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.
Oceans Networks Canada's community observatory in Cambridge Bay, Nunavut, installed in 2012, is the first location in Canada's Arctic for year-round continuous undersea monitoring of the northern coastal environment.
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 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 observatories 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 realtime. These facilities extend and complement other research platforms and programs, whether currently operating or planned for future deployment.

Smart Ocean Systems™ combine existing and new marine sensing technology with Oceans 2.0 so that coastal and offshore areas of Canada can be managed safely, following environmentally sound approaches. The system includes an expanded network for:

- Public safety through natural hazard warning for earthquake ground-shaking, underwater landslides, and near-field tsunamis using NEPTUNE and VENUS sensing technologies;
- Marine safety by monitoring and providing alerts on sea state, marine mammal locations, and ship traffic; and
- Environmental protection by gaining a baseline of critical areas – information for science-based decision-making – and providing realtime environmental observations for managing operations and accidents should they occur.

The Canadian and international research, educational, maritime 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 over the next five years (2016–2021). To achieve these goals, priority actions were developed and set out in an internal action plan. Foundational to all of these actions is the scientific research enabled by the observatories and described in the science section of this plan.

While this Strategic Plan focuses on the observatories’ research and commercial potential, Ocean Networks Canada’s scientific and technology footprint will continue to expand through collaborations with other programs and observatory efforts.

Jim Roche
Chair, Ocean Networks Canada Board of Directors

An octopus inhabiting a CORK drillhead was captured by the remotely operated during an annual maintenance expedition.
In 2015, Ocean Networks Canada conducted a detailed strategic review to align the Strategic Plan with the expanded stakeholder community that includes new scientific areas of research (e.g., along the British Columbia coast and in the Arctic Ocean) and other partners (e.g., ports, industry, and government). This retrospective look resulted in a fresh strategic vision that requires Ocean Networks Canada to deliver on its goals through directed actions by all staff. Together, these elements — vision, key goals, and action — form the foundation of this Strategic Plan from 2016 through 2021.

**VISION**
Ocean Networks Canada enhances life on earth by providing knowledge and leadership that deliver solutions for science, society and industry.

**KEY GOALS**
1. Become indispensable to the Federal and BC governments and the national and international ocean science community. “The go-to organization of ocean science”.
2. Develop & deliver world-leading ocean data, products and services “A bridge between academia and commerce”
3. Expand infrastructure nationally “A network of underwater observatories around the country”.
4. Develop brand and enterprise leadership capabilities “Become deliberate, united and focused organization that is one of Canada’s top employers”

**ACTIONS**
To reach these goals over the next five years Ocean Networks Canada will:
- build world-leading reputation and awareness;
- create invaluable partnerships;
- ensure stable, ongoing funding;
- deliver reliable infrastructure;
- lead with innovative solutions;
- develop progressive data strategy and execution;
- expand the user community; and
- create an engaging culture.
The Ocean Networks Canada observatories facilitate research that addresses important science questions. Ocean Networks Canada disseminates these 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 used for public policy purposes are important considerations 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, and 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 has strong partnerships with federal and provincial science-based departments and agencies. Ocean Networks Canada carefully and critically assesses the alignment of its scientific programs with the evidence-based policy needs of these departments. 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 develops close collaborations with this community to maximize the overall public benefits and policy impacts of the research as described in the Science Plan section.
Ocean Networks Canada (ONC) is an international facility hosted and owned by the University of Victoria, and managed and operated by the ONC Society, a not-for-profit established by the University of Victoria in 2007. ONC operates world-leading NEPTUNE and VENUS ocean observatories with no other equivalent in Canada. ONC collects and provides essential data required to address pressing scientific questions and policy issues.

The innovative cabled infrastructure supplies continuous power and Internet connectivity to a broad suite of subsea instruments from coastal to deep-ocean environments. ONC also supports sensors installed on ferries, gliders and moorings, coastal radar, and community-based observatories located in remote locations (e.g. the Arctic, along the BC coast, and in the Bay of Fundy). They are a crucial investment for Canada because these observatories collect data on physical, chemical, biological, and geological aspects of the ocean over long time periods, supporting research on complex ocean system science.

ONC also has an Innovation Division that commercializes these advanced ocean observing technologies. The planning for an integrated, international ocean observatory system extends back to the late 1990s when a joint Canada-U.S. approach was envisioned. Thanks to funding from CFI, Canada was able to move ahead while the U.S. plans were delayed for several years.

The U.S. Ocean Observatories Initiative (OOI) is slated to become operational in 2016, and the international vision now has the potential to be achieved in the northeast Pacific Ocean. OOI in the Pacific includes a cabled array similar to ONC’s NEPTUNE observatory, coastal systems similar to VENUS, and an observatory located at Station Papa. OOI research themes align with ONC initiatives, thus global “competitiveness” will be greatly enhanced through connecting OOI and ONC together as an international enterprise.

The overall observing power that spans an entire tectonic plate and the overlying ocean that extends to weather Station Papa is markedly augmented as an international enterprise. With OOI operational, we expect a growth in community and technological advances, with the potential to increase international interactions to address greater complexity questions in Earth and ocean system science. No other cabled networks serve multi-disciplinary user groups in realtime, with interactive access to instruments and large data volumes. Moreover, the ONC networks provide an open and scalable architecture allowing researchers to attach new instruments, taking advantage of continuously available power. On many existing cabled or other ocean observatories, data are unavailable except to a select group

Operations and maintenance expeditions include cable recovery and installations which are supported by a Global Marine cable ship home-ported in Victoria, British Columbia.
of researchers, few “live ocean data” are available (rather, only summaries of averaged conditions), data may not be downloadable, archived data are either unavailable or very difficult to access, and/or visualization capabilities are rudimentary, at best. The observatory facilities currently operating represent many important achievements, but none come close to the hundreds of instruments currently reporting from the ONC observatories. The ability to accommodate high current/voltage systems in a flexible deployment design with the wide variety of sensors to serve all disciplines is unique to ONC. A key aspect of ONC that stands out from other systems operating today is the sophisticated interface for users (Oceans 2.0), including the ability to interact with specific instruments, download data in a variety of formats, explore visual and acoustic data sets, and create a variety of plots and images. Oceans 2.0 features data and information for the public and educators.

Earth processes, including climate change, in ways not previously possible. ONC is unique on the global stage because the infrastructure makes these data available, free and in realtime, from hundreds of instruments distributed across the most diverse ocean environments found anywhere on Earth.

The ONC Innovation Division provides business development functions for ONC through new technologies and data products that inform good decision-making about ocean management and ocean use. Ocean management and use is exemplified through ONC’s Smart Ocean Systems™ installations that build upon the NEPTUNE and VENUS technologies and are being installed along the west coast of Canada. These systems not only deliver new infrastructure to conduct coastal ocean research, but also use ONC technologies for public and marine safety and environmental monitoring for even broader benefit to Canada.
The Science Plan is organized under four themes:

1. Understanding Human-Induced Change in the Northeast Pacific Ocean.
2. Life in the Environments of the Northeast Pacific Ocean and Salish Sea.
3. Interconnections Among the Seafloor, Ocean, and Atmosphere.
4. 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 realize benefits to Canadians. Although the observatories are regional in scope, they attract many international researchers. In addition to ocean scientists the “big data” produced by Ocean Networks Canada and the challenges they create represent a rich resource for computer scientists. Finally, social scientists conduct research on the use of data products that impact society. 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 AND ARCTIC 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 pCO2 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 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 pCO2 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.

CAN WE INSERT A MAP of BC Coastal here and talk about the Coastal Question in a caption?

Determining the key environmental sensitivities across the diverse coastal margins of Canada’s oceans and the health of the coastal environment are key coastal science questions.

The vast character of Canada’s coastal marine environments results in a long list of regional parameters that are key for assessing the state of the coastal habitat. In some locations low oxygen or pH conditions are key, while in others the pressing issues are related to coastal erosion, industrial pollution, or changes in land-fast sea-ice during fall freeze-up or spring melt. ONC’s installations in a number of coastal communities along the BC coast and in the Arctic will start addressing those questions, together with the quantification of industrial impact (i.e. ship noise), and data products leading to improved transport safety.

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
Three British Columbia Ferries are now instrumented allowing scientists to observe ocean surface properties continuously while ferries transit the Strait of Georgia between Vancouver and Vancouver Island.

Ecosystem Function. Cameras show high abundances of juvenile squat lobsters when oxygen levels are lowest.

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 pCO2 (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).
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.
How are changes in the Northeast Pacific and Arctic 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 and future Ocean Networks Canada infrastructure including mobile platforms will continue to provide data that contribute to understanding population dynamics of a number of marine species in the Strait of Georgia and the Arctic, including out-migrating juvenile salmon from the Fraser River. Satellite imagery, in conjunction with 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 and vertical profilers can 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 as well as anthropogenic sources (e.g., ship noise) and serve as the basis for impact assessments. Altogether, ONC’s observing assets will provide indices on marine ecosystem health and qualification of human impact.

Recent advances in computer vision, pattern recognition, and data mining will enable the automatic understanding and discovery of salient data patterns and events of interest.

Interdisciplinary collaborations are crucial to optimize development of relevant computational methods for scientific discovery across all science themes. For instance, computer vision techniques will be used for monitoring species abundance, as well as detecting behavioural patterns of organisms from video data and still camera imagery. Similarly, 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.
The remotely operated vehicle collects push cores of sediment in Barkley Canyon for studies of benthic organisms.

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

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 seafloor 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 7: What limits life in the subseafloor?

It is estimated that the subseafloor contains up to one-third of Earth’s biomass. In subseafloor sediments, 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 the subseafloor 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 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 pCO2 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:
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-windspeed 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: 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 oceanatmosphere boundary can be studied by adding surface gliders and regular, repeat UAV overflights at Barkley Canyon and Clayoquot Slope. AUVs 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 CO2 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 CO2 into voids in young basalt because of its vast reservoir capacity. Oceanic crust has closed circulation pathways that stabilize CO2 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.

The NEPTUNE observatory 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 CO2 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 CO2 into the ocean, which is currently reducing the ocean’s pH.
Coastal communities are facing a wide range of rapid ocean changes. Having access to up-to-date scientific data is essential to enable communities to make informed decisions about their own coast.

Inuksuks are handmade stone cairns used by Indigenous people to navigation home from the tundra.

Question 14:
How are Canada’s coastal marine environments impacted by climate change and how should we best monitor these impacts?

Climate change may result in both slow steady trends, or it can manifest itself as abrupt and significant events superimposed on the background variations. Monitoring at strategic locations in order to collect the necessary long-term time series necessary to quantify and measure climate change is offset by the need to make specific measurements at locations already experiencing rapid variations. Two key examples include the monitoring of sea-level rise and the evolution of storm surge conditions for coastal infrastructure requires long-term pressure records, while monitoring increases in ocean acidification and the encroachment of low pH seawater near aquaculture facilities requires real-time detection and reporting. ONC’s installations monitor both long-term variations, and provide immediate notification of specific conditions important for commerce and safety.
Brightly coloured deep-sea coral grows on volcanic rock at Main Endeavour Vent Field.

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 15:**

**How is the physical state of the subseaflor 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 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 possible 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 Tohoku 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.

Additional sensors on either sides of the Cascadia subduction zone, supplemented by a dense land-based network of accelerometers provide automatic detection of P waves, which indicate initiation of an earthquake. Real-time transmission of data from detected events to a central compute centre on shore is 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 16:
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 helped improve 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 subseaflloor 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.

Modelling is critical for advancing research in oceanographic and public safety domains. Statistical modelling and numerical analysis methods are employed for predictive analysis. High-performance computing systems and cloud computing are needed to meet big data challenges and ONC has invested in them. Accurate modelling in any area, but including tsunami, depends on integration of data from multiple sources including, for example, Environment Canada, Natural Resources Canada (NRCan), the National Oceanic and Atmospheric Administration (NOAA) and community and local research initiatives. This need for data exchange necessitates leadership in data interoperability and collaboration on international data and metadata standards.

Question 17:
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.

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.
DESIGNATED AS ONE OF CANADA’S FOUR MAJOR SCIENCE INITIATIVES—AND THE ONLY ONE IN THE OCEAN—OCEAN NETWORKS CANADA IS AN INITIATIVE OF THE UNIVERSITY OF VICTORIA, FUNDED BY THE GOVERNMENT OF CANADA, AND INVOLVES PARTNERSHIPS WITH INDUSTRY.