VENUS – A bottom up approach to building an ocean observing system

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Abstract- The University of Victoria's VENUS coastal observatory is the most technologically advanced system of its kind. Forty five kilometers of telecom cable link two shore stations to three primary science sites at 100, 170 and 300 m depth in Saanich Inlet and the Strait of Georgia, respectively. These science sites are flush with instrumentation and sensing systems, from cameras and streaming hydrophones, to physical and chemical sensors, and since 2006 have been sampling the near and far field 24 hours a day, 365 days a year.

Now that the cabled infrastructure on the seabed is well established and robust, the facility is entering a new growth phase following a successful grant award through the Canada Foundation for Innovation. The existing system will be expanded over the next 4 years to include remote and direct measurements at the surface (HF Radar and TSGs on Ferries), to interactive profiling of the water column (Vertical Profiler), and to remote measurements made by mobile assets (gliders and AUV). All these data streams will converge in near real-time in a database at the University of Victoria, and be made available through the VENUS web portal (www.venus.uvic.ca).

VENUS is already well established as a leader in the implementation and operation of a cabled observatory, and is now moving towards becoming a fully integrated marine observing system. In Saanich Inlet, the Facility will install a large powered buoy, cabled back to the subsea terminus of the telecom cable. On the buoy will be a sophisticated winching system which will allow for hourly profiles of the water column. The system will be designed to be modular, and capable of supporting more than 20 sensors at any given time. The Inlet is an ideal location for biogeochemical research and the understanding of hypoxia in the ocean. This profiling system will allow scientists to probe the water column in ways never considered before.

The Strait of Georgia is the 2nd busiest waterway in North America, and is also home to the outflow of a major salmon bearing river (Fraser). The city of Vancouver resides on its eastern shore, and the majority of the infrastructure is built on unstable river delta sediments. The VENUS cabled array in the Strait allows for real-time science to be carried out on whale vocalizations, sediment transport, salmon abundance and the stability of the delta slope. In addition to this existing capability, the Facility will install HF radar sites, providing surface current and wave information to scientists, shipping, rescue coordination agencies, ferries etc. In addition, the Facility will instrument several coastal ferries to enable the measurement of oceanic and meteorological surface conditions in the Strait. These data, as with the radar information, will be transmitted back to the central database and made available online.

For the first time, the Facility will deploy mobile assets to allow scientists to sample in ways, places and conditions that would otherwise remain unexplored. In order to obtain water column properties in the tidally dynamic Strait of Georgia, ocean gliders will be used on weekly to monthly deployments, gathering oceanic data as they travel from surface to seabed. In collaboration with a University of Victoria engineering partner, the Facility will now offer access to an AUV. The vehicle will undergo a retrofit to enable additional sensor technologies and capabilities, including modes for seabed tracking and profiling.

All of these systems are reliant on a complex data management system. Individual instruments are controlled and output data through software drivers that continue to monitor the health and performance of the observatory systems. The existing infrastructure is now well understood and managed. The advent of new technologies and data arriving through alternate means suggests there are many challenges to come, both at the outset and operationally over the years.

I. VENUS PHASE 1

The air-sea interface is more than a boundary between fluids; it is a barrier to human involvement. The Victoria Experimental Network Under the Sea (VENUS) is a pioneering approach to studying the oceans. It is a research station on the seafloor, a public attraction in the ocean, and a classroom in the sea. Observations from the ocean are available continuously in real time over the Internet from a centralized data warehouse at the University of Victoria. With cabled arrays in the Strait of Georgia near Vancouver and Saanich Inlet near Victoria, British Columbia, VENUS spans a wide range of coastal marine ecosystems. The Facility website www.venus.uvic.ca is the portal for both the research community and the public.

VENUS began operations in Saanich Inlet in February 2006 as the world's most advanced cabled ocean research facility. The Strait of Georgia primary infrastructure was installed in 2007 and at present, the initial vision conceived over a decade ago has been realized.

Although the existing suite of fixed sensors (30+) is providing unprecedented access to the benthic environment, VENUS is now entering a new phase of growth and diversification. This new phase will encompass novel experimental approaches on the seafloor and the extension of high fidelity measurements throughout the water column and at the sea surface.

The existing cabled Facility is now in a "steady-state" mode with regularly scheduled semi-annual maintenance cruises. VENUS has developed standard operating procedures to ensure the sub-sea arrays and shore stations are stable and well

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monitored. There are also standardized interaction protocols with the Data Management and Archiving System (DMAS) to ensure minimal data loss during times of upgrade, software changes and power disruptions.

The principle Facility components are the individual subsea instruments, their interface modules, the science Nodes, the shore-stations, and the data archive. Interactions with each of these components are constantly monitored. The Saanich array has been available 97% of its working life (4 yrs) and the Strait of Georgia array for 98% (2.5 yrs).

VENUS is the world's first advanced cabled sub-sea ocean observatory and the only major sub-sea Facility reliably delivering continuous real-time data from a wide range of sensors over the Internet. With its high-power (kilowatts), high band width (1 Gbps) system linked to dozens of observing systems in the ocean, VENUS has accomplished what seven other nations are striving to achieve at multiple sites around the world. This system allows anyone with an Internet connection to view and download large complex ocean data sets, 24 hours a day.

A. Nodes

The VENUS Node is equivalent to an "under-water Ethernet hub". Each Node provides power and Ethernet communications at wet-mate science ports, with "plug and play" access for any compatible system. When an instrument package is plugged into one of these ports, the port and down-stream system are powered up manually. Once the new suite of instruments are deemed to be stable and free from ground faults, the instruments are controlled directly with a custom software interface or "driver". The driver manages setup of the instrument, and parsing and packaging of the output data. In addition to the custom driver for each instrument, other software runs in the background with the sole purpose of controlling and monitoring the infrastructure systems. This software is responsible for monitoring system health and managing power should fault conditions arise.

Some of the more notable infrastructure innovations include:

1. Repair of a Node is relatively easy. All active components are in a removable "pod" that can be returned to the surface by a Remotely Operated Vehicle (ROV). A fibre-optic and electrical connector must be unplugged by the ROV before the pod can be freed from its base. The oceanographic research world had not previously used such connectors.

2. No wet-mate connectors designed for passing Ethernet signals were available to allow the instrument packages to be plugged into the Node. In 2005, VENUS, in collaboration Ocean Design Inc. and several US partners, was involved in a significant engineering effort to configure and certify connectors to meet the Ethernet specification. As a result, Ethernet is rapidly becoming a new standard for sea-floor equipment.

3. The use of telecom grade cable with only one power conductor drove the development of a high voltage direct current sea-water return power system. The 1200 VDC Medium Voltage Converter (1200 to 360 V) was critical to the success of the Strait of Georgia array. The development of this converter paved the way for other cabled observatories with cable lengths of up to 100 km.

4. Integrating terrestrial COTS network and power equipment into small, fan-less pressure vessels was a significant task. Dissipating internal heat proved to be a constant challenge.

The VENUS Node design has fused technology from terrestrial computer networks, sub-sea telecommunication systems, and the sub-sea oil and gas industry into a highly reliable research tool for ocean science. This innovative use of these technologies in a "non-traditional setting" has yielded a system that represents a "step function" increase in data though-put capacity and power delivery compared to earlier cabled observatories.

Figure 1: A graphic of the VENUS Node Pod and Base.

B. SIIMs

The Scientific Instrument Interface Module (SIIM) is the physical link between the instruments and the primary underwater infrastructure (Nodes). A SIIM provides and controls low power to multiple instruments and converts the various communication protocols used by the instruments into an Ethernet data stream. The first generation SIIM accommodates up to four serial devices (EIA-232, 422, 485) and two Ethernet devices. Power at five of the SIIM instrument ports is 24 VDC, with 360 VDC available at the remaining port for high-power devices or daisy-chaining SIIMs together.

The power and communications to each SIIM port can be monitored and controlled from the Network Operations Centre. The SIIM is a unique solution to a complex and essential component, and it provides a flexible architecture for increased observatory expansion. Other planned observatories around the world have adopted this interface, either directly (NEPTUNE contracted SIIM developer OceanWorks Inc. to build a new version, known as the Junction Box), or indirectly using similar technologies.

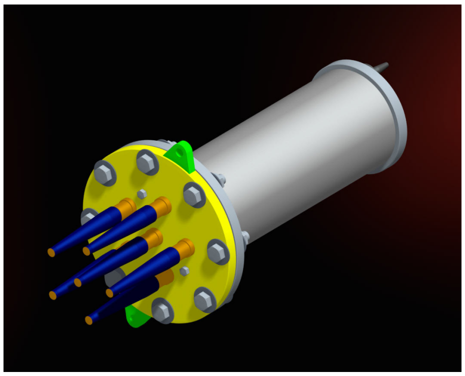

Figure 2: The VENUS Scientific Instrument Interface Module.

C. DMAS

The Data Management and Archive System (DMAS) consists of a complex data acquisition layer coupled with an interactive data warehouse. The data itself can be mined and downloaded from the Facility web site www.venus.uvic.ca. The data acquisition system (drivers, parsers, calibration algorithms, QA/QC etc) retrieves temporarily archived data at the shore stations, sorts the data by type and complexity, stores it in various formats and on multiple servers, and facilitates delivery of advanced data products to all users through the web site. This user-friendly site is a one-stop shop for all data and interactions with VENUS.

The development of DMAS was undertaken in a collaborative fashion to support the VENUS and NEPTUNE Canada observatories at the University of Victoria. This leveraging of resources, mutually shared between the two projects has proven extremely beneficial. This communal approach to the IT solutions is on-going, and improvements to all aspects of the software systems are based on feedback from both the VENUS and NEPTUNE Canada scientists and the experience gained through a number of years of continuous operation of a quickly expanding system. DMAS, with its specific focus on data acquisition, archiving and distribution has no equal in the oceanographic world in terms of functionality, quantity of data available and uptime. The novelty of the ocean observatory projects, with initially loose and then rapidly evolving requirements, led to an agile strategy requiring in-house development and recruitment of highly qualified software developers. New ways for accessing imagery, acoustic and video data, or navigating the observatory components are under constant release on the web sites.

New software features under development will provide users the ability to subscribe to select data streams, detect user specified events and directly interface with instruments. In addition, users have the ability to report issues with instruments, to access post-processed data (e.g. hourly or daily averages) and to use a geographical interface to visualize and access the data. Another development underway will allow researchers to organize themselves in project-specific groups with complementary skills (e.g., biology and statistics, ocean science and climate) to perform on-line data analysis and visualization. DMAS is also planning to simplify user access to Grid processing facilities directly from the on-line collaborative science environment. The applicability of DMAS to other sensor networks and its scalability (upward for large systems or downward for smart instruments) makes it an “off the shelf” solution for other observing stations in Canada and around the world.

Figure 3: The above satellite image shows the approximate locations of the existing VENUS Nodes.

II. VENUS PHASE 2

In 2008 the VENUS Team submitted a new proposal (Phase 2) to the Canada Foundation for Innovation (CFI) on behalf of researchers across Canada.

The research group that designed the Phase 2 proposal included over 40 individuals from academic and government labs across Canada, with links to the world. A major strength of this research group is the encompassed range of disciplines. Principal Users demonstrate a breadth of research excellence in oceanography, engineering, and applied and social sciences research.

The proposal was accepted by CFI in 2009, and the VENUS team is presently preparing to implement over the next 4 years all the new systems and innovative instrument ideas outlined in the proposal.

This next phase of VENUS has two fundamental objectives:

1. To provide Canadian researchers with the opportunity to design observatory-compatible systems that will support new methodologies in the study of critical ocean phenomena

2. To extend Canada's position in the technology of integrated ocean observing systems

The proposed core research areas for the new phase are separated into five categories:

1. 'Ecosystem Services', which encompasses the role that organisms play in maintaining ecosystem health such as the fluxes of carbon, nutrients and other compounds across the sediment –water interface.

2. Documentation of the rate and effects of 'Ocean Change' using parameters that range from temperature, to dissolved gases, to water mass behaviour.

3. Data and data products that support agencies involved in 'Coastal Ocean Management', including assessment of water mass renewal, algal blooms, and eutrophication.

4. 'Operational Services' that aid service organizations, such as search and rescue, hazard monitoring, storm surges, and forensic research.

5. 'Product Development' and testing through online capabilities and ancillary data support, including novel sensors, AUVs, and data delivery tools.

6. 'Basic Research', which is the core to advancing ocean understanding, the training of new researchers, and the discovery of new applications.

VENUS/DMAS, through its open and shared data access policy, have helped to strengthen collaborations of ocean scientists across Canada, including researchers based far from the coast.

The fact that VENUS Phase 2 was funded is a demonstration of the strong collaborative nature and recognized success of this Facility. Because ocean research with VENUS is no longer entirely expedition-based, distant land-locked researchers at remote institutions can observe, manipulate and interact with the same instruments. Many data types are presented together on the VENUS website, exposing researchers to unfamiliar instruments and data. The data presentation is a common ground that promotes dialogue across disciplines.

Phase 2 will include a multitude of innovative and developmental instruments in configurations that are unique. These ideas and technologies represent a radical shift in our ability to observe and test hypotheses. It is the coupling of full-time access and novel instrumentation that has captured the attention of the various proposal proponents. There will be a wide range of systems for integration in VENUS Phase 2: from basic upgrades, to customized benthic modules, test beds for sensing technologies to mobile assets, real-time ship based systems with satellite linkages to completely new, developmental systems (e.g. guided AUV, profiling system).

A. Sub-sea Laboratories

The new sub-sea Laboratories will include a diverse array of instruments and the support infrastructure necessary to both integrate them with a cabled observatory and deliver data to users.

Seafloor processes will be studied with five platforms that will be configured to suit the studies and capable of relocation within the observatory. Each platform will have up to 12 instruments focused on a study theme. Cameras (Near-Infra-Red, Acoustic, Digital), current and turbulence sensors, chemical and sediment sensors etc. will be used in often novel applications.

The core areas of research in the proposal are as follows:

- Seafloor Processes
- Animal Behaviour
- Animal Sediment Interactions
- Forensic Research
- Sediment Dynamics

These sub-sea Laboratories will be unique in scope, flexibility, and access. Researchers will be able to examine the complexity of phenomena through one portal, integrating information from other co-located instruments on the seafloor with data from mobile sensors in the water column and at the surface.

B. Profiler System

One of the more significant systems being developed for VENUS Phase 2 is a real time surface based profiling system for Saanich Inlet. The biological and biogeochemical features of this seasonally hypoxic basin instigated a wide range of requests for a profiling capability in the Inlet with a variety of sensors, including carbon dioxide, pH, methane, nitrate, oxygen, chlorophyll, and turbidity. Ultimately, the profiler system will contribute to understanding the dynamics of hypoxia, acidification, and microbial metabolism in the ocean.

The core components for this system are:

1. A large 5 m platform buoy, secured geographically through a 3-anchor mooring.

2. A winch and telemetry system that will allow an instrument suite to report real time measurements as it travels from surface to seabed (200 m) up to 12 times a day.

3. An instrument cage and interface module that will support up to 16 instruments.

4. A 4 km fibre-optic cable linking the profiling system at the surface to the VENUS Node at 100 m depth in Saanich Inlet.

Scientists will be able to use real-time data to decide on profiling and sampling protocols and intervals.

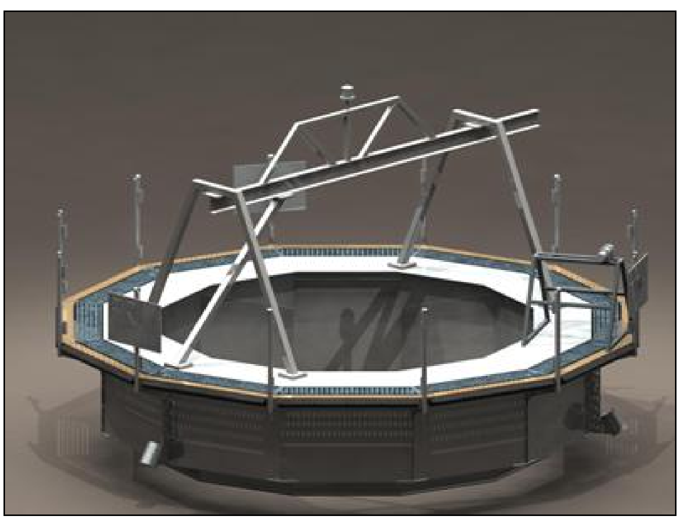

Figure 4: A graphic of the 5 m buoy that will be used to support the profiler system in Saanich Inlet.

Figure 5: The SeaKeepers 1000 ferry instrument system.

C. Instrumented Ferries

As other countries begin to design and install their own sub-sea cabled systems, VENUS is taking the next step: to release researchers from conducting real-time science at fixed locations on the seafloor.

Passenger ferries cross over the Strait of Georgia – and the VENUS array – many times each day. In collaboration with BC Ferries, VENUS will instrument their newest fleet of ferries with SeaKeepers 1000 systems. This technology will enable automated, near-real-time transmission of surface water data back to the archive at the University. Ninety kilometers of surface data will be gathered every few hours, extending the temporal and geospatial foot-print of VENUS across one of Canada's most stressed marine basins.

These on-board systems will enable the Facility to acquire long-term surface data – useful for addressing questions about the coupling of physical and biological processes and their roles in the transport pathways of organic matter over various temporal scales. Scientists will be able to observe how the Strait responds to diurnal (tides), episodic (storms), seasonal (Fraser discharge), and inter-annual and decadal (ENSO and Pacific Decadal Oscillation) events.

These surface observations will also aid in the validation and calibration of satellite derived data products such as SeaWiFS, MERIS and RADARSAT-2, which are heavily used in this area.

Figure 6: The city of Vancouver with a superimposed line showing the separation between proposed antenna sites.

D. Coastal Radar

In addition to surface water properties, researchers have requested a synoptic view of the wave and surface current conditions in the Strait of Georgia using land based radar. VENUS Phase 2 will include the installation of two CODAR antennae south-west of Vancouver, linked to our shore station. A system frequency has been identified that will provide coverage across the Strait, including the majority of the ferry routes and the entire sub-sea array.

Providing adequate infrastructure to ensure horizontal variability is captured is the most elusive and costly endeavour for a cabled observatory. Thus, technology such as HF radar is an ideal approach for capturing the horizontal variability in the surface currents and wave field in the Strait. Furthermore, it will be possible for researchers on VENUS to assess the accuracy of these measurements through comparison with current measurements determined by seabed mounted ADCPs.

The Fraser River plume is a complex turbulent feature that dominates the oceanography of the southern Strait of Georgia, and a better understanding of its dynamics will be useful in managing this system. Here, hazards to vessels have claimed many lives; both research and on-line information for mariners will be served. Data from HF radar in the Strait will be a useful tool for search and rescue and shipping agencies, and will undoubtedly become of relevance to the marine community at large.

Figure 7: A CODAR antenna installation.

E. Gliders

The spatial structure of the water column in the Strait of Georgia will be mapped using low-power underwater gliders from Webb Research. Mission oriented glider surveys within the Strait and over the continental shelf west of Vancouver Island will inform researchers of the encroachment and extent of changing water conditions. These technologies are well-tested. The challenge for VENUS and DMAS will be building a reliable infrastructure for data ingestion and delivery in near real-time.

Gliders are preferred to fixed profiling assets at the surface in the Strait due to the strong tidal currents; however, operating a glider in such a dynamic environment is not without its own challenges. The introduction of gliders to the VENUS community will be a developmental project, including the integration of mission planning tools, regional circulation models, and in situ trials. In addition, glider data will feed coastal models through measurements of temperature, salinity, fluorescence and oxygen, filling the spatial gap between the mooring observations and the temporal gap associated with periodic shipboard surveys.

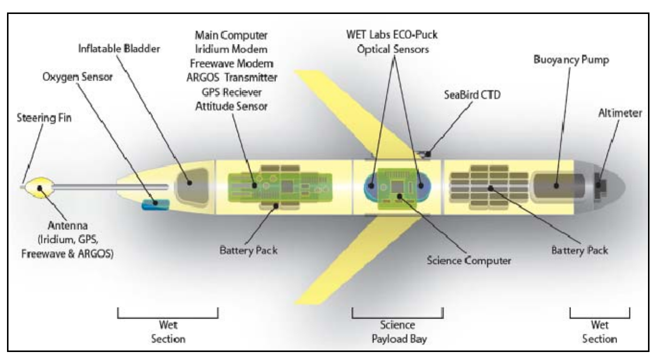

Figure 8: A schematic showing the main features of the Webb Research Slocum 2 glider.

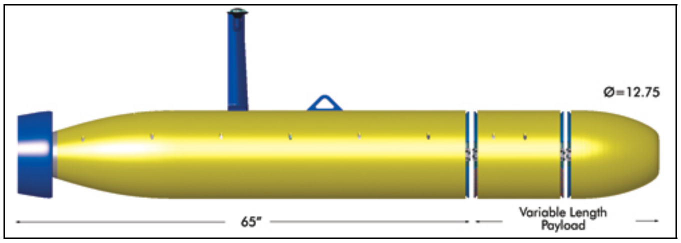

Figure 9: A graphic representation of the Bluefin AUV, with some general dimensions (in inches).

F. AUV

To aid in our mandate to improve our geospatial coverage in Saanich Inlet, VENUS Phase 2 will include a well instrumented Autonomous Underwater Vehicles (AUV). The University of Victoria's Bluefin AUV will initially run user specified science missions within a proposed acoustic tracking range, and will eventually travel far a-field in Saanich Inlet.

The initial step for the AUV implementation will be the development of precision navigation capability using a seafloor acoustic navigation array currently in development for the Ocean Technology Test Bed (OTTB) facility connected to VENUS.

The implementation plan for the AUV is as follows:

1. Enabling Precision Transects – Deploy and test the vehicle within the Integrated Acoustic System (IAS) and investigate the impact of the precision tracking on the collection of science data.

2. Baseline Data Delivery System - Develop the system for acquiring and delivering valid scientific data for a variety of missions using the default sensor suite.

3. Vertically Profiling the Water Column – Investigate and develop the means to profile the water column.

4. AUV Flights in Close Proximity to the Bottom - Develop the capacity to fly very close to the bottom to enable the collection of underwater video.

G. Ocean Acidification

VENUS Phase 2 plans to make a substantial contribution to the global effort to understand ocean acidification. Together with NEPTUNE Canada, VENUS will provide seabed stations for testing and calibrating carbon dioxide and pH sensors.

To this end, VENUS plans to collaborate with the Alliance for Coastal Technology to assess and select appropriate sensing technology for monitoring ocean acidification.

The implementation plan includes a VENUS/NEPTUNE Canada collaboration, where CO_2 and pH sensors will be deployed in the inner Strait of Georgia and out on the continental shelf. Once instruments are in place, researchers will be able to track intrusions of low pH water as it upwells onto the shelf and moves into the Strait.

Variations in dissolved inorganic carbon and pH are critical to evaluate the ability of marine organisms to handle fluctuating alkalinity. Along the coast, the seasonal and even weekly variability is large. These sensors will support the first continuous high temporal resolution observations of the carbon system in any coastal environment.

H. Environmental Sampler Prototype (ESP)

Another major innovative development for VENUS Phase 2 is the plan to deploy an in-situ genomic sequencer in Saanich Inlet.

In consultation with MBARI engineers, designers of the ESP, VENUS will procure a bench-top prototype suitable for measuring the diverse microbial community in Saanich Inlet. In collaboration with the Hallam laboratory at the University of British Columbia, VENUS will transition the bench top system to a 200 m rated underwater enclosure for in situ genomic analysis. The wet version of the ESP will then be integrated on the profiling system.

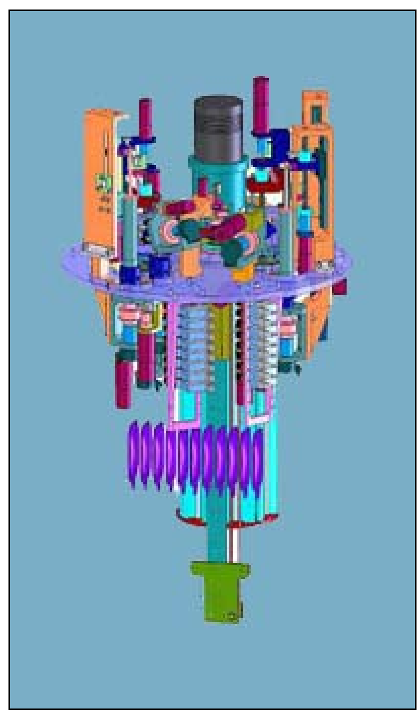

Figure 10: A solid model of the ESP developed at MBARI.

Saanich Inlet is a model for microbial processes that occur in many places in the ocean. The transition to fluctuating anoxia at depth provides a wide range of reducing conditions in which to study diverse metabolic designs and biogeochemical products. The proposed research includes:

1. Cataloging the local microbes in Saanich Inlet and establishing a comprehensive database for ecosystem classification based on genomic variations.

2. Quantifying the carbon and nitrogen cycles in this partially closed, but seasonally dynamic inlet from the phyto-productive surface layers to the microbial diverse sediments.

3. Monitoring and assessing the trace and redox elements (i.e. iron, copper) throughout the water column in this bio-chemically reactive environment.

III. PHASE 2 INNOVATIONS

This new phase of development on VENUS represents a shift in innovation emphasis from the development of a robust seabed infrastructure (Phase 1), to that of novel and complex sensing systems, specified and designed by the research community.

Below are some highlights of the sensing technology developments and new capabilities associated with the implementation of VENUS Phase 2:

Sub-sea laboratories

- Detailed long-term examination of small-scale processes in representative deep coastal waters.
- Near-IR-sensitive and acoustic cameras providing biologists a new view beyond the visible spectrum to examine natural behaviour of animals in the aphotic zone.
- The capability to study how bio-turbation affects a wide range of conditions.
- A world first, trans-disciplinary sub-sea forensics lab.
- A 3D camera array that moves beyond the present planar 2D view of the seabed. This development will be a world first and is especially powerful for researchers in Alberta due to its connectivity through the internet.
- Continuous monitoring of marine water mass intrusion and potentially disruptive events.
- Real-time data on water mass properties to assimilate into circulation models.
- Evaluating ocean acidification using the latest sensing technologies.
- Long-term, regional scale studies on ocean acidification and how it impacts deep and coastal environments.
- Complex, high-bandwidth acoustic sensors to resolve and measure near bottom ocean turbulence over extended periods at distinct geographic stations.
- High-bandwidth, broadband echo-sounders for differentiating between back-scatter resulting from ocean turbulence and that due to the presence of zooplankton.

Profiling System and Gliders

- Extending the VENUS bottom centric observations up into the water column in Saanich Inlet to provide both spatial and temporal data on the structure and evolution of this naturally hypoxic laboratory.
- Providing insight into the vertical structure of water masses in the Strait of Georgia; information in conjunction with surface and seabed measurements that can be used to complete the picture.

Ferries and CODAR

- Providing surface measurements of currents and waves to scientists and local agencies operating in the Strait, from SAR units to shipping.
- On-line surface water properties measured in high spatial resolution along ferry routes; information of key interest to oceanographers for calibration of satellite data, and input to ocean circulation models.

AUV

- The capabilities of present day AUVs will be enhanced to enable novel science missions and new ways of sampling the far field.

ESP

- Core bio-chemical assessments for marine ecosystems will no longer be limited to sparse quantification.
- The development of a deep genomic knowledge of Saanich Inlet, which has implications for other extreme environments.

Please join us as we explore the ocean at www.venus.uvic.ca

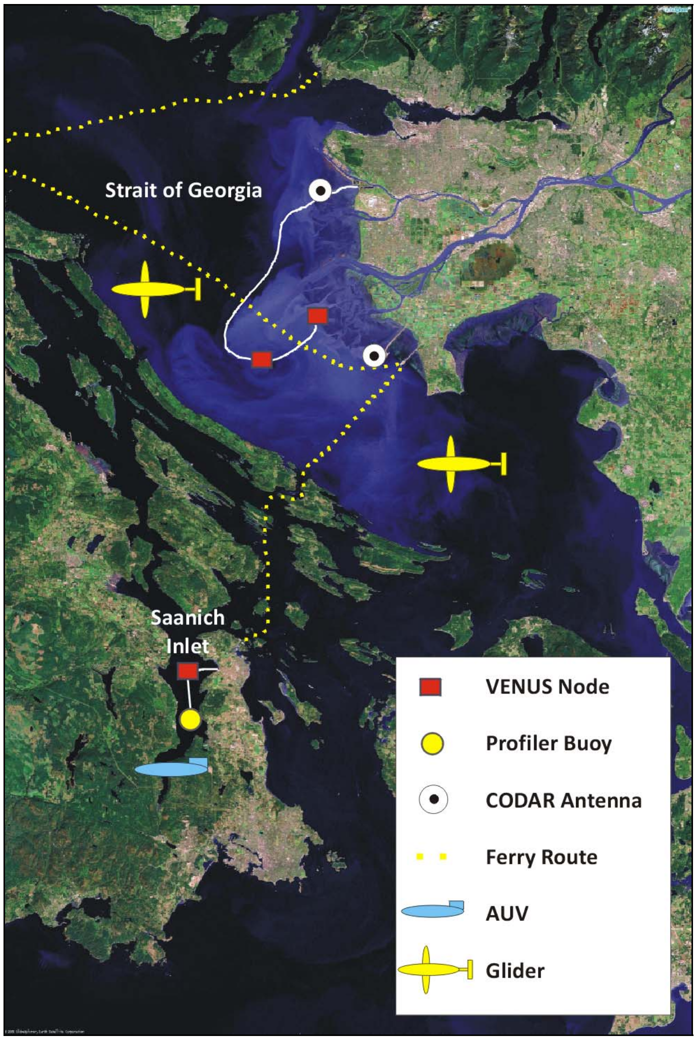

Figure 11: The above satellite image shows the approximate locations of the existing VENUS Nodes and highlights some of the new systems that will be on-line in the next few years.

ACKNOWLEDGEMENTS

Figure 4: Jeff Kennedy, University of Victoria
Figure 5: SeaKeepers website
Figure 7: Chad Whelan, CODAR
Figure 8: Teledyne Webb website
Figure 9: Bluefin website
Figure 10: Chris Scholin, MBARI

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[1] Tunnicliffe, V., "Sub-sea Laboratories on VENUS: enhancing the capabilities of Canada's cabled ocean networks," Proposal submitted to Canada Foundation for Innovation, October 2, 2008