The VENUS Network:

Monitoring the Strait of Georgia Ecosystem

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A Submission to the Cohen Commission

September 27, 2011

Executive Summary: The VENUS cabled network of the University of Victoria has been observing environmental variables (temperature, salinity, oxygen, etc.) continuously since 2008 in the deep waters of the Strait of Georgia off the mouths of the Fraser River. In addition, sonars sense daily vertical migrations of zooplankton, many of which are part of the diet of juvenile salmon, as well as finfish (currently being identified) and whales. We are currently installing: (i) sensors packages on BC ferries on three main routes in the Strait of Georgia, that will monitor surface seawater continuously on each crossing for temperature, salinity, oxygen, phytoplankton abundance, water turbidity, etc; and (ii) a high frequency radar system that will monitor surface currents and waves across the Strait adjacent to the mouths of the Fraser River (Figure 1). VENUS is designed to operate for 25 years into the future.

We are keenly interested in participating with DFO and other agencies in monitoring the ecosystem and environment of the Strait of Georgia, as is being recommended in proceedings of the Cohen Commission. For example, as reported in the Globe and Mail (20 September 2011) on one of the studies commissioned earlier by Judge Cohen:

> 'Mr. Marmorek's report concludes that … the most likely explanation is that something went wrong in the Strait of Georgia, Queen Charlotte Sound and the Gulf of Alaska, where the young sockeye feed and grow. He said there is intriguing research pointing to the role of sea temperatures, phytoplankton levels and ocean salinity, among other things, but much more research is needed. "Since the early marine environment appears to be a major potential source of declining productivity, it is particularly important [to] improve information on potential stressors affecting sockeye along their migratory path from the mouth of the Fraser River through Queen Charlotte Sound," '.

All VENUS data are available from our website in nearly real time, and the products available and graphics presentations are being improved continuously.

Background: VENUS is part of a modern cabled ocean observatory, operated by the University of Victoria under the management of Ocean Networks Canada. VENUS, which has received half its funding from the Canada Foundation for Innovation (CFI) and most of the rest from the Province of BC, is the coastal network component of the ONC Observatory, with sensor arrays in Saanich Inlet and the Strait of Georgia (http://www.venus.uvic.ca/). The networks were proposed, funded and built as research platforms, wiring the ocean to enable interactive, real-time marine research. However, the base suite of measurements provides an unparalleled set of high-resolution time series related to key marine indicators of ecosystem health. With a focus on the southern central Strait of Georgia, the VENUS network is contributing to a variety of ecological initiatives to monitor, study, understand and predict oceanographic conditions in the Strait of Georgia. With an estimated operating life from 2006 to 2026, this valuable collection of marine data should be considered in any assessment, evaluation or predictions related to the ecological health of the Strait of Georgia as it relates to both juvenile and mature Sockeye salmon both exiting from and returning to the Fraser River, respectively.

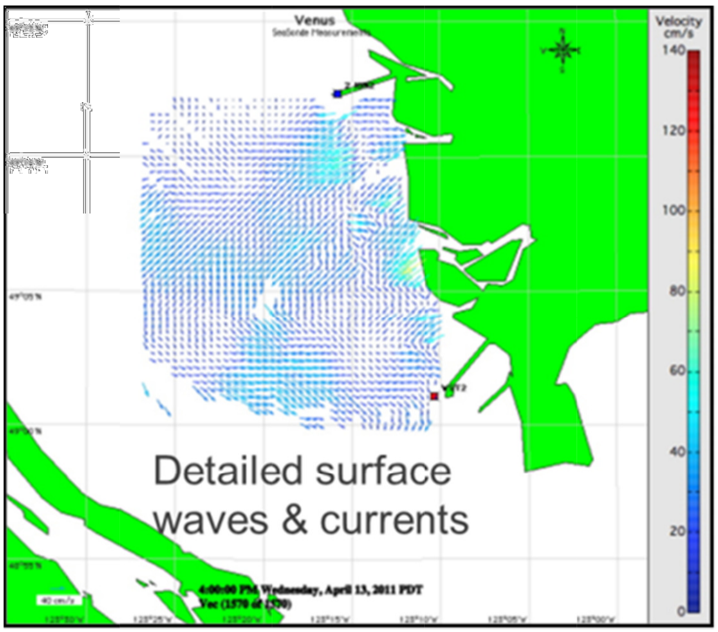

Figure 1. Shows a test of the high frequency radar system presently being installed. Arrows show the resolution of surface currents that the system will provide. The area of the Strait of Georgia covered once the system is operational will probably be larger than shown.

The Health of the Strait of Georgia ecosystem: Although there cannot be one single definition nor is there a simple set quantities that define or bound a marine environment's "health", there are indicators that both qualitatively and quantitatively provide evidence of the health of an ecosystem. If we define an ecosystem as the habitat and the species that live there, then there are quantities measured by the VENUS network that relate specifically to changes and properties of the habitat, and others that relate to the species living there. Specifically, the VENUS network has been monitoring the season variations in seawater temperature, salinity, density, and dissolved Oxygen at a number of stations in the southern central Strait of Georgia. Appendix A is the most recent (2011) VENUS contribution to the Department of Fisheries and Ocean's Annual State of the Ocean report, where the annual variations in these properties are discussed, with a particular focus on capturing the annual deep water renewal events that replenish oxygen and nutrients in the deep waters of the Salish Sea. VENUS, with its cabled infrastructure, has also been able to support continuous inverted echo-sounder logging, that captures the vertical and temporal variation in both zooplankton and fish abundance.

Shown below is a single day of 200kHz inverted echo-sounder data from the VENUS Delta Dynamics Laboratory site, at the base of the slope near the mouth of the Fraser River.

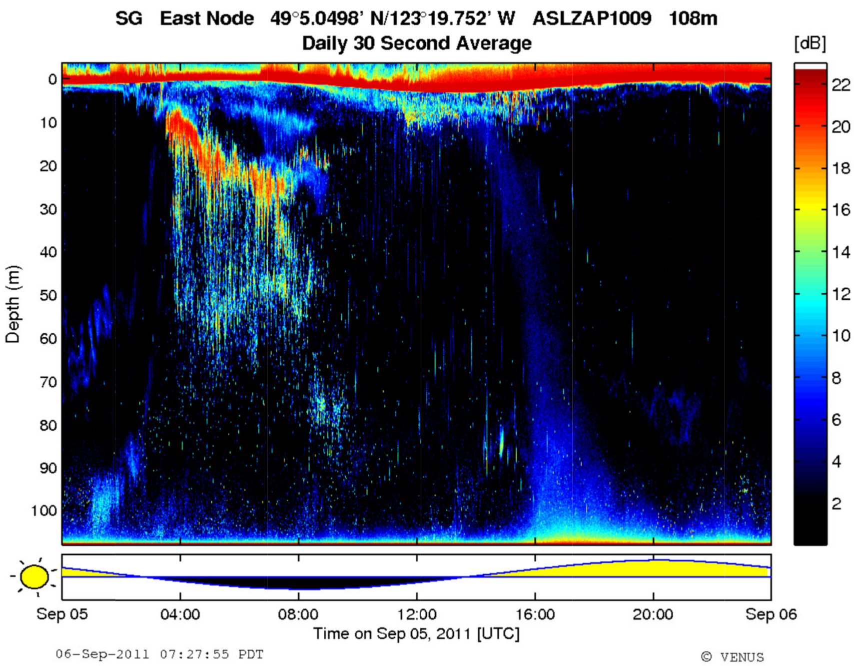

Figure 2. Inverted 200kHz echo-sounder (Zooplankton Acoustic Profiler: ZAP) image from near the mouth of the Fraser River for September 5, 2011. The lower panel shows the timing relative to local sunset and sunrise.

The echo-sounder is mounted on the ocean bottom in 108m of water, looking upward to the ocean surface, which shows up as a wide red band near depth 0, the ocean surface. Superimposed on a faint zooplankton migration pattern (a bluish band migrating upwards at sunset and downwards at sunrise) are high concentrations of larger targets (fish) between 10 and 50m depth, between 04:00 and 08:00 UTC. Although these measurements cannot determine the fish species directly, this corresponds with the known arrival of high returns of salmon to the Fraser River (personnel communications, Yunbo Xie, Pacific Salmon Commission). A parallel research topic by one of our researcher users at Memorial University is analyzing the co-located Acoustic Doppler Current Profiler to tease out swimming fish from ocean currents, further identifying salmon swimming towards and near the mouth of the Fraser River.

Present and Future Developments on VENUS

The VENUS network presently consists of fixed instruments connected to cables on the sea floor at three sites in the southern central Strait of Georgia. Under development are new measurement platforms that will sample geospatially throughout the water column. In particular, VENUS is augmenting our cabled time series with CODAR HF Radar derived maps of surface currents, thermosalinographs and meteorological data collected along several BD Ferry routes, and autonomous gliders that will fly along predetermined routes in the Strait of Georgia during specific periods of the year to map out the 3-dimensional water properties. These new mobile platforms will also include additional sensors, such as Chlorophyll that can be used to both quantify and qualify the amount and distribution of plankton in the Strait of Georgia. Finally, VENUS has a proposal under review that will develop a comprehensive suite of ocean models to simulate and predict ocean and ecological conditions in the Strait of Georgia, further enhancing our ability to characterize the health of the ocean in this important region.

Following are two Appendices, the first is the VENUS contribution to the 2011 DFO State of the Ocean report, and the second is a description of a new coastal research vessel to be operated by the University of Victoria, funded primarily by the Canada Foundation for Innovation.

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Appendix A: The 2011 VENUS report to the Annual DFO State of the Ocean Report

VENUS Observes Mild and Fresh Waters in the Salish Sea

Richard Dewey, Victoria Experimental Network Under the Sea (VENUS), University of Victoria

The Victoria Experimental Network Under the Sea (VENUS) is a coastal observatory network with arrays in both Saanich Inlet and the southern Strait of Georgia. VENUS provides continuous records of ocean properties below the ocean surface in southern British Columbia. The Saanich Inlet (SI) array includes a shore station at the Institute of Ocean Sciences and a 3-km cable to a Node at 100-metres depth in Patricia Bay ("SI" at 48° 39.0540'N 123° 29.2027'W). The Strait of Georgia (SoG) array consists of a shore station at the Iona Waste Water Treatment Plant, a 40 km cable and two Nodes, one in the "central" southern strait at 300 metres depth ("SoG Central" at 49° 2.41'N 123° 25.53'W), and a second on the "eastern" flank at 170 metres depth ("SoG East" at 49° 2.52'N 123° 19.06'W). At each VENUS Node there is a standard VENUS instrument platform (VIP) hosting a variety of oceanographic instruments including a CTD to measure temperature and salinity, an ADCP to measure currents, and an inverted echo-sounder to detect zooplankton.

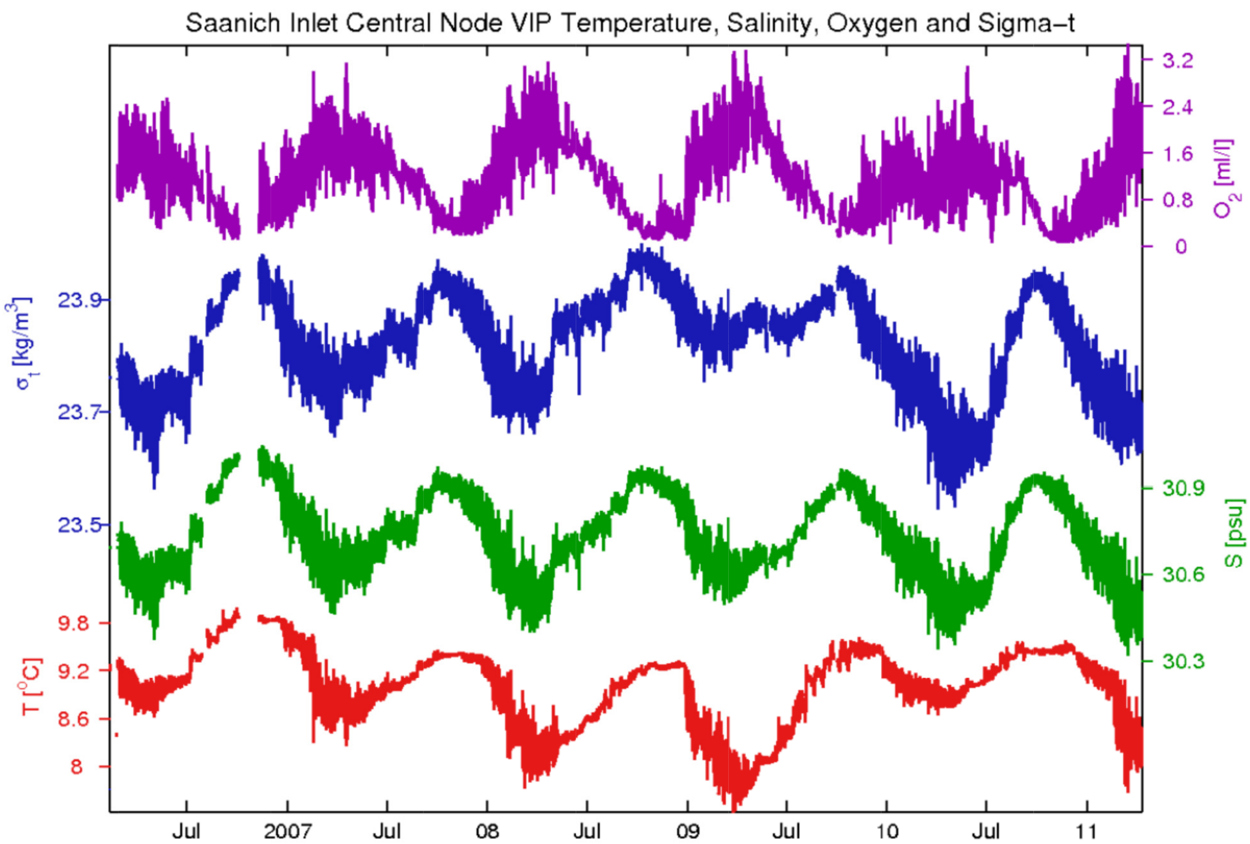

Figure 1 Temperature (red), salinity (green), density as σ_t (blue) and dissolved oxygen (magenta) from the VENUS Station in Saanich Inlet., located at the mouth of Patricia Bay at a depth of 97 m. Shown are the full VENUS records, from 2006 through to early 2011.

The data records from Saanich Inlet sensors reveal that the winter of 2009/10 was the mildest since VENUS was installed in 2006 (Figure 1). The coldest seawater temperatures recorded near 100 metres depth in the winter of 2009 reached 7.4 °C, while in 2010 the minimum temperature recorded was 8.6 °C, more than a degree warmer. The winter of 2010 was fresher than in the previous few years, a result of higher than usual local rainfall in the late fall of 2009 and the first few months of 2010. By May 2010, when conditions at 100 metres depth should have been their coldest and freshest, the waters were both abnormally warm (8.6°C) and fresh (30.4 psu). This combination resulted in the low seawater density of 1023.5 kg/m^3, recorded at 100 metres depth at the VENUS Saanich Inlet site.

In addition to the anomalous temperatures and salinities recorded during the winter of 2010, the dissolved oxygen concentration at 100 metres depth remained suppressed (Figure 2) during the winter cooling period, with concentrations rarely exceeding 2.4 ml/l (3.35 mg/kg). This is normally the season of renewal of oxygen in these deep waters. Peak oxygen levels in the previous 4 winters were in excess of 3.0 ml/l at this time of year.

The spring and summer seawater warming in 2010 was minimal, a trend mirrored by mild atmospheric temperatures during June, July, and August 2010. Forced by strong upwelling along the west coast of Vancouver Island in summer 2010, late summer salinities increased, with pulses of salty, dense water penetrating into deep waters of Saanich Inlet during the weeks following the monthly weak neap tides. By the end of 2010, as a result of both minimal cooling the previous winter and minimal spring/summer warming, seawater conditions (temperature, salinity, density, and dissolved Oxygen) in Saanich had returned to climatic norms (Figure 2).

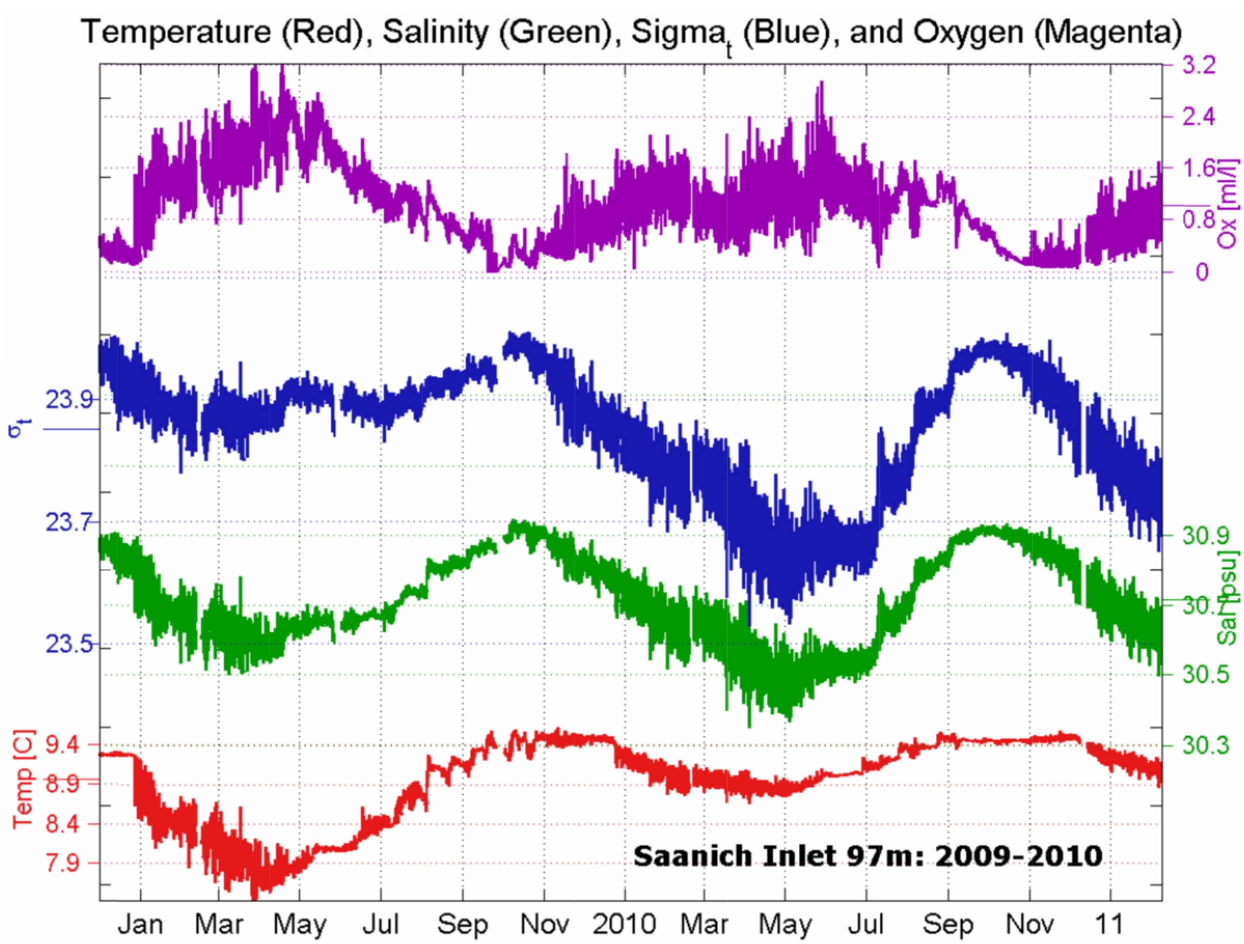

Figure 2. Temperature (red), salinity (green), density as σ_t (blue) and dissolved oxygen (magenta) from the VENUS Station in Saanich Inlet. Shown are the VENUS records, from January 2009 through to early 2011, high-lighting differences between 2009 and 2010. The 2010 winter was rather mild (<1 °C cooling) followed by a cool summer that resulted in minimal heating (<1 °C warming)

Seawater variations in the Strait of Georgia were similar to those seen in Saanich Inlet in many respects. At the VENUS SoG East site (170 m depth, Figure 3) winter cooling ceased by the end of January, with a minimum temperature of 8.4 °C. In comparison, the coldest temperatures in 2009 occurred in late March and reached 7.2 °C. The minimum salinity at this site was reached in February 2010 at 29.8 psu, also coinciding with the minimum density of 1023.1 kg/m^3. From January through to the end of June, both salinity and density (which is dominated by the salinity variations) revealed very large, daily variability, suggesting that very different water masses were advecting back and forth past the sensors every tidal cycle.

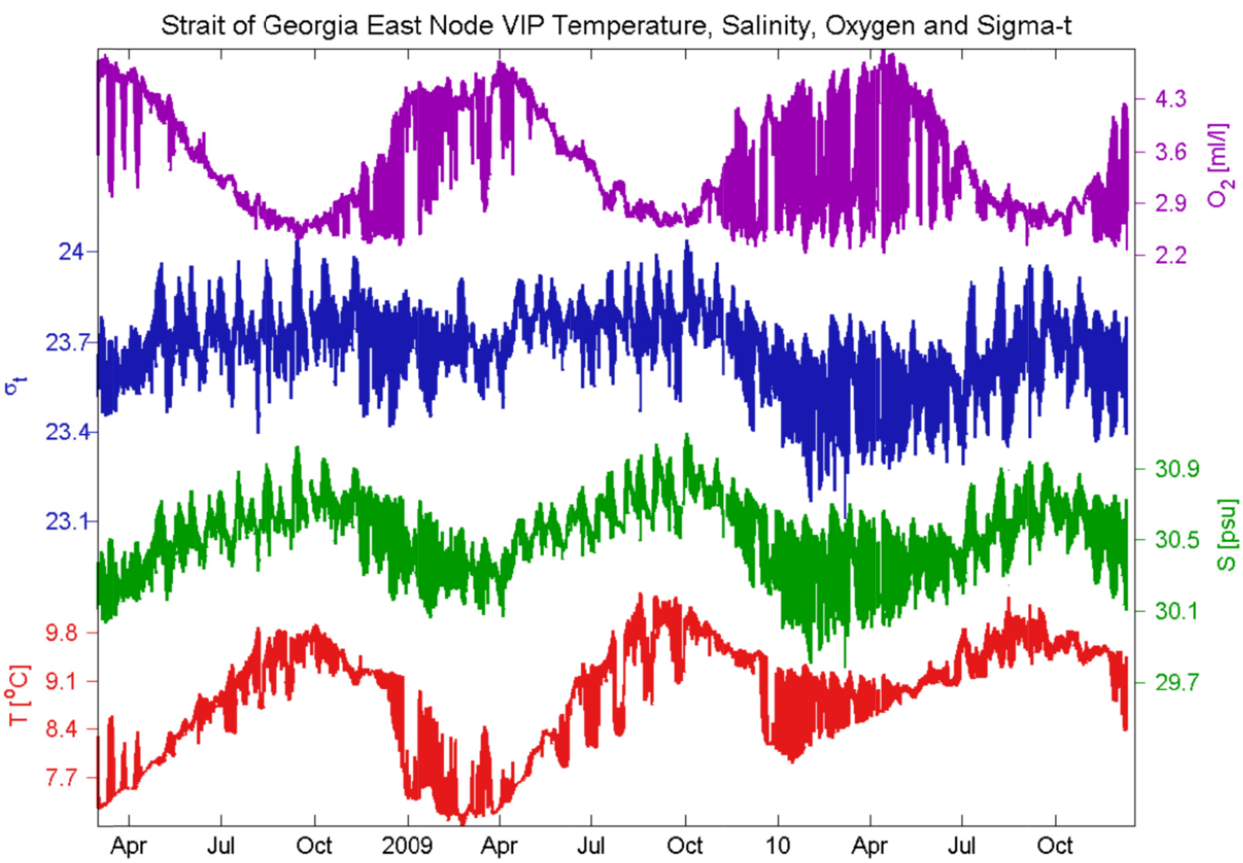

Figure 3. Temperature (red), salinity (green), density as σ_t (blue) and dissolved oxygen (magenta) from the VENUS Station (SoG East) in south eastern Strait of Georgia at a depth of 170 m. Shown are the full VENUS records, from September 2008 through to early 2011.

Higher salinity water at 170 metres depth (advecting along the bottom from west of Vancouver Island) arrived in the Strait in several significant pulses, starting in early July (Figure 4). At least four pulses of high salinity (and therefore dense) water were detected during each of the weak neap tides during July, August, and September (vertical lines, Figure 4). This is consistent with the hypothesis that during neap tides, although the volume exchange associated with the large scale estuarine circulation decreases, the reduced vertical mixing results in less-diluted bottom water entering the Strait. These dense, salty pulses also bring essential nutrients, which feed the ecosystem for the next year. An alternate perspective is the freshening and lightening of the water during each spring tide (Figure 4), when surface waters infused with Fraser River freshet from June to August are mixed down to the bottom by the turbulent tidal currents.

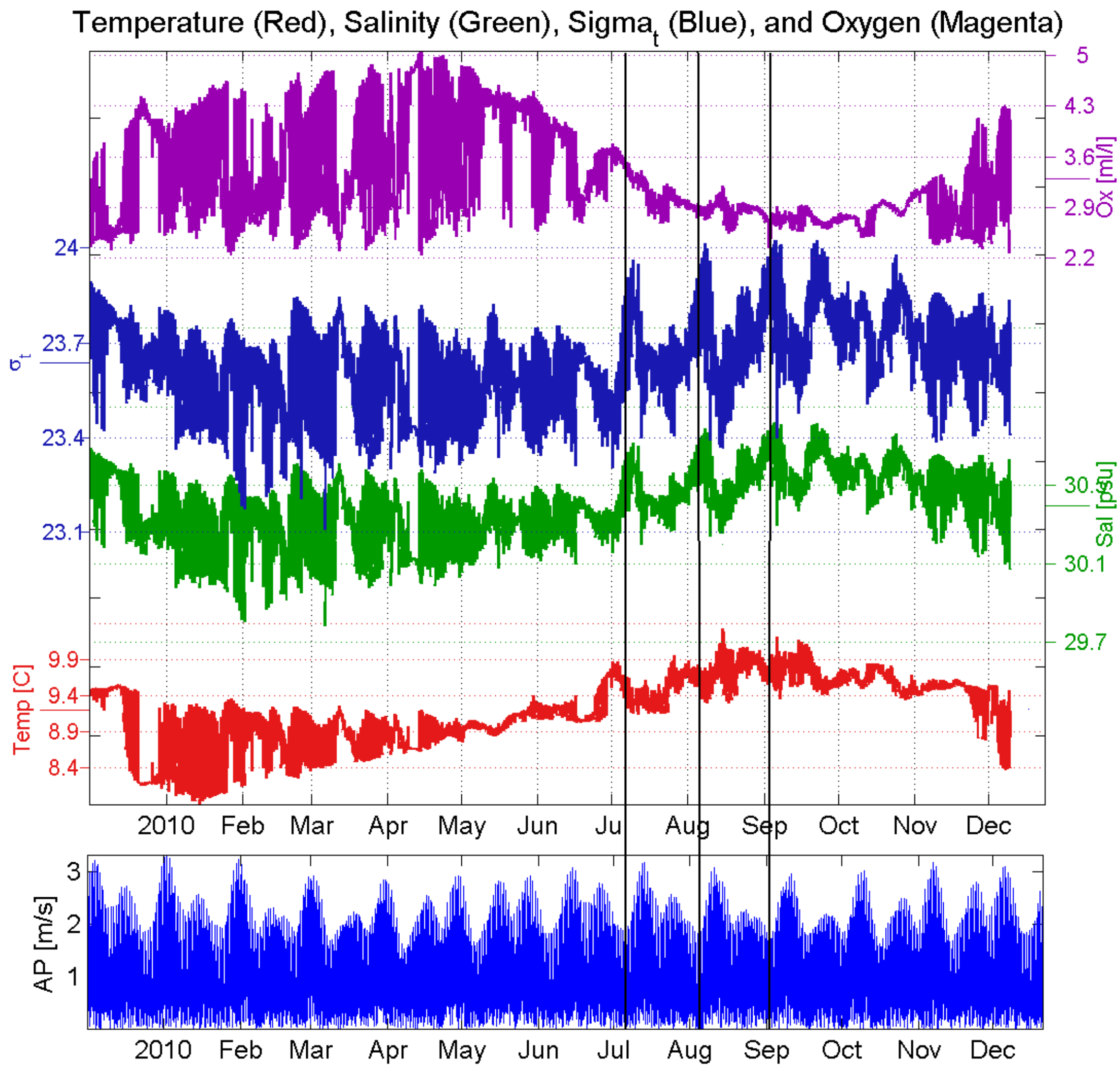

Figure 4. Temperature (red), salinity (green), density as σ_t (blue) and dissolved oxygen (magenta) from the VENUS Station (SoG East) in south eastern Strait of Georgia at a depth of 170m (upper panel) in 2010. The bottom panel shows the speed of tidal currents in Active Pass (tidal prediction), where we have identified (vertical black lines) the weak neap tidal periods in July, August, and September. Each neap tide coincides with an influx of salty/dense water (green/blue traces, upper panel).

In conclusion, several important annual cycles continue to be recorded by the sensors on the VENUS network. Seasonal changes in temperature through atmospheric cooling and solar heating dominate the temperature variations, where the mild winter and summer of 2010 is reflected in the seawater temperatures. Salinity variations are tied to both the regional rain and river discharge in the fall and winter, when rain/run-off causes salinity to decrease, while salinity increases associated with tidal modulations of the inflow of deep, salty Pacific water entering via Juan de Fuca are evident during the late summer upwelling season. Deep-water inflows show up as pulses correlated tightly with the spring-neap tidal cycle, and are likely forced by vertical mixing and water mass formation within the Gulf Islands. At the depths of the VENUS sensors (100-300 m) the role of the Fraser River appears to be secondary, through its ability to drive regional estuarine circulation is essential in the infusion of deep, salty, nutrient rich ocean water during the later summer months.