Transformative ocean science through the VENUS and NEPTUNE Canada ocean observing systems

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Abstract

The health of the world's oceans and their impact on global environmental and climate change make the development of cabled observing systems vital and timely as a data source and archive of unparalleled importance for new discoveries. The VENUS and NEPTUNE Canada observatories are on the forefront of a new generation of ocean science and technology. Funding of over $100M, principally from the Governments of Canada and BC, for these two observatories supports integrated ocean systems science at a regional scale enabled by new developments in powered sub-sea cable technology and in cyber-infrastructure that streams continuous real-time data to Internet based web platforms. VENUS is a coastal observatory supporting two instrumented arrays in the Saanich Inlet, near Victoria, and in the Strait of Georgia, off Vancouver. NEPTUNE Canada is an 800km system on the Juan de Fuca Plate off the west coast of British Columbia, which will have five instrumented nodes in operation over the next 18 months. This paper describes the development and management of these two observatories, the principal research themes, and the applications of the research to public policy, economic development, and public education and outreach. Both observatories depend on partnerships with universities, government agencies, private sector companies, and NGOs. International collaboration is central to the development of the research programs, including partnerships with initiatives in the EU, U.S., Japan, Taiwan and China.

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1. The NEPTUNE Canada and VENUS programs

Understanding the oceans has never been so critical to our national and global futures. The oceans feed us, determine climate patterns and harbour in their depths many of the biological, chemical and geological processes that continue to shape this planet; yet in many ways we know little about them. The NEPTUNE Canada and VENUS ocean observatories, both led by the University of Victoria, are securing Canada's place at the forefront of international ocean science and technology. Canada is pioneering a new generation of ocean observation systems that provide continuous, long-term monitoring of ocean processes and events, as they happen, and the ability to remotely control sensors and instruments in response to changes in the ocean. Ocean observatories help us understand how marine environments change over time both in their natural variability and with anthropogenic forcing. Built to operate for at least 25 years, NEPTUNE Canada and VENUS will accelerate our understanding of and responses to ocean and climate change in ways not previously possible.

VENUS, or the **V**ictoria **E**xperimental **N**etwork **U**nder the **S**ea, is a coastal, cabled seafloor observatory and the world's first operational, real-time portal into the ocean (www.venus.uvic.ca). Through the Internet, its network of electro-optic cable and instruments is already providing around-the-clock biological, oceanographic and geo-science observations and images and an interactive experimental capability. The first array of VENUS, installed in Saanich Inlet near Victoria in 2006, is supporting studies on ocean processes, animal behaviour, ocean engineering and even forensic pathology. A second array with two nodes is located in the Strait of Georgia near Vancouver, one of Canada's busiest and biologically richest waterways. Here VENUS is supporting research on water currents and ocean mixing, fish and marine mammal movements, and sediment and slope dynamics of the Fraser River delta. VENUS has also tested and proven the fundamental concepts and technology for cabled observatories, including data delivery and interactive remote control of sub-sea instruments.

NEPTUNE Canada, the **N**orth-**E**ast **P**acific **T**ime-series **U**ndersea **N**etworked **E**xperiments, is the world's first regional scale cabled deep ocean observatory (www.neptunecanada.ca). It consists of an 800km network of electro-optic cable laid on the seabed over the northern Juan de Fuca tectonic plate, off the coast of British Columbia. This tectonic plate serves as an exceptional natural laboratory for ocean observation and experiments. NEPTUNE Canada instruments will yield continuous real-time data and imagery from the ocean surface to beneath the seafloor, and from the coast to the deep sea. They will be interactive, responding to events such as earthquakes, tsunamis, fish migrations, plankton blooms, storms and volcanic eruptions. Via the Internet, land-based scientists anywhere in Canada or around the world will instruct instruments to conduct offshore and deep-sea experiments and to send data, without leaving their laboratories and offices.

The NEPTUNE Canada observatory will support broad multidisciplinary, interactive studies on topics such as seismic and tsunami activity, ocean-climate interactions and their effects on fisheries, gas hydrate deposits, and seafloor ecology. It will also promote new developments in marine technology, fibre-optic communications, power systems design, data management, and sensors and robotics. While regional in scale, NEPTUNE Canada will have worldwide impact. It will be available to the international research community to conduct oceanographic experiments and its data archives will be an invaluable, interactive and expanding resource for scientists, educators, students and policy-makers everywhere.

VENUS and NEPTUNE Canada are collaborating on the development and operation of an Internet-based Data Management and Archiving System (DMAS) common to both observatories, with the DMAS team housed within NEPTUNE Canada.

The anticipated research programs are multidisciplinary and will significantly impact all of the areas identified as priorities in Canada's recently released S&T strategy, *Mobilizing Science and Technology to Canada's Advantage* [1]: environmental science and technologies; natural resources and energy; health and related life sciences and technologies; and information and communication technologies.

Partnerships have been central to the development and success of NEPTUNE Canada and VENUS, and will continue to be instrumental as both facilities become fully operational. From coast-to-coast, Canada's leading universities are fully engaged in

and supportive of the NEPTUNE Canada and VENUS observatories. Sustaining and strengthening these research collaborations is vital for all aspects of the science program to move forward and for the economic and social benefits that flow from them. A formal agreement with the National Science Foundation (NSF) ensures a beneficial partnership with the planned US northeast Pacific Regional Cabled Observatory. Other memoranda of understanding (MoUs) are also in place or being approved with major research institutions in France, Ireland, Japan and Taiwan.

Governments at all levels are also recognizing the value of data produced by NEPTUNE Canada and VENUS to help them make informed and effective public policy decisions. Several ministries at the provincial and federal levels are actively involved in shaping the direction and management of the observatories.

2. Ocean Networks Canada

University research in Canada and many other advanced nations has seen an evolution from traditional project based activity led by individual scientists to more comprehensive research programs, and more recently the advent of major research infrastructure platforms. In Canada, funding through the Canada Foundation for Innovation (CFI) has in recent years supported the Canadian Light Source, Sudbury Neutrino Observatory, the Amundsen Arctic Icebreaker, and NEPTUNE Canada. With these platforms has come an urgent need to develop appropriate and effective governance and management structures recognizing the scope, complexity, duration, and fiscal magnitude of the activities. In this context, the Board of Governors of the University of Victoria (UVic) recognized the need to establish Ocean Networks Canada (ONC) as a not-for-profit society to govern and manage the NEPTUNE Canada and VENUS ocean observatories as they move from the design and construction to the operational stage. The purpose of ONC is to fulfil the scientific, educational and societal outreach objectives of the observatory programs. The investments by the Canadian and British Columbia governments in these initiatives provide an unprecedented opportunity for Canada to be an international leader in a field of research of major scientific and societal importance. This is reinforced by the fact that over the next five to ten years we can expect comparable investments in ocean observatories by the U.S., Japan, Taiwan and the European Union.

Of particular importance, as a signal of ONC's commitment to international partnership, is the UVic/ONC relationship with the National Science Foundation (NSF) and the Consortium for Ocean Leadership (COL) in the U.S. These two agencies have responsibility for funding and managing the development of the Regional Science Nodes (RSN), which form the southern component of the ocean observing system on the Juan de Fuca plate as part of the U.S. Ocean Observatories Initiative (OOI). An MoU, signed in 2004 between UVic and NSF, establishes the basic terms and conditions for our international collaboration and our commitment to the inter-operability of the NEPTUNE Canada and OOI-RSN observatories.

The mission of ONC is to govern and manage the NEPTUNE Canada and VENUS ocean-observatory initiatives to meet the highest standards of research excellence, societal contribution, and best operational and business practices. ONC has five principal goals: supporting transformative science and technology; informing evidence-based public policy; creating opportunities for economic and commercial development; promoting public education and outreach; and demonstrating best practices in the governance and management of a national science facility. All five involve the development of national and international partnerships commensurate with the evolution of the ocean observatories as national/international facilities. A major strength of ONC is the composition and membership of its Board of Directors. Its 15 members are all senior level and highly experienced individuals drawn in equal numbers from the academic, government and private sectors.

3. Strategic planning

The need for a strategic and business plan for ONC derives from the scope, scale, complexity and expense of operating ocean observatories on a

sustained and sustainable long-term basis (25 years or more). This is currently estimated at $15M per year for NEPTUNE Canada and VENUS combined. It follows that ONC is proactive on two fronts: in discussions with the federal government to establish a program for funding the operating costs of Major Science Initiatives (MSIs) in Canada, including the ocean observatories; and in securing additional funding from other sources to augment what might be provided through a new federal program, both to cover the full operating costs of the facilities as well as to support further enhancement of the capabilities, performance, and contributions of the observatories. Central to this business and resource planning is determining the user community for the facilities and the immediate development of recruitment and retention strategies to ensure that the facilities are used to maximum advantage and yield the scientific and societal contributions which justified the funding for their capital construction.

NEPTUNE Canada and VENUS have the advantage of being the first multi-node regional and coastal cabled ocean observatories in the world, and as such are regarded as prototypes for systems that will be built elsewhere as we move towards a wiring of the oceans globally. However, that advantage is quite short-lived as the U.S., the EU, Japan, Taiwan and other countries are in various stages of conceiving, designing and building cabled ocean observatories with attendant implications for recruiting and retaining the international user community who will have access to other facilities as they come on line over the next decade.

The ONC strategic and business planning are based on a logic model. The central elements of the model are the inputs, outputs and outcomes specified for each priority area identified through a situational analysis. These elements correspond with the assets, activities and performance measures associated with the primary goals and objectives of ONC over a prescribed period of time. The five priority areas of the ONC logic model are: *supporting transformative ocean science and technology (S&T); contributing evidence to inform public policy; creating opportunities for economic and commercial development; promoting public education and outreach; and demonstrating best practices in governance and management*.

By example, the inputs, outputs and outcomes are shown for *supporting transformative S&T* for the period 2008-11(Table 1). The S&T area is the most developed since this is foundational and the reason for the entire enterprise. The applications of the S&T (areas 2-4) are in early stage development and a prime objective of the planning and activities over the first three years will be to establish a base that will make each of them productive and sustainable in the longer term. One of the strengths of a logic model approach is that it forces alignment among all three elements: outcomes are consistent with outputs, and both outputs and outcomes should be realistically achievable with the inputs available.

4. Business planning

In developing the business plan from the logic model, it is necessary first to identify the receptors for the research generated by the ocean observatories. They fall into five main segments: universities with researchers engaged in basic and applied earth-ocean systems science; science-based government departments and agencies with oceans-related mandates; public policy concerns, particularly of governments and NGOs; private sector companies engaged in marine S&T and related information and communication technology activities; and private and public sector agencies in the public education and outreach sector. To date, most attention has been paid to the first two segments, given the university base of the proponents of the original funding applications and the support from their principal partners in government Science-Based Departments and Agencies (SBDAs). The market is international, particularly at this stage in the early development of a new generation of cabled ocean observatories for which NEPTUNE Canada and VENUS are prototypes in the world.

In diffusion terms, it is important to plan for early, middle and later ‘adopters’ of the observatories and their data in each segment. There is also good reason to expect that, while each segment will develop concurrently, growth rates will likely be sequenced in the order of universities, government SBDAs, and lastly the two private and public sector groups. Also, considerable cross-over between segments will occur with user groups commonly consisting of multi-sector teams.

Table 1

Transformative Science & Technology 2008-11		
Inputs	Outputs	Outcomes
• NEPTUNE Canada and VENUS as world leading ocean observatories • International leadership advantage for at least three years • Capacity to support transformative science • World class science and technical leadership • Potential to attract top national and international researchers, PDFs and students • Capital costs fully funded ($100M) • Operating costs secured to 03-10 ($18.9M) for NC/V • S&T Partnerships - Consortium of Canadian Universities - CANARIE (Canadian Advanced Network and Research for Industry and Education) - Federal and Provincial Depts and Agencies - U.S. NSF/COL-OOI/UW-UCSD - Other International - EU - Ifremer/ESONET - Taiwan - MACHO - Japan – DONET	• Provide global desktop access to NC and V - For instrument control - For data access • Attract and support user-supplied observing systems • Involve users in ongoing development • Create “Oceans 2.0” Web platform for collaborative research • Develop web-based user manuals • Promote research opportunities through web-sites , conferences and workshops • Support a seminar series on ocean observing systems S&T (providing remote access) • Build national/intl research teams for funding proposals • Recruit post-doctoral fellows (PDFs) and graduate students nationally and internationally to work on NC/V programs • Provide seed funds for proposal development • Establish awards for innovative research • Develop inter-university graduate courses in ocean observing systems • Communicate and celebrate research progress and achievements • Increase UVic faculty involvement in NC/V S&T • Increase Canadian university faculty involvement	• Doubling of NC/V based principal investigators by 12-2011 • Additional 10% of observing systems on N/V provided by users by 12-2011 • Five-fold increase in number of intensive data users by 12-2011 • 50%/yr increase in the active web-based analysts • Annually updated user manuals in place • Tripling in expressions of interest to participate in research teams by 12-2011 • Doubling of conference papers presented and journal articles published using NC/V data by 12-2011 • At least 3 high profile seminars offered annually • 20 NSERC applications submitted by 12-2011 with focus on NC/V research • At least one CFI application submitted to enhance NC/V systems by 12-2011 • 5 PDFs and 25 graduate students (at least 10 PhD) recruited by users to work on NC/V by 12-2011 • $50K in seed funding provided by 12-2011 • Faculty and student awards in place by 12-2011 • At least two new user-developed graduate courses in place by 12-2011 • 50%/yr increase in national level media coverage of NC/V S&T • 6 additional UVic faculty engaged in NC/V Science by 12-2011 • 20 additional Canadian faculty engaged in NC/V by 12-2011

A useful characterization of user groups which cut across these segments is as follows:

- ***Builders****: for NEPTUNE Canada these are the eight multidisciplinary science teams that have been funded through existing capital grants (and support from host agencies) to install the first sets of instruments - comprising 80 scientists, technicians and students from 16 institutions in Canada, the US, and Europe. In 2007, 22 users were directly involved in VENUS instrument deployments.*
- ***Future Builders****: these are the researchers and R&D staff that will compete for/secure new funding to install additional instruments; the current projection is for this group to grow by 70 researchers over the first 5 years of operation.*
- ***Bridge-builders****: these are researchers and scientists deployed on related facilities or programs whose work will be enhanced/advanced by accessing the capabilities provided by the observatories; examples are Integrated Ocean Drilling Program science teams and the Ocean Tracking Network program.*
- ***Data Analysts****: the open data policy provides for a world-wide network of users through the Internet web-sites; use rates for comparable sites suggest annual user numbers in the thousands though intensive data analysis will be restricted to a smaller number of scientifically qualified researchers. In 2007, there were 202 users registered to access data through the VENUS website.*
- ***Knowledge Beneficiaries****: these are principally users in private and public sector agencies who will normally require translation of the scientific data into ‘knowledge products’ which are easily understood and applied by the non-expert in the*

context of public policy, economic development and public outreach domains.

4.1. Sustaining Transformative Science and Technology

Achieving this goal depends foremost on a proactive approach to engaging the research community. Moreover, this has to be viewed as an international outreach even though it has been Canadian consortia that have secured the capital funding for the VENUS and NEPTUNE Canada observatories. NEPTUNE Canada was funded through the International Access Fund of CFI and there is a UVic/NSF MoU to facilitate Canada/US collaboration. Rapid engagement of this community is the *sine qua non* for the future of the facilities for two basic reasons: the observatories are first and foremost research facilities and all the benefits from the investment will flow from a very active and productive research program; and the argument for securing the essential and substantial core operating funding rests on the vitality and enthusiasm of the research user community.

So what are the incentives that can and should be in place to attract research users? A prime incentive is the opportunity to participate in and contribute to transformative science enabled by a new generation of ocean observing technology that is the first of its kind in the world. Claiming the capability to produce transformative research is bold and ambitious but credible for NEPTUNE Canada and VENUS, in line with this definition from a recent U.S. National Science Board report:

> *Transformative research is defined as research driven by ideas that have the potential to radically change our understanding of an important existing scientific or engineering concept or leading to the creation of a new paradigm or field of science or engineering. Such research is also characterized by its challenge to current understanding or its pathway to new frontiers.* (Steven Beering, Chairman, National Science Board, May 2007 [2])

In this context, there is the additional incentive and opportunity to engage in international collaborative research in ways that would not necessarily otherwise be possible. To a significant degree, this is already reflected in the composition of the research teams that comprise the initial users of the observatories. A further related incentive is the potential for being more competitive and successful in peer-reviewed grant competitions for what is still relatively limited funding for oceanographic research through NSERC (Natural Sciences and Engineering Research Council of Canada) and other agency programs. Again, there is early evidence of success in funding applications involving use of VENUS and NEPTUNE Canada.

4.2. Informing Evidence-based Public Policy

NEPTUNE Canada and VENUS are national facilities, funded by the federal and provincial governments, to support transformative research and to serve the public interest through applications of the research results to issues of high priority on the public policy agenda. In fact, evidence of the potential societal benefits (economic, environmental, social and health) to Canada and B.C. was an explicit requirement in the original CFI and BCKDF (British Columbia Knowledge Development Fund) applications for the capital funding. It follows that forging links and establishing partnerships with SBDAs at the federal and provincial levels continues to be a priority for the observatory programs. This relationship building is already well underway, for example NEPTUNE Canada has partnerships with several federal departments and agencies (Fisheries and Oceans Canada, Environment Canada, Parks Canada, Natural Resources Canada, Department of National Defence, Industry Canada, CANARIE Western Economic Diversification and the National Research Council) with formal MoUs in some cases and significant in-kind support provided. VENUS has established similarly strong relationships. In the larger federal context, these links are entirely consistent with the stronger alignment between universities and federal facilities being promoted through the federal S&T strategy and the related work of a federal committee examining the possibilities for co-locating (physically or virtually) selected universities and federal laboratories.

These partnerships are grounded in the mutual vested interest of universities and governments to optimize the use of valuable and scarce infrastructural and human capital resources in the national interest. For NEPTUNE Canada and

VENUS, this lofty goal translates to a careful and critical assessment of the alignment of scientific programs with the evidence-based policy needs of SBDAs. There is an obvious fit in general, but the details matter so that primary objectives are not distorted, expectations are realistic, and timelines are respected. It follows that alignments will be closer and easier to actualize for some relationships than others in the set of potential linkages. Moreover, assessing this will not always be self-evident and so careful and honest appraisal will be necessary on the part of both the research teams and their government colleagues.

4.3. Creating Economic Development and Commercial Opportunities

There is considerable pressure from government to stimulate stronger links between public sector research and economic development in and through the private sector. Central to this thinking is developing ways and means to encourage and accelerate the commercialization of research. The risk, acutely felt within some sectors of academia, is that pressure in this direction will result in a distortion of fundamental research in favour of over-emphasis on applied research of direct benefit to the private sector and short-term over long-term research objectives. There is clearly a balance to strike, not least because fundamental research has frequently been the source of unanticipated practical applications of profound economic significance – the history of basic research in physics and chemistry is replete with examples.

In this context, NEPTUNE Canada and VENUS, as world-leading ocean observatories, combine transformative science and technologies with substantial potential for private sector involvement and economic development benefits. That said, it is important at the outset to delineate the products and services that these facilities, which are fundamentally research platforms, can and should actively pursue, either independently or in partnership with commercial firms. There are at least five distinct areas which have significant potential for commercial application deriving from the innovative S&T that NEPTUNE Canada and VENUS support: the backbone infrastructure for powered cable observatories; the novel submarine instrumentation; potential life and health science applications including the development of new pharmaceuticals; the data management and archiving system (DMAS); and educational products.

Implicit in these potential commercial applications of the observatory-based science, data delivery and technology development represent a comprehensive range of relationships with private sector partners. It is feasible to conceive of the following: development of a spin-off company to manage DMAS applications; partnership with a major company for the design and implementation of turnkey remote control operated systems; licencing agreements with small and medium-sized enterprises (SMEs) for submarine instrumentation; royalty agreements for public education products; and contracts for services for scientific, engineering and DMAS support provided to other observatory programs. While hypothetical at this stage, thinking in these terms about preferred business models for different applications needs to be considered *a priori*, to avoid the risks of *ad hoc* arrangements once the pressure of specific cases arises.

4.4. Promoting Public Education and Outreach

NEPTUNE Canada and VENUS are well positioned to capitalize on the public appetite for more knowledge and better understanding of the oceans, an interest only heightened by increasing recognition of ocean-climate dynamics, and the catastrophic consequences of recent signal events, especially the Indian Ocean tsunami and hurricane Katrina.

The public should be thought of in the plural, because in reality there is obviously a broad range of audiences that can and should be reached both directly and virtually through public outreach and education initiatives. A challenge is to secure the substantial funding required to support the translation of vast data streams from the observatories to understandable and digestible forms of value and interest to lay audiences, whether in school, college or university settings, in science centres, aquaria and museums, or through the Internet. Perhaps ironically at a time when increasing priority is being placed on the integration of research and education, it remains difficult to access funding to support the development

of educational components, at least through the main research agencies such as NSERC. That said, there are other sources, including foundations (Moore, Suzuki, Vancouver, Victoria), where such funding can be sought, and there is certainly potential, as indicated above, to explore possible private sector collaboration to produce commercializable educational materials.

This is perhaps above all other areas the one that lends itself most to fully exploiting the power and exciting dynamics of the rapidly evolving web-based world. The potential for developing an 'Oceans 2.0' platform as a virtual public information forum for the oceans is huge. The very recent award to the DMAS team from CANARIE to support the development of a web 2.0 platform for global collaborative analysis of VENUS and NEPTUNE Canada data is an immediate stimulus to accelerating this exciting area of opportunity.

4.5 Demonstrating Best Practices in Governance and Management

The creation of major research infrastructure platforms brings the need to institute governance and management policies and procedures commensurate with the scope, complexity, duration and fiscal magnitude of the activities. This need has been recognized by CFI as the agency primarily responsible for the funding of the new MSIs in Canada, including NEPTUNE Canada. CFI now requires a governance and management review for all of its major projects and accordingly ONC/NEPTUNE Canada was reviewed in January 2008 with the final report and recommendations currently being considered by the CFI senior management.

Clearly, governance and management is not a business line for ONC in the way that the other four priority areas of the logic model are, yet it undergirds the rest. The absence of best administrative practices runs the risk of *ad hoc* management, the lack of clearly defined objectives and performance measures, and ineffective/inefficient use of resources. In this regard, the development and implementation of the ONC business plan is itself a good practice indicating at this early stage that the organization has established a strategic and business direction that serves as the basis for internal and external accountability. Indeed, if there was a principal message running through this plan, it is that sustaining the success of the observatories - in ways that fully capitalize on the major capital investment in their construction and fully realize the benefits of the research programs - is rooted in sound practices in governance and management at all levels from the ONC Board through senior management to the day-to-day activities of the research teams.

5. Conclusions

By combining continuous power, the remote operation of numerous instruments and sensors, and the streaming of real-time data on to Internet web platforms, the NEPTUNE Canada and VENUS ocean observatories are ushering in a new generation of ocean observing systems to support transformative research. The science advance lies in the ability to perform integrative studies at a regional scale that take account of the complex earth-ocean system interactions of physical, chemical and biological processes. Moreover, the results of the research have applications to societal issues of profound consequence, including hazard mitigation, ocean-climate dynamics, resource assessment, and sovereignty and security. Achieving the full scientific and societal benefits of the observatories requires a comprehensive strategic and business planning approach commensurate with the scale, complexity, cost and longevity of the facilities. It also requires creating governance and management structures and practices suited to administering the *business of research* conducted on large scale research platforms designed to serve as international science facilities. In this context, *Ocean Networks Canada* has been established by the University of Victoria to oversee the planning and operations of NEPTUNE Canada and VENUS.

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