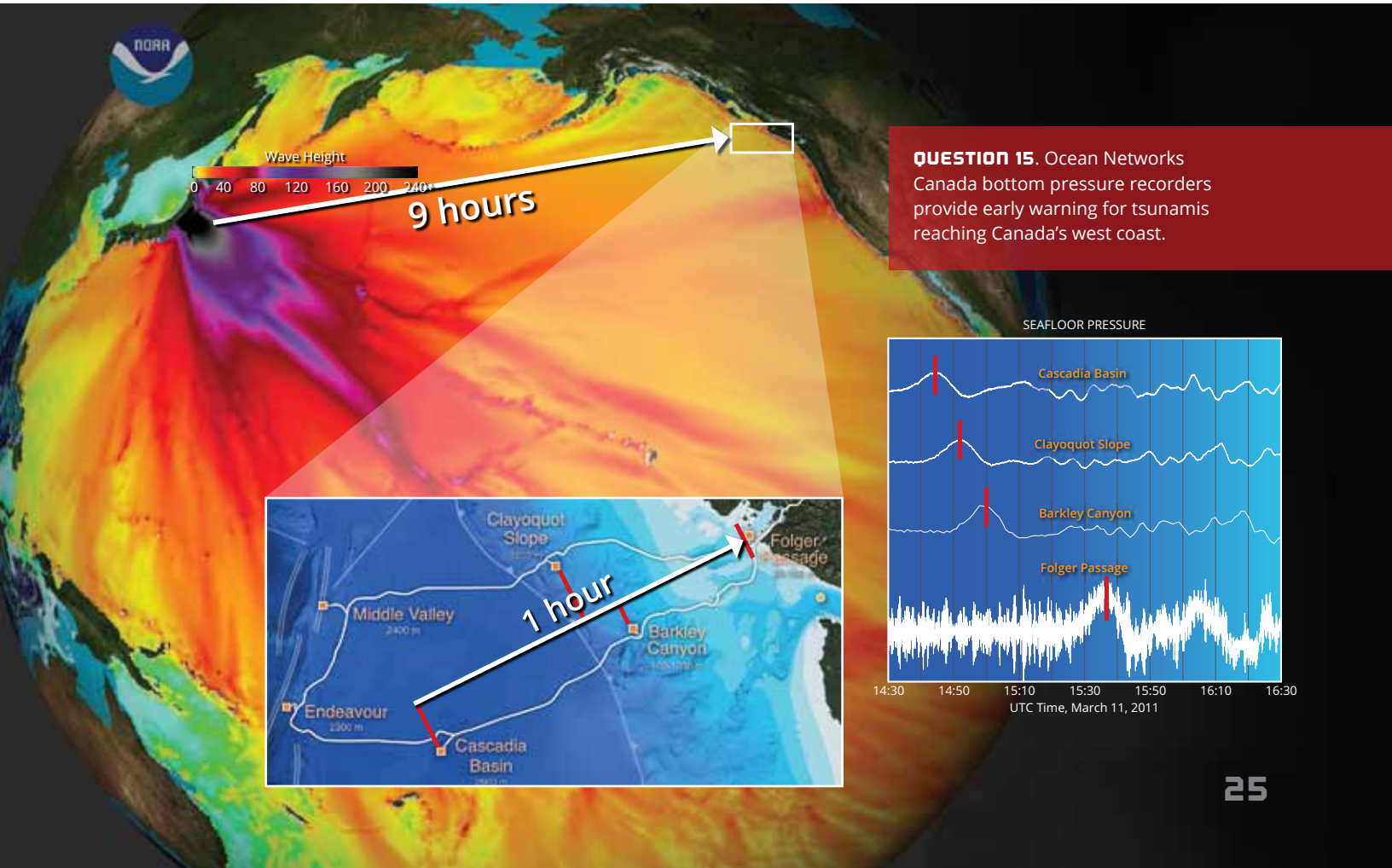
Existing NEPTUNE instruments should be modified to provide automatic detection of P waves, which indicate initiation of an earthquake. Real-time transmission of data from detected events

to laboratories on shore could potentially be used to provide up to one minute of warning to cities, such as Vancouver and Victoria, of the arrival of seismic surface waves that cause the most ground shaking and damage.

QUESTION 15: HOW CAN WE IMPROVE PREDICTION OF THE SPEED AND SIZE OF TSUNAMIS?

With wave heights over 20 metres, tsunamis can inundate and potentially destroy coastal communities, as demonstrated by the 2004 Indian Ocean and 2011 Japanese tsunamis. NEPTUNE's bottom pressure recorder-based tsunami sensors have improved tsunami models that forecast tsunami wave heights. A significant improvement at NEPTUNE would be to complete installation of a triangular array of bottom pressure sensors at Cascadia Basin (ODP Site 1027). Real-time data from this sensor array will provide wave speed and direction that could be used in conjunction with regional numerical tsunami models for real-time warning.

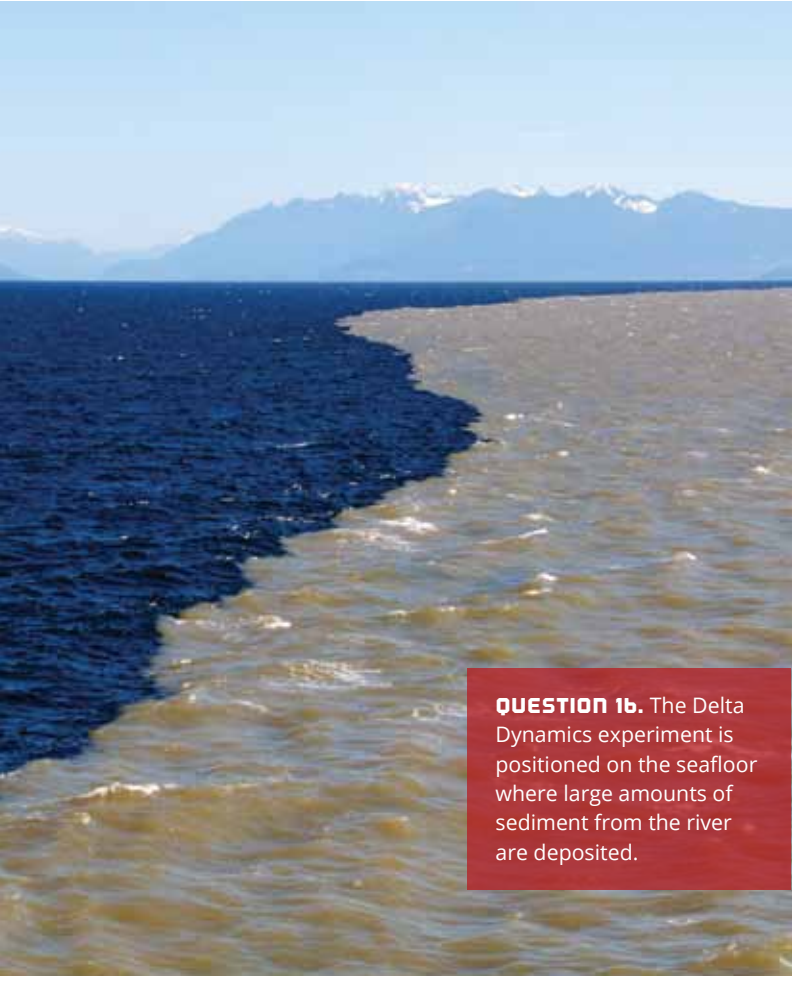
Large earthquakes could trigger underwater landslides on unstable slopes, resulting in tsunamis that would inundate adjacent coastal cities. Increased pore pressure in sediment is an indicator of unstable slope conditions. The VENUS observatory supports subseafloor pore pressure sensors in the Fraser River delta. An improved and more extensive array of pore pressure sensors would enable seafloor instability maps to be produced, indicating the areas of greatest potential for landslides during extreme flood events and earthquakes, and provide input to forecast models of landslide-induced tsunamis.



QUESTION 15. Ocean Networks Canada bottom pressure recorders provide early warning for tsunamis reaching Canada's west coast.

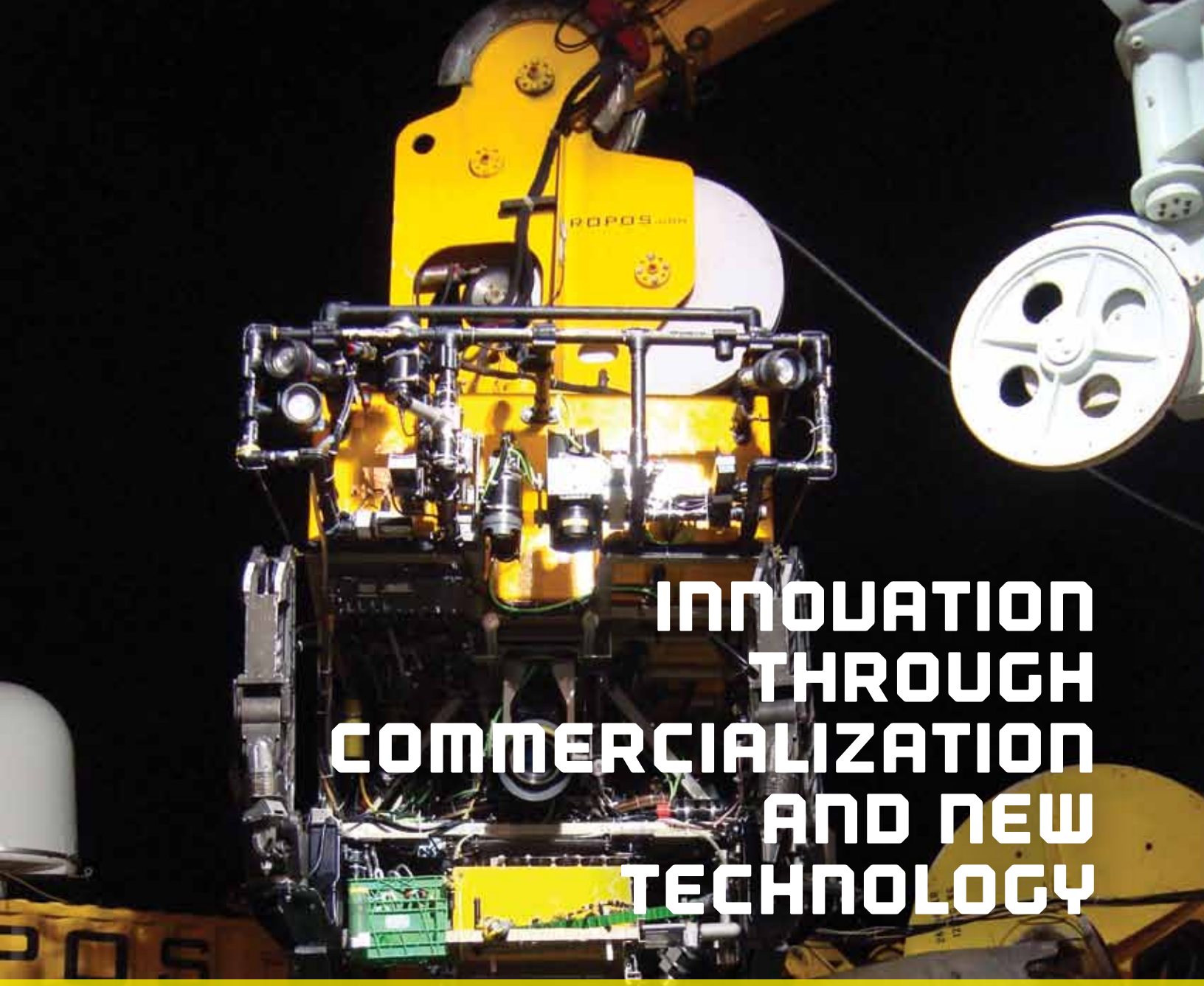
QUESTION 16: WHAT MECHANISMS REGULATE UNDERWATER LANDSLIDES ON THE FRASER RIVER DELTA?

Underwater landslides near coasts have led to hundreds of millions of dollars in damage to infrastructure and pose a tsunami threat to coastal areas. In fact, in Canada, a country preparing a world-class tsunami warning system, the only documented deaths by tsunami to date have been a result of underwater landslides. Infrastructure projects on unstable seafloor slopes around the world would benefit from a better understanding of the mechanisms that precondition seafloor sediment for failure or that trigger underwater landslides at deltas.



QUESTION 16. The Delta Dynamics experiment is positioned on the seafloor where large amounts of sediment from the river are deposited.

The Fraser River delta is the ideal location for a laboratory to examine how relevant processes can precondition sediment. The Ocean Networks Canada extension cable to the delta has permitted measurement of key processes at all times scales. Previous attempts by Natural Resources Canada (and other groups around the world) using battery-powered moorings were either unable to record at high data rates, or the batteries expired before landslides were measured. In all previous measurements, the slow data rates required to extend the operating life of a mooring to a year or more to increase the likelihood of capturing a landslide meant that at most one or two properties could be measured during an event. Ocean Networks Canada can continue to be a leader in this area of study by developing new sensors to measure more variables that can affect slope stability.



Innovation through commercialization and new technology

NEPTUNE and VENUS, the first multinode cabled undersea observatories, have been archiving and serving data since early 2006. For Ocean Networks Canada observatories to maintain leadership and benefit Canadians, Ocean Networks Canada, through its Innovation Centre (previously called the Centre for Enterprise and Engagement), must continue to adopt new technologies where they exist and facilitate new developments where they do not in cooperation with industry, government, and academia. In particular, maintaining a robust observatory infrastructure depends on the development of reliable components. Scientific requirements will drive advances in deep-sea instrumentation, leading to the development of new sensor types and the adaptation of existing instruments for cabled observatory deployments. Analysis of the large volume of high-resolution data will necessitate advances in modelling, data management, data visualization, automated event detection, and real-time control. Meeting these challenges will enable and enhance the oceanographic research conducted with the observatory assets, in addition to contributing to fundamental advances in engineering and computational research.

NEW SENSORS, PLATFORMS, VEHICLES, AND ARRAYS

Ocean observation depends on the availability of effective sensors. A mass spectrometer, passive listening devices, and pH, pCO_2, methane, and gas bubble sensors have already been identified as essential. In addition, some existing sensors and instrument packages need to be adapted for long-term deployment, including incorporation of new approaches for maintaining calibrated instruments.

Constraints imposed on oceanographic studies by the locations of Ocean Networks Canada cabled nodes can, to some extent, be overcome by future use of autonomous underwater vehicles such as gliders and autonomous recording instruments. To maximize utility of autonomous vehicle data, their navigation systems need to be integrated with those of the Ocean Networks Canada observatories.

Power for autonomous underwater vehicles could come from docking stations connected directly to nodes. The docking stations would have multiple roles—they would provide a safe parking position for the vehicle between missions and act as a battery charging station and data download/mission upload terminal. With the docking station connected close to the node, power of up to several kilowatts would be available to quickly charge high-capacity batteries.

"Smart" instruments can react to environmental changes and adapt their behaviour through machine learning. It is anticipated that increasing computational power will not significantly raise power consumption. Very low power processors such as the ARM chips used in smartphones are capable and easily programmed. Their use in smart junction boxes might be included in the future, for example, to enable instruments' behaviours to be modified to capture events detected locally.

Sensor arrays, most notably those composed of two- or three-dimensional matrices of hydrophones with dozens of sensors digitized at 192 kHz, have already been considered for deployment (currently a three-hydrophone array is deployed in the Strait of Georgia). While large arrays would require large bandwidth capabilities, a nominal array of 100 such hydrophones would produce a sustained throughput of ~60 Mbps, well within the current capabilities of each node. Three-dimensional imaging from underwater camera arrays still suffers from refraction of light. Researchers are now developing novel algorithms to deal with refraction: their test subject is a sessile (non-mobile) benthic suspension feeder (a sponge) that is imaged from an array of eight high-resolution cameras installed at Folger Pinnacle off Barkley Sound.

DATA FUSION AND VISUALIZATION

Data fusion from visual and nonvisual sensors (e.g., combining sonar and video/image data to create visualizations) will yield new data products and enhance the research conducted on the network. Visualization efforts will include:

- Conducting multibeam surveys and processing, archiving, and sharing these data
- 3D visualization and integration with other environmental variables (e.g., currents, temperature)
- Generation of visual data from nonvisual data sets (e.g., spectrograms, visual representations of echosounder and acoustic Doppler current profiler data)
- Web-based real-time interactive visualization of underwater phenomena (e.g., Endeavour mooring current data)

Automated processing of large data sets will include data abstraction based on automated detection of salient events; production of shorter, more information-rich annotated videos; automating biologically relevant observations (e.g., species counts, organism density, species identification); interpreting and identifying features

detected in sonar data (e.g., seafloor sediment pits) using computer visualization techniques; and computer vision-based event detection (e.g., presence/absence of bubble plumes, bubble counts, and rates). Concomitant with new processing and visualization data products, new tools are needed for video and image management to permit annotation for easy searching, querying videos by example or keyword, and content-based image and/or video retrieval.

Event Detection, Responsive Sampling, and Remote Experimental Manipulation

Continuous monitoring of environmental variables permits sampling in response to a change in conditions, such as the density structure of the water column, circulation pattern, phytoplankton bloom or other organic deposition event, increased sedimentation, and venting or gas release. The timing of these fluctuations may be broadly predictable (e.g., the timing of the spring bloom, arrival of a distant tsunami), but the exact onset of these events can only be determined with Ocean Networks Canada-like continuous monitoring. For some extreme or rare events, the timing can be unpredictable (e.g., earthquakes, local tsunamis, weather). Once an event is detected, sampling must begin rapidly to capture associated changes in geological, physicochemical, and biological conditions. Such a rapid response is not possible using ships.

Cabled observatories make it possible to sample an event within a few hours after detection. Addressing research questions such as those related to environmental change requires a combination of: (1) continuous monitoring to provide baseline information and (2) responsive sampling during extreme or rare events to capture a response at the appropriate temporal scales and resolution. Instruments might be reprogrammed to increase sampling frequency and intensity or to alter sample collection timing to better coincide with event characteristics such as current reversals or deposition pulses. The Ocean Networks Canada observatories provide the means for both continuous long-term sampling and the rapid response to individual events.

Modelling in Ocean Networks Canada

Over the next five years, data from Ocean Networks Canada observatories will be used in the development of ocean models from local and regional scales to ocean basin and global scales.

On very small scales at Endeavour, in Barkley Canyon, and in the near-bottom layers of Saanich Inlet and the Strait of Georgia, acoustic Doppler current profilers, video cameras, and acoustical particle and turbulence sensors are probing the ocean's bottom boundary layer. The scientific objectives vary at each site, from estimating the transport of materials and gases ejected from hot vents, to determining physical and chemical stresses on organisms that live at the bottom of the ocean, to determining the resuspension, transport, and eventual relocation of sediment, dissolved materials, and planktonic larvae in areas of high tidal currents. Opportunities exist to use these data in developing and evaluating purpose-built, very high-resolution transport and mixing models of the bottom boundary layer. These models must be embedded in high-resolution coastal numerical models, such as ROMS (Regional Ocean Modeling System) framework-based models developed at the Institute of Ocean Sciences, Fisheries and Oceans Canada, and NEMO (Nucleus for European Modelling of the Ocean framework), which is being implemented by MEOPAR (the Marine Environmental Observation, Prediction

and Response network) and the Canadian Centre for Climate Modelling and Analysis of Environment Canada.

MEOPAR is a new Canadian Network of Centres of Excellence. Ocean Networks Canada is partnering with MEOPAR to develop a "relocatable" ocean forecasting model (based on the NEMO architecture) that can be deployed within days anywhere in Canadian coastal waters along with limited observing platforms in the event of a marine environmental emergency (e.g., oil or chemical spill, ship in distress). The first test deployment of the relocatable model will be in the Strait of Georgia using existing observations from Ocean Networks Canada as well as surface wind forcing on a 200 m grid from an operational model developed by Environment Canada for the 2010 Winter Olympics.

The ocean research community is actively assimilating data into regional and global models to provide regular, complete descriptions of temperature, salinity, and vertical structure of the ocean on different time scales. Ocean Networks Canada data are being made available for global ocean data assimilation projects such as GODAE (Global Ocean Data Assimilation Experiment) and GODAS (Global Ocean Data Assimilation System) in their specified format and for regional ocean models that rely on assimilating data from the Northeast Pacific. Similarly, Ocean Networks Canada data will be made available to ocean and climate modellers in near-real time, for example, to initialize regional tsunami warning models.

STIMULATING NEW CANADIAN TECHNOLOGY

Ocean Networks Canada, through its Innovation Centre, continues to expand partnerships with Canadian industry and to position Canada as an international leader in ocean observing science and technology. First funded in 2009 as the ONC Centre for Enterprise and Engagement, Ocean Networks Canada is currently applying for additional funding to achieve sustainability under its new name, the ONC Innovation Centre. The Innovation Centre has successfully leveraged the technology and know-how from the premier ocean observatories, NEPTUNE and VENUS, to advance the Canadian ocean industry sector. The Innovation Centre will achieve sustainability by strengthening existing and building new industry partners in its three successful markets: sensor technology, observing systems, and digital infrastructure. The Centre's business model for achieving sustainability includes leveraging activities with partners, building national ocean technology membership in the Centre, securing international revenues from a range of observing services, and developing a portfolio of unique ocean industry services ranging from new technology demonstrations to product development.

These activities—demonstrating and testing new technologies and systems—are not only limited to working with industry. The Natural Resources Canada Delta Dynamics Laboratory located on the VENUS observatory off the mouth of the Fraser River probes the stability and vulnerability of the leading edge of the delta to underwater landslides, which can trigger tsunamis. When mature, this technology may be transferred to other marine deltas or areas prone to underwater landslides in Canada to assess these risks in other locations.

GROWING RESEARCH AND DEVELOPMENT COMMUNITIES

Data from Ocean Networks Canada's underwater observatories are freely available in as close to real time as possible. Our multinode network of cabled observatories—the first in the world—is helping to transform how ocean science is conducted. Because the Canadian ocean sciences community is finite, expanding the ocean observatory research community requires that we continually seek out two types of new international collaboration: (1) researchers whose primary work involves the Ocean Networks Canada observatories, such as the German group that operates the tethered bottom crawler *Wally,* and (2) organized multi-observatory studies, such as the Intergovernmental Oceanographic Commission's International Quiet Ocean Experiment and the Global Ocean Observing System. By contributing to these international cooperative programs, Ocean Networks Canada will gain access to data from the observing networks of many countries around the globe, leading to a deeper understanding of how large-scale climate-related changes are impacting British Columbia waters.

THE NEXT GENERATION OF OCEAN SCIENTISTS AND ENGINEERS

Addressing the stresses facing the ocean, including those related to climate change, requires a well-educated and technically astute workforce. Ocean Networks Canada's observatories are ideal platforms for training this next generation of scientists and engineers because of the breadth of research it enables and the sophisticated technology it deploys. Ocean Networks Canada will engage undergraduates, graduate students, and postdoctoral fellows, along with their major professors, with its online collaborative tools, hands-on workshops, ebooks, and other video-rich content. Ocean Networks Canada will provide students with the tools needed to undertake research projects at their own institution. Ocean Networks Canada, in collaboration with the US Ocean Observatories Initiative, is pursuing funding from the US National Science Foundation Research Experiences for Undergraduates program under an information and communication technologies theme. Increasing opportunities for undergraduates to conduct research is a key plank in the current Strategic Plan for the University of Victoria.

TRAINING FUTURE OBSERVATORY RESEARCHERS

Training is different for researchers using the cabled observatory compared with those using more traditional data collection methods. The main challenge in using observatory data is learning how to handle extremely large and diverse data sets. Ocean Networks Canada's users will need to receive additional training in data management, statistical and pattern-recognition techniques, programming, sensor technology, and modelling.

Instrumentation purchased off the shelf is rarely optimal for specific scientific tasks. Sensors need to be well understood before they are used. Careful testing of sensors, performance modelling, and reconciliation of model results with measurements are required to maximize the quality of data acquired by ocean observatories. Ocean Networks Canada will develop educational programs for workshop settings that will advance students' understanding of sensors used in the observatory and their limitations in a wide range of ocean conditions, resulting in higher-quality research outputs. Currently, Ocean Networks Canada collaborates with engineering faculties to use observations as source data for student projects in a senior-level signal processing and pattern recognition course. This activity is being expanded to other faculties and universities.

COMMUNICATING OBSERVATORY SCIENCE

Communicating scientific results is an important part of public and scientist engagement at all levels. Ocean Networks Canada's communications strategy promotes engagement of a broad audience, from specific science users, to the broader community of ocean and Earth scientists, to potential government and industry users. The strategy includes:

- Maintaining a high-quality Internet presence, including a special Web presence (e.g., live video cruise portals such as "Wiring the Abyss 2013")
- Actively participating in conferences (sessions, booths)
- Contributing to theme/location/technical workshops and sessions
- Presenting at and participating in speakers' bureaus

Ocean Networks Canada supports a visiting scientists program to engage users from across Canada and other countries. These scientists are hosted at headquarters where they work with the science team on specific research programs and on the development of new technologies or new applications of observatory data. Similarly, Ocean Networks Canada supports undergraduate and graduate student interns who work with researchers to develop new data products or tools.

In addition to the Web-based products, Ocean Networks Canada will develop:

- E-books and other publications (e.g., Invitation to Science, data stories)
- Media stories for TV, radio, news, websites, magazines, events, and special publications
- Museum and aquarium displays

DEVELOPED THROUGH

A consortium of 12 Canadian universities
Government labs and international institutions

MAJOR FUNDERS

Government of Canada
Canada Foundation for Innovation
Government of British Columbia
Natural Sciences and Engineering Research Council of Canada
Western Economic Diversification Canada
Canada's Advanced Research and Innovation Network
National Centres of Excellence

IN PARTNERSHIP WITH

Federal and provincial departments and agencies
US and international academic institutions
Canadian, US and international companies

OCEAN NETWORKS CANADA

CONTACT

Ocean Networks Canada
Technology Enterprise Facility (TEF)
University of Victoria
160 – 2300 McKenzie Avenue
Victoria, BC Canada V8P 5C2
250.472.5400
info@oceannetworks.ca

Follow us on **Twitter** | Like us on **Facebook**

oceannetworks.ca

AN INITIATIVE OF University of Victoria