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DETERMINATION OF ELAPSED TIME SINCE DEATH IN HOMICIDE VICTIMS DISPOSED OF IN THE OCEAN

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For the:

Canadian Police Research Centre

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TECHNICAL REPORT

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INVESTIGATION INTO THE EFFECTS OF OCEANIC SUBMERGENCE ON CARRION DECOMPOSITION AND FAUNAL COLONIZATION USING A BAITED CAMERA PART I.

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EXECUTIVE SUMMARY

Body decomposition in an aquatic environment is not well understood. Human bodies are frequently recovered from the ocean, usually eventually washed ashore. However, it is extremely difficult to determine the elapsed time since submergence or death as so little is known of decompositional parameters in the ocean. Animal, primarily insect, colonization of a body is a valuable method to estimate elapsed time since death in bodies on land. This research was conducted in collaboration with the Victoria Experimental Network Under The Sea (VENUS) to follow decomposition and animal scavenging on a carcass to help to explain artifacts and decomposition of a body submerged in deep water off British Columbia. A remotely operated submersible was used to position a pig carcass under a remotely controlled video and still digital camera in order to observe the impact of submergence. The carcass was observed several times a day until it was no longer in range of the camera.

INVESTIGATION INTO THE EFFECTS OF OCEANIC SUBMERGENCE ON CARRION DECOMPOSITION AND FAUNAL COLONIZATION USING A BAITED CAMERA. PART I.

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ABSTRACT

A recently killed pig carcass was dropped into the ocean in the Saanich Inlet of Vancouver Island in British Columbia. In collaboration with the Victoria Experimental Network Under The Sea (VENUS), a Remote Operated Platform for Ocean Science, ROPOS, was used to position the carcass at a pre chosen site on an area covered in silt, under a remotely operated still and video digital camera. The site was at a depth of 94 m. From a remote site, the cameras and light arrays were switched on and the carcass and animal life observed, several times a day until the carcass was dragged out of camera range when mostly consumed. The carcass was rapidly scavenged by large Three Spot Shrimp, Dungeness crabs and squat lobsters. A dogfish shark inflicted a wound to the rear end of the pig and the arthropods rapidly removed tissue at the site. Half the pig was completely consumed within 23 days of submergence.

ABSTRACT (Non-technical)

Forensic entomology is an extremely valuable tool to estimate elapsed time since death in homicide victims found on land. However, many bodies are recovered from the ocean

and much less is known about the animal colonization of these bodies and the decompositional changes which occur. In collaboration with the Victoria Experimental Network Under The Sea (VENUS), a killed pig carcass was placed in the ocean in the Saanich Inlet off Vancouver Island in British Columbia using a remotely operated submarine. A remotely controlled VENUS camera was used to observe the effects of submergence on the pig decomposition until nothing was left.

INTRODUCTION

Entomological evidence has played an extremely valuable role in estimating elapsed time since death in Canada for many years (Anderson 2001; Anderson 1997; Anderson and VanLaerhoven 1996; Anderson 1995). Dead bodies, whether human or animal, are a rich but ephemeral resource for a range of carrion insects. These insects colonize in a predictable sequence, depending on a variety of important parameters such as geographical region, microclimate, season, habitat and scenario (Anderson 2001). Insects also develop in a predictable manner, again dependent on a number of factors, most notably temperature (Anderson and Cervenka 2001). I have done a great deal of research in collaboration with the Canadian Police Research Centre and colleagues and graduate students across Canada, to establish databases of insect succession on carrion in a variety of geographical areas, seasons and habitats (Hobischak *et al.* 2006; Gill 2005; Sharanowski 2004; Anderson *et al.* 2002; VanLaerhoven and Anderson 1999; Anderson *et al.* 1996; Dillon and Anderson 1996; VanLaerhoven and Anderson 1996; Dillon and Anderson 1995). This has been invaluable in estimating time of death in many terrestrial homicides in Canada.

However, a lot less is known about decomposition and faunal colonization when a body is dumped in water. In collaboration with the Canadian Police Research Centre and a graduate student, Niki Hobischak (now Huitson), we conducted studies on decomposition in fresh water habitats and determined the impact of freshwater submergence in both still and flowing waters (Petrik *et al.* 2004; Hobischak and Anderson 2002; Hobischak and Anderson 1999; Hobischak 1998). However, the marine environment is very different from fresh water and the ocean, unfortunately, provides an

attractive dumping site for a killer's victim. Bodies are frequently dumped in the ocean in the expectation that the body will simply "disappear". Of course, it does not and is frequently recovered. However, when a body has been recovered from the ocean, the normal parameters used to estimate time since submergence are of little value. Very little research has been conducted in the marine environment (Sorg *et al.* 1997).

Water deaths are frequently the most difficult deaths to investigate, especially when the decedent has been immersed for a prolonged period of time. British Columbia, in particular, and Canada in general, have a large number of waterways and extensive coastlines, so water deaths due to recreational activities are, unfortunately, common. As well, bodies of victims of crime are frequently disposed of in water. Post mortem interval determinations are vital to an investigation, but are particularly difficult in water deaths.

Time of death determination is often pivotal in a forensic investigation, but is difficult (Chorneyko and Rao 1996; Teather 1994; Wentworth *et al.* 1993; Lawlor 1992; Mant 1960) or impossible when prolonged immersion has occurred (Wentworth *et al.* 1993; Picton 1971). Post mortem interval (PMI) tends to be established by police inquiries into time last seen alive and not by examination of the body (Wentworth *et al.* 1993). Although time last seen alive may be valid in determining PMI in accidental drowning cases, it may not be valid in a homicide.

There have been only a few studies which have examined the decompositional rates of human (O'Brien and Kuehner 2007; Petrik *et al.* 2004; Hobischak *et al.* 1999; O'Brien 1997; O'Brian 1994; Tomita 1976) or animal (Hobischak *et al.* 2002; Hobischak 1998; Kelly 1990) corpses in aquatic environments. Although some investigators have described a sequence of decompositional changes which the body progresses through in

specific cases (Teather 1994; Simpson and Knight 1985), these were single cases occurring in variable conditions, so are somewhat anecdotal.

My early work with the CPRC in the marine environment looked at carrion in two shallow marine habitats in Howe Sound, B.C. Research data demonstrated that depth, season and sediment type all impacted the rate of decomposition as well as marine faunal colonization (Anderson and Hobischak 2004; Anderson and Hobischak 2002).There are many factors that have been shown to impact decomposition of a body in water, and hence estimations of PMI. These include, but are not limited to, parameters such as the season in which the body is dumped (Polson and Gee 1973), the depth of submergence (Anderson *et al.* 2004; Anderson *et al.* 2002; Jaffe 1976), the temperature of the water (Simpson *et al.* 1985; Spitz 1980; Fisher and Petty 1977; Jaffe 1976; Picton 1971; Mant 1960), water chemistry (Keh 1985; Polson *et al.* 1973; Mant 1960) the amount of adipose tissue in the body (Kelly 1990; Keh 1985) and the level of scavenging (Anderson *et al.* 2004; Anderson *et al.* 2002; Spitz 1980; Jaffe 1976; Picton 1971; Mant 1960, Teather, 1994 #1006).

To date, a major limitation of working in submerged environments has been the lack of easy access to the experiments. In particular, sampling times in the research have been limited by diver and boat availability as well as weather conditions, safety and prohibitive costs. This study eliminated all these concerns as the work was done in collaboration with Dr. Verena Tunnicliffe at University of Victoria, and the VENUS project (Victoria Experimental Network Undersea). VENUS allowed remote access to the research site to place and then observe the carrion.

This study, therefore, involved the remote investigation of pig carrion submerged at a depth of 94 m in the Saanich Inlet, near Vancouver Island.

MATERIALS AND METHODS

VENUS (The Victoria Experimental Network Under the Sea) is an underwater laboratory which includes a massive array of fibre optic cables linked to cameras and an array of instruments and sensors on the seabed close to Vancouver island, British Columbia. These cameras and instruments are remotely operated so can be controlled from the surface anywhere on earth, as long as a network connection is available (www.venus.uvic.ca).

This study was conducted in the Saanich Inlet, a glacially carved fjord (www.venus.uvic.ca). It is 24 km long (Herlinveaux 1962). The bottom sediment is primarily mud and sand and there is a deep basin close to where this experiment was situated, which is 234 m deep at its deepest (Herlinveaux 1962). The inlet does not have much freshwater coming into it, as the major river feeding into this area is the Cowichan River which is northwest of the inlet (www.venus.uvic.ca). Figures 1 and 2 indicate the location of the Saanich Inlet.

In early August 2006, a pig (*Sus scrofa* L.) carcass was deployed by VENUS. On 5 August, a 26 kg (58 lb) pig was killed by electricity to avoid causing wounds or injecting chemicals which might have impacted the experiment. There were no wounds on the carcass. The carcass was taken immediately to the CCGS *John P. Tully*, the ship used by VENUS (Figure 3). The pig was placed in cold storage at 4^{o}C on the ship.

On 5 August, in the evening, the *Tully* (Figure 3) left the dock at the Saanich, Patricia Bay, Institute of Marine Sciences and entered the Saanich Inlet. Over the course of the 6 August, the instrument platform and the camera and tripod were deployed by ROPOS, the Remote Operated Platform for Ocean Science (Figure 4). The camera tripod attached to the platform used to place it and a close up of the camera and lighting arrays can be seen in Figures 5 and 6. The camera was an eight mega pixel Olympus C8080© housed in copper to prevent fouling. The camera was controlled topside through a computer server at the Saanich station. With VENUS access, I could control the digital still camera, the video and the lighting array from my own laptop anywhere in the world. The computer controls the tilt and range of the camera allowing it to move 360^{o}. The camera also had an array of different types of lighting and flashes, as well as a laser measure to generate a scale. These could all be controlled via a remote computer.

The Venus Instrument Platform (VIP), seen in Figure 7, included various instruments such as an oxygen optode, measuring temperature and oxygen levels; the Falmouth and Seabird CTD's measuring conductivity, pressure, salinity and temperature at 1 second and 60 second intervals respectively, a Transmissometer which measured light transmission (which gives clarity of water) and a Gas Tension Device which measured dissolved gas pressure. The VIP and camera were all connected via fibre optics to a Node which was previously deployed in the Saanich Inlet. This supplied all the power. Figure 8 shows the VIP being lowered by crane from the deck of the *Tully* to the chosen site in the Saanich Inlet. Figure 9 shows the camera platform and tripod being lowered into the water at a separate but linked site. Original problems with the camera meant a delay, and technicians worked through the night to rectify the problem, delaying

deployment of the carcass until 7 August 2006. Once rectified, ROPOS was used to lift the camera tripod from the platform and position it at the previously chosen site. The site was at a depth of 94 m on silt which covered rock approximately 20 cm below the silt.

On 7 August, the carcass was removed from storage and weighted with four five pound weights to keep it close to the camera. Due to the delay the carcass was in rigor and lividity was set when it was placed (Figure 10). Figures 11 and 12 show ROPOS being deployed to receive the pig when dropped from the ship. The carcass was attached to an acoustic transponder to allow it to be located once dropped (Figure 13). The carcass was lowered into the water to ensure that the transponder was working before being released to drop naturally to the ocean floor. The carcass was deployed at 1122h on 7 August 2007, 44 h after death. The carcass sank immediately to the bottom.

Inside the command centre on the *Tully*, all the instruments and the team necessary to drive ROPOS and to operate the two arms of ROPOS, were positioned (Figure 14). One arm, the RAPTOR (Figure 15) is extremely delicate and can handle the most minute of movements. Several people are required to operate ROPOS at any time, and the team worked 24 hrs a day, with several shifts.

The pig was located by transponder and picked up by ROPOS. It was carried to the camera tripod and carefully placed where I requested it be positioned. I was able to adjust this position minutely using ROPOS. The carcass was placed at a depth of 94 m on the silt substrate. It was placed approximately 100 m from the VIP. The transponder was released and recovered by ROPOS. Figure 16 shows ROPOS being recovered..

I then left the ship by zodiac and went to the onshore Saanich station housing the main computer controlling the camera and saw the first images of the carcass *in situ.* Large herring balls were present during the placement, as well as some dogfish and flounder (see Video 1). The area was very silty and cloudy due to the activity of ROPOS.

Once deployed, the carcass was observed several times a day for approximately 1 hour at a time. Observations were kept to a limited number per day to avoid impacting the local environment too much. The ocean at this depth is completely dark so nothing could be seen until I accessed the VENUS network and turned on the lights and cameras. Each session was videotaped in its entirely and many digital still images were recorded each time. An array of lights were available. The carcass was videoed, photographed and observed daily until it was no longer in view of the camera. Oxygen level, salinity, clarity (transmission) and temperature were monitored at 1 and 60 second intervals by VENUS equipment. Observations were all made by remote computer and the VENUS array was accessed from various sites including Vancouver and Ontario.

RESULTS

The temperature of the water at the depth at which the pig laid remained very constant ranging from approximately 9.5^{o}C to 9.8^{o}C. Figure 17 shows the temperatures at the VENUS Instrument Platform (VIP) from the SEABIRD CTD for the month of August. The VIP was positioned 100m from the carcass. Appendix I gives daily temperatures for the duration of the study. Measurements were made every 60 seconds.

Oxygen levels were measured by an oxygen optode on the Venus Instrument platform every 60 seconds. Oxygen is measured as the dissolved oxygen in mL/L. Dissolved oxygen levels fluctuated around 2.1 mL/L in early August, with means around 1.8 mL/L and dropped gradually over the month to lows of 0.2 mL/L with means around 0.7 mL/L. Figure 18 shows the dissolved oxygen levels for the month of August and Appendix II shows the daily levels and range of fluctuations.

Salinity was measured at the Venus Instrument platform 100 m from the carcass using the SEABIRD CTD. Salinity fluctuated around 31.02 and 31.18 PSU (Practical Salinity Units) (Figure 19). Daily values are shown in Appendix III.

The turbidity of the water was measured using a Transmissometer on the Venus Instrument platform 100 m from the carcass. The Transmissometer measures light transmission through water. Completely clear water gives a reading of 100%. Transmission varies if the water is clouded by sediment or animal activity. Figure 20 shows the transmission in percent for the month of August. Transmission varies regularly depending on animal activity and sediment levels in the water column. Appendix IV shows the daily fluctuations in transmission.

Days are listed as days since submergence. The pig died 44 hours prior to submergence. Photographs and video of each session indicate that turning on the VENUS lights did not have an immediate effect on the local fauna. There was no sign that animals fled the area when the lights were turned on. Nor did they appear to be attracted to the lights.

Day 0. When dropped into the water, the carcass sank immediately. Although weighted down, the rope attaching it to the weights would have allowed a certain amount of flotation to occur. However, the carcass did not re-float after it had been placed at the research site, and did not re-float at any time. The only movement exhibited by the carcass was due to animal activity and not to gases or currents, which are absent at this depth. The activity of ROPOS created a great deal of turbidity in the water surrounding the carcass and fine silt was deposited all over the carcass. The silt made the water very cloudy and difficult to see through at first, see Figures 21 and 22. The pig rested directly on its left side. A large herring (*Clupea* sp.) ball was present when the carcass was deposited but the fish did not exhibit any attraction to the remains. The carcass was immediately attractive to a number of arthropods, including large Three Spot Shrimp, Dungeness crabs *Cancer magister* (Dana) and squat lobsters *(Munida quadrispina* Benedict, Family Galatheidae) (Figures 21-24). Flounder were seen in the silt nearby and went under the carcass several times. Anemones and sponges were also in the general area. The carcass was lying on sediment. A Three Spot Shrimp (*Pandalus platyceros* Brandt*)* was seen to be picking at the silt on the carcass. Dissolved oxygen levels in the water ranged from 1.5 to 1.9 mL/L (Appendix II).

Day 1. Twenty-one hours after the carcass was deployed, the silt had settled and various crustacea, primarily squat lobsters, Dungeness crabs and Three Spot Shrimp, were attracted to the expected areas, the anus region (Figure 25) and the facial orifices (Figure 26). The pig had been moved slightly and rested more on its back than side. Rocking activity by large Dungeness crabs was capable of moving the carcass slightly. Only minor scavenging was noticed. The carcass did not show any signs of

decomposition or bloat. This is expected at the pressure found at a depth of 94 m and also at the low average temperatures of around 9.5^{o}C. The carcass did not float at any time. Dissolved oxygen levels in the water ranged from 0.8 to 2 mL/L (Appendix II).

Day 2. The carcass was observed five times between 0820h and 2200h PDT. At 0820h, large numbers of squat lobsters were seen on the head region of the carcass (Figure 27 and 28), with many others attracted across the silt to the carcass, moving actively towards the carcass (Video 2). The pig had been moved from the base of tripod leg one to the base of tripod leg two, with its back towards tripod leg two. This indicates a movement of approximately 1.5 m and 180^{o}. A large piece of tissue had been removed from the rear left flank of the carcass, and a large flap of skin and tissue from the stomach region lay open (Figure 29). The removal of the tissue occurred sometime between the last observation at 1820h the previous night and 0820h on the morning of Day 2. The animal which removed this tissue was not observed, but the size and shape of the bite and the ragged indentations of triangular teeth indicate that it may have been caused by a sixgill shark *(Hexanthus griseus)* (Tunnicliffe, personal communication). This site immediately became the focus of almost all scavenging activity. By 1000 h, all the crustacean feeding was at the rear end where the tissue had been removed (Figure 30) with little or no activity at the head end (Figure 31). By 1830h, squat lobsters were again seen all over the carcass but the majority of the feeding activity was centred around the damaged region in the flank (Video 3 and Figure 32). The scavengers were almost entirely squat lobsters, with only one Dungeness crab seen at 2200h (Figure 33). A video scan of the surrounding areas shows large numbers of squat lobsters crossing the seafloor to the carcass. No Three Spot Shrimp were present at this time. Jellyfish and flounder

were seen swimming through the area. Dissolved oxygen levels in the water ranged from 0.4 to 1.6 mL/L (Appendix II).

Day 3. The carcass was observed twice at 0827h and 1830h PDT. The damaged area of the flank was extremely attractive to squat lobsters and also Dungeness crabs (Figure 34). The Dungeness crabs were also seen going under the back, which moved the carcass somewhat. Squat lobsters were still seen at the eyes and ears, picking at the eyes and into the ear. Silt was still visible on the carcass, and animal tracks could be seen throughout the silt. The jagged lines of the damaged area were still clearly visible. Dungeness crabs and many squat lobsters fed on the damaged area, picking chunks of flesh away, as well as at the underside of the flap of belly skin and flesh (Video 4 and Figure 35). They picked at the flesh side of the flap. Herring, jellyfish and flounder were still in the area. There was no sign of bloat or flotation. Dissolved oxygen levels in the water ranged from 0.5 to 1.5 mL/L (Appendix II).

Day 4. The carcass was observed twice at 0635h and 1850h PDT. More flesh had been removed from the damaged area of the carcass (Figure 4). The laser indicates the size of the area. The lasers are positioned 10 cm apart. Both flanks were missing the bulk of their tissue. The left rear leg was partially severed from the rest of the carcass. Squat lobsters and Dungeness crabs were feeding extensively at damaged area. Squat lobsters were combing through the silt on the surface of the pig and also were found at the head region, although the face and eyes were still intact. Flounder and jellyfish were seen in the area. Dungeness crabs were removing large pieces of tissue from the damaged region and also from the fleshy area of the stomach flap (Video 5). Squat lobsters swim out of the way of the Dungeness crabs when they were near. By late afternoon, a large number

of Three Spot Shrimp were feeding actively on the remains at the damaged area and on the inside of the stomach flap (Figures 37 and 38). Figures 39 and 40 indicate the lesions left from feeding by these crustacea. There was no sign of bloat or flotation. Dissolved oxygen levels in the water ranged from 0.9 to 1.5 mL/L (Appendix II).

Day 5. The carcass was observed at 1720h PDT. A large amount of tissue had been removed from the hind end of the carcass. The abdominal cavity had been breached and the spinal column and the intestines were clearly visible (Figure 41). Several Dungeness crabs and many lobster and Three Spot Shrimp were actively feeding in this region. Approximately 30 cm of spinal column were exposed although not picked clean. Coiled loops of intestine were visible. Both back legs were partially de-fleshed at the rear of each leg. The facial area remained intact although one or two squat lobsters still showed an interest in this region. There was no sign of bloat or flotation. Dissolved oxygen levels in the water ranged from 1 to 1.45 mL/L (Appendix II).

Day 6. The carcass was observed at 0835h, 1705h and 2237 h PDT. At 0835h, the lower half of the carcass was mostly gone (Figure 42). Large Three Spot Shrimp and Dungeness crab were feeding in the visceral region. The Dungeness crabs were also feeding at the spinal column. The activity of a single Dungeness crab was capable of rocking the whole carcass. A starfish (*Pycnopodia helianthoides*) (Figure 43) and a ruby octopus (*Octopus rubescens*) (Figure 44) were attracted to the remains and fed briefly. The carcass appears to have been moved about 15 cm from its site the previous day, based on its relationship to the tripod leg (Figure 42). Three Spot Shrimp were feeding on the skin at the edge of the wounds as well as the soft tissue. By 1705 h there was a lot more activity on the carcass with a large number of squat lobsters and some Three Spot

Shrimp on the surface of the carcass (Figure 45). Three Spot Shrimp were actively feeding at the edge of the wound area (Video 6). Squat lobsters seemed to be picking through the silt and detritus on the skin of the pig, which close up views seem to indicate has many small crustacea in it, although these are difficult to identify. Dungeness crabs were seen to be picking at the tissue along the back. Much of the skin flap from the stomach has been devoured by this time, but was still being fed upon by squat lobsters. Also, there was some activity at the head, particularly around the ear and in the ear as well as the eye region although this area still seems intact (Figure 45). By 2237 h, the carcass mostly hosted Dungeness crabs and Three Spot Shrimp, although squat lobsters were nearby on the silt. The carcass was still firmly on sediment with no sign of bloat or flotation. Three large Dungeness crabs pulled and picked at the wound area. Dissolved oxygen levels in the water were low, ranging from 0.85 to 1.3 mL/L (Appendix II).

Day 7. The carcass was observed three times at 1110h, 1740h and 2215h PDT. The head was still intact although Dungeness crabs and squat lobsters were picking at it. Several squat lobsters were concentrated near the snout and ear, picking into the ear and around its base, creating scrape marks (Figure 46). Several squat lobsters were also seen combing through the silt and detritus on the surface of the skin of the carcass, presumably feeding on zooplankton or phytoplankton (Figure 47). Five or six large Dungeness crabs were feeding on the carcass, some at the back and others at the back of the legs or the wound. They left distinctive clipped, jagged marks in the flesh (Figure 48). The wound site was still a major focus of squat lobsters, Dungeness crabs and Three Spot Shrimp. Later in the day, only Three Spot Shrimp and squat lobsters were seen at the wound area, but Dungeness crabs returned by 2215h. The carcass has been moved a few centimetres

towards the centre area. There was no sign of bloat or flotation. Dissolved oxygen levels in the water ranged from 0.9 to 1.1 mL/L (Appendix II).

Day 8. The carcass was observed three times, at 0807 h, 0920 h, and 1742 h. When first viewed at 0807 h, the carcass had been moved from the central part of the tripod area closer to one tripod leg. The carcass' head was approximately 30-40 cm from the tripod leg (Figure 49). Squat lobsters were feeding at the mouth and ear area. One and a half hours later, the pig was again observed and was found to have been moved so that the forehead area rested up against the tripod leg, indicating that the carcass had been moved approximately 30-40 cm in less than 90 minutes (Figure 50, Video 7). Dungeness crabs, three spot shrimp and squat lobsters on carcass (Figure 51). Crab feeding and pulling at the carcass caused it to rock back and forth and almost push it over at one point. By 1742 h, the head region of the carcass has been pulled about 15-20 cm away from the tripod leg (Figure 52). Several large Dungeness crabs were feeding at the head and rear end of the carcass. Despite recent interest in the head area, this still appears mostly intact and it is the rear area that is almost completely depleted. The tissue appears to be greyish white in colour. Dissolved oxygen levels in the water ranged from 0.85 to 1.1 mL/L (Appendix II).

Day 9. The carcass was observed three times, at 0230 h, 0730 h and 1720 h. At 0230 h, the activity on the carcass seemed very similar to that observed during the daytime hours. Dungeness crabs and squat lobsters were feeding at both ends of the carcass. The carcass is no longer restrained at all by the ropes and weights. The carcass seems to be in the same position as at last observation. The ropes were attached together which meant that when part was lost, the whole was lost. By 0730 h, the carcass head had

been moved a bit closer to the tripod leg again (Figure 53). Laser lights indicate a distance of 10 cm between lights in photos. Figure 54 shows damage caused primarily by crab activity as they rip at the tissue. Several dog fish were seen to swim over the carcass but showed no interest in the carcass. Dungeness crabs, three spot shrimp and squat lobsters were all feeding at the carcass, with crabs ripping pieces of tissue away. The activity was similar at 1720 h, with primarily just crabs and squat lobsters feeding (Figure 55). Crabs again were moving and rocking the carcass as they feed. Dissolved oxygen levels in the water ranged from 0.9 to 1.04 mL/L (Appendix II).

Day 10. The carcass was observed three times, at 0830h, 1737h and 2250h. Dungeness crabs and squat lobsters were the dominant fauna, with a few Three Spot Shrimp present but these were only in low numbers (Figure 56). The pelvis bones have been completely cleaned, although the spinal column still has some tissue attached to it which is attractive to the squat lobsters (Figure 57). The crabs were more interested in the fleshier area (Figure 58). The carcass is still heavily silted over the upper part of the torso. At 0830 h, the carcass had again been moved so that the head is closer to the tripod leg and just past it. The ropes are below and to the back of the carcass but do not constrain it at all. There appears to have been some feeding in the belly area and a strand of tissue is floating up from this region. By 1737h, this strand had gone. The lowest rib in the rib cage is now visible and clean, but there still seems to be tissue inside the cavity, although actual organs cannot be identified (Figure 59). By 2250h, the carcass has been moved closer to the tripod leg with the head just past the tripod leg and the right, lower ear, pushed up against the tripod leg (Figure 60). Lobsters and Dungeness crabs dominate the carcass still. The squat lobsters appear to stay clear of the crabs and will swim away if

a crab gets too close. Crab activity was capable of moving the carcass by rocking it back and forth from front to back. At one point, the actions of two crabs were seen to lift the carcass several times and almost roll it over, from its right side to its left (Video 8). A crab could also be seen reaching in through the belly area into the central cavity and reaching at tissue deep in the cavity (Video 9). Pieces of tissue dropped by crabs were rapidly grabbed and eaten by squat lobsters nearby. Dissolved oxygen levels in the water ranged from 0.84 to 1.02 mL/L (Appendix II).

Day 11. The carcass was observed twice, at 0835h and again at 2026h. At 0835h, the carcass was lying close to where it was at the previous observation, having been moved about 7-10 cm away from the tripod leg at the head area. The previously exposed rib had been pulled down and out of the cavity, although it, and all other bones still seem fully articulated (Figure 61). Dungeness crabs and squat lobsters were feeding on the carcass, and one or two Three Spot Shrimp. By 2026h, the carcass had been moved about 30-50 cm towards the central area of the tripod. Figure 62 shows the increasing damage occurring to the tissue in the stomach region and a Dungeness crab pulling at a large piece of tissue and skin in this region. Dissolved oxygen levels in the water ranged from 0.8 to 1 mL/L (Appendix II).

Day 12. The carcass was observed once at 1506h. High numbers of plankton were observed at first, almost obscuring the carcass. Many squat lobsters were all over the carcass (Figure 63). The carcass had again been moved so that the top of the head was almost against the tripod leg. Squat lobsters were seen to pull large pieces of tissue from under the skin at the side area (Figure 64). The upper region of the body appears to be completely intact, apart from some grazing damage to the basal part of the left ear. No

crabs and only a few shrimp were seen at this time. The vertebral column was skeletonized, as was the pelvis. By this time the pig was free of its ropes so was no longer held to the centre of the camera's view. Dissolved oxygen levels in the water ranged from 0.8 to 0.96 mL/L (Appendix II). Dissolved oxygen levels had been steadily dropping over the previous days but from this point onwards, they did not rise above 1mL/L until Day 21 (28 August 2006).

Day 13. The carcass was observed twice, at 0625h and again at 1505h. At 0628h, the carcass was still in the same position as at the previous observation, with the head close to the tripod leg Figure 65). The dominant large fauna feeding at the carcass were squat lobsters which were numerous on and around the carcass. Plankton and small fish were also present and almost obscured the carcass at times. A single Dungeness crab was noted approaching the carcass. The feeding damage at the stomach has been extended and appeared deeper. A few very small, red amphipods, also known colloquially as sea lice, were first observed on the edge of the tissue bordering the open cavity (Figure 65). By 1510 h, the body had again been moved so that the back of the head area now lies about 10-20 cm away from the tripod leg and above it. Many more small red amphipods can be seen on the skin near the stomach region (Figure 66) and on the exposed tissue near the spinal column (Figure 67). Several Dungeness crabs were feeding actively at the stomach and exposed portion. Dissolved oxygen levels in the water ranged from 0.83 to 0.93 mL/L (Appendix II).

Day 14. The carcass was observed twice, at 0743 h and again at 1845 h. Large numbers of small fish and plankton were present, almost completely obscuring the carcass at times. The plankton mainly seemed to consist of small shrimp. The tiny red

amphipods were not visible on the carcass. The water was also very silt-laden, which also impeded vision. At 0743h, the carcass had again been moved and now lay with its back close to the tripod leg, indicating that the entire carcass had been moved about 30 cm out of the tripod area. This has meant that the legs are now extended out at the back, but still articulated. As well as large numbers of small fish, several Dungeness crabs were present and also squat lobsters. Other fauna, including flounder, herring and several dogfish swam through the area a few times, but showed no interest in the carcass (Figure 68). At some times the dogfish pushed the carcass slightly and at others simply swam over. They showed no active interest in the carcass but remained in the area for some time. The stomach area displayed further feeding activity. By 1845h, the carcass had been moved a little further past the tripod leg, and a large piece of tissue from the stomach area had been pulled away and was being eaten by a crab (Figure 69). The bottom two ribs were exposed on the left hand side, indicating further feeding in this area. A few tiny red amphipods were present on the exposed areas of tissue. Dissolved oxygen levels in the water ranged from 0.75 to 0.87 mL/L (Appendix II).

Day 15. The carcass was observed twice, at 0633h and again at 1716h. At 0633h, the carcass had been moved further away from the camera tripod area and was lying with its pelvis level with the tripod leg (Figure 70). Squat lobsters were on the carcass and the sand, and one Dungeness crab was seen nearby. A squat lobster was feeding inside the cavity. The snout area shows signs of grazing, but in general the upper part of the body is still intact. The large flap of skin from the stomach area is still present. One small bone was lying a distance from the body but the rest appears articulated. Plankton was common. By 1716h, the carcass had been moved considerably and the entire carcass was

approximately 30 cm past the tripod leg, except for the rear left foot and part of leg which had become disarticulated (Figure 71). At this time, very few fauna were present on or near the carcass. A single Dungeness crab was near the disarticulated leg but not actively interested in it and one or two squat lobsters were present on the carcass. Dissolved oxygen levels in the water ranged from <0.65 to 0.85 mL/L (Appendix II).

Day 16. The carcass was observed twice, at 0405h and again at 1843h. At 0405h, the carcass was attractive to many squat lobsters, on the detached leg, carcass and sea floor (Figure 72). Plankton was plentiful consisting primarily of small shrimp. A seal swam past and disturbed the sediment. Seals are playful and it is quite possible that some of the carcass movement may have been due to a seal bumping the carcass. By 1843h, the carcass had been dramatically moved more than 100^{o} (Figure 73). The lower part of the carcass appears to have been completely removed so that only a few bones of the spinal column are still visible below the skin and tissue of the upper body. The pelvis and right leg are not visible. The upper body is still intact and appears very little damaged. The tissue and skin is intact. The first detached leg is still at the same site, and many squat lobsters are present on the sea floor, carcass and detached leg. This was the first time that the head could be clearly seen, although the movement of the carcass has meant that it is at the further ranges of the camera so cannot be clearly seen. Grazing damage can be seen at the snout and eyes, as well as the ears, and the nasal bones and orbits have been exposed (Figure 73). Dissolved oxygen levels in the water ranged from 0.35 to 0.8 mL/L (Appendix II).

Day 17. The carcass was observed once at 2100h. It has been moved even further so that now the head end is facing the tripod leg (Figure 74). It can now clearly be seen

that the snout area has sustained significant grazing damage, with the sides removed down to the teeth. The left eye socket is empty and there is a whitish grazed area between and behind the ears. Squat lobsters are on the sea floor, detached leg and carcass. The other rear leg can now be seen under the body, sticking out at the back (Figure 74). Squat lobsters were feeding on the disarticulated leg and carcass and were also seen all over the sea floor. A single Dungeness crab was observed but did not appear to be feeding. Dissolved oxygen levels in the water ranged from 0.3 to 0.7 mL/L (Appendix II).

Day 18. The carcass was observed twice, at 0630h and 2025h. At 0630h, the carcass itself was in the same position as the previous day, but the detached leg is now out of sight, except for the cleaned femur which remains at the same site as yesterday (figure 75). Squat lobsters are present on the femur, carcass and sea floor. A detached rib can be seen near the carcass. Figure 76 shows a close up of the carcass. The snout has been grazed down to bone and the back of the right ear has been grazed. There was little change observed at 2025h. The carcass and disarticulated bones were still *in situ* (Figure 76). Many squat lobsters were feeding on the carcass and disarticulated bones. The rear leg under the carcass now seems skeletonized. Dissolved oxygen levels in the water ranged from 0.3 to 0.8 mL/L (Appendix II).

Day 19. The carcass was observed three times, at 1010h, 1840h and 2206h. By 1010h, the carcass had been moved a little further on its axis (Figure 77). This meant that the head was clearly visible as were the front legs. The front legs appeared entirely intact. The nasal area had been grazed down to bone, but other than a few grazed areas, the upper body and head were intact. They appeared fully fleshed and skin and hair was intact. Figure 78 shows a close up of the facial area, showing the skeletonized nasal

region. As the carcass was a distance from the optimal camera and lights area, the carcass was dark and hard to see. The only major fauna appeared to be squat lobsters which were feeding at the nasal area and on the carcass and bones in general. Some leg bones were visible to the right of the carcass (Figure 78). No differences were observed at 1840h or 2206h. Dissolved oxygen levels in the water ranged from 0.3 to 0.85 mL/L (Appendix II).

Day 20. The carcass was observed three times, at 0335h, 1110h, and 1950h. At 0335h there appeared little change. The carcass appeared to be in the same location and was not well lit. One femur remained close to the tripod leg. However, by 1110h, the carcass had been moved about 120^{o} (Figure 80). From this position, it was obvious that much more tissue had been removed from the lower part of the torso, with much of the spinal cord revealed and skeletonized. There appeared to still be some organs present in the upper part of the torso, but this is difficult to tell. The femur has been moved a short distance so obviously still has some attraction to fauna despite appearing completely skeletonized. Squat lobsters were present on the carcass and sea floor. By 1950h, the carcass had been moved again (Figure 81). No organs appeared to be present in the body cavity, and a flap of tissue had been pulled back. It was not possible to determine whether the spinal vertebrae were still articulated as the carcass was partially behind the tripod leg (Figure 81). Squat lobsters were present on and around the remains and a Dungeness crab was observed near the carcass. A round grazed area was visible on the underside of the right leg, near the joint. Dissolved oxygen levels in the water ranged from 0.4 to 0.9 mL/L (Appendix II).

Day 21. The area was observed twice, at 0835h and at 1740h. The bulk of the carcass has been moved out of the line of site of the camera. A large piece of tissue and

some bones are visible to the left of the tripod leg (Figure 82) and some tissue, possibly the rest of the carcass is faintly visible in the top right area of the figure. Squat lobsters were the only large fauna noted. There was little change by 1740h, with one leg with hoof attached noted to the right of the tripod leg and a femur very near the tripod leg. A dog fish swam through the area many times. Dissolved oxygen levels in the water ranged from 0.4 to 1.1 mL/L (Appendix II). This was the first time since Day 12 that dissolved oxygen levels reached above 1mL/L.

Day 22. The carcass area was observed twice, at 0855h, and 1855h. At 0855h, the femur and attached tissue had been moved but the carcass was clearer and could be seen in the top right hand area of figure 83. The spinal column was still attached and exposed, but the carcass had been turned over and was now lying on its left side. Several Dungeness crabs were in the vicinity, feeding at the leg bones. By 1855h, it was difficult to tell whether the carcass was still in range of the camera (Figure 84). It appears that it may have been turned around so that the head and ears face the camera, but this is difficult to determine as the carcass is at the furthest range of the camera and the lights. A femur is still visible behind the tripod leg. Squat lobsters were still present throughout the area. Dissolved oxygen levels in the water ranged from 0.5 to 1 mL/L (Appendix II).

Day 23. The area was observed once at 1630h but the carcass was no longer visible, nor any parts. Dissolved oxygen levels in the water ranged from 0.3 to 1 mL/L (Appendix II).

The area was viewed several times in the subsequent days, but no sign of any body parts were seen, except on Day 44, when some squat lobsters were seen feeding on

something that may have been pig tissue in sight of the camera again (Peters 2007). In November, ROPOS was deployed again for other experiments. The experimental area was carefully searched but no remains were found.

DISCUSSION

This study looked at only one carcass, but was a unique opportunity to study the decomposition of a carcass in the ocean on a very regular basis. Other experiments and reports have either consisted of studies where carcasses were observed sporadically, due to the difficulties of regularly accessing a submerged carcass (Anderson *et al.* 2004; Anderson *et al.* 2002), or were the result of interpretations from actual cases (Ebbesmeyer and Haglund 2002; Haglund and Sorg 2002; Davis and Goff 2000; Kahana *et al.* 1999; Boyle *et al.* 1997; Ebbesmeyer and Haglund 1994; Haglund 1993).

Although obviously it would be better to study submerged human remains when making conclusions about human decomposition and carrion colonization, ethical and moral constraints eliminate this possibility in Canada, at least for the foreseeable future. Pig carcasses have been considered to be good models for human decomposition (Catts and Goff 1992) and have been shown to decompose in a similar manner to human cases (Anderson *et al.* 1996), including those in water (Petrik *et al.* 2004).

The carcass was undisturbed after placement, except for the operation of the camera, which involved turning on lights. This obviously changed the environment by lighting an area that is normally dark. This was kept to a minimum. Turning on the lights did not appear to have an obvious impact as no animals were seen to scatter as the lights

came on or, conversely, appeared to be attracted. Therefore, it is anticipated that the lights did not have a major effect on the study.

This carcass was very specifically killed on land, then transported to a ship, weighted down and dumped in the ocean. Due to the weights, it remained at the same site for 21 days, until, once free of the constraints of the ropes, it was dragged out of camera range. One could argue that this is not a realistic scenario for a homicide victim, however, it is not particularly far-fetched. Most homicide victims that end up in the ocean are not killed at sea, but merely disposed of at sea. So a terrestrial, non- drowning death is quite realistic. Although a body may be dumped immediately, it would not be uncommon for it to remain on land, or hidden somewhere for a day or two until a boat could be secured and a suitable dumping time could be arranged. If a killer wished to dispose of a body, using some sort of weight would be probable to prevent the body from rising. Realistically, if a body sinks to the depths in this experiment, it is unlikely to refloat due to pressure preventing bloat (Teather 1994). Therefore, although not all body disposals would mimic this scenario, the study here was not unrealistic.

The carcass decomposition and scavenging in this study was very different from that seen before in earlier experiments in these waters (Anderson *et al.* 2004; Anderson *et al.* 2002). In past experiments, six carcasses were placed in Howe Sound, just off the Vancouver Coastline, in early summer and in fall. In each season, three carcasses were placed in "shallow waters" with an average depth of 7.6 metres and three were placed in "deep waters" with an average depth of 15.2 metres (Anderson *et al.* 2004; Anderson *et al.* 2002). The carcasses were tethered to weights but given enough slack so that flotation, if it occurred, could be observed. Observations were made by divers swimming down to

the carcasses and photographing the remains, or by carcasses being briefly recovered to be examined on land, then re-deployed. In these experiments, the carcasses floated immediately when placed, and at this depth, would probably have been carried away by tidal action at this time. After a few hours, they sank and remained settled on the sea floor until bloat occurred, at which time, some of the carcasses re-floated, and again would have been carried away by tidal action. Due to the presence of gas in some organs, some of the carcasses remained suspended for many weeks (Anderson *et al.* 2004; Anderson *et al.* 2002). This had a major impact on the decomposition and colonization of these carcasses, as those that became suspended decomposed much more slowly than those that fell to the ground (Anderson *et al.* 2004; Anderson *et al.* 2002). Carcasses that remained suspended were only accessible to organisms that readily swim, so those that sank to the ground were much more scavenged (Anderson *et al.* 2004; Anderson *et al.* 2002).

In the present study, the carcass did not float at any time. Although tethered, there was enough rope to allow a small amount of flotation, so had it occurred, it is expected that this would have been observed. At such a great depth, water pressure prevents the expansion of gases from bacterial decomposition, and the low water temperature would have retarded the bacterial activity (Teather 1994). At this depth there are no currents and no tidal pull is felt.

In the earlier experiments, normal underwater decompositional changes were observed which included the formation of lividity, the carcass bloating, skin and hair sloughing from the body, adipocere formation, algal staining of the bones, as well as the normal sequence of decomposition, from fresh, through bloat, active decay, advanced decay and remains (Anderson *et al.* 2004; Payne and King 1972). These expected

decompositional stages were similar to those seen on land, but were different in appearance and duration (Anderson *et al.* 2004; Anderson *et al.* 2002; Anderson *et al.* 1996). In this study, the decompositional pattern was completely different and was almost entirely scavenger-driven. The carcass could only be observed not actually sampled, so small tissue changes could not be seen, however, no overt signs of typical decomposition were seen in this case. Tissue loss was much more rapid than in the previous experiments and a good proportion of the carcass had been removed entirely by faunal activity by Day 6.

The body did silt up, but otherwise no other typical decompositional changes were observed. No adipocere formation was observed as the remains were skeletonized too fast. Tissue loss appeared to be almost entirely due to animal feeding.

The primary carrion feeders were large shrimp, crabs and squat lobsters. Although no actual control was employed, the presence of the carcass clearly attracted large numbers of animals. These were seen on the carcass day and night and the density of marine organisms was much greater at the carcass than elsewhere (Peters 2007). Peters recorded the density of the squat lobster, *Munida quadrispina,* to be as high as 1.6/dm^2 when the pig was present, in contrast to 0.7/dm^2, when it was absent (Peters 2007). *Munida quadrispina* was the most common large scavenger feeding on the carcass and was found in 85.7% of images (Peters 2007). *Cancer magister,* the Dungeness crab, was the second most common (61.8% of images) and *Pandalus platyceros* the next at 35.5% (Peters 2007). No classic succession was observed. All these organisms were attracted to the carcass and were absent or only sporadically seen when the carcass was not present.

In the previous experiments, very large sunflower sea stars (*Pycnopodia helianthoides*) were attracted to the remains immediately after death and in some cases completely covered the carcass. In this study, a much smaller specimen was seen once, attracted to the rear of the carcass.

On land, the primary sites of colonization of carrion insects are the wounds and natural orifices (Rodriguez 1997; Anderson *et al.* 1996; Rodriguez and Bass 1987; Nuorteva 1977). However, in the previous marine experiments, the head wounds of the carcasses were not of particular interest to marine organisms, and many of the animals fed directly on the skin creating openings in the skin that could mimic wounds (Anderson *et al.* 2004; Anderson *et al.* 2002). In this study, there was immediate attraction to the carcass and although the fauna did seem to concentrate around the anus and face, animals were found all over the body. Then, in Day 2, a large animal, probably a sixgill shark, bit a chunk of flesh out of the flank. This then immediately attracted almost all the animals and this area became the main site of animal activity, with very little activity in other areas, including the face. Even by Day 19, most of the face was still intact, so obviously, opening up the carcass made it much more attractive to animals.

Sharks are not known to readily feed on human flesh and pig flesh is considered to be very similar to human flesh. Therefore, it is possible the dog fish was just tasting or playing with the pig and only took one bite. They may have been attracted to the carcass due to the large numbers of squat lobsters, Dungeness crabs and Three Spot Shrimp on the carcass (Tunnicliffe 2006) although stomach contents analysis showed that they may occasionally scavenge carcasses (Ebert 1986). The animals fed very cleanly on the carcass, so that there was a very clear line of demarcation between scavenged and non-

scavenged flesh. This was also seen in a homicidal dumping case which I attended in Fall in the Vancouver area, indicating similar scavenging. Such feeding is quite different from damage caused by wave action, or erosion. It is also entirely different from arthropod colonization on land, which although concentrated in wound sites etc, does not usually show this very clear demarcation between scavenged and non-scavenged flesh.

Approximately a third of the external carcass had been consumed and all the internal organs appear to have been removed within 21 days of submergence. Carcass decomposition and scavenging in the marine environment is very variable, much more so that on land where biomass loss, and insect succession is very predictable within habitats, regions and seasons. In the ocean, carcasses may remain relatively intact for weeks (Anderson *et al.* 2004; Anderson *et al.* 2002), or can be scavenged very rapidly as in this case. In some human cases, the bulk of the exposed tissue can be removed down to bone in less than 24 h (Teather 1994). In the North Atlantic Ocean, a partial carcass of a dolphin was skeletonized within five days (which was the result of removal of approximately 60 kg of tissue) primarily by tiny lysianassid amphipods at depths of 4000-4800 m (Jones *et al.* 1998). In a case this author attended, a diver was recovered and was fairly intact after submersion at 100 m of the Vancouver Coast, after five years submersion. The good preservation resulted primarily from the adipose tissue turning to adipocere and the protective actions of the dive suit. In experiments in the Arabian Sea, two shark carcasses were deployed at depths of 4040 m and 1900 m and monitored with a time lapse camera (Witte 1999). At 4040 m, the carcass rapidly and continually attracted zoarcid fish and decapod shrimp which removed approximately 20% of the carcass

within 11 days. At 1900 m, the primary scavengers were deep-sea stone crabs which removed approximately 20% of the carcass in five days (Witte 1999).

When a human body is recovered from water, there are many different types of damage observed. These can sometimes be mistaken for antemortem injuries. Therefore, it is imperative to recognize animal feeding marks as opposed to deliberately inflicted wounds. Also, an understanding of injury patterns by animals may help to indicate to investigators the type of environment in which the body has been. In this study, marks created by shrimp and crab feeding were very clear. These create very distinct artifacts.

The oxygen levels during the study were always below 2 mL/L, which is considered hypoxic (Diaz and Rosenburg 1995). From Day 12 to Day 21, oxygen levels dropped to below 1 mL/L, which is usually considered to be too low for most animals to survive comfortably, and crustacean are often considered to be very sensitive to this (Diaz *et al.* 1995). However, the carcass obviously proved attractive enough to bring animals to the carcass even in low oxygen conditions. However, when the levels dropped below 0.5 mL/L, only the squat lobster, *Munida quadrispina* remained on the carcass (Peters 2007). The Saanich Inlet is one that experiences regular low oxygen conditions (Anderson and Devol 1973), so animals in this area have adapted to low dissolved oxygen levels (Tunnicliffe 1981), so the continued colonization of the remains at low oxygen levels may be specific to areas such as this. However, species such as *M. quadrispina* (Burd and Brinkhurst 1884) and *Cancer magister* are capable of surviving periods of hypoxia, by utilizing various physiological mechanisms (Bernatis *et al.* 2007).

This work has shown a snap shot into the decomposition of a carcass at 94 m in the ocean in Saanish Inlet. It has provided valuable information on the scavenging and disarticulation of a carcass under these conditions and will be useful in assessing human cases of death in the water.

Future experiments are planned and a repeat experiment was conducted in September of 2007, the results of which will be published shortly.

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Figure 1. *Aerial view showing the location of the Saanich Inlet, in relation to the southern part of Vancouver Island, the Lower Mainland of British Columbia, north western Washington State and the Olympic Peninsula. Downloaded from Google Earth, 15 June 2007.*

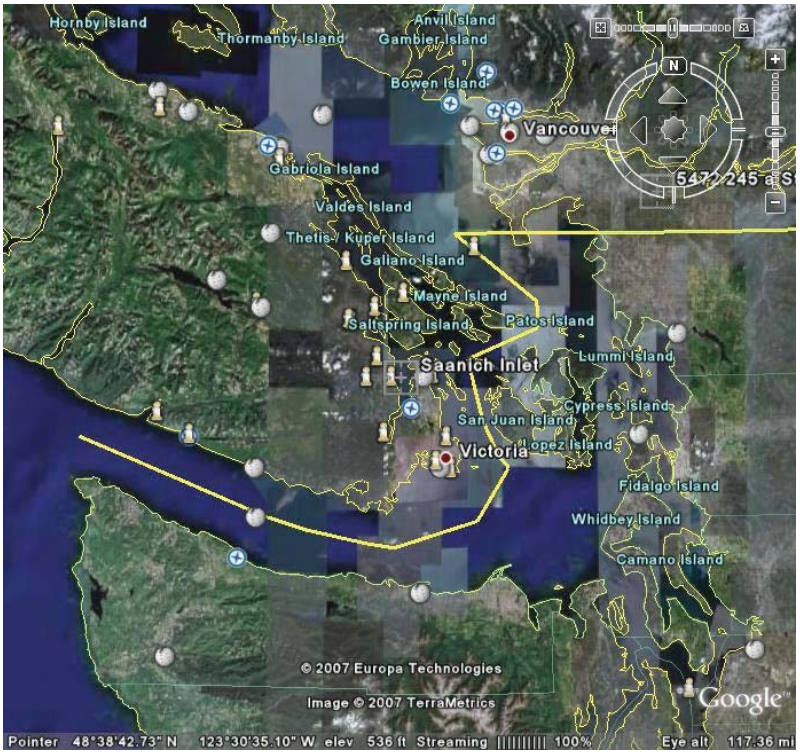

Figure 2. *Close up of the Saanich Inlet. Downloaded from Google Earth, 15 June 2007.*

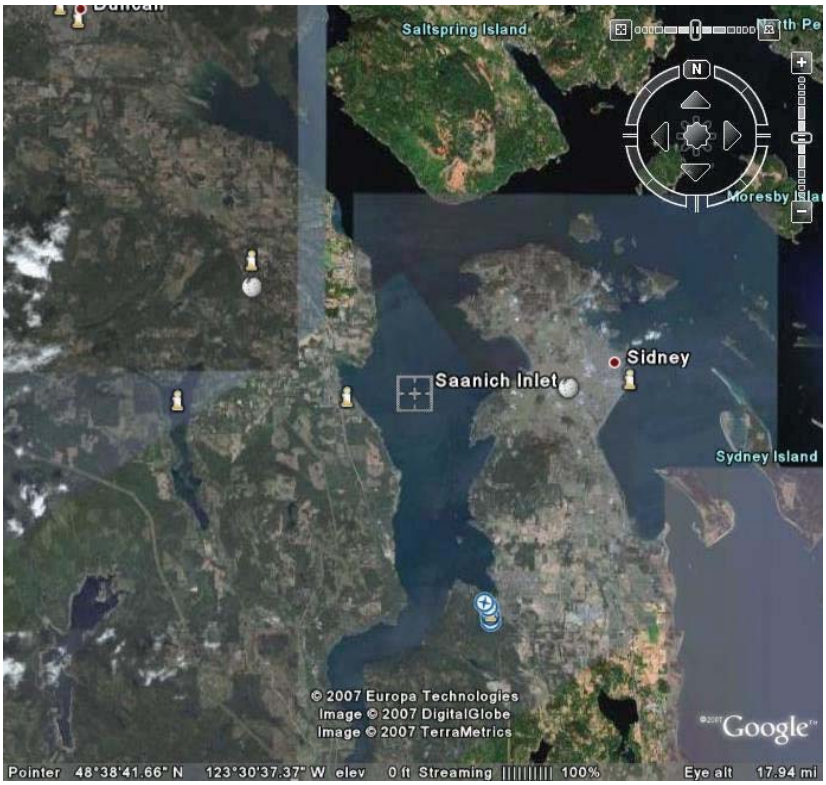

Figure 3. *CCGS John P. Tully, used to deploy ROPOS*

Figure 4. *ROPOS, the remote operated vehicle used to deploy VENUS equipment and the carcass*

Figure 5. *Camera tripod and platform prior to deployment*

Figure 6. *Close-up of underwater camera, "cyclops" and lighting array, before deployment*

Figure 7. *Instrument platform before deployment.*

Figure 8. Instrument platform and cable being deployed from CCGS Tully

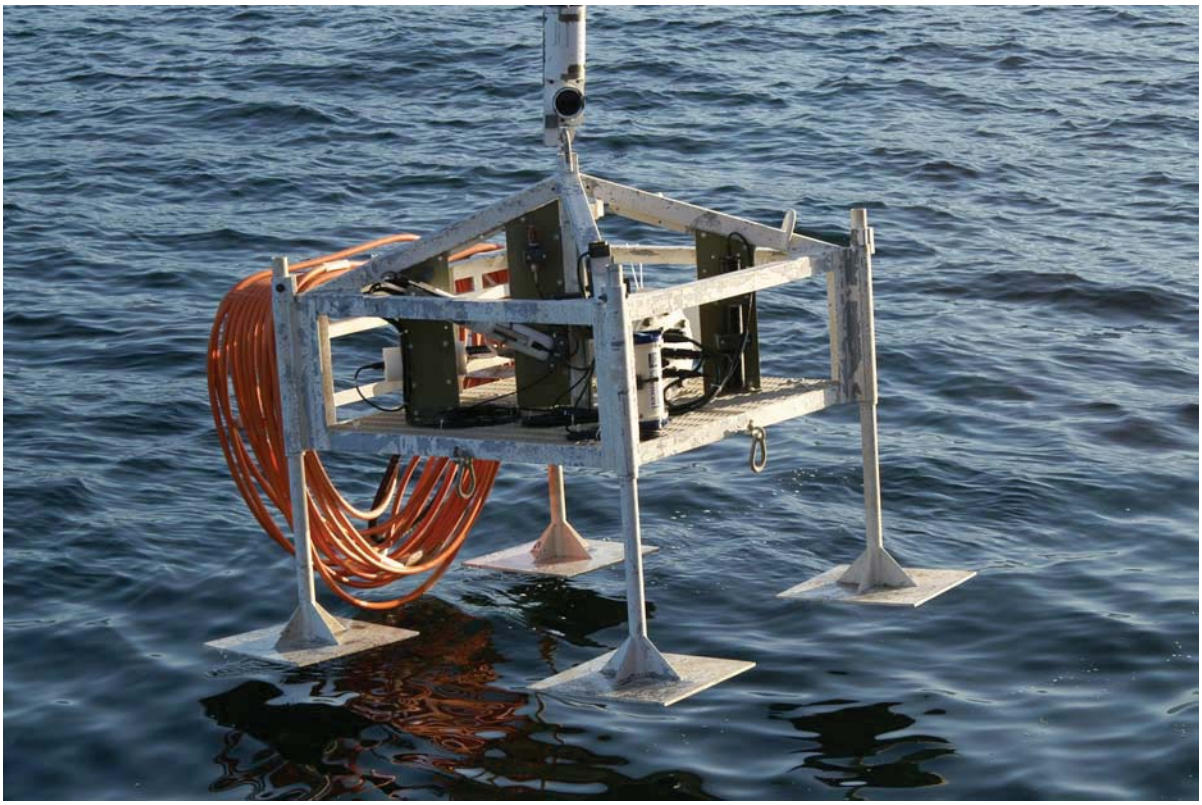

Figure 9. Cyclops and platform being deployed

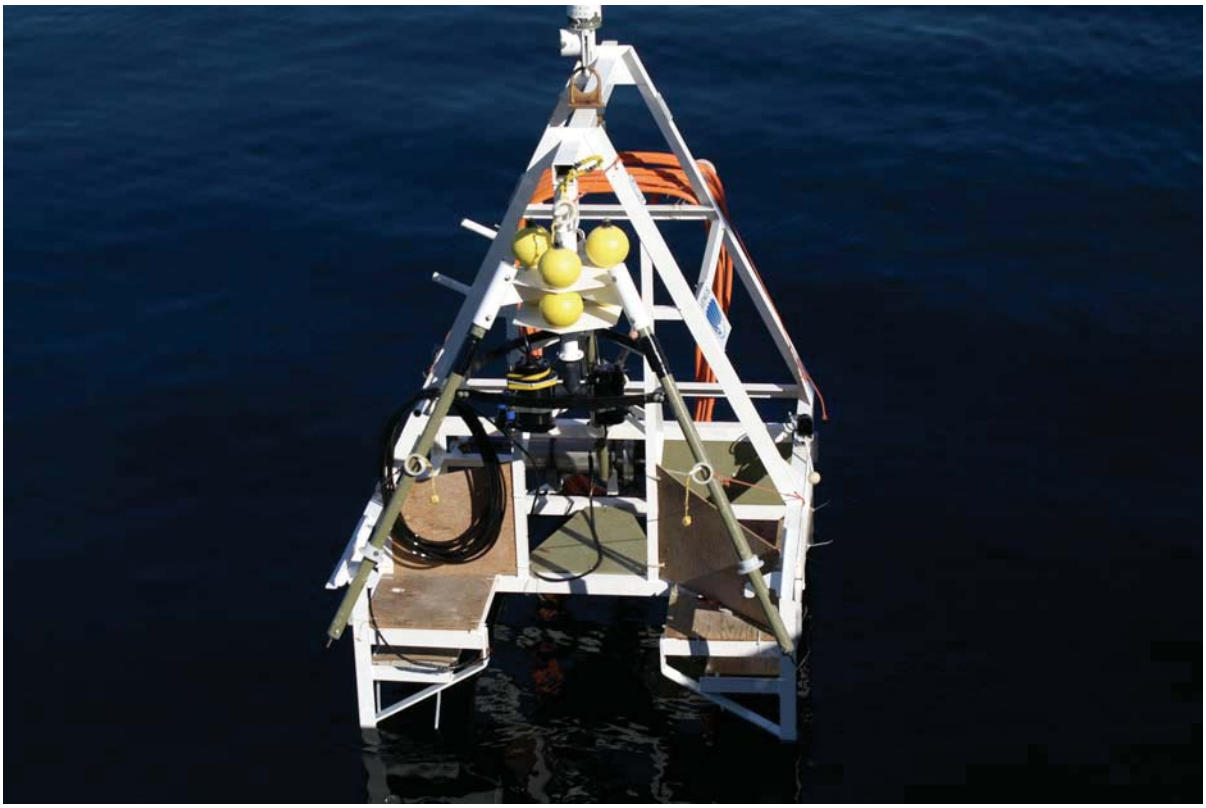

Figure 10. Pig carcass prior to being rigged with weights

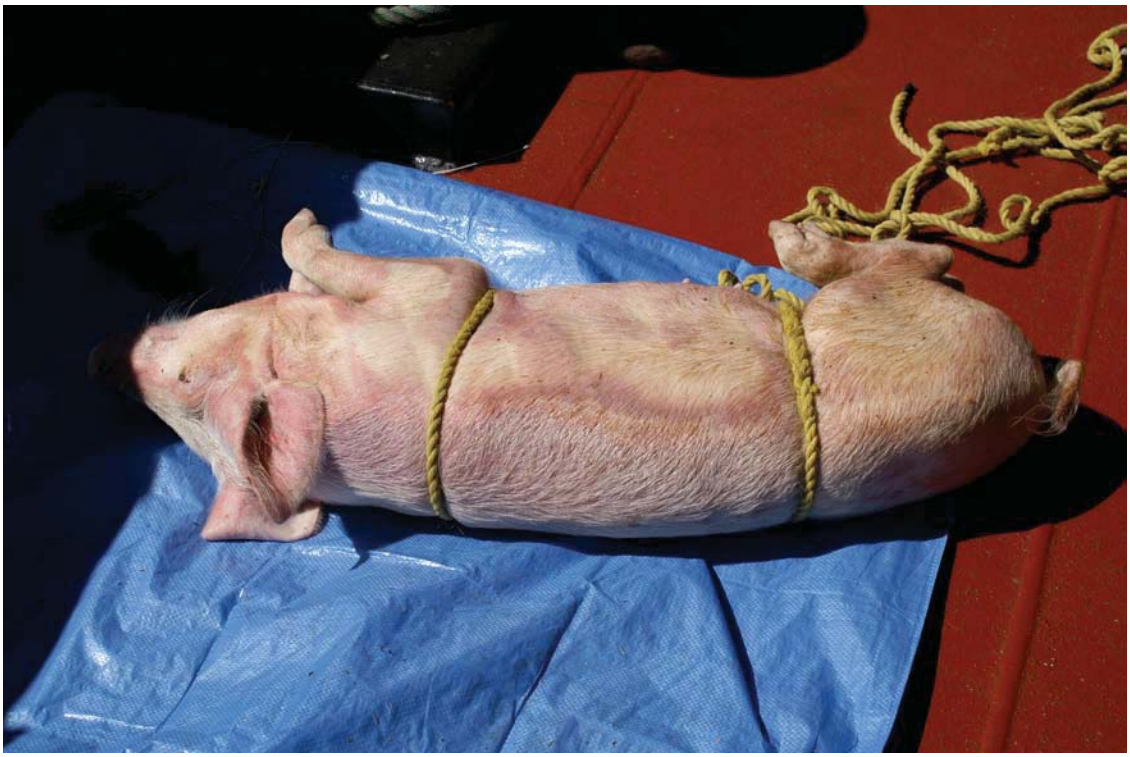

Figure 11. *Deploying ROPOS prior to dropping pig carcass, for ROPOS to place carcass at camera site.*

Figure 12. *Deploying ROPOS prior to dropping pig carcass, for ROPOS to place carcass at camera site.*

Figure 13. Pig carcass weighted, with transponder attached

Figure 14. *Command centre on Tully, controlling ROPOS*

Figure 15. *Raptor arm of ROPOS used to minutely position carcass under camera tripod.*

Figure 16. *ROPOS being recovered after deploying carcass*

Figure 17. *Ocean temperature for August 2006 at a depth of 95 m measured at the Venus Instrument Platform 100 m from the carcass.*

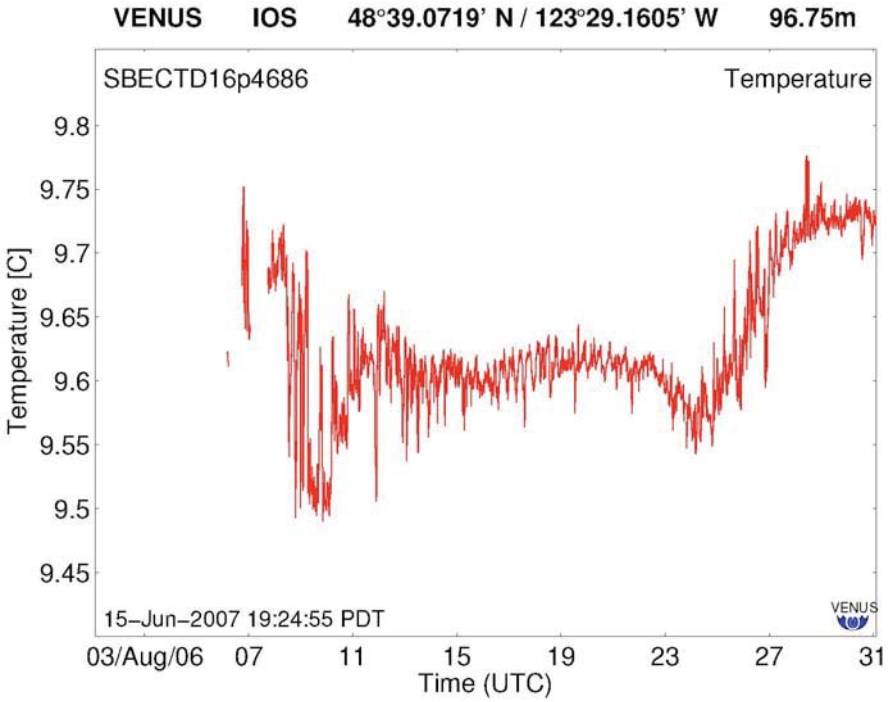

Figure 18. *Dissolved oxygen levels for August 2006 at a depth of 95 m measured at the Venus Instrument Platform 100 m from the carcass.*

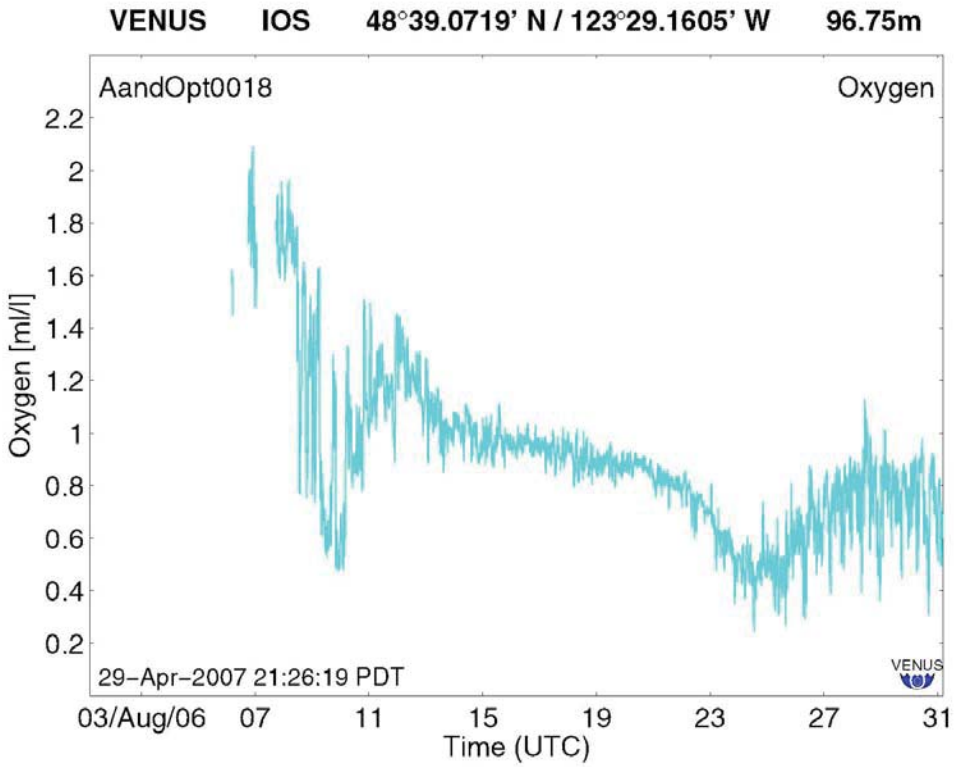

***Figure 19**. Salinity values for August 2006 at a depth of 95 m measured at the Venus Instrument Platform 100 m from the carcass.*

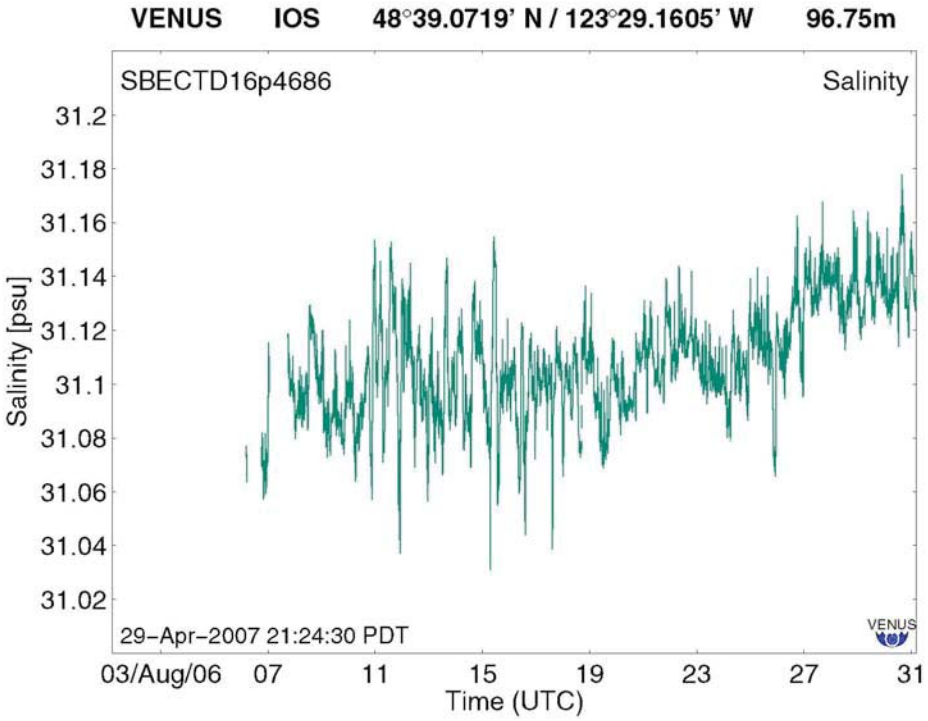

***Figure 20**. Transmission values for August 2006 at a depth of 95 m measured at the Venus Instrument Platform 100 m from the carcass.*

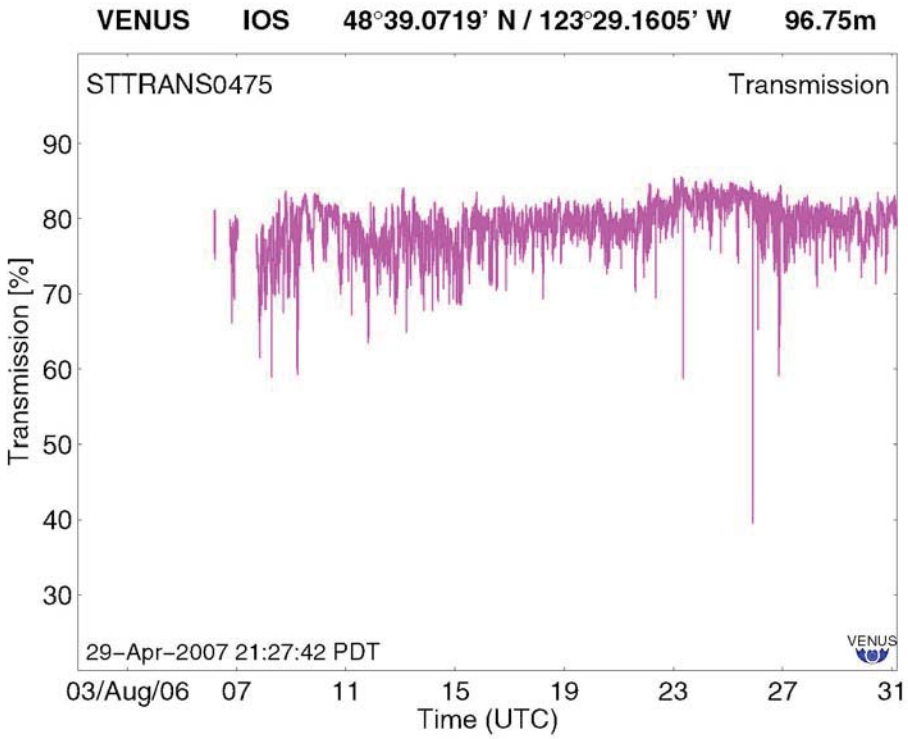

Figure 21. *Carcass immediately after placement. All underwater photographs taken with VENUS (VENUS Project, University of Victoria).*

Figure 22. *Day 0 Pig lying directly on side. Weights visible near hind legs (VENUS Project, University of Victoria).*

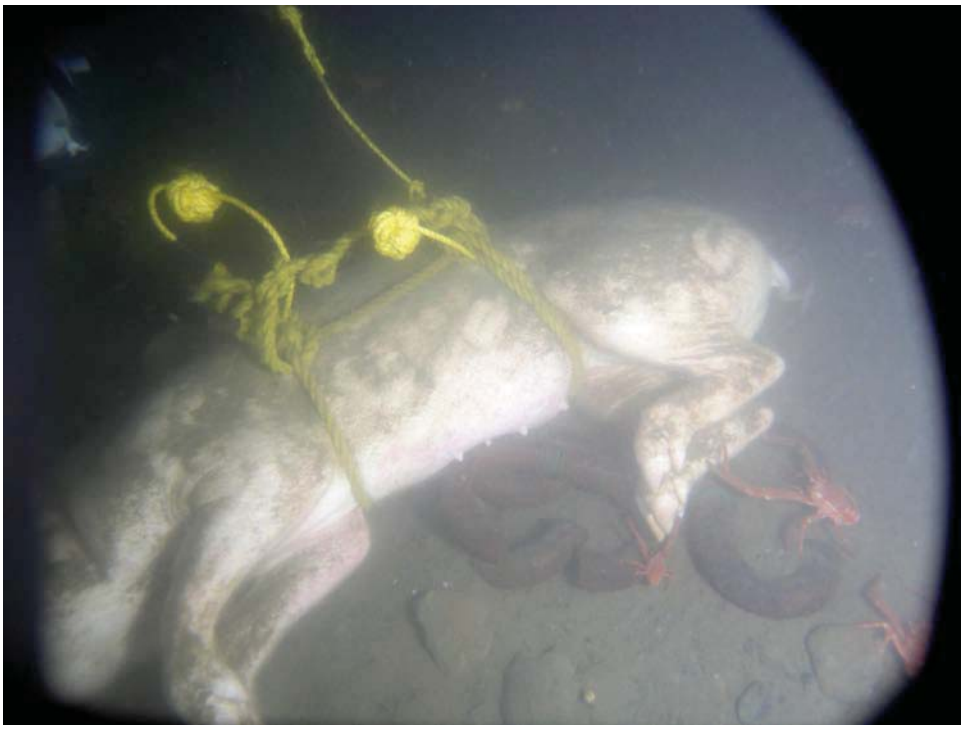

Figure 23. *Day 0, hours after placement (VENUS Project, University of Victoria).*

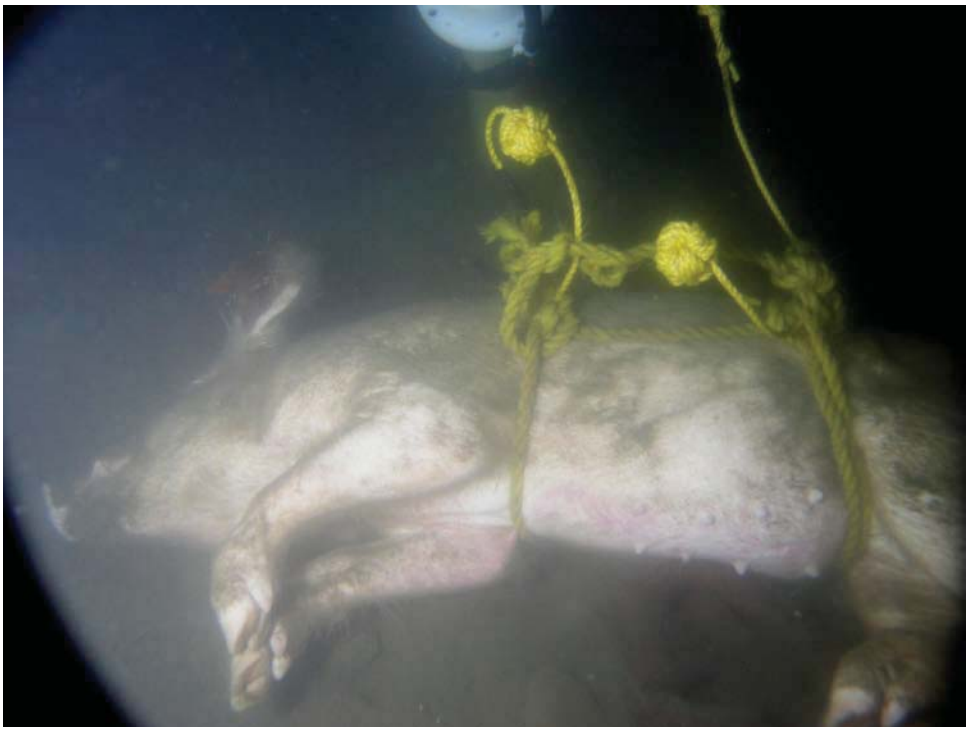

Figure 24. *Day 0, hours after placement (VENUS Project, University of Victoria).*

Figure 25. *Day 1 (24 hours after submersion), 0850 h. Squat lobster at tail end (VENUS Project, University of Victoria).*

Figure 26. Day 1. Squat lobster on snout (VENUS Project, University of Victoria).

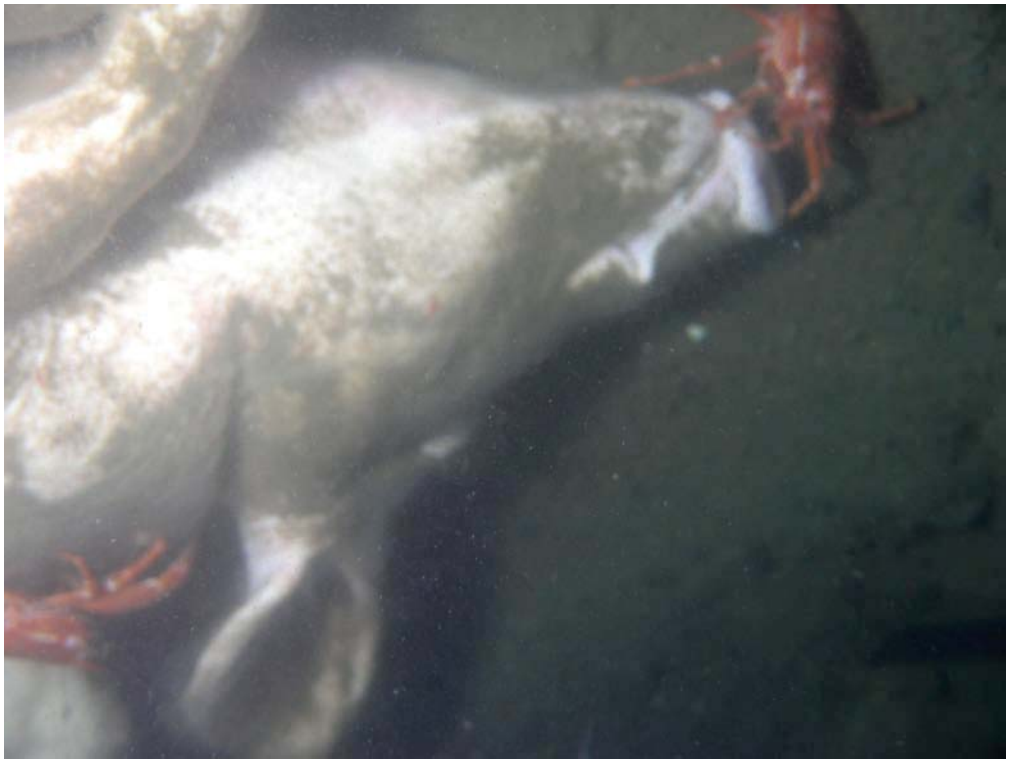

Figure 27*. Day 2, 0820h. Large numbers of squat lobsters attracted to the head region (VENUS Project, University of Victoria).*

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Figure 28. *Day 2, 0820h. Dungeness crabs and squat lobsters(VENUS Project, University of Victoria).*

Figure 29. Day 2, 0820h. Large piece of flesh removed from left flank region (VENUS Project, University of Victoria)..

Figure 30. Day 2, 1000h. All activity at damaged area (VENUS Project, University of Victoria).

Figure 31. *Day 2, 1000h. All activity has moved from head end to damaged region (VENUS Project, University of Victoria).*

Figure 32. *Day 2, 1830h. Activity all over pig again, but concentrated in open wound area (VENUS Project, University of Victoria).*

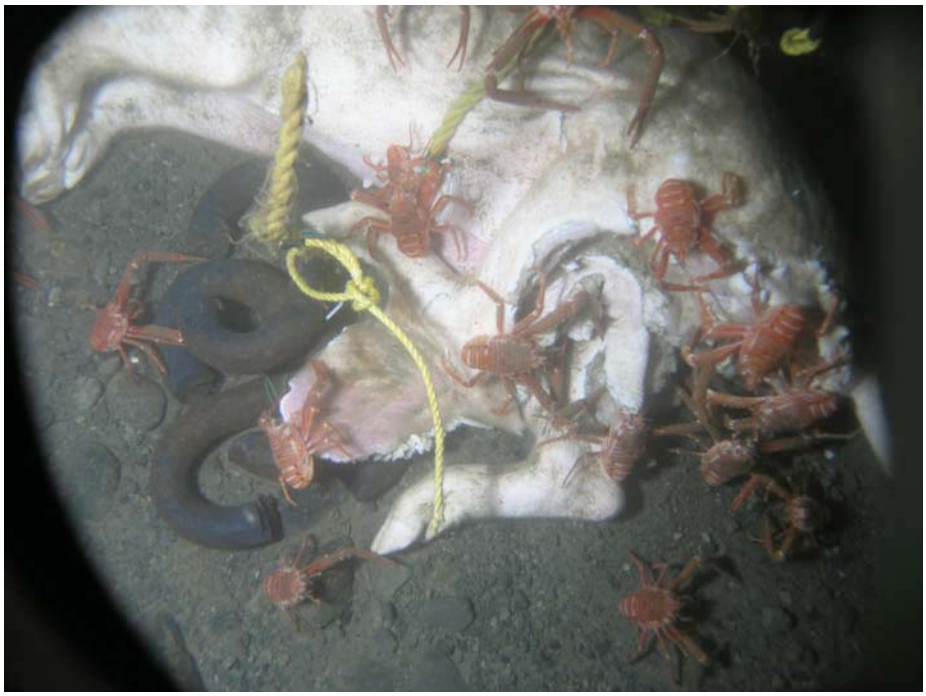


Figure 33. *Day 2, 2200h Dungeness Crab feeding at scavenged area (VENUS Project, University of Victoria).*

Figure 34. Day 3, 1830h (VENUS Project, University of Victoria).

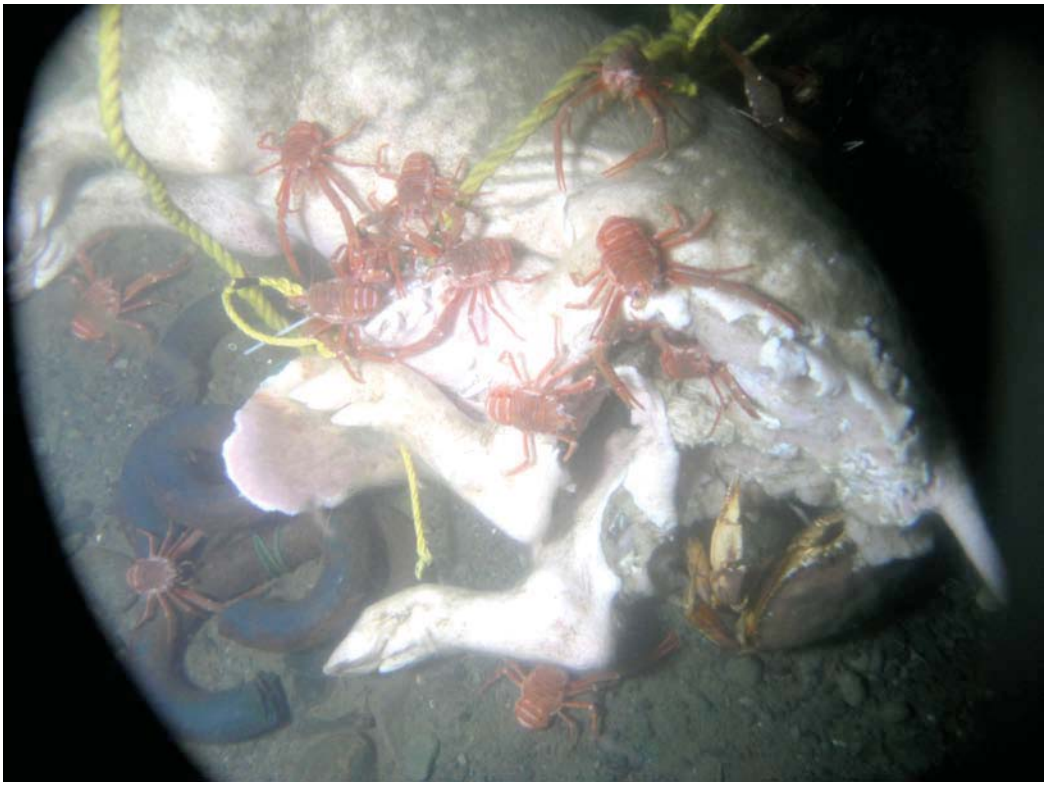


Figure 35. Day 3, 1830h. Close up of squat lobsters feeding at damaged region of flank. (VENUS Project, University of Victoria).

***Figure 36**. Day 4, 0635h More flesh has been removed. Lasers used to create scale. (VENUS Project, University of Victoria).*

Figure 37. *Day 4, 1850h Crabs and shrimp feeding on carcass (VENUS Project, University of Victoria).*

Figure 38. *Day 4, 1850h. Shrimp on wound (VENUS Project, University of Victoria).*

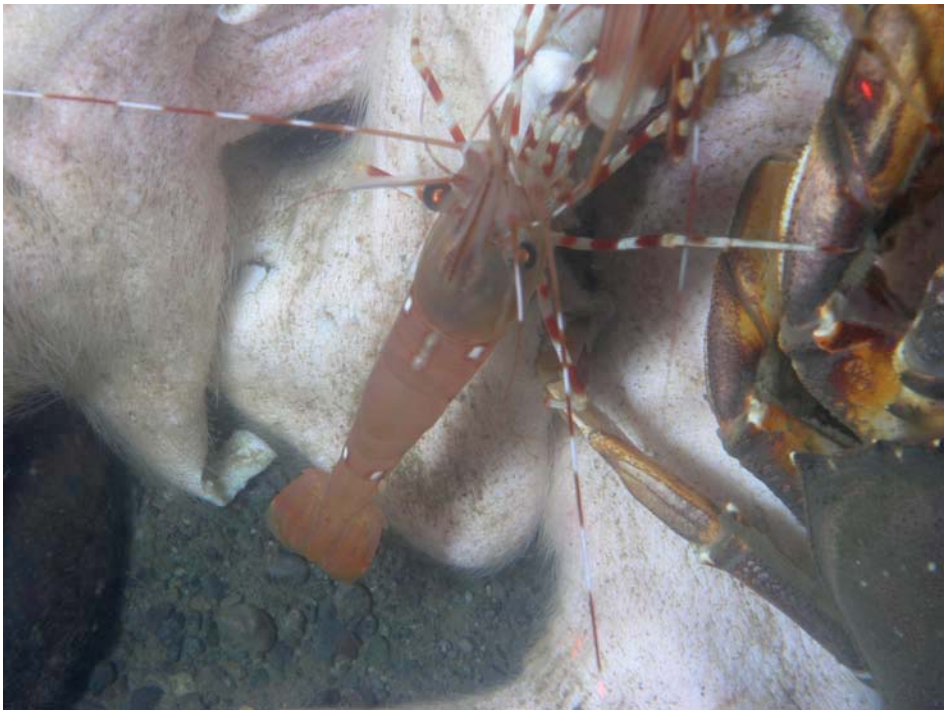


Figure 39. *Day 4, 1850h. Shrimp feeding (VENUS Project, University of Victoria).*

Figure 40. *Day 4, 1850h.Damage caused to tissue by feeding from lobsters and shrimp (VENUS Project, University of Victoria).*

Figure 41. *Day 5, 1720h. Large amount of tissue removed and spinal column and intestines exposed (VENUS Project, University of Victoria).*

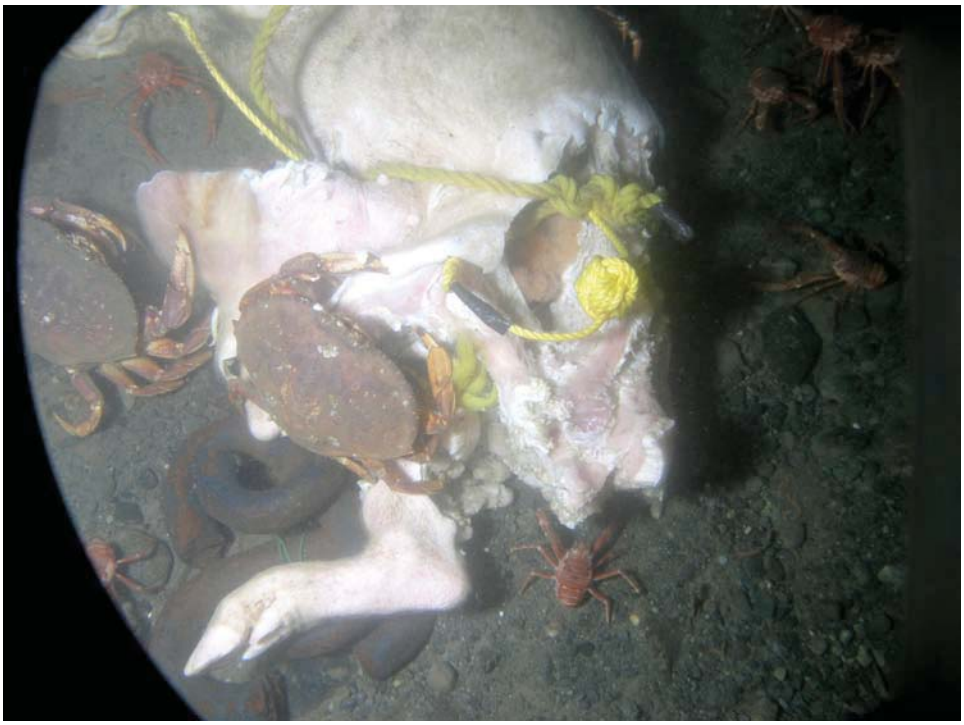


Figure 42. *Day 6, 0835h. Some activity at head end, but most at rear end. Removal of some of the viscera (VENUS Project, University of Victoria).*

Figure 43. Day 6, 0835h.Starfish and shrimp feeding (VENUS Project, University of Victoria)..

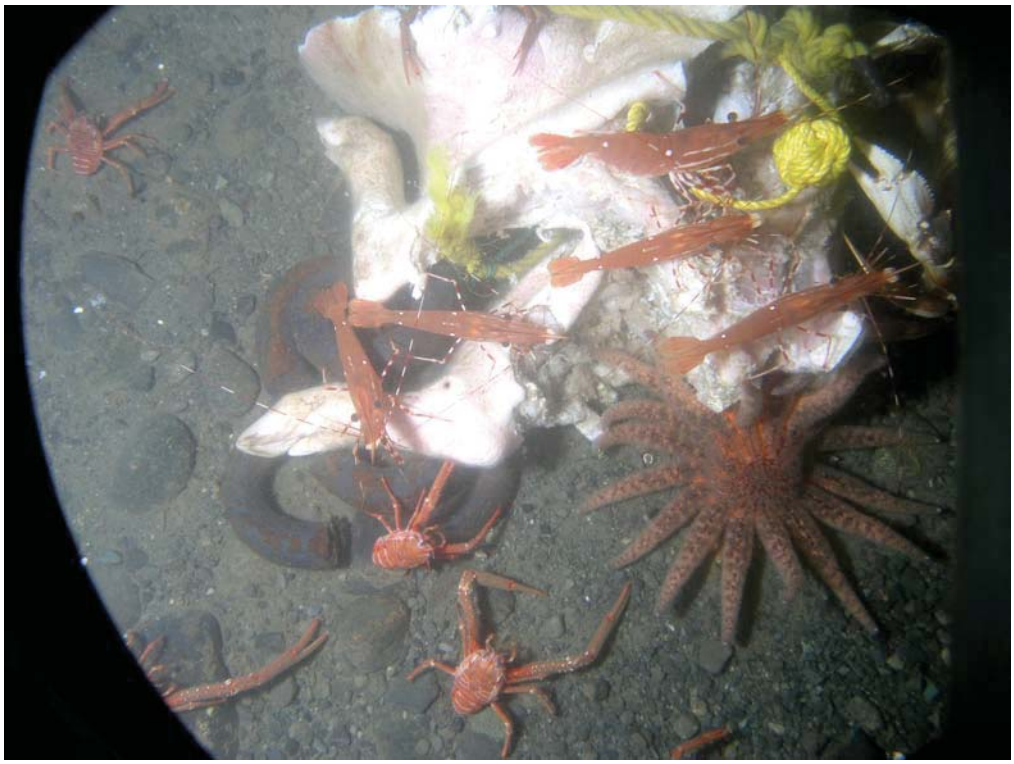


Figure 44. Day 6, 0835h. Small octopus attracted to remains (VENUS Project, University of Victoria).

Figure 45. *Day 6, 1705h. Much more activity on carcass at this time (VENUS Project, University of Victoria).*

Figure 46. *Day 7 1151h , Squat lobsters feeding at ear and snout (VENUS Project, University of Victoria).*

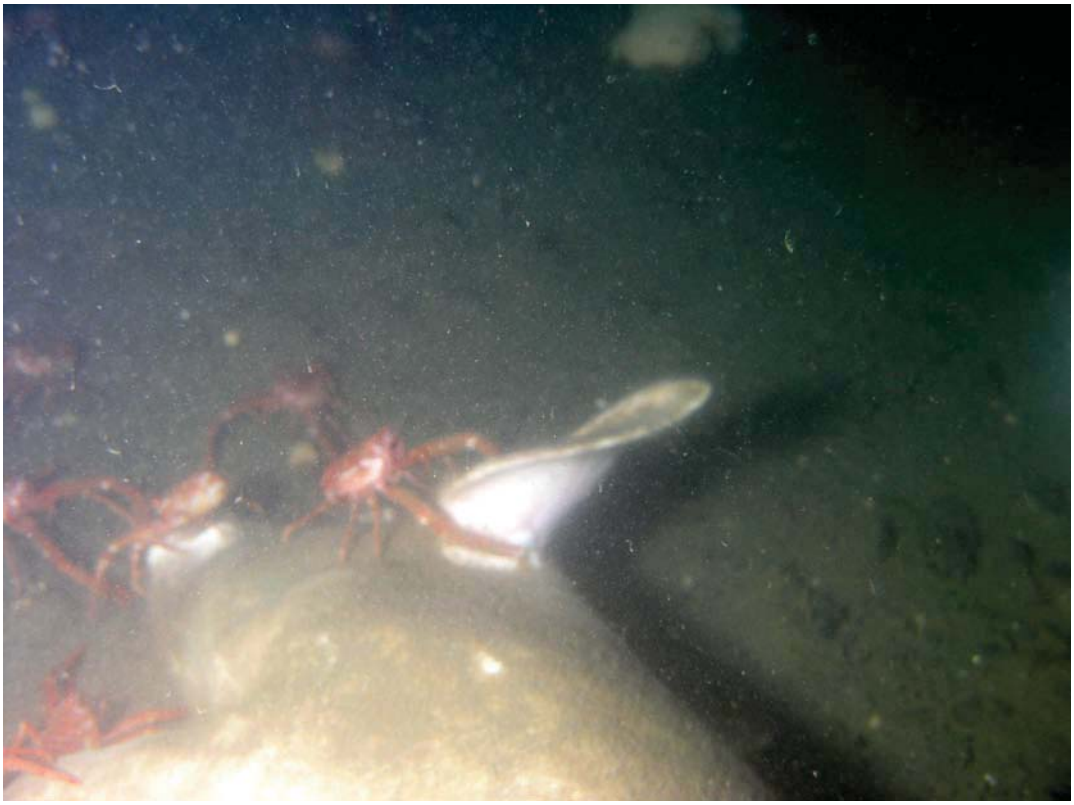


Figure 47. *Day 7 1151h , Squat lobster feeding on zooplankton or phytoplankton on the skin. (VENUS Project, University of Victoria).*

Figure 48. *Day 7, 11151h, Damage to skin caused by crabs (VENUS Project, University of Victoria).*

Figure 49. *Day 8, 0807h. Note position of head in relation to tripod leg. (VENUS Project, University of Victoria).*

Figure 50. *Day 8, 0930h. Carcass has been moved in past 1.5 h and is now very close to tripod leg (VENUS Project, University of Victoria).*

Figure 51. *Day 8, 0930h.Crabs feeding at rear en (VENUS Project, University of Victoria).*

Figure 52. *Day 8, 1742 h. Carcass has been pulled further from tripod leg (VENUS Project, University of Victoria)..*

***Figure 53**. Day 9, 0730 h. Carcass has been moved closer to tripod leg. Laser lights indicate 10 cm (VENUS Project, University of Victoria).*

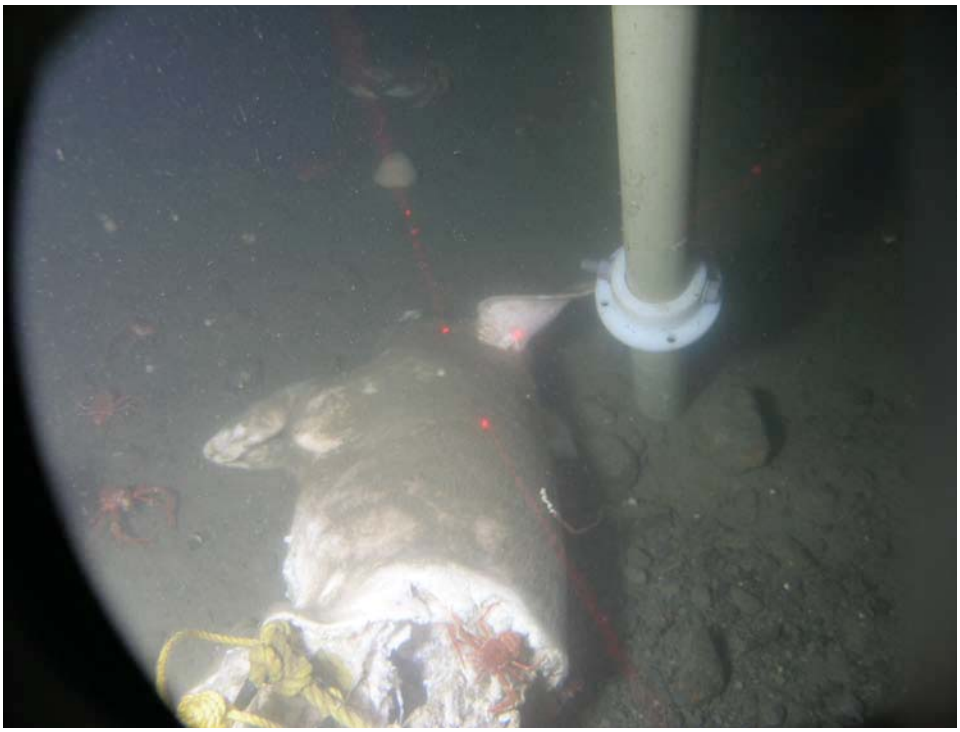


***Figure 54**. Day 9, 0730 h. Close up of tissue and feeding area (VENUS Project, University of Victoria).*

Figure 55. *Day 9, 1720 h. Dungeness crabs and squat lobsters feeding on carcass (VENUS Project, University of Victoria).*

Figure 56. *Day 10, 0830 h. Dungeness crabs and squat lobsters on carcass (VENUS Project, University of Victoria).*

Figure 57. *Day 10, 0830 h. Some tissue still remaining on spinal column (VENUS Project, University of Victoria).*

Figure 58. *Day 10, 0830 h. Crab claw damage (VENUS Project, University of Victoria).*

Figure 59. *Day 10, 1737 h. Pelvis bones picked clean and lowest part of rib cage now visible (VENUS Project, University of Victoria).*

Figure 60. *Day 10, 2250 h. Carcass has been moved closer to tripod leg again. (VENUS Project, University of Victoria).*

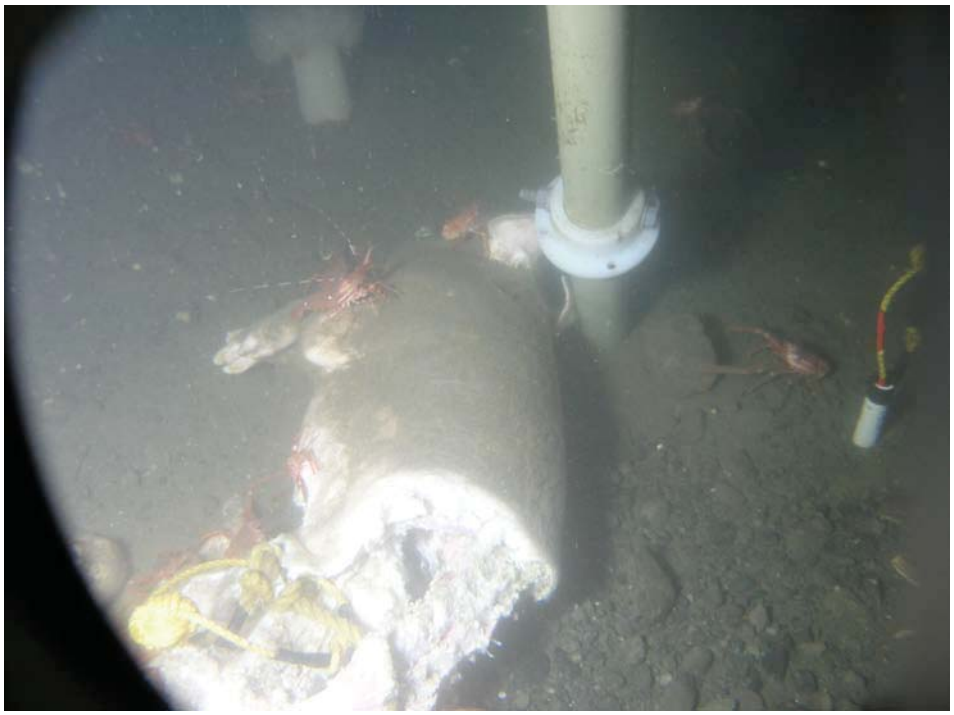


Figure 61. *Day11 0835 h. Rib has now been exposed further and pulled out of cavity a short distance (VENUS Project, University of Victoria).*

Figure 62. *Day11 2026 h. Carcass has again been moved closer to the centre are. Note crab pulling at skin, and damage to stomach area (VENUS Project, University of Victoria).*

Figure 63. *Day 12, 1506 h. Squat lobsters feeding on carcass (Photo taken by V. Tunnicliffe) (VENUS Project, University of Victoria).*

Figure 64*. Day 12, 1506 h. Squat lobster feeding on tissue (Photo taken by V. Tunnicliffe) (VENUS Project, University of Victoria).*

Figure 65. *Day 13, 0628 h Primary fauna are squat lobsters. Note feeding damage to stomach region. (VENUS Project, University of Victoria).*

Figure 66. *Day 13, 1510 h Crabs feeding at stomach region. Note small red amphipods on skin (VENUS Project, University of Victoria).*

Figure 67. *Day 13, 1510 h. Small red amphipods can be seen feeding on edge of exposed tissue (VENUS Project, University of Victoria).*

Figure 68*. Day 14, 0743 h. Crabs, plankton and a dogfish present. Carcass has been moved at least 30 cm (VENUS Project, University of Victoria).*

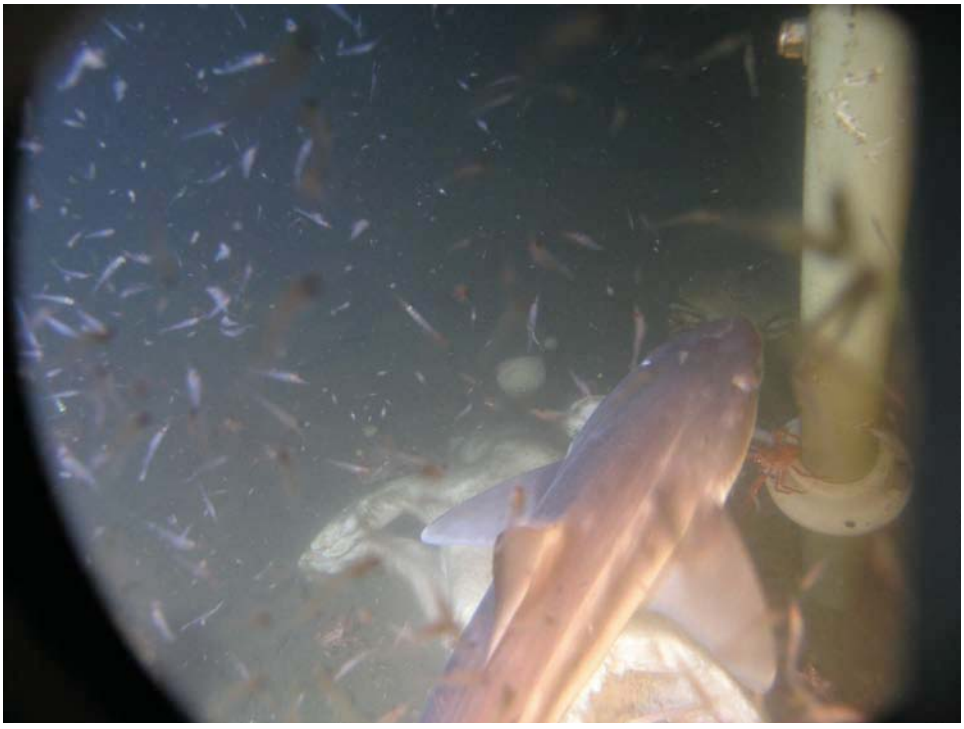


Figure 69. *Day 14, 1845 h. A large piece of tissue has been removed from the stomach area (VENUS Project, University of Victoria).*

Figure 69. *Day 14, 1845 h. Only a few small red amphipods are present. (VENUS Project, University of Victoria).*

Figure 70. *Day 15, 0633 h. Carcass has been dragged further out. (VENUS Project, University of Victoria).*

Figure 71. *Day 15, 1716 h. Carcass has been dragged further and is partially disarticulated at hind leg (VENUS Project, University of Victoria).*

Figure 72*. Day 16, 0405 h. Carcass and detached leg have been moved slightly (VENUS Project, University of Victoria).*

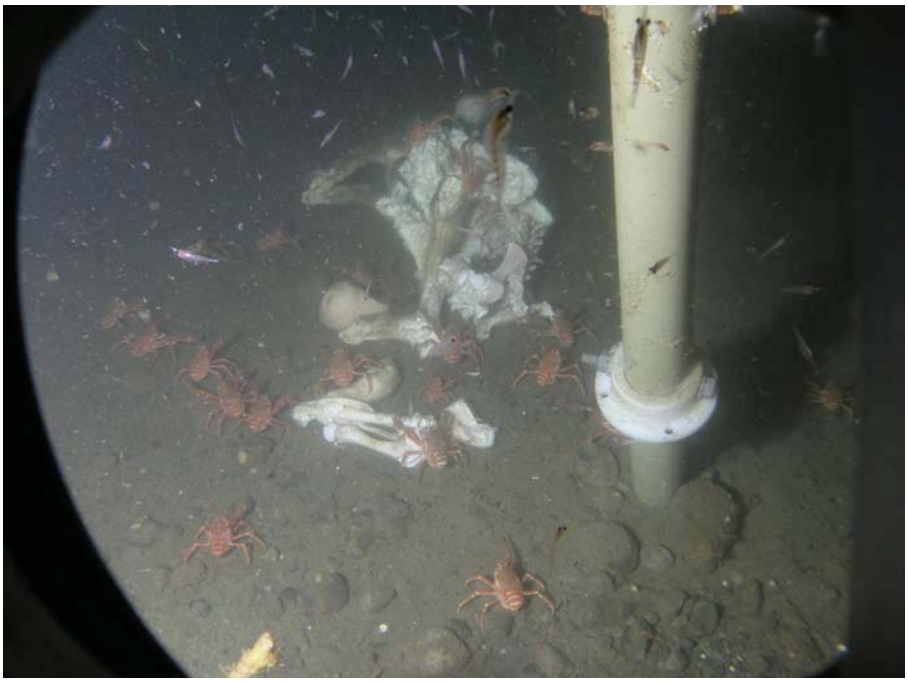


Figure 73. *Day 16 1843 h,. Carcass has been turned around, and most of tissue and bone at rear area is no longer visible (VENUS Project, University of Victoria).*

Figure 74. *Day 17 2100 h,. Carcass has been turned further. Back leg is under body and can be seen near back. (VENUS Project, University of Victoria).*

Figure 75*. Day 18, 0630 h. Most of detached leg has been removed (VENUS Project, University of Victoria).*

Figure 75. *Day 18, 0630 h. Close up of carcass (VENUS Project, University of Victoria).*

Figure 76. *Day 18, 2025 h. squat lobsters on carcass (VENUS Project, University of Victoria).*

Figure 77. *Day 19, 1010 h. Carcass moved further around tripod le (VENUS Project, University of Victoria).*

Figure 78. *Day 19, 1010 h. Close up of facial region (VENUS Project, University of Victoria).*

Figure 79. *Day 19, 2206 h. Little change observed (VENUS Project, University of Victoria).*

Figure 80. *Day 20, 1110 h. The carcass has been turned approximately 120* ^{o} *(VENUS Project, University of Victoria).*

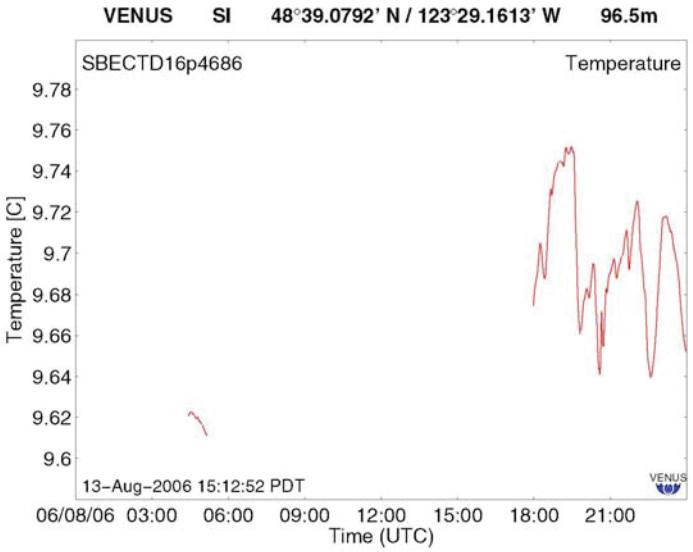
Figure 81. *Day 20, 1940 h. Carcass has been moved further and flap of skin has been pulled back. (VENUS Project, University of Victoria).*

Figure 82. *Day 21, 0835 h. Bulk of carcass out of sight. (VENUS Project, University of Victoria).*

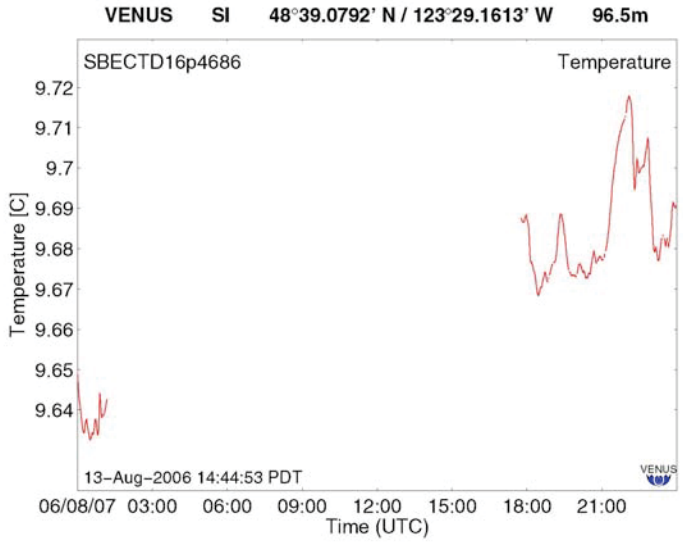
Figure 83. *Day 22, 0855 h. Carcass can just be seen at top right of picture (VENUS Project, University of Victoria).*

Figure 84. *Day 22, 1855 h. Carcass may still be in sight at top right, (VENUS Project, University of Victoria).*

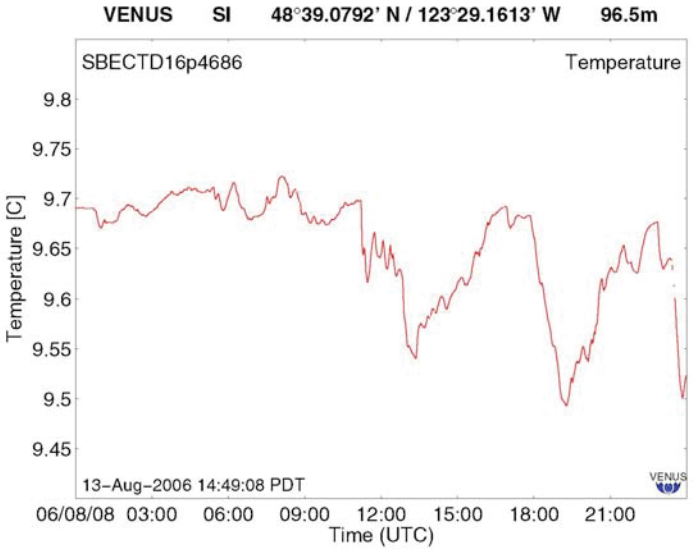
APPENDIX I, TEMPERATURE – SEABIRD CTD



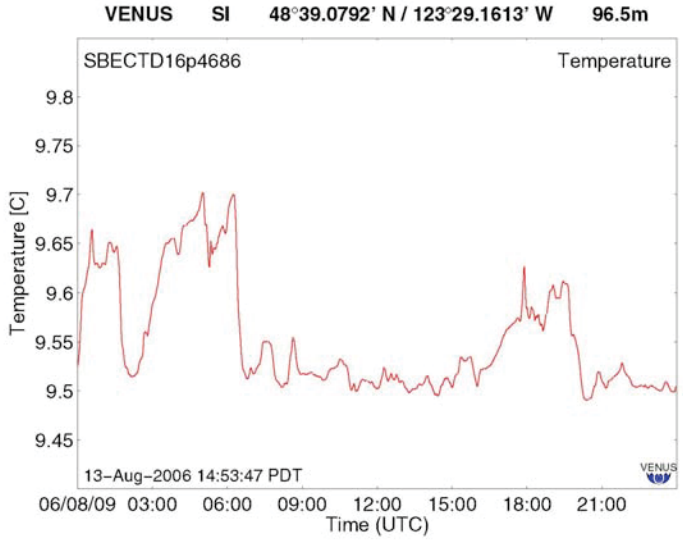
Day -1, 6 August 2006



Day 0, 7 August 2006

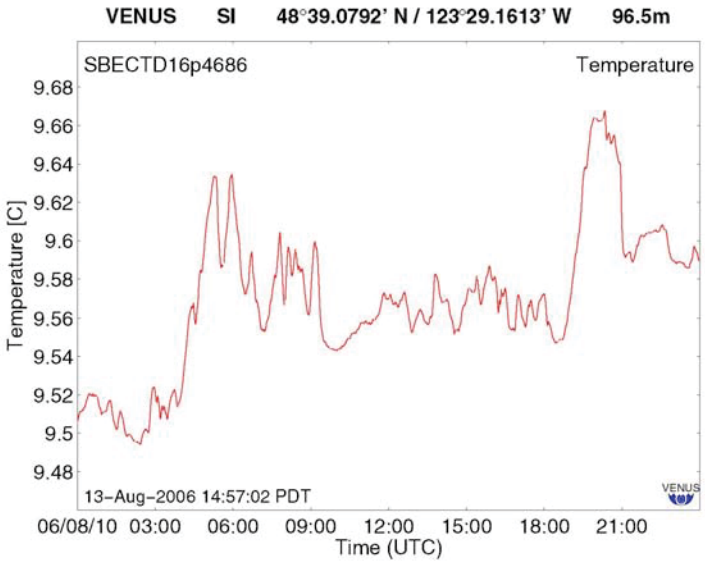


Day 1, 8 August 2006

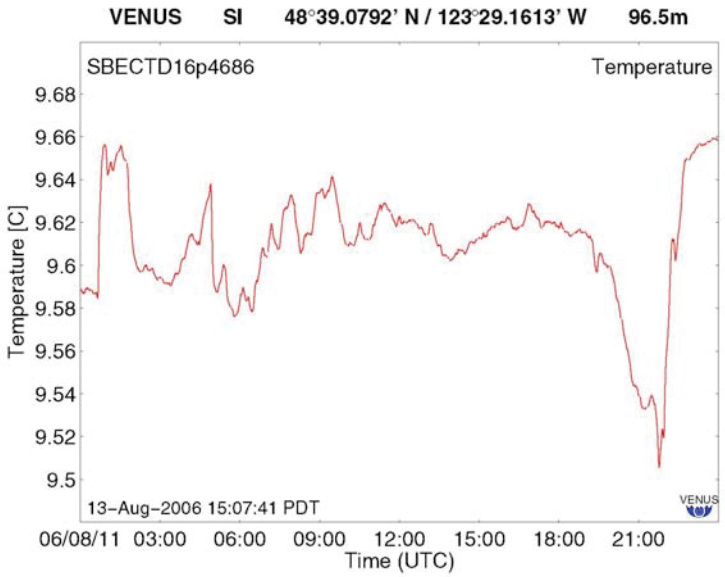


Day 2, 9 August 2006

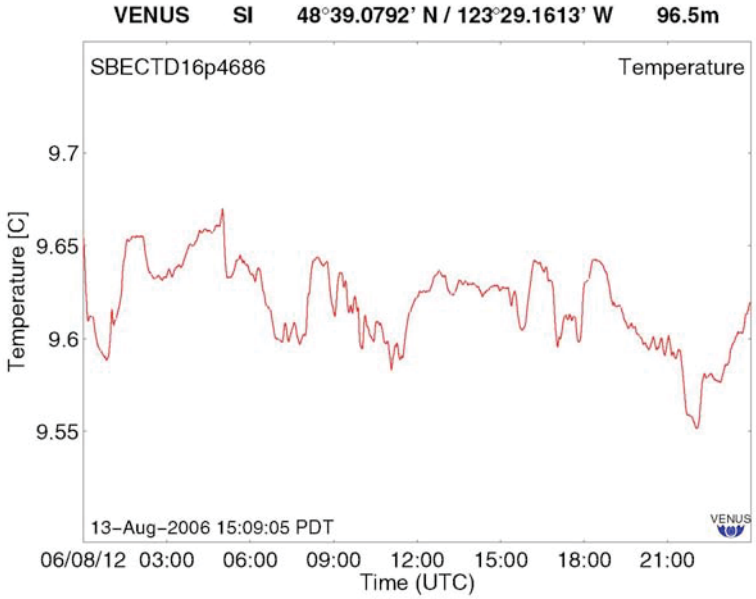
TEMPERATURE – SEABIRD CTD



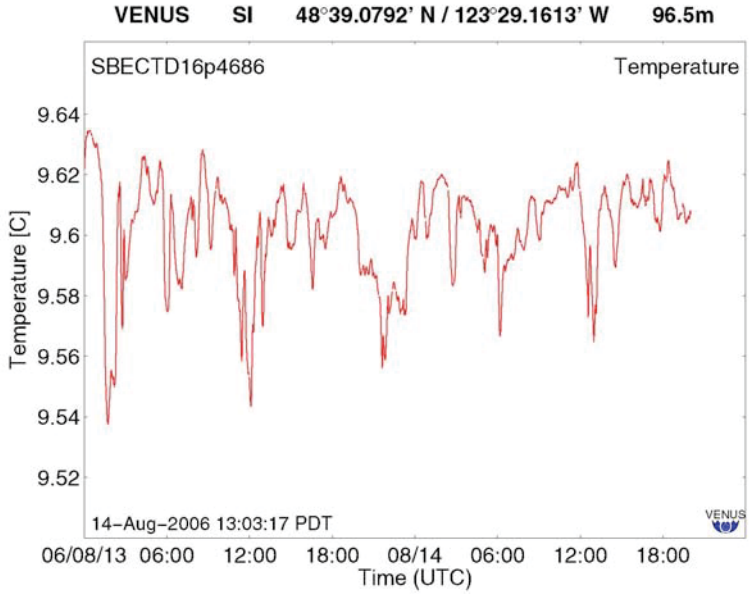
Day 3, 10 August 2006



Day 4, 11 August 2006

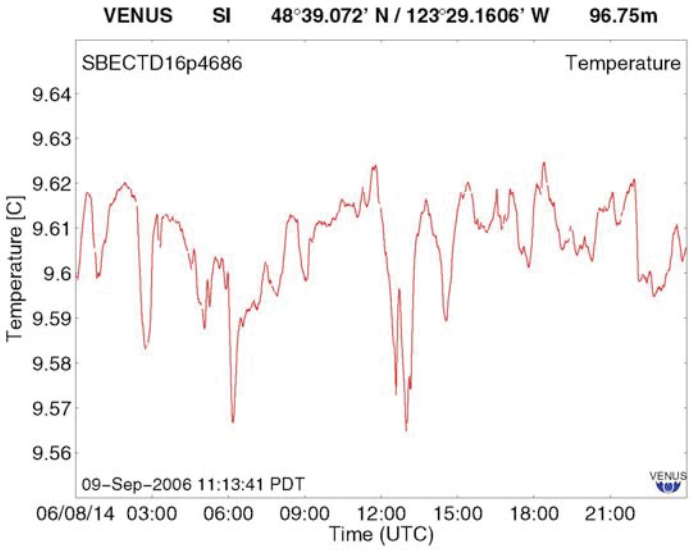


Day 5, 12 August 2006

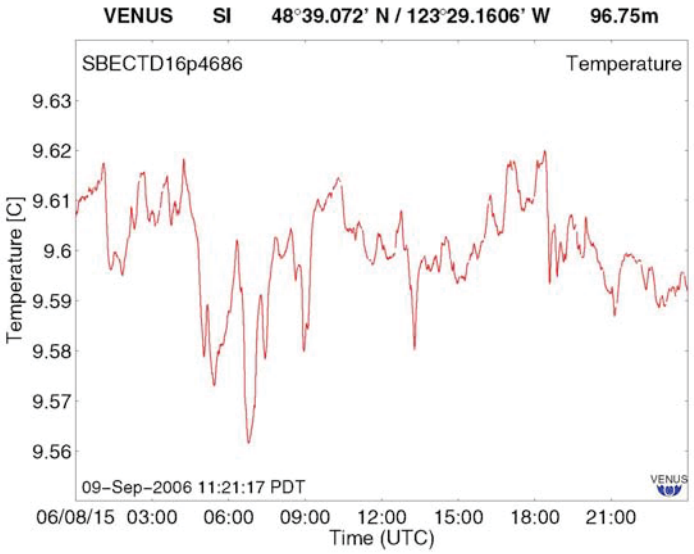


Day 6, 13 August 2006

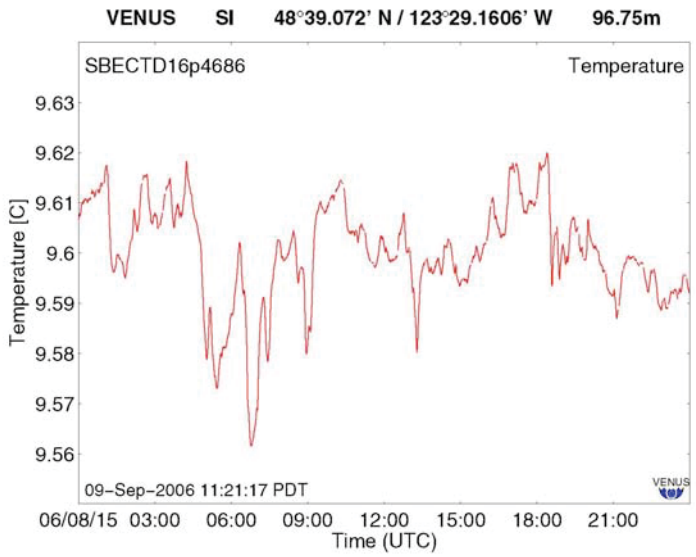
TEMPERATURE – SEABIRD CTD



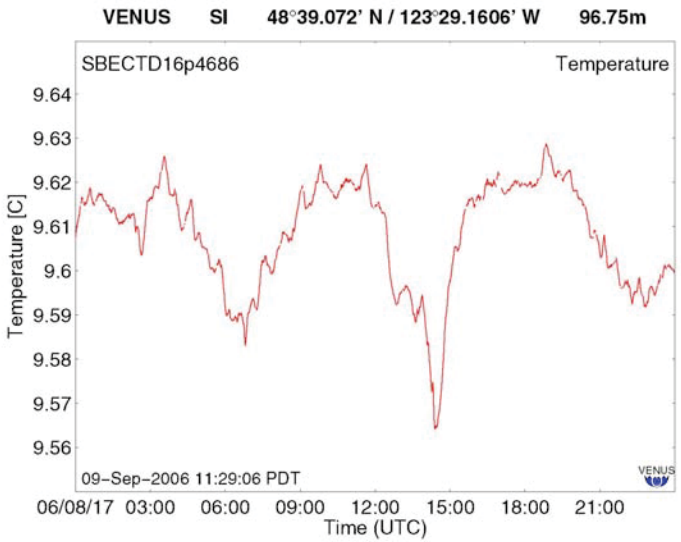
Day 7, 14 August 06



Day 8, 15 August 06

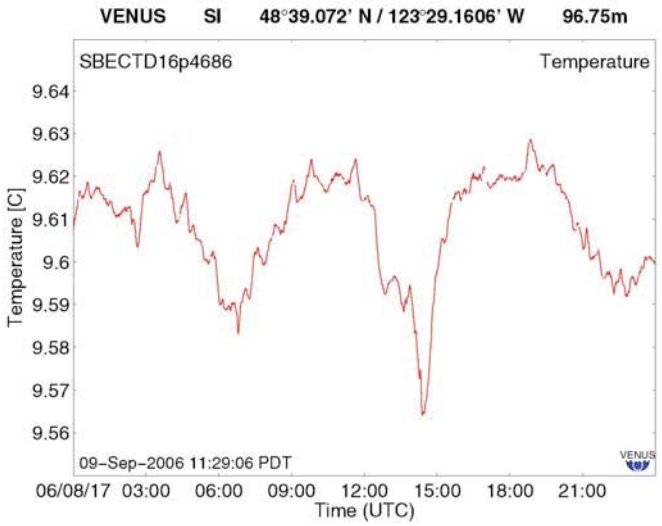


Day 9, 16 August 06

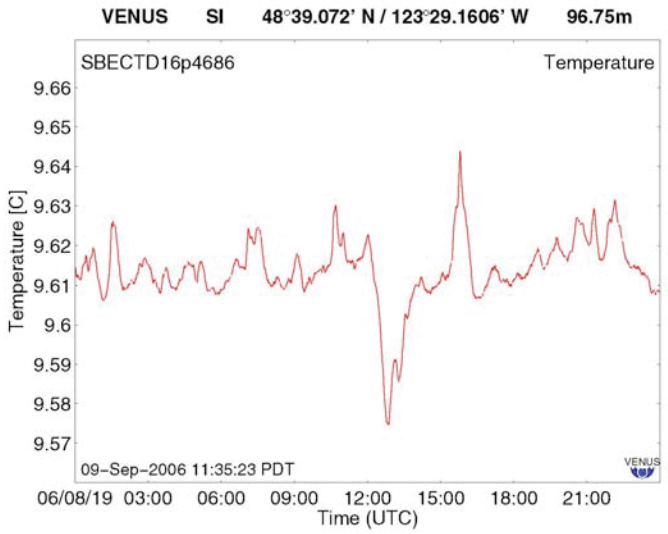


Day10, 17 August 06

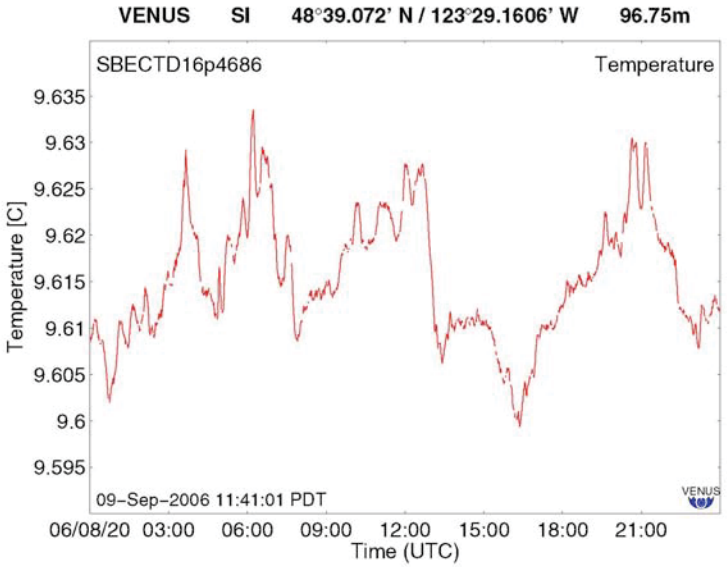
TEMPERATURE – SEABIRD CTD



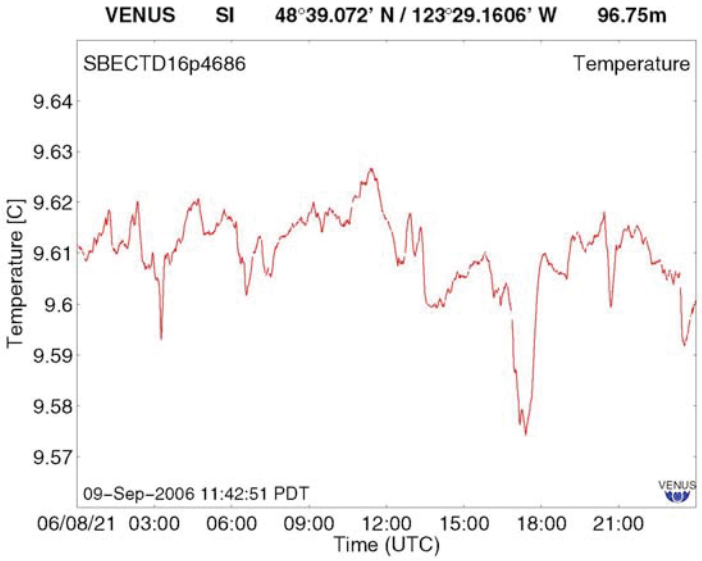
Day 11, 18 August 06



Day 12, 19August 06

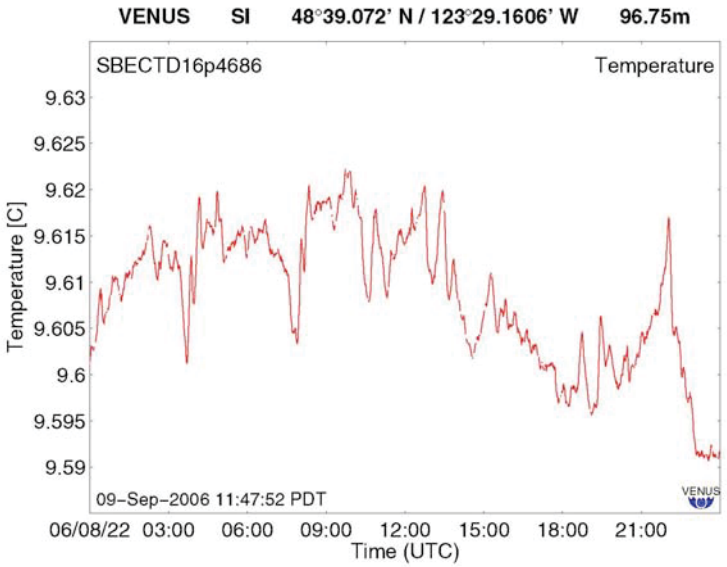


Day 13, 20 August 06

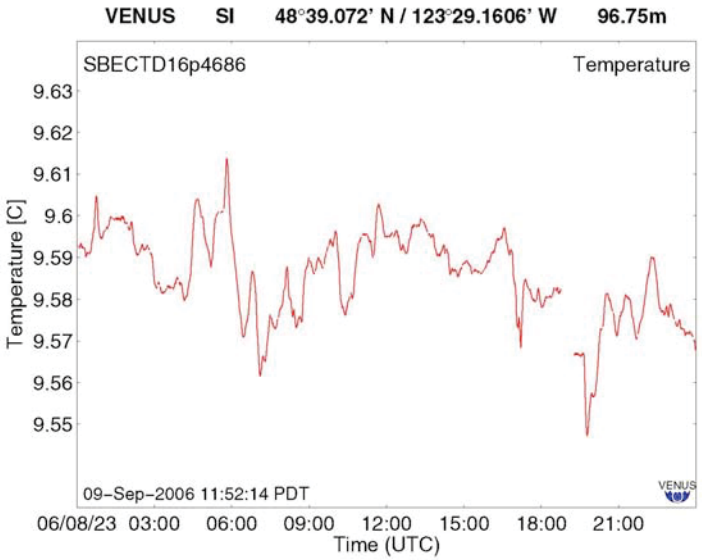


Day 14, 21August 06

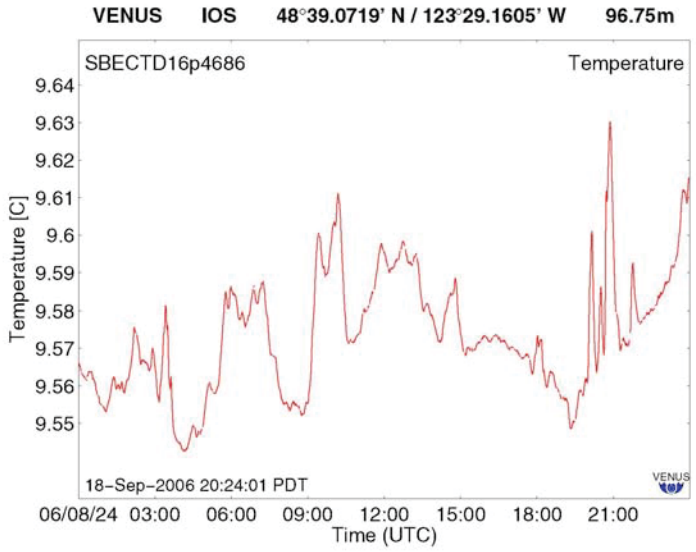
TEMPERATURE – SEABIRD CTD



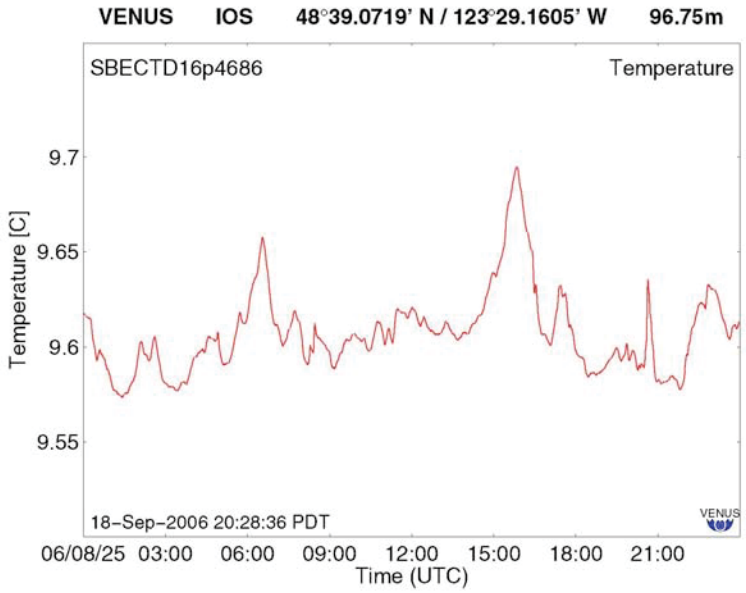
Day 15, 22 August 06



Day 16, 23August 06

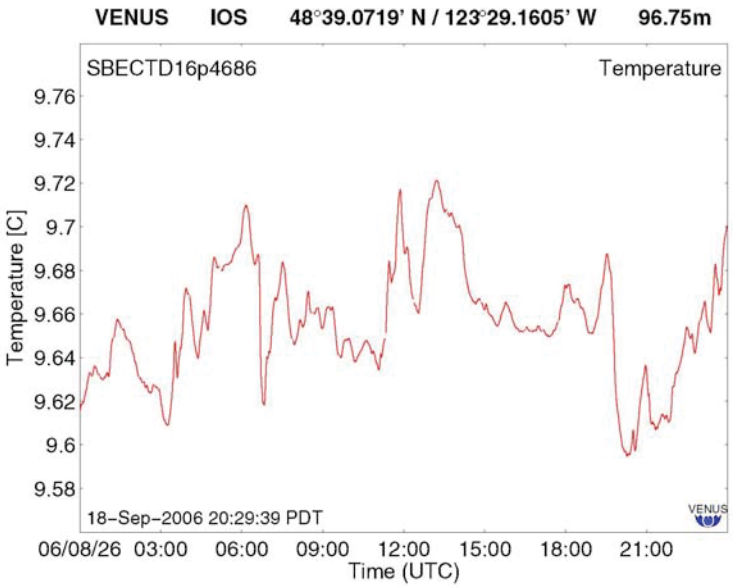


Day 17, 24 August 06

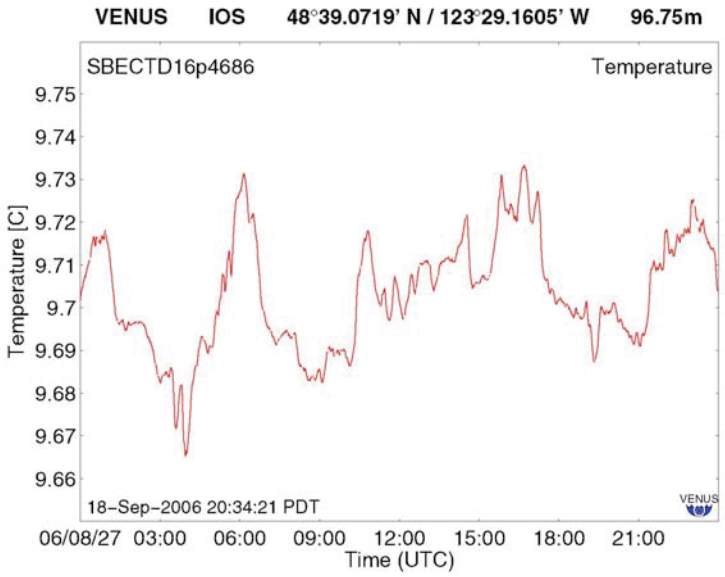


Day 18, 25 August 06

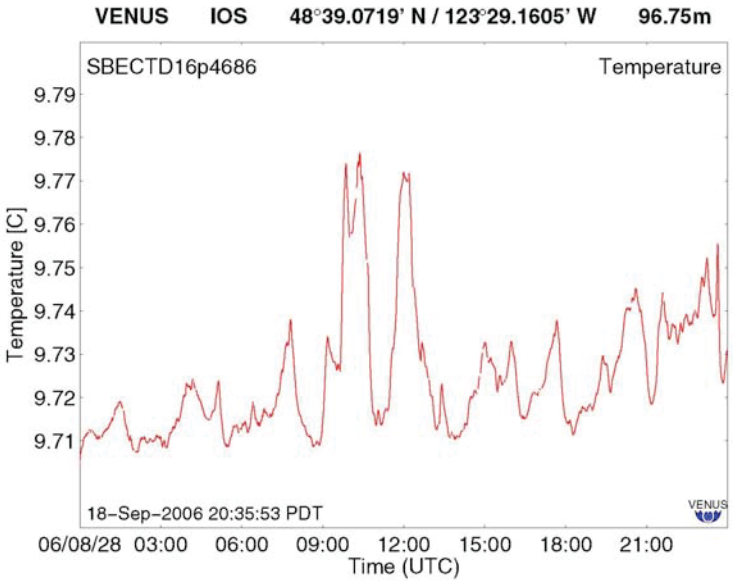
TEMPERATURE – SEABIRD CTD



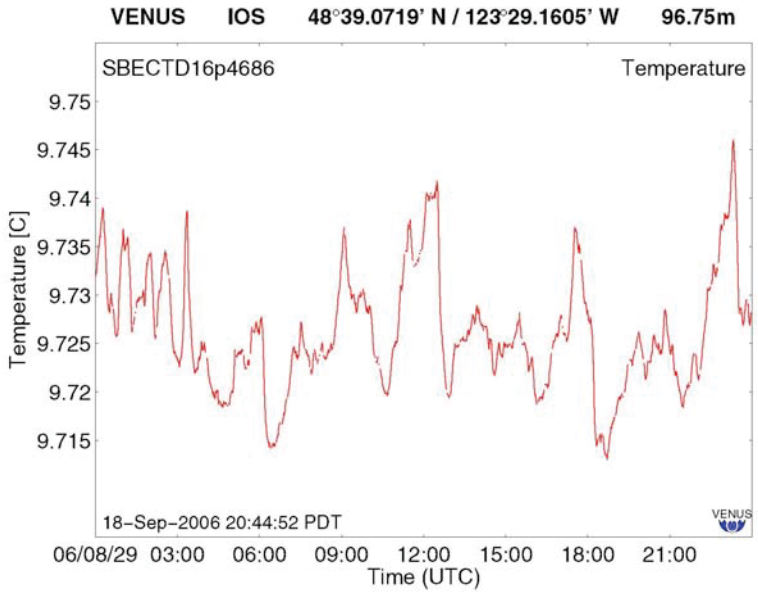
Day 19, 26 August 06



Day 20, 27 August 06

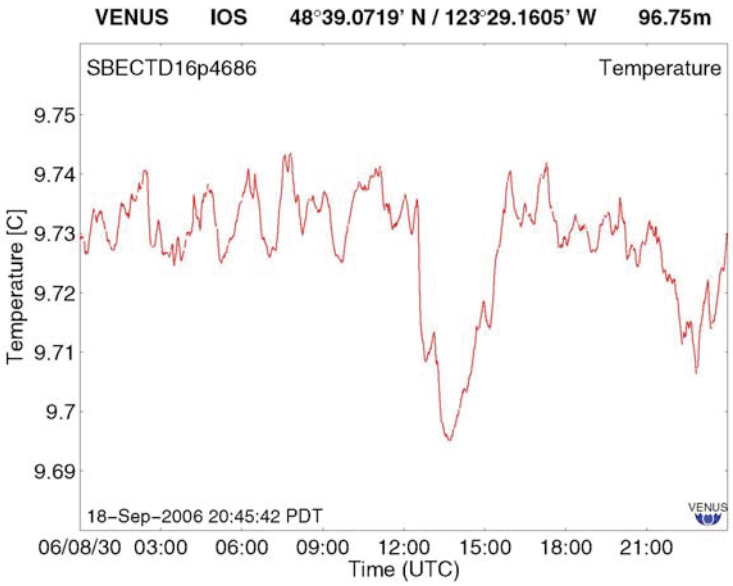


Day 21, 28 August 06

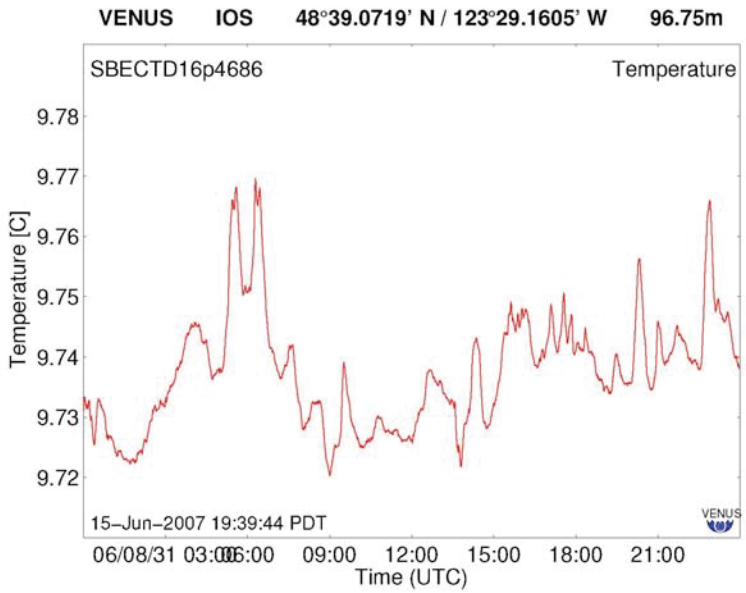


Day 22 29 August 06

TEMPERATURE – SEABIRD CTD

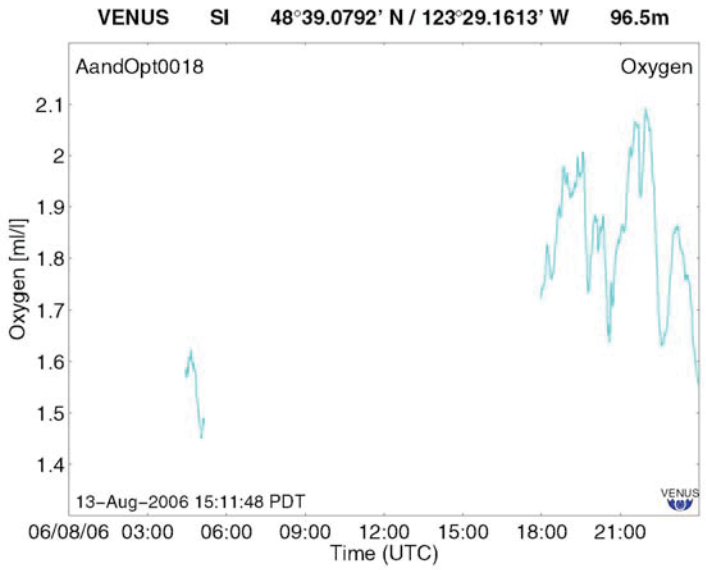


Day 23, 30 August 06

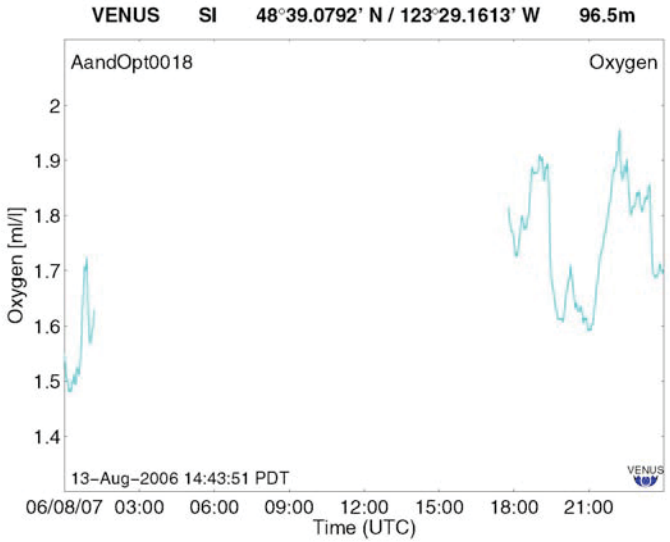


Day 24, 31 August 06

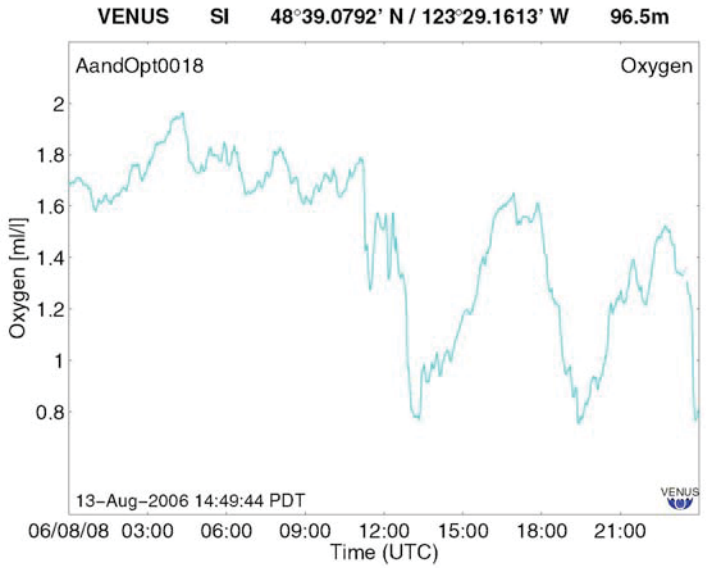
APPENDIX II, OXYGEN – OXYGEN OPTODE



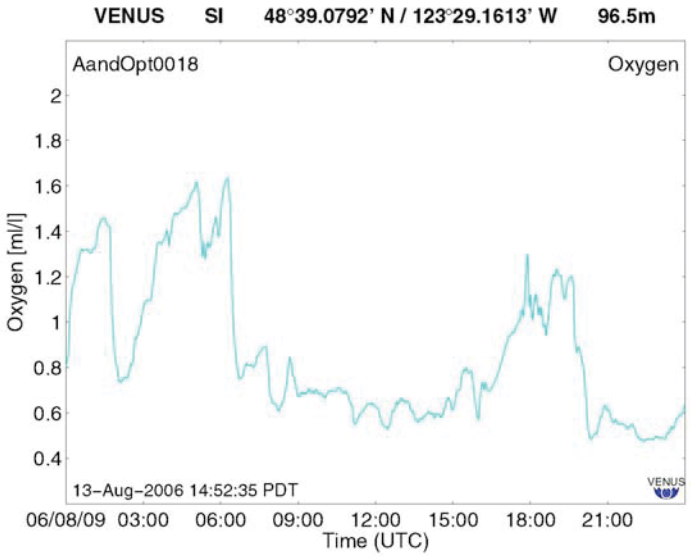
Day -1, 6 August 06



Day 0, 7 August 06

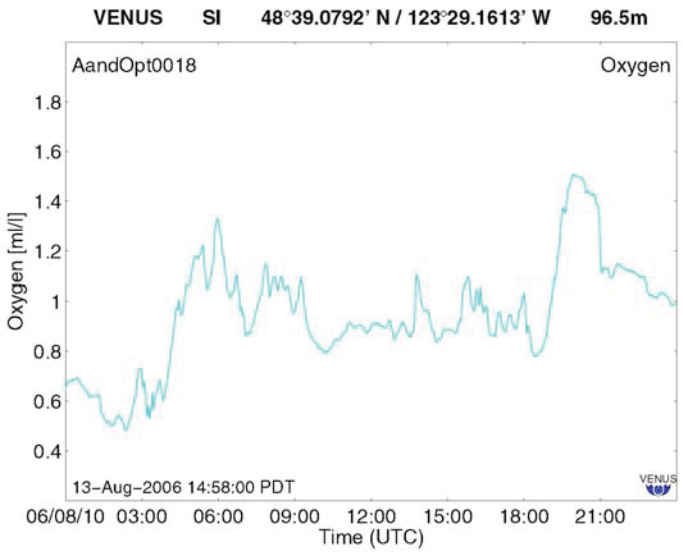


Day 1, 8 August 06

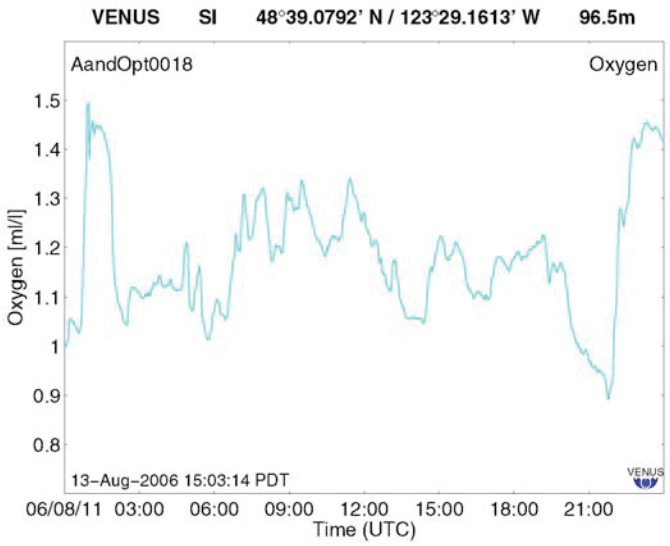


Day 2, 9 August 06

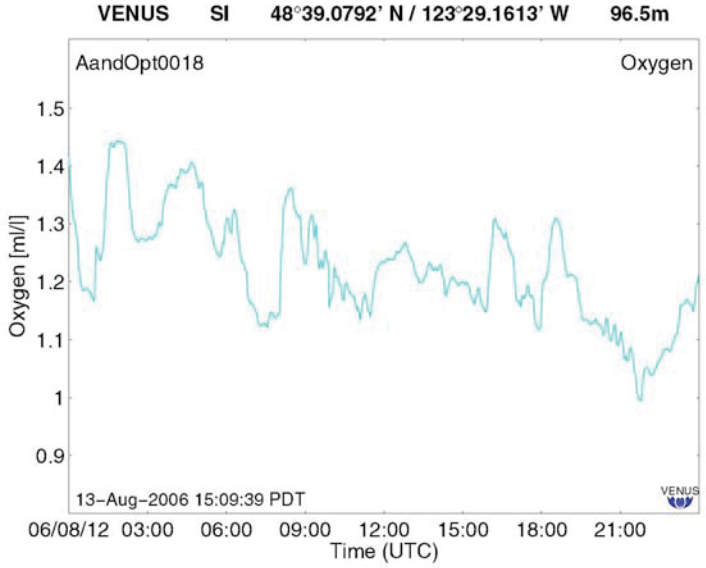
OXYGEN – OXYGEN OPTODE



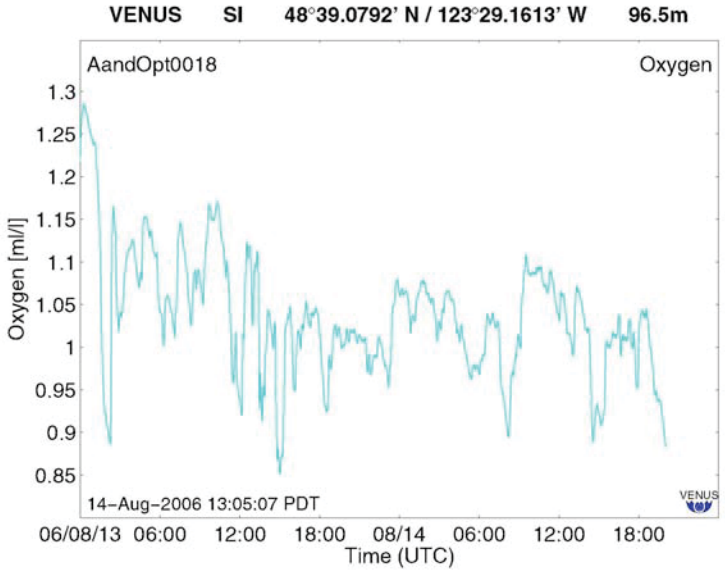
Day 3, 10 August 06



Day 4, 11 August 06

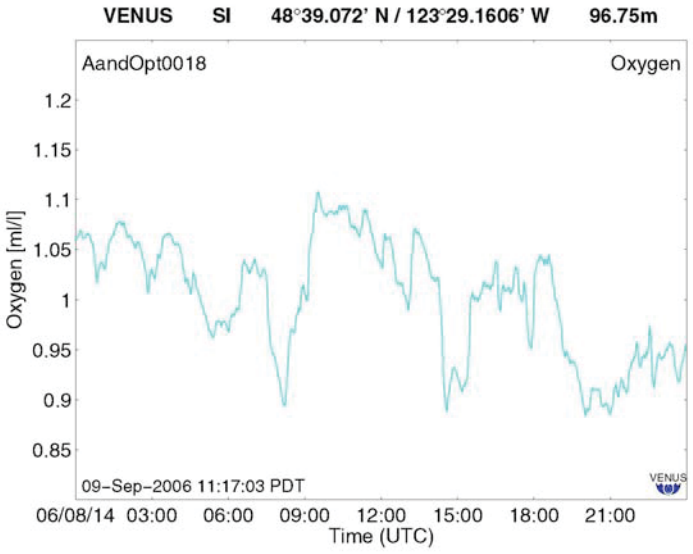


Day 5, 12 August 06

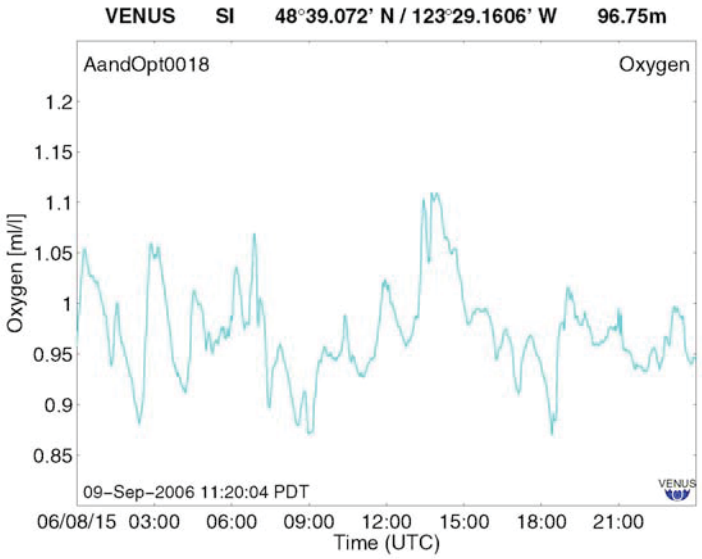


Day 6, 13 August 06

OXYGEN – OXYGEN OPTODE

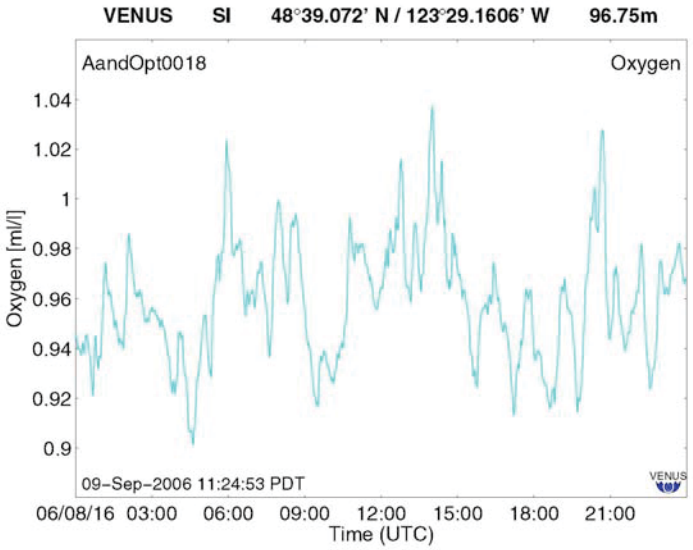


Day 7, 14 August 06

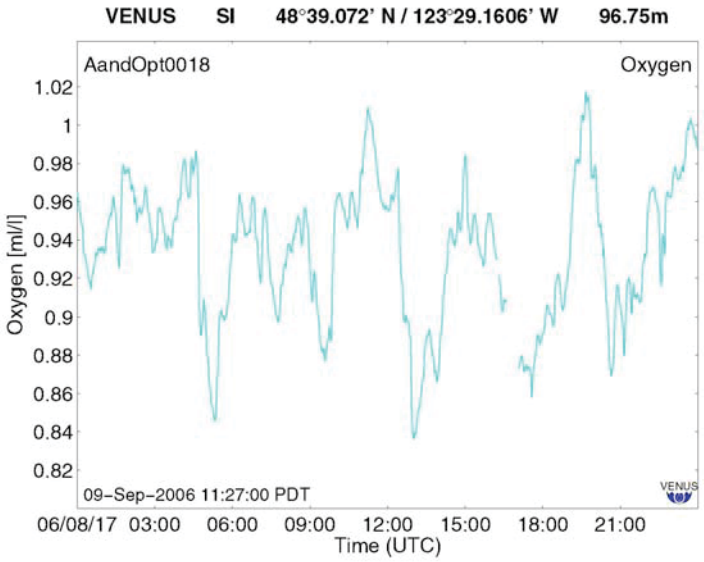


Day 8, 15 August 06

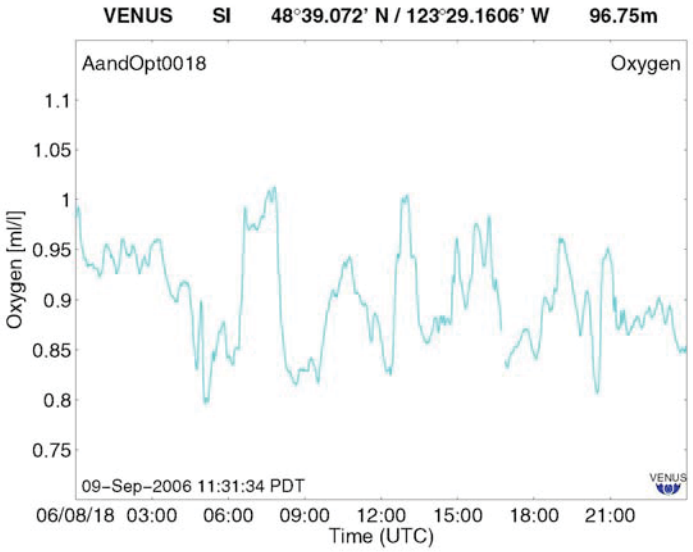
OXYGEN – OXYGEN OPTODE



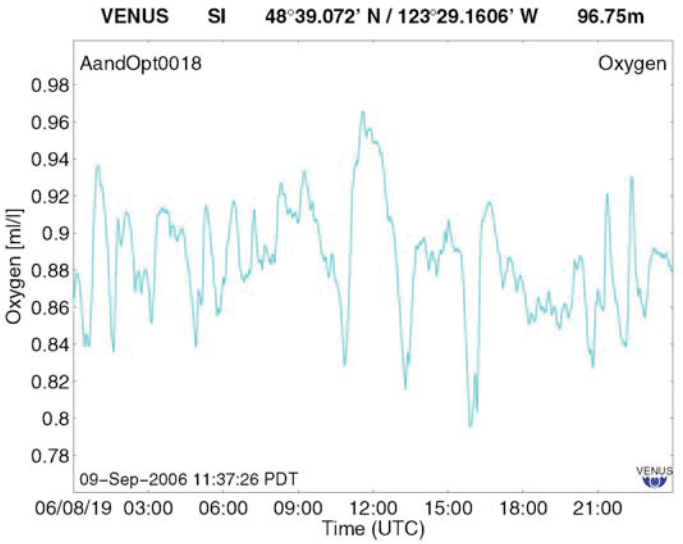
Day 9, 16 August 06



Day 10, 17 August 06

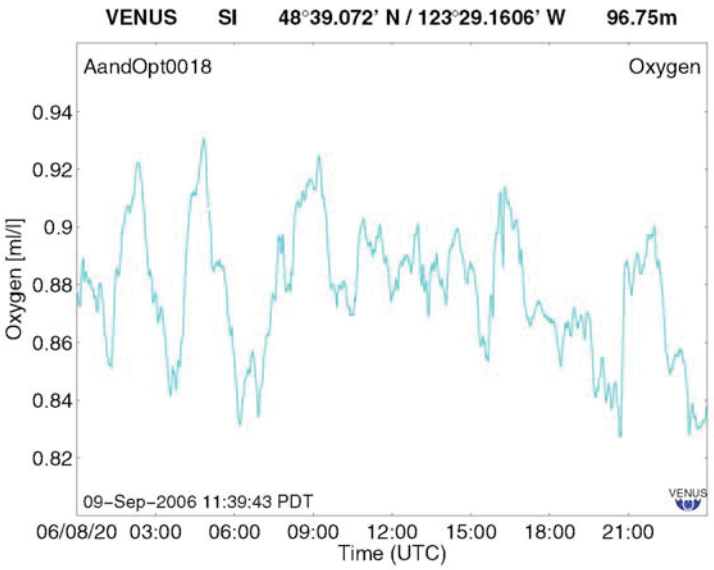


Day 11, 18 August 06

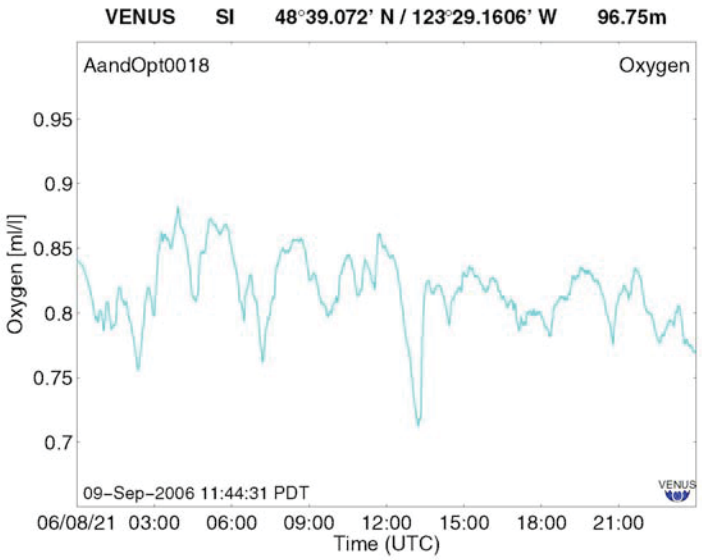


Day 12 August 06

OXYGEN – OXYGEN OPTODE

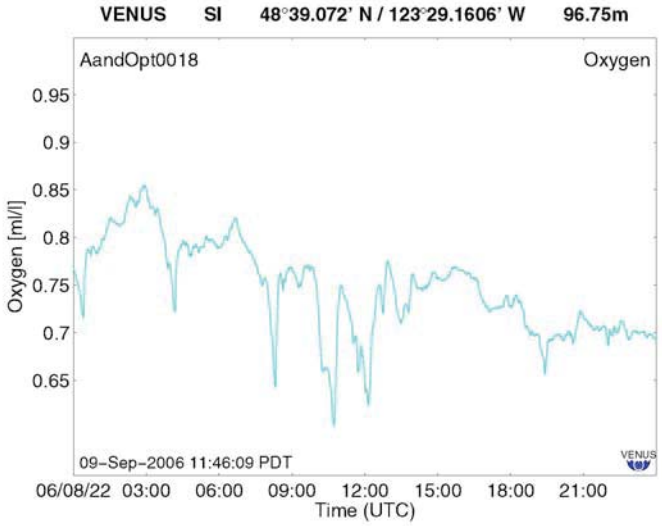


Day 13, 20 August 06

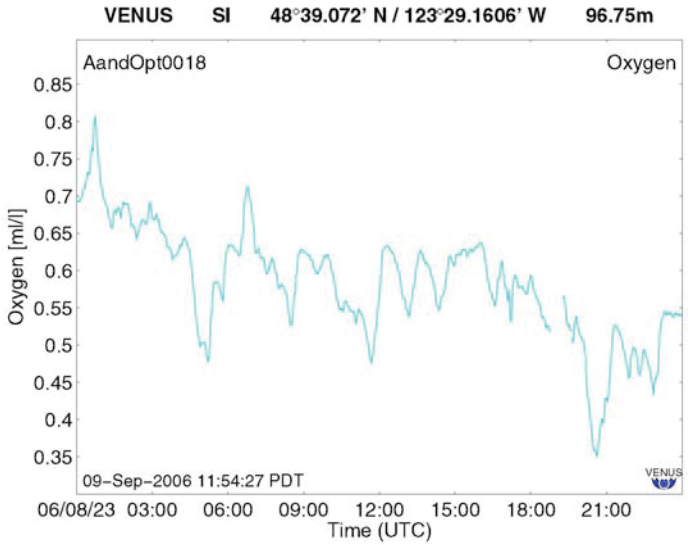


Day 14 August 06

OXYGEN – OXYGEN OPTODE

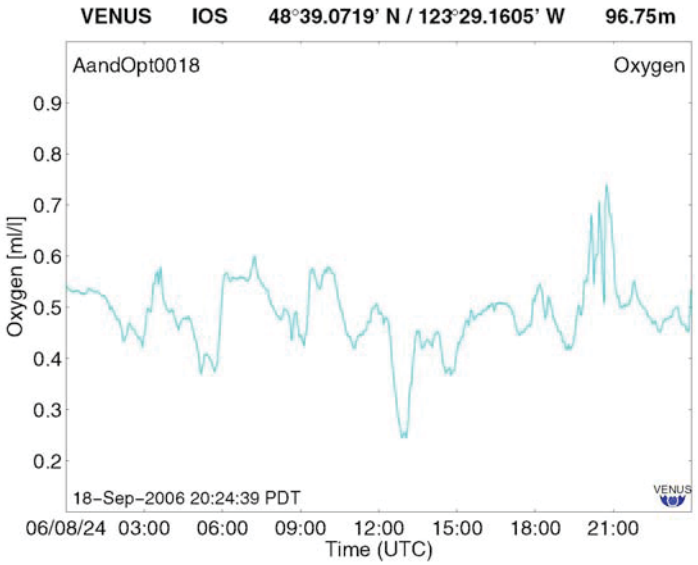


Day 15, 22 August 06

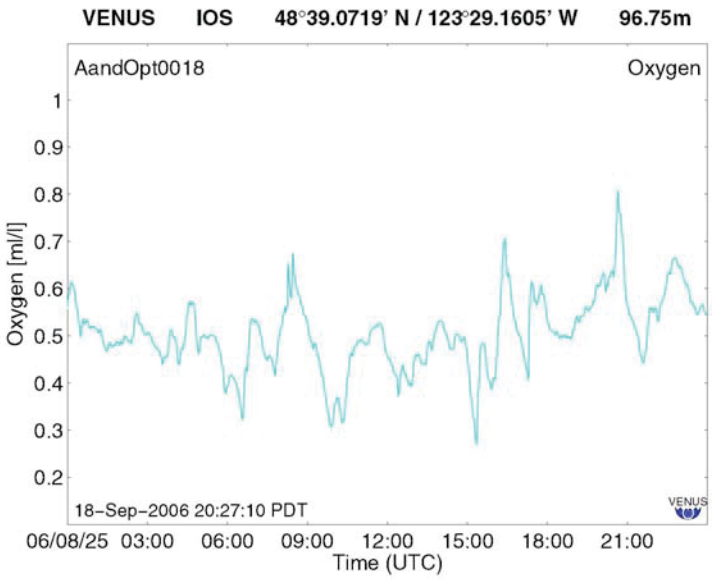


Day 16,August 06

OXYGEN – OXYGEN OPTODE

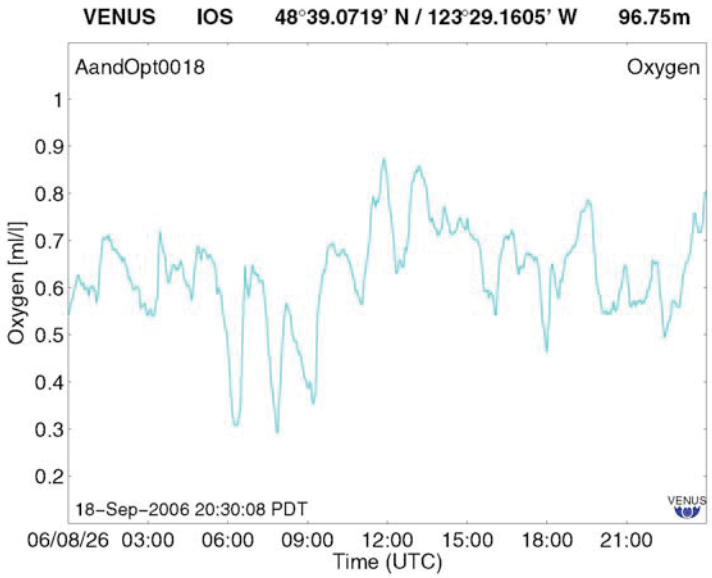


Day 17, 24 August 06

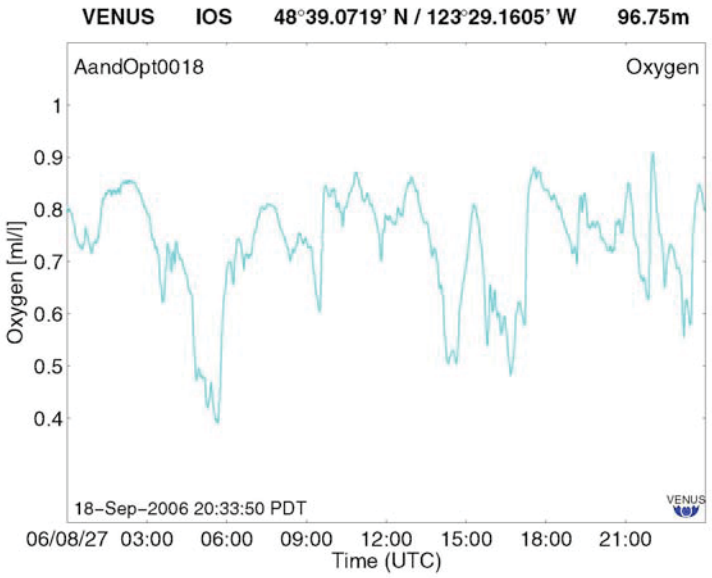


Day 18, 25 August 06

OXYGEN – OXYGEN OPTODE

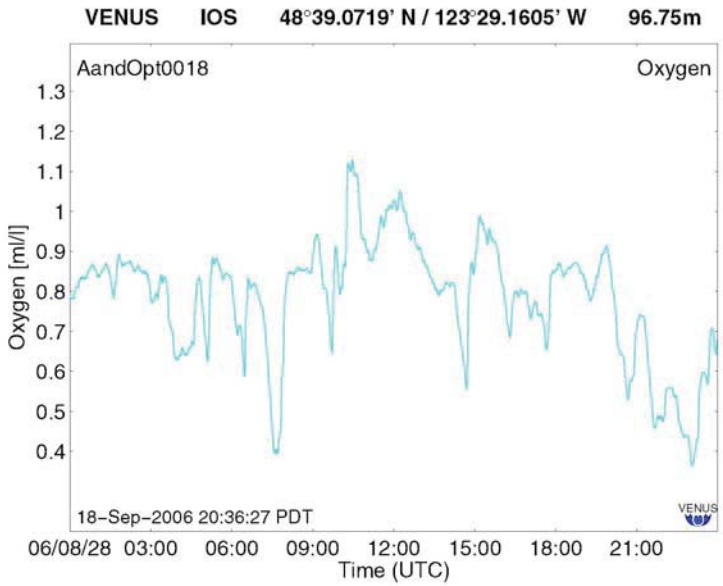


Day 19, 26 August 06

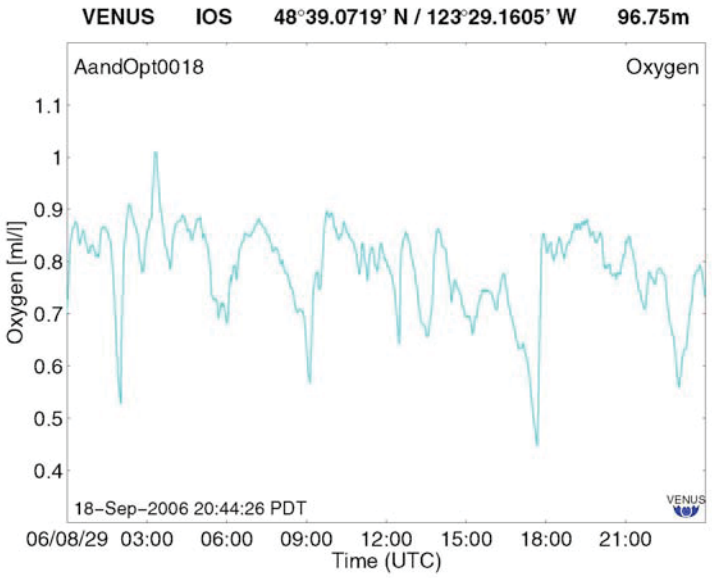


Day 20, 27 August 06

OXYGEN – OXYGEN OPTODE

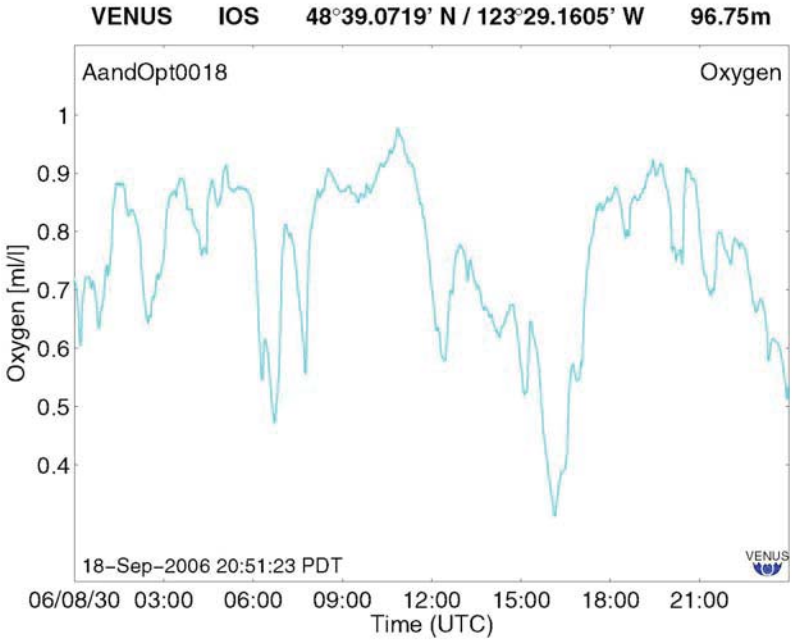


Day 21, 28 August 06

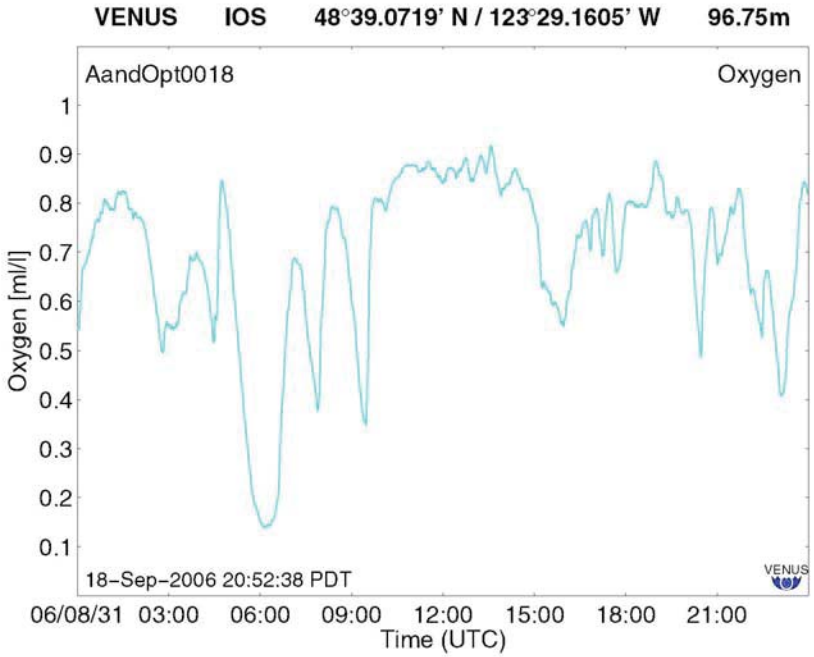


Day 22, 29 August 06

OXYGEN – OXYGEN OPTODE

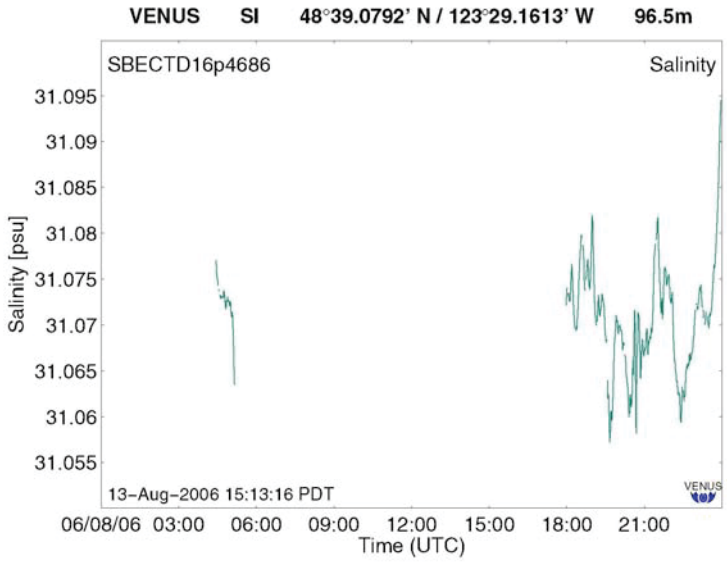


Day 23, 30 August 06

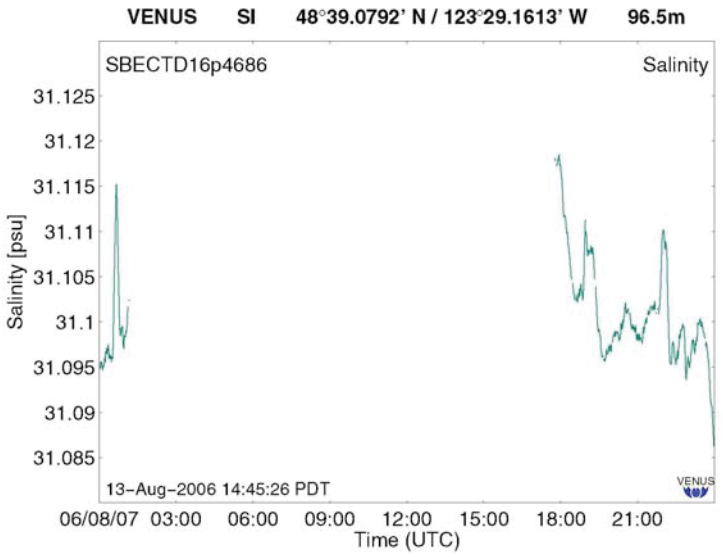


Day 24, 31 August 06

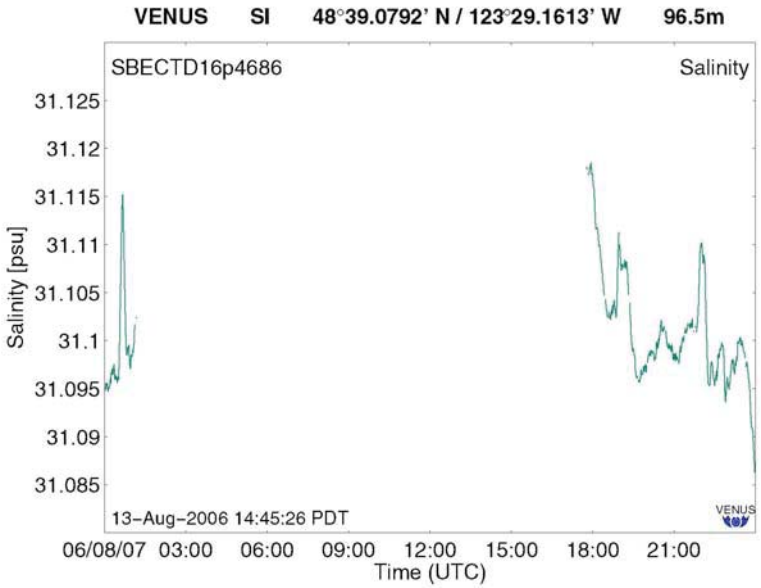
APPENDIX III. SALINITY – SEABIRD CTD



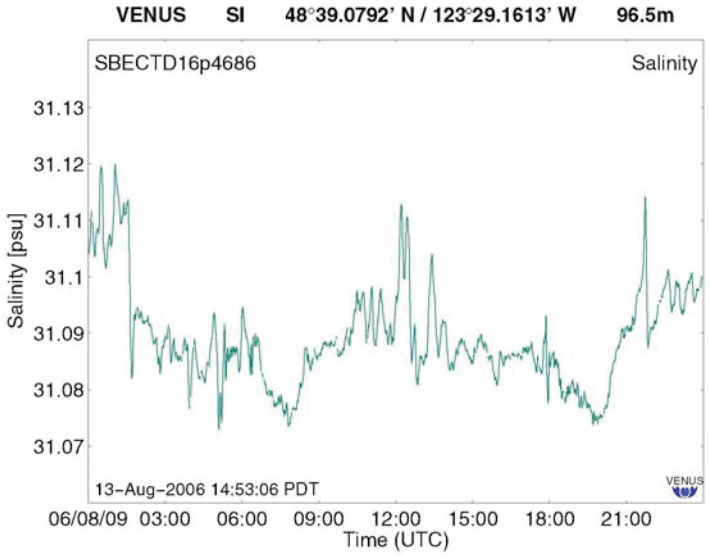
Day -1, 6 August 06



Day 0, 7 August 06

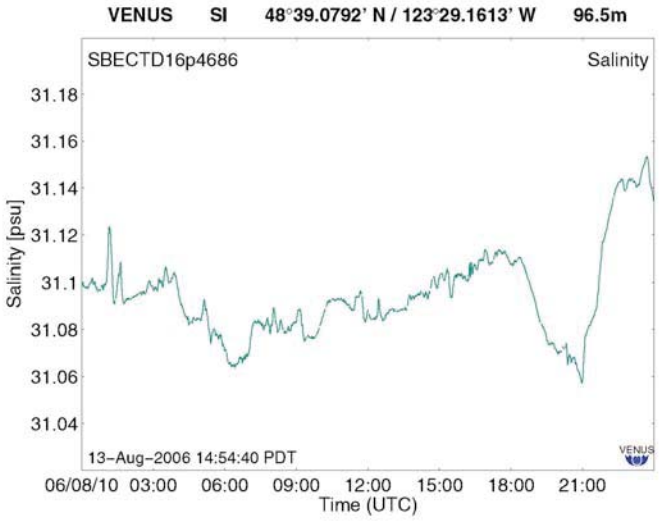


Day 1, 8 August 06

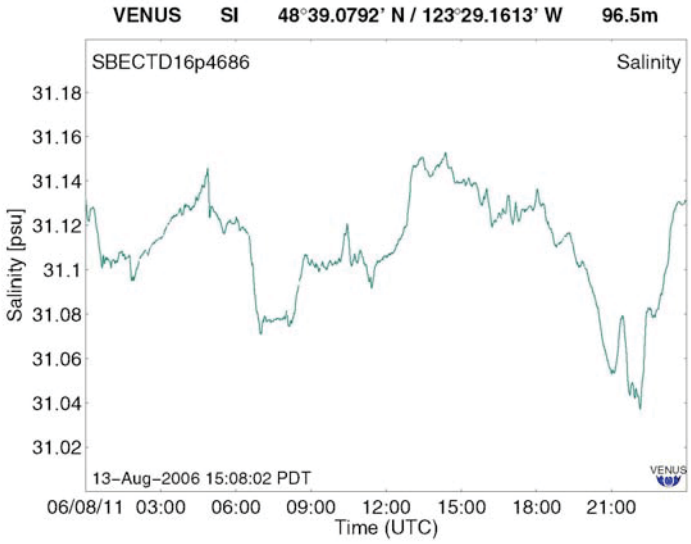


Day 2, 9 August 06

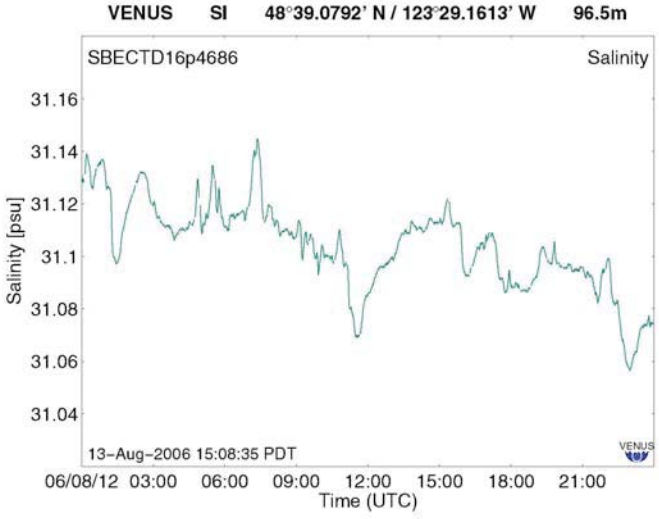
SALINITY – SEABIRD CTD



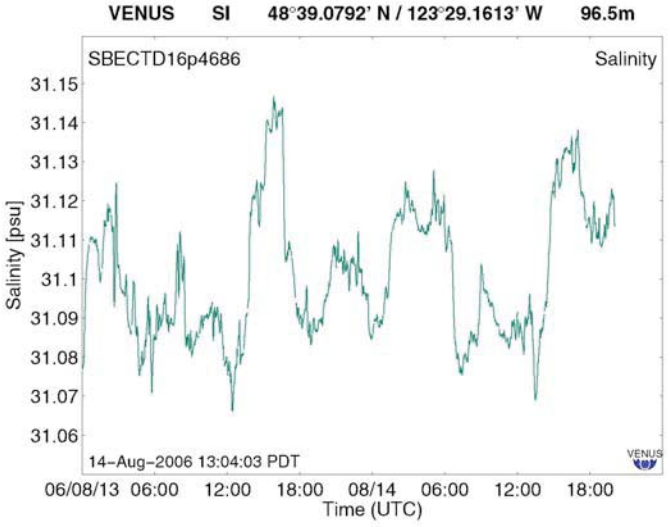
Day 3, 10 August 06



Day 4, 11 August 06

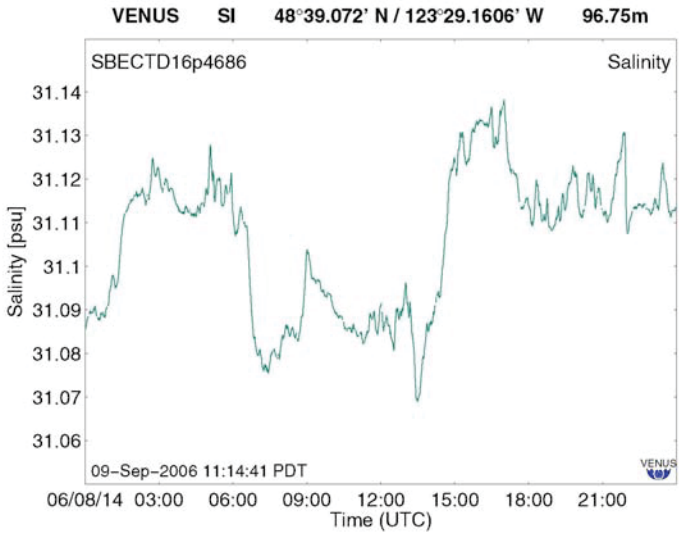


Day 5, 12 August 06

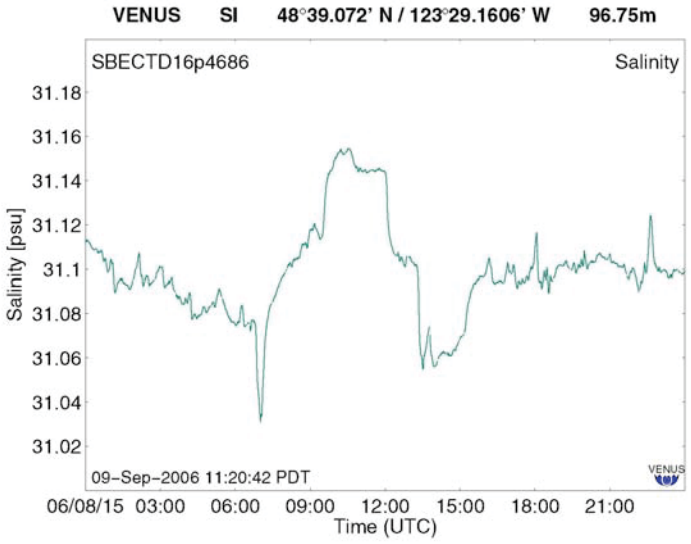


Day 6, 13August 06

SALINITY – SEABIRD CTD

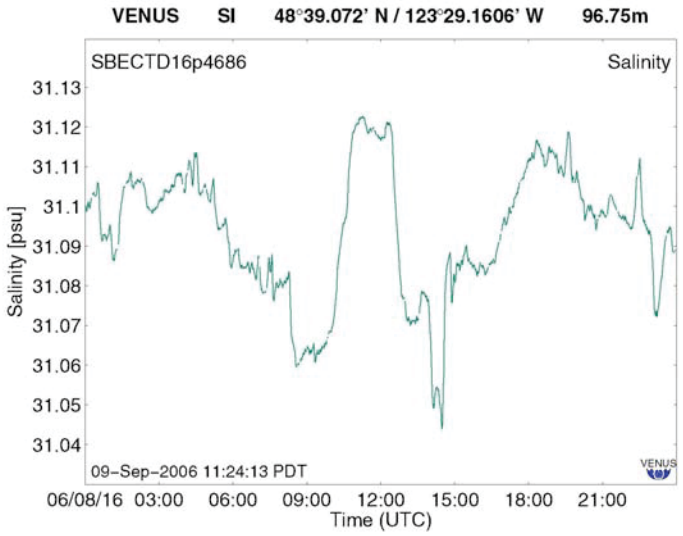


Day 7, 14 August 06

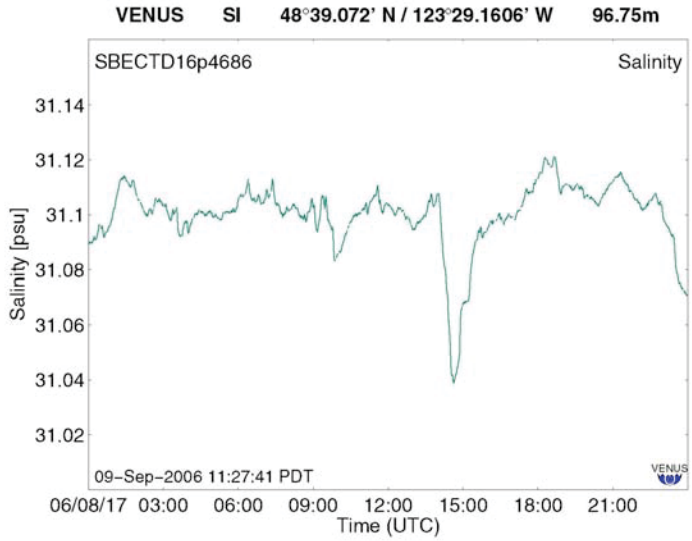


Day 8, 15 August 06

SALINITY – SEABIRD CTD

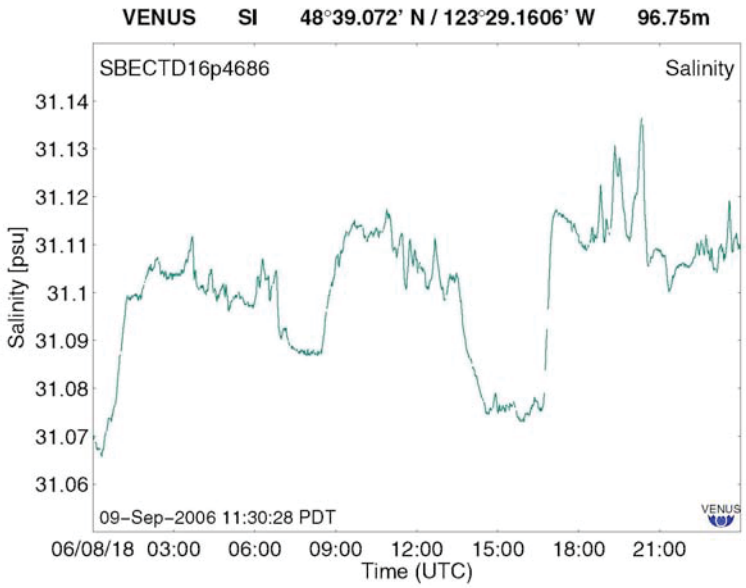


Day 9, 16 August 06

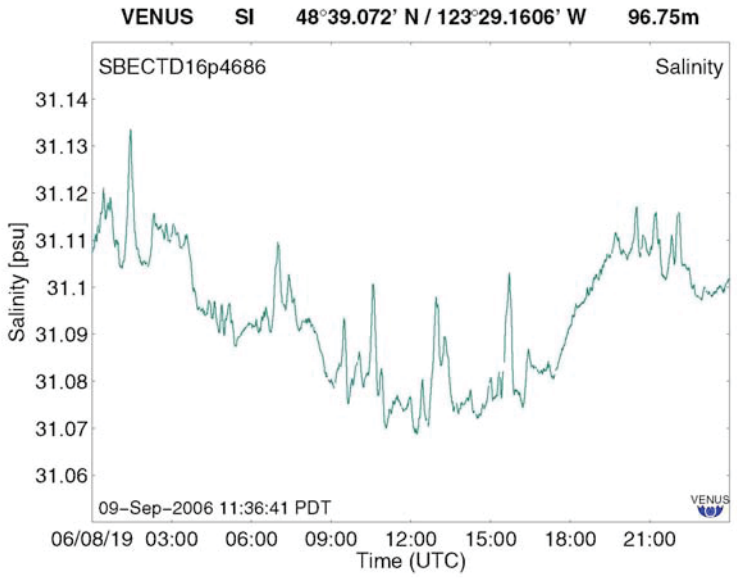


Day10, 17 August 06

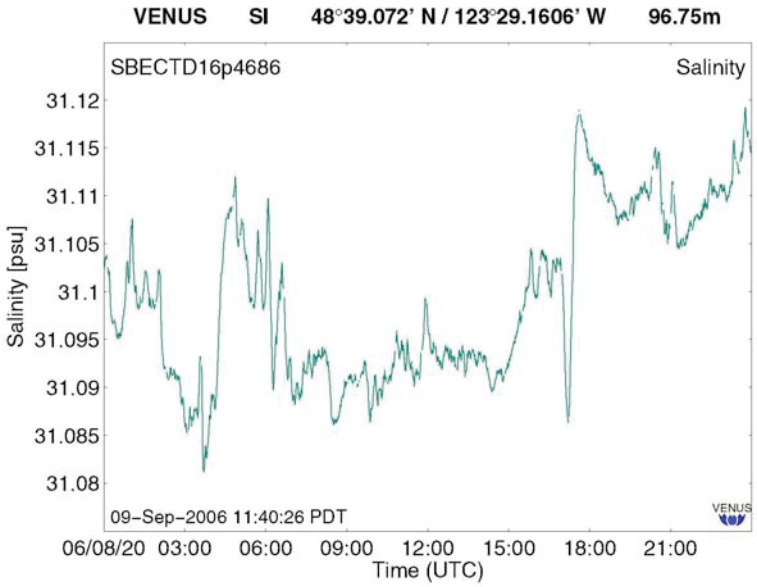
SALINITY – SEABIRD CTD



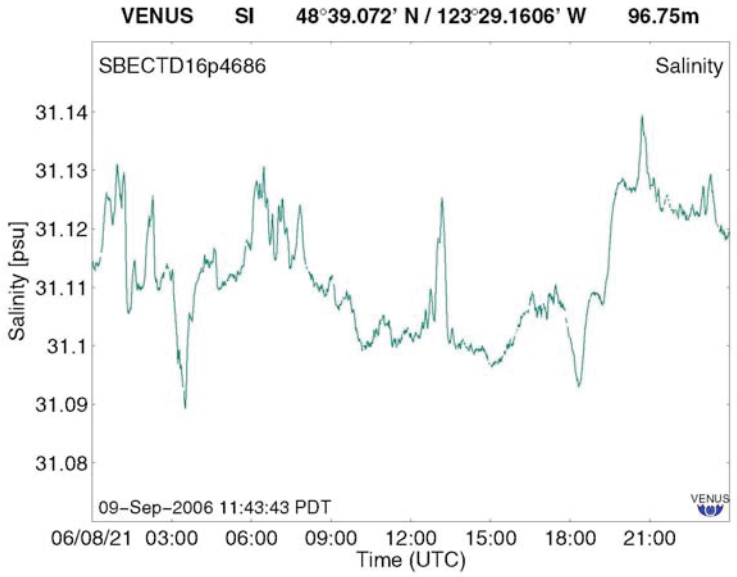
Day 11, 18 August 06



Day 12, 19 August 06

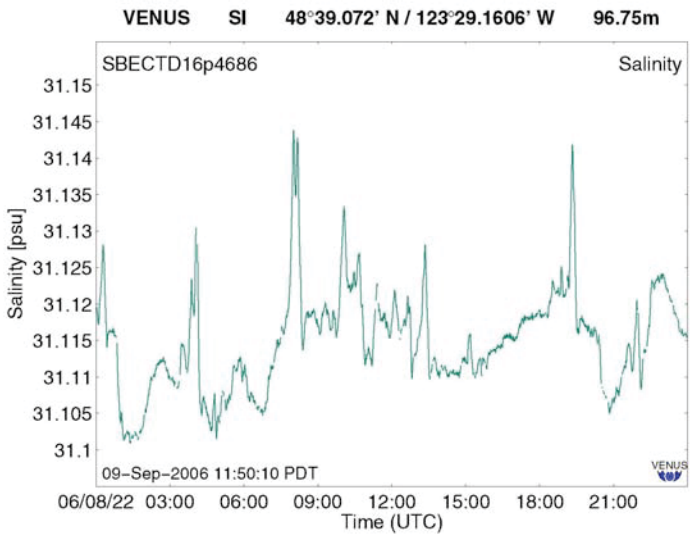


Day 13, 20 August 06

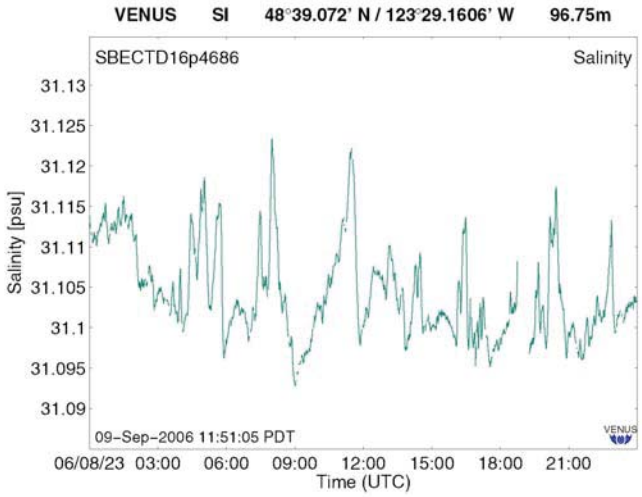


Day 14, 21 August 06

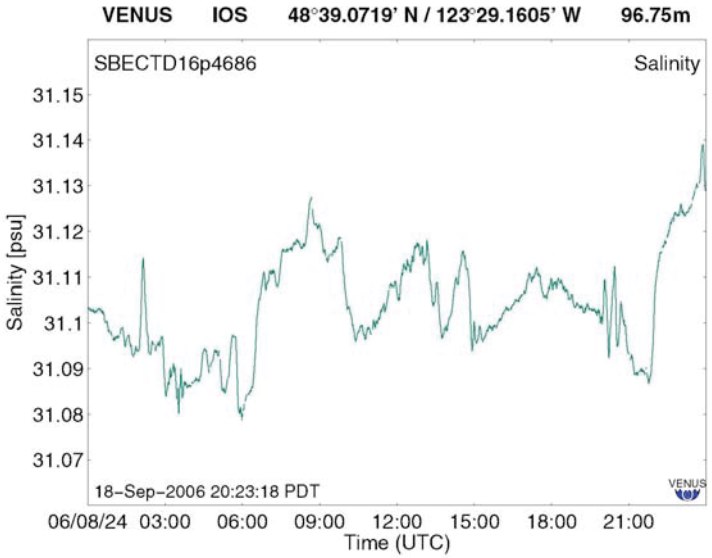
SALINITY – SEABIRD CTD



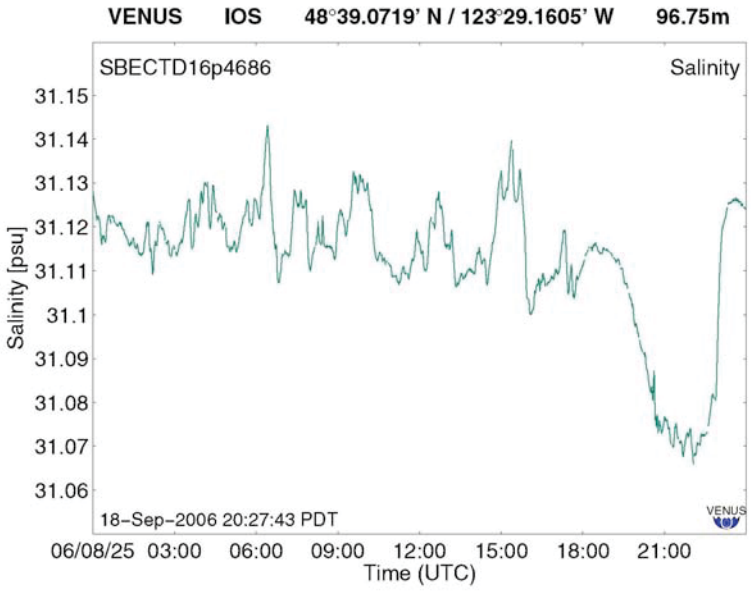
Day 15, 22 August 06



Day 16, 23 August 06

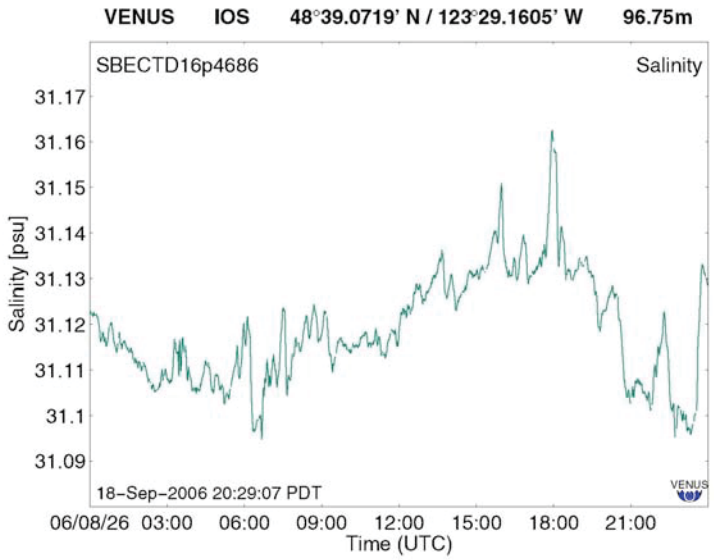


Day 17, 24 August 06

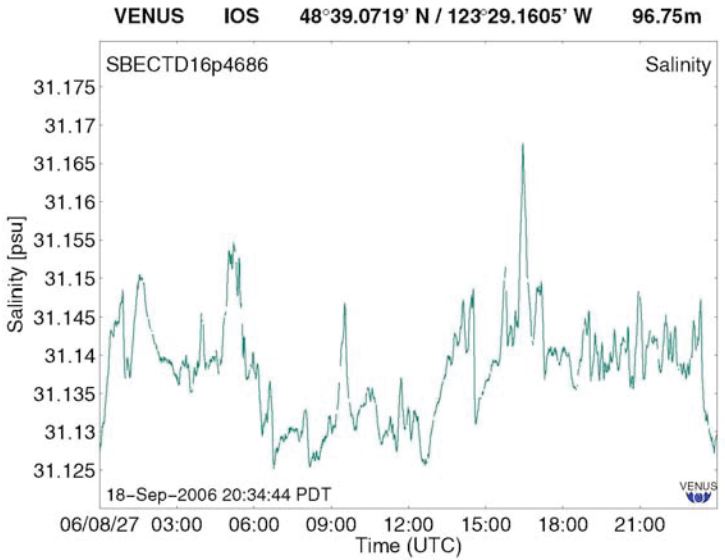


Day 18, 25 August 06

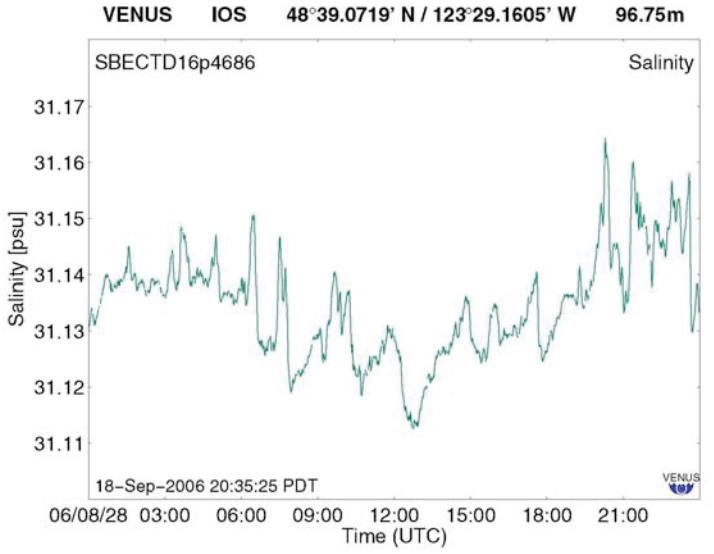
SALINITY – SEABIRD CTD



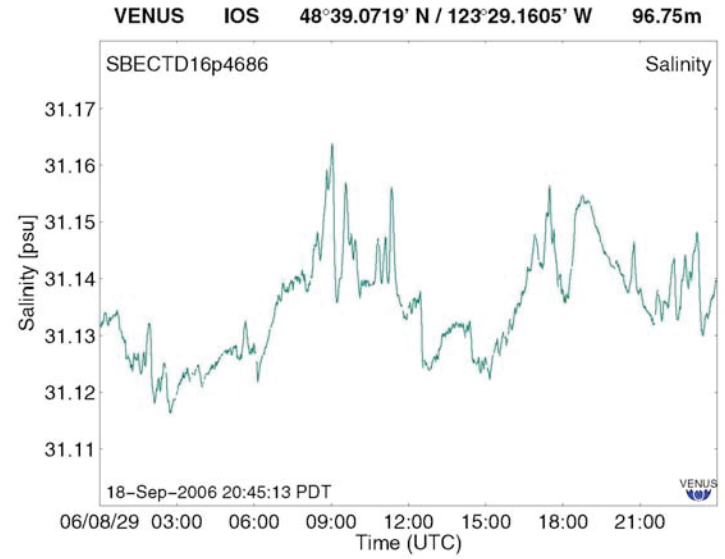
Day 19, 26 August 06



Day 20, 27 August 06

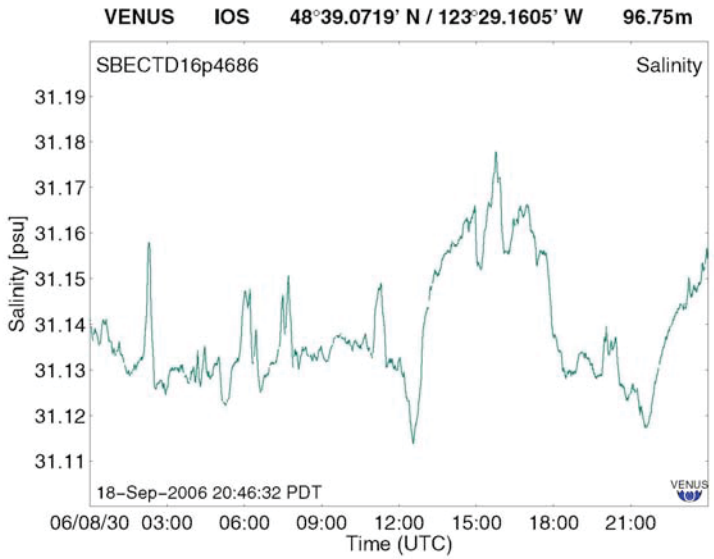


Day 21, 28 August 06

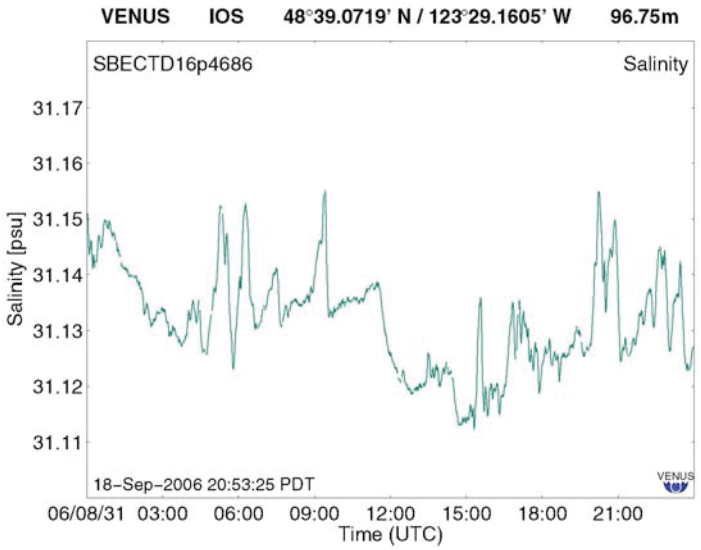


Day 22, 29 August 06

SALINITY – SEABIRD CTD

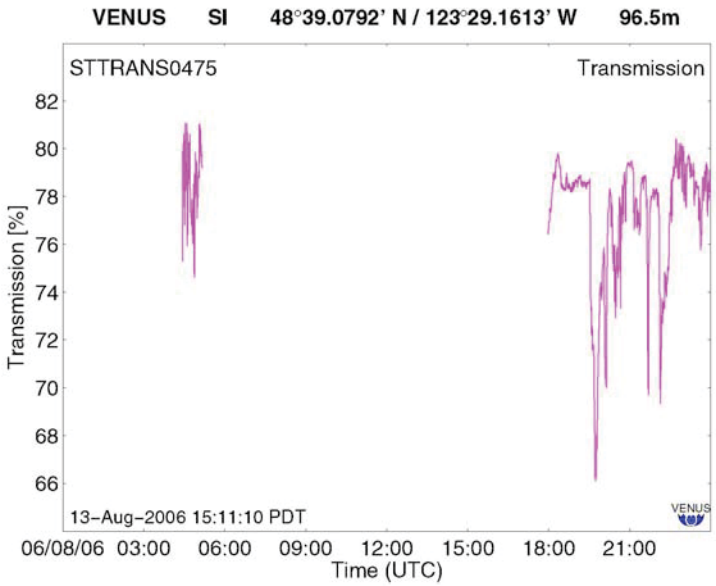


Day 23, 30 August 06

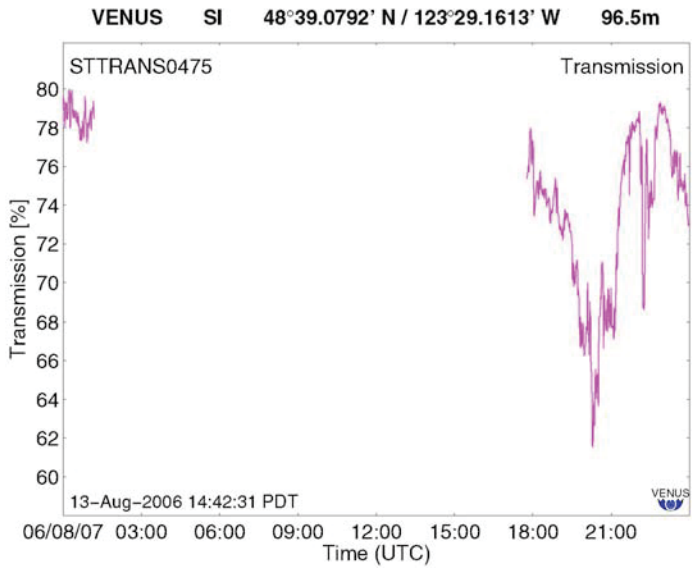


Day 24, 31 August 06

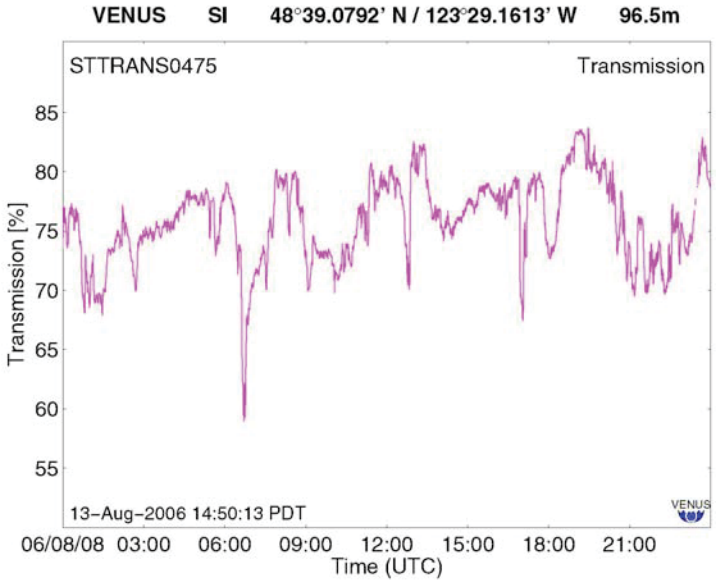
APPENDIX IV, TRANSMISSION – TRANSMISSOMOTER



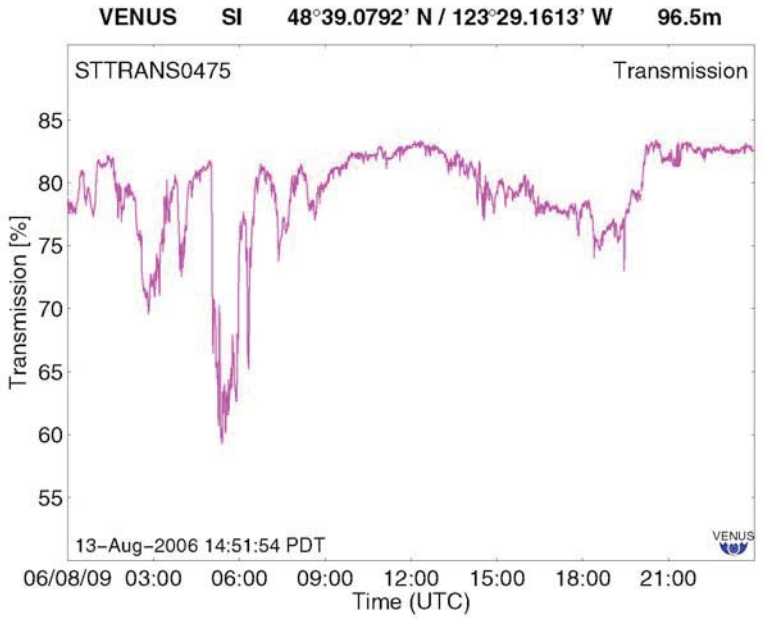
Day -1, 6 August 06



Day 0, 7 August 06

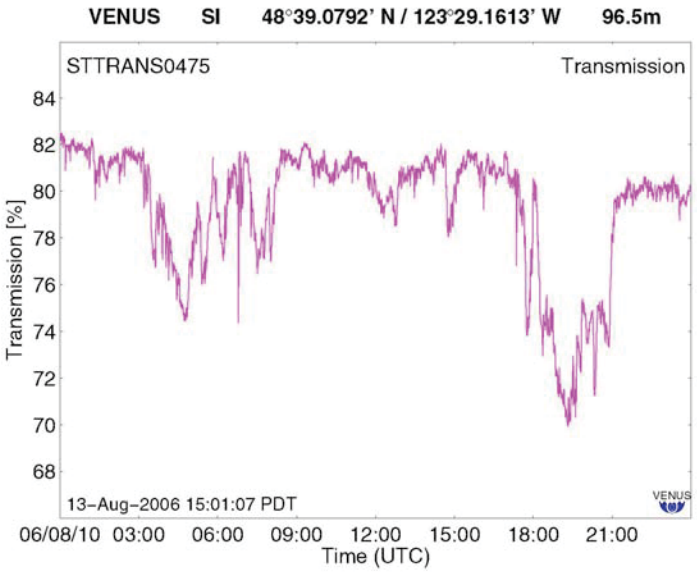


Day 1, 8 August 06

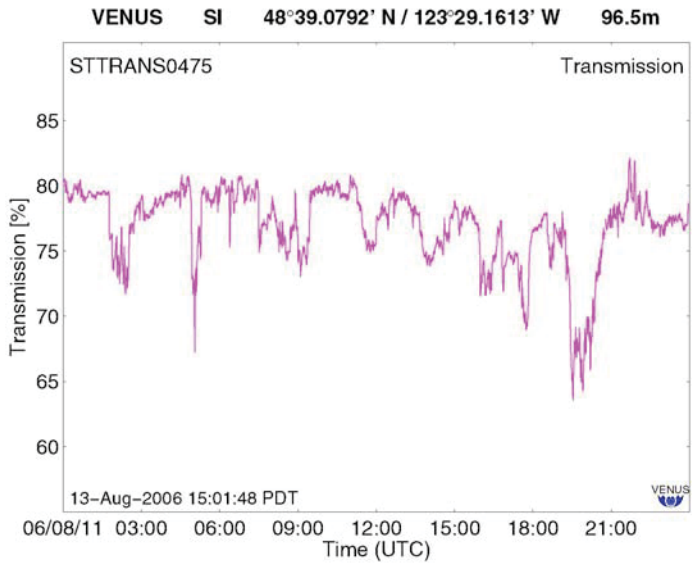


Day 2, 9 August 06

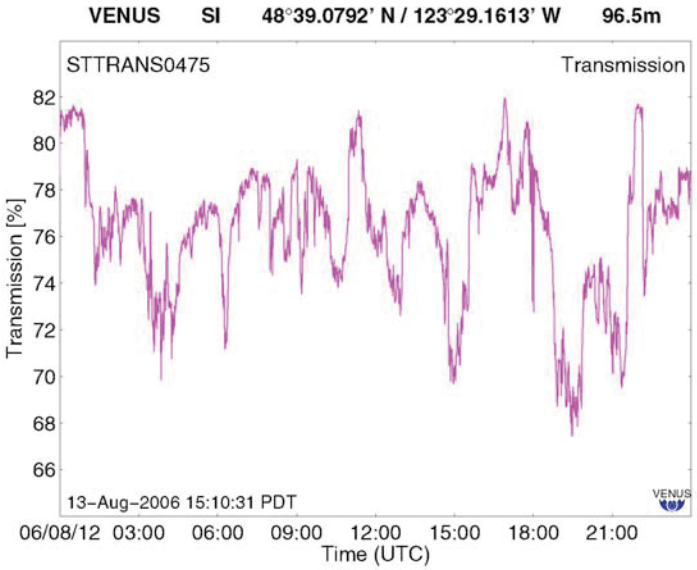
TRANSMISSION – TRANSMISSOMOTER



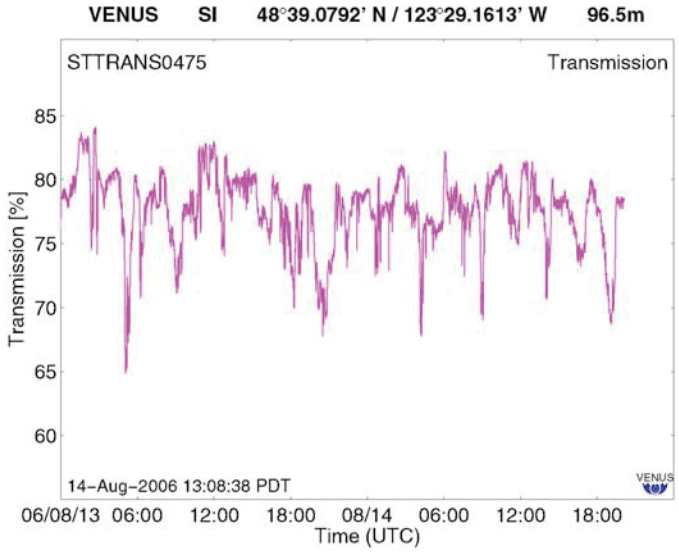
Day 3, 10 August 06



Day 4, 11 August 06

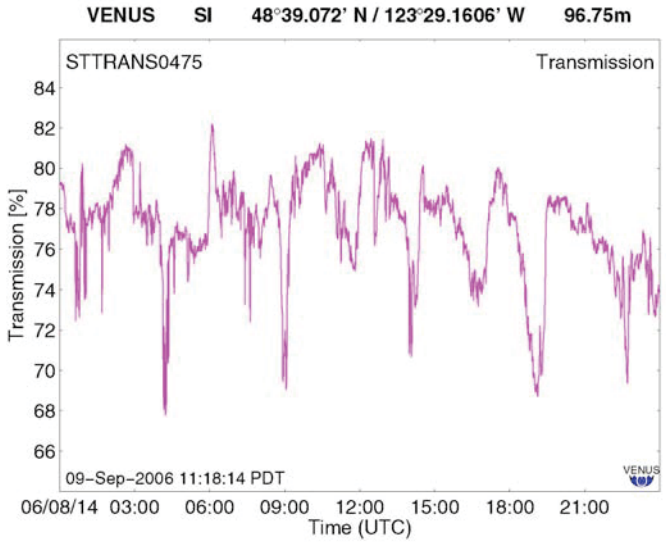


Day 5, 12 August 06

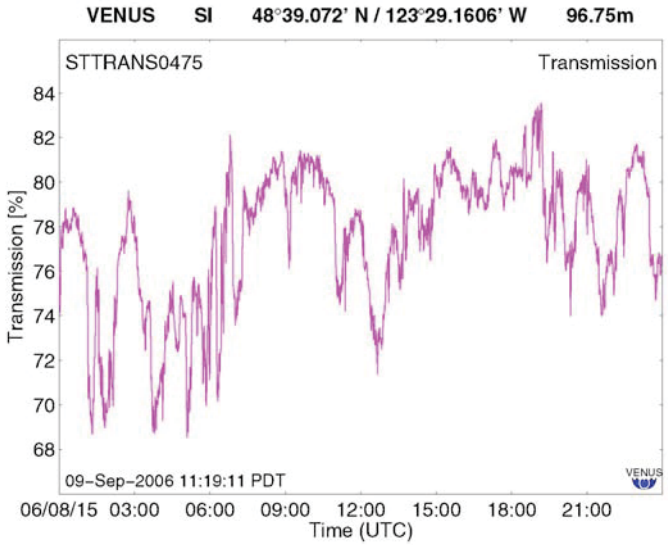


Day 6, 13 August 06

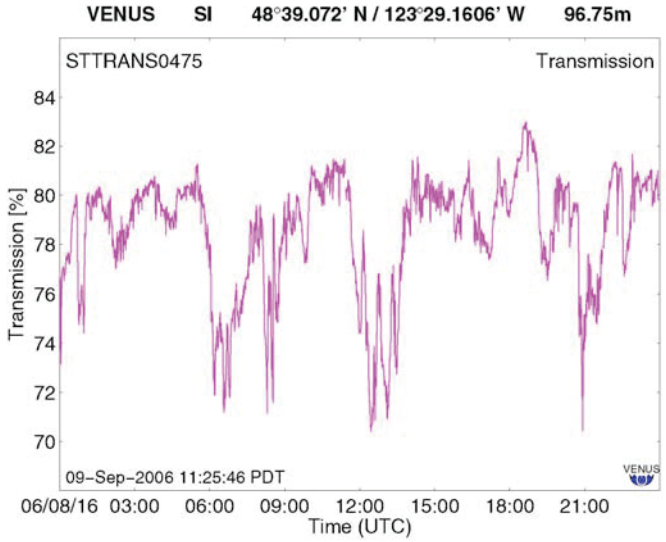
TRANSMISSION – TRANSMISSOMOTER



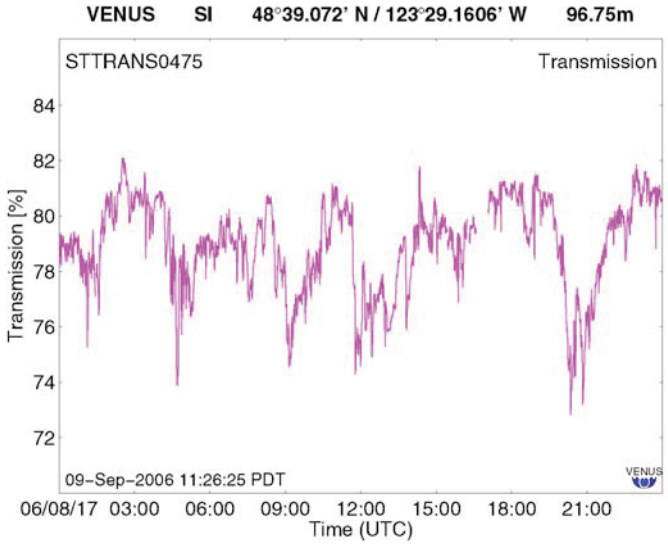
Day 7, 14 August 06



Day 8, 15 August 06

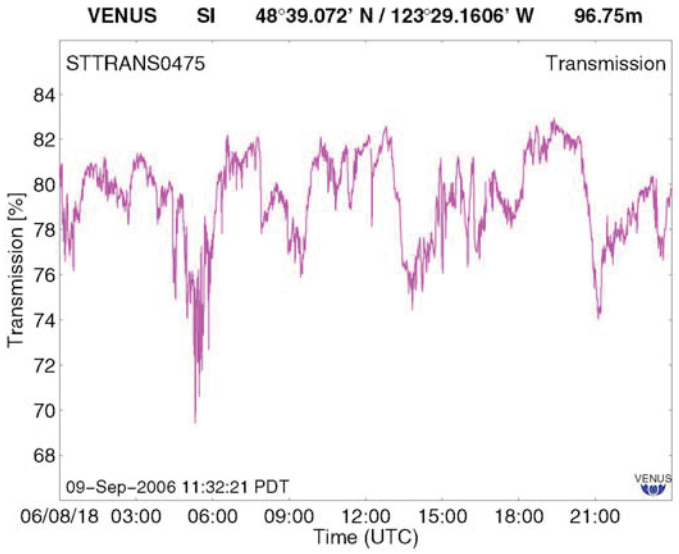


Day 9, 16 August 06

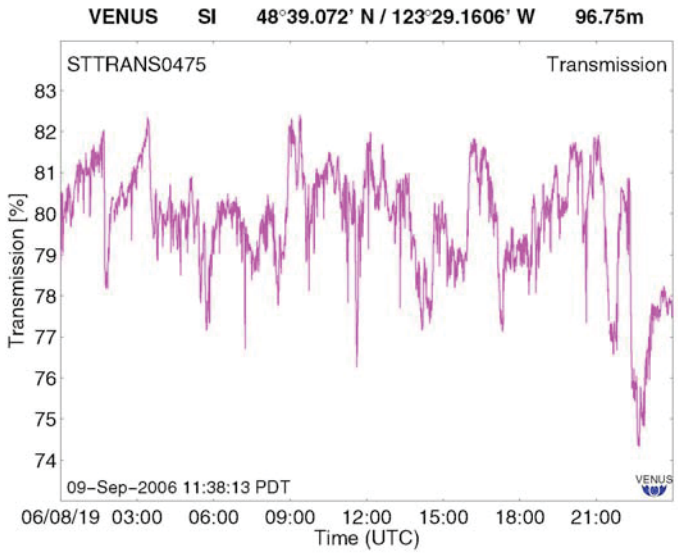


Day10, 17 August 06

TRANSMISSION – TRANSMISSOMOTER

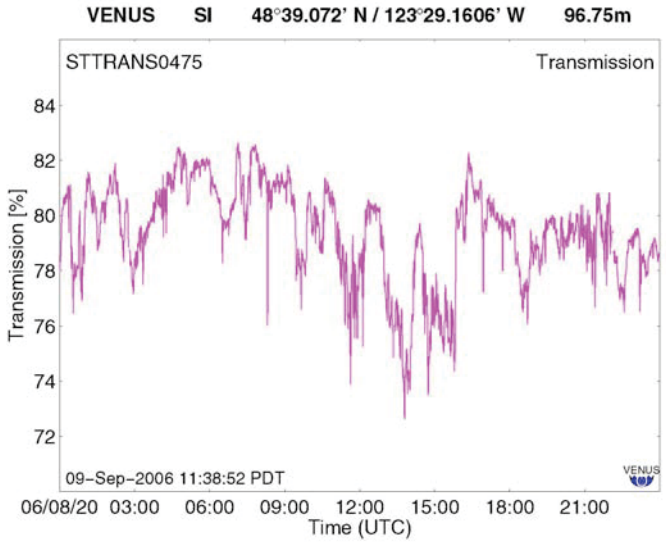


Day 11, 18 August 06

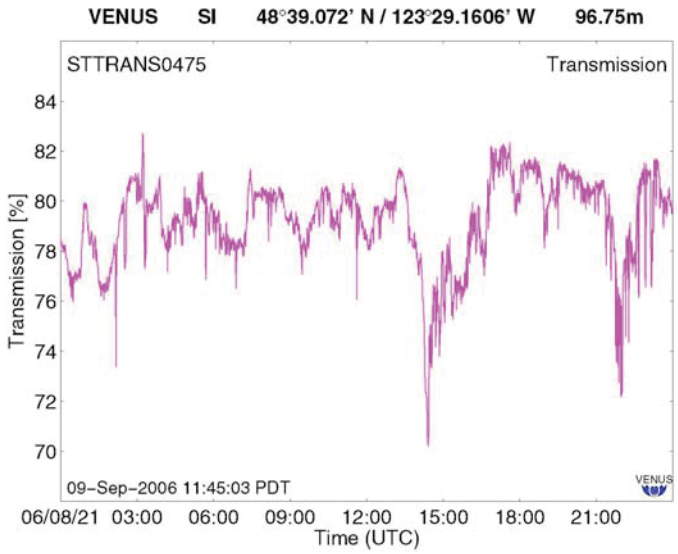


Day 12, 19 August 06

TRANSMISSION – TRANSMISSOMOTER



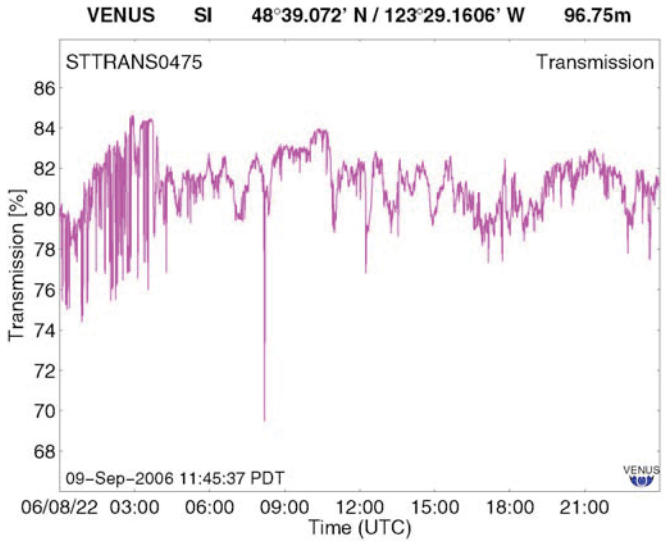
Day 13, 20 August 06



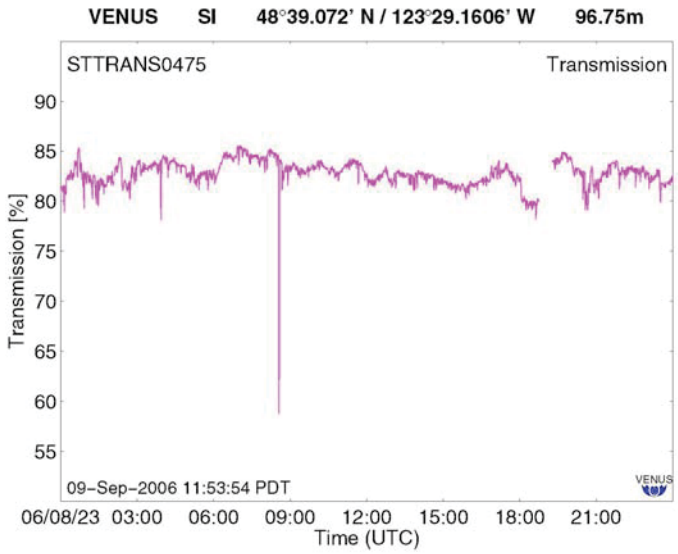
Day 14, 21 August 06

TRANSMISSION – TRANSMISSOMOTER

TRANSMISSION – TRANSMISSOMOTER

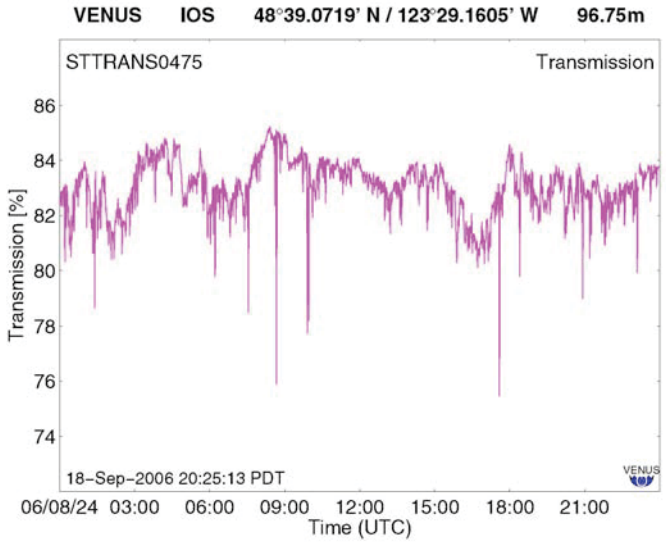


Day 15, 22 August 06

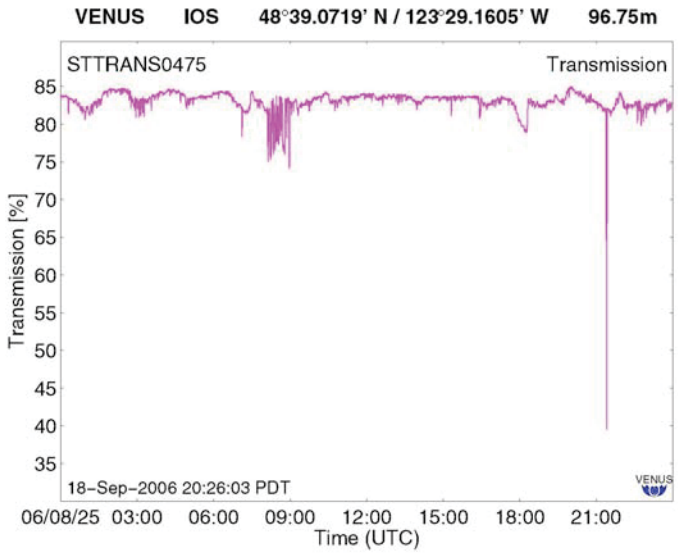


Day 16, 23 August 06

TRANSMISSION – TRANSMISSOMOTER



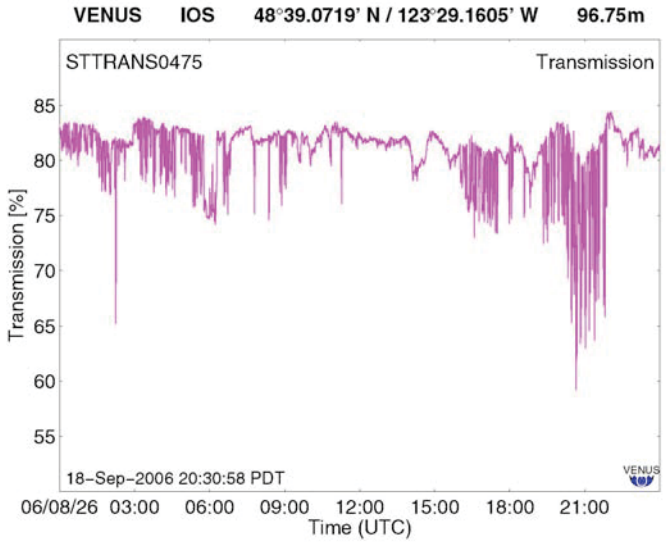
Day 17, 24 August 06



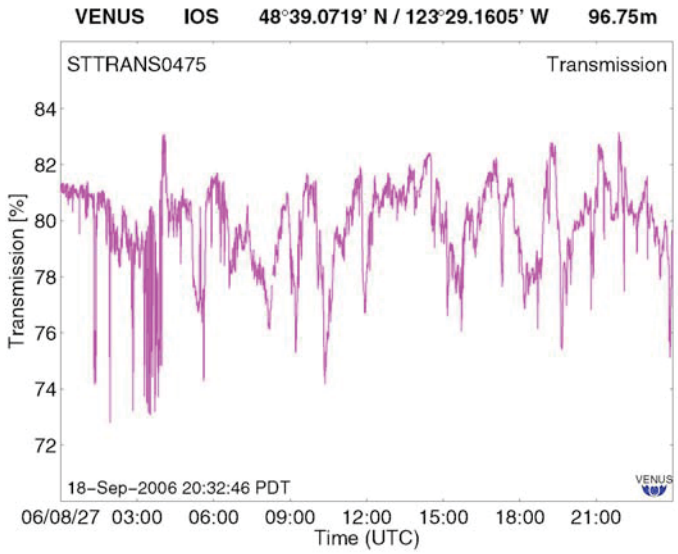
Day 18, 25 August 06

TRANSMISSION – TRANSMISSOMOTER

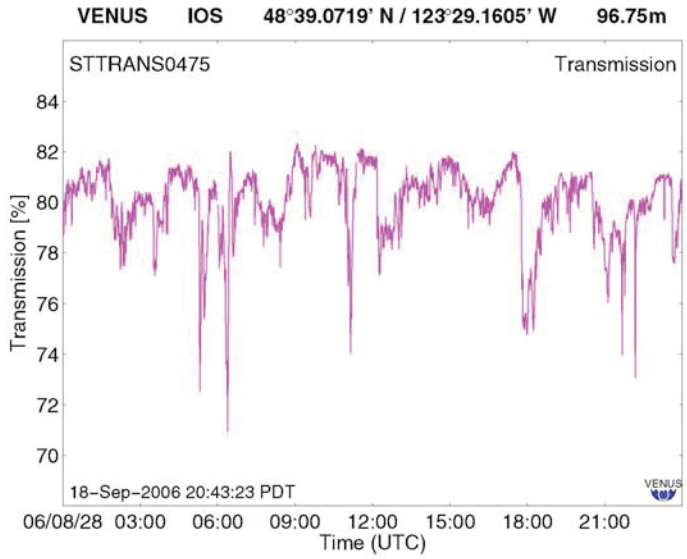
TRANSMISSION – TRANSMISSOMOTER



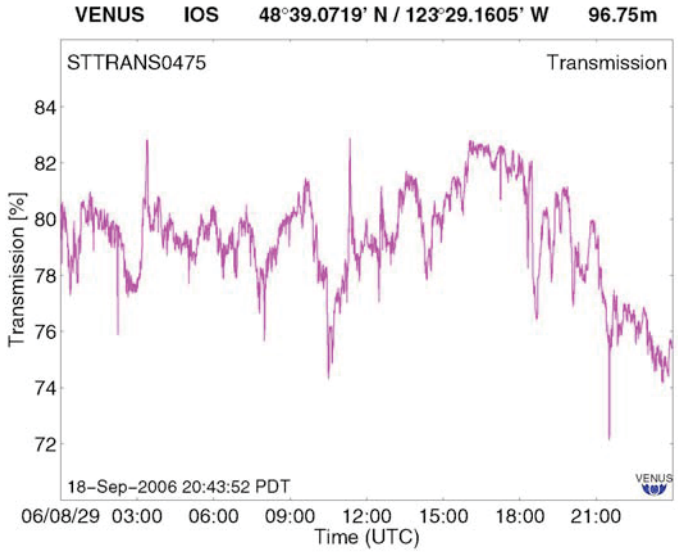
Day 19, 26 August 06



Day 20, 27 August 06

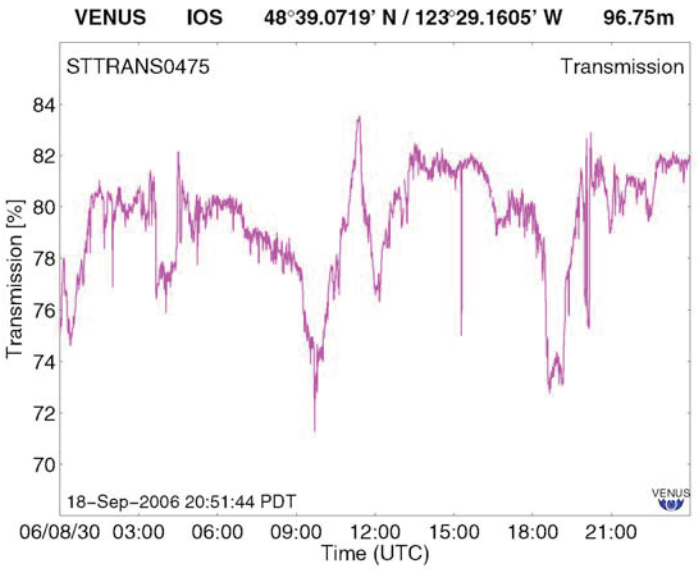


Day 21, 28 August 06



Day 22 29 August 06

TRANSMISSION – TRANSMISSOMOTER



Day 23, 30 August 06

Day 24, 31 August 06