

Design, Installation, and Operation of the PLUTO Observatory, Isla de Canales de Tierra, Panama

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Abstract

PLUTO (Panama LJI Underwater Tropical Observatory) is a cabled observatory deployed in January 2006 in approximately 20 m of water 1.5 km to the south west of the Liquid Jungle Lab, Isla de Canales, on the Pacific coast of Panama. The observatory consists of an underwater node with 1000 BT Ethernet connectivity to a shore station over an electro fiber-optic cable. The node provides diver accessible connectivity to four Ethernet ports, four 120 AC power outlets, and eight ports with serial RS232 communications and 12 and 24 VDC. All power and communications ports are under relay control from shore. Sensors currently installed include salinity, temperature, pressure, water current speed and direction (ADCP), chlorophyll, turbidity, oxygen, down-welling light at surface and two depths (PAR), and an array of temperature sensors extending from the bottom to near surface. A high definition pan and tilt camera was installed in April, 2008 to allow remote observations of fish community structure in relation to high frequency internal waves that propagate through the region during the dry season (Dec-April). The shore station houses three computers for data acquisition and processing. All data are distributed via satellite back to WHOI and made available on the web (<http://4dgeo.whoi.edu/panama/>).

The first 29 months of operation of PLUTO has provided unprecedented opportunities to study the relative roles of offshore ocean forcing (tides, upwelling of nutrient-rich, cool, salty deep water, large scale currents), surface forcing (winds, insolation, and precipitation – evaporation), and terrestrial runoff of nutrients and particulates in a relatively undisturbed tropical region. While it is well known that plankton production in the Bay of Panama is limited by upwelling of nitrate during the dry season, it was thought that no such upwelling exists to the north in the Gulf of Chiriqui where the Isla Canales de Tierra is located. However, during the dry season, observations from PLUTO show influx of cold (14-16°C) water along the bottom followed by depression and strong vertical oscillations of the thermocline, which we interpret as internal waves. These features disappear several weeks following cessation of upwelling in the Bay of Panama as seen from AVHRR satellite data. At the PLUTO site in 2006, chlorophyll reached a maximum 20 days following the most intensive period of internal wave activity while acoustic backscatter (zooplankton and particulates) from the 1.2 mHz ADCP peaked 25 days following the chlorophyll maxima (data available on the PLUTO website). A similar sequence of events occurred in 2007. During the 2006 wet season variability in hydrography, chlorophyll, and backscatter were low until late in the season when a second bloom occurred concomitant with the lowest salinity, presumably due to nutrients from runoff.

PLUTO is an example of a relatively inexpensive state-of-the-art underwater observatory, deployed on a remote tropical island, that is providing unique, high frequency, long term observations of events, which would otherwise go undetected.

INTRODUCTION

Observatory systems- Oceanographic processes occur over a wide range of temporal scales from seconds to decades making it necessary to sample at high frequency over long periods of time to capture the true mean and variance associated with a given oceanographic signal. Oceanographic observatories are being designed with the intent of providing high bandwidth bidirectional communications with substantial power to supply new, power hungry sensor packages. In this paper we describe a relatively inexpensive state-of-the-art fiber optic observatory system (PLUTO, Panama LJI Underwater Tropical Observatory), deployed January 2006 in approximately 20 m of water 1.5 km to the south west of Isla de Canales, Panama. The observatory consists of sensors for salinity, temperature, pressure, water current speed and direction (ADCP), chlorophyll, turbidity, oxygen, down-welling light at surface and two depths (PAR), and an array of temperature sensors extending from the bottom to near surface. A high definition pan and tilt camera allows remote observations of fish school activity in relation to high frequency internal waves that propagate through the region during the dry season (Dec-April). All data are distributed via satellite back to the Woods Hole Oceanographic Institution and made available on the web (<http://4dgeo.who.edu/panama/>).

Science questions being address by PLUTO include the following: What are the factors controlling terrestrial runoff and transport of freshwater, particulates, nutrients, and plankton? What are the mechanisms for mixing of these materials into the upper mixed layer? What controls sedimentation from the water column onto the seafloor? What are the influences of these processes on primary (photosynthesis) and secondary (zooplankton) production in the water column? Are CO₂ levels and pH changing and what is the impact of this change on calcification in corals? How do physical processes such as upwelling and internal waves influence the biological community structure from plankton, to benthic and coral diversity, to pelagic fish?

Background to region- The Isthmus of Panama is a narrow east-west strip of land that lies in a zone where the trade winds from each hemisphere converge to form a low atmospheric pressure trough known as the Inter-Tropical Convergence Zone (ITCZ). The ITCZ is associated with weak winds (known as the doldrums) and frequent, heavy rains, which migrate annually from the equator to 10 degrees north, a distance that spans the entire width of the Panamanian Isthmus. The combination of high net heat flux and minimal wind mixing results in a warm (> 27°C) surface layer [1] and very sharp thermocline at a depth of about 30m [2]. However, high pressure atmospheric conditions in the Caribbean during the winter months

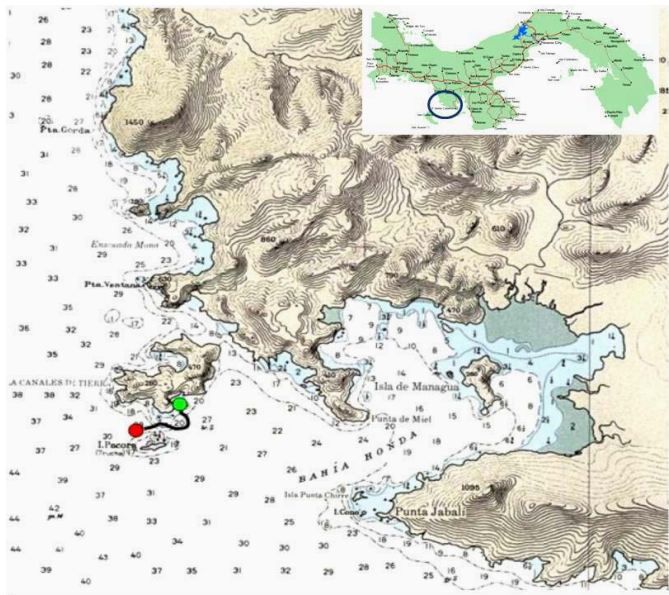


Figure 1. Liquid Jungle Lab (green dot) located on Isla de Canales de Tierra to the northwest of Bahia Honda. Panamanian Isthmus (insert) with circle indicating area of enlargement. Cable (black line) and PLUTO observatory (red dot) also shown.

promote strong westerly wind jets which cross the Isthmus where topological features are low [3]. On the western side of the Isthmus, offshore winds drive the surface layer across shelf thereby reducing sea level and inducing a shoaling of the thermocline and upwelling along the coast of cool, nutrient rich water from depth [4]. Several studies have documented upwelling in the Gulf of Panama (e.g., [1] and references cited therein), but the region to the west referred to as the Gulf of Chiriqui is thought to be protected from offshore winds and therefore not affected by upwelling [2;5]. Where upwelling of cool, nutrient rich water does occur, primary and secondary biological production and the local pelagic fisheries flourish [6]. In addition, upwelling has

been known to be associated with the onset of red tide blooms in the Gulf of Panama that can lead to serious local toxic events.

The Panama Liquid Jungle Lab (LJL) is located on the Pacific side of the Isthmus in the Gulf of Chiriqui at 7.67N, 81.65W and is centrally located in proximity to the annual movement of the ITCZ causing intense seasonality in this area (Fig. 1). When the ITCZ is located south of the LJL during January through March, strong, dry northern winds dominate the LJL area initiating biological production. In contrast, when the ITCZ has migrated to the north of LJL during April through December, southern winds, rains, river run-off, and terrigenous and lithogenic material will dominate the LJL area. It was thought that the region was not influenced by

upwelling and therefore was driven, biologically, by nutrient injection from terrigenous sources during the wet season. However, the high resolution hydrographic measurements made at the PLUTO observatory over the past 30 months show clearly that substantial upwelling year-round, but particularly strong in the dry season, brings cool, high salinity and nutrient rich water onto the shelf, which mixes to the surface due to breaking internal waves.

The physical and biological consequences of coastal upwelling and vertical mixing on the phytoplankton and zooplankton communities will be explored in a subsequent paper. Here we introduce the design, installation and maintenance of the cabled observatory that has provided insight into these bio-physical processes.

METHODS AND MATERIALS

Design- The underwater telemetry housing (node) contains components to provide a gigabit Ethernet Local Area Network for sensor control and data acquisition (Fig. 2). A fiber optic to copper gigabit Ethernet media converter (Fiberdyne) provides access to four Ethernet ports accessible to the outside and connection to a network switch for further distribution off the LAN. Two 4 port Nport (Moxa, Inc.) serial to Ethernet converters provide network accessibility to eight RS232 serial ports for external sensors. An eight channel Ethernet controlled relay board provides power switching capabilities for each sensor. Power reaches the telemetry housing as 120 VAC which is then rectified and reduced to 12 and 24 VDC (Vicor FlatPac).

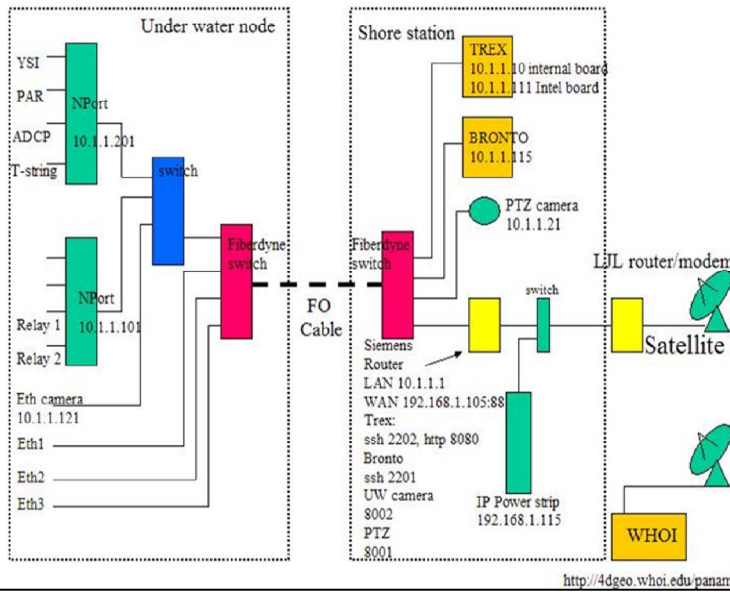


Figure 2. Flow diagram for components of the PLUTO observatory.

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Sensors- Sensors currently connected to the node include a YSI 6600 Sonde (salinity, temperature, pressure, turbidity, chlorophyll, oxygen, pH), an uplooking 1.2 mHz Acoustic Doppler Current Profiler (RDI Navigator), a sensor to detect Photosynthetically Active Radiation (PAR, Biospherical), a

string of temperature sensors positioned in the water column with sensors at 1m intervals (Fondrist Corp.), and a 10 MegaPixel pan and tilt still camera. A matched PAR sensor is located on a tower along with a weather station to provide a reference for underwater PAR propagation and calculation of an absorption coefficient (Kd). A secondary conductivity, temperature, depth sensor (Sea Bird SBE 37) provides backup for the YSI. Four additional Ethernet ports allow expansion for additional nodes at deeper depths or high bandwidth sensors such a Video Plankton Recorder (Sea Scan, Inc) in the future.

Pan and tilt camera- The pan and tilt camera system was designed and constructed at WHOI to provide high resolution still images combined with image streaming capability, and strobe and continuous lighting (Fig. 3). The camera is a 10 mega pixel Cannon G7 with remote control capability. Software was developed for controlling the camera (for features such as zoom and image resolution), the pan and tilt interface to control the Remote Ocean Systems pan and tilt mechanism, and the interface so that scientists can remotely setup experiments to take sequences of images at particular time intervals and locations. The camera is housed in an aluminum housing with a fused silica window. Fused silica was used rather than glass to allow light from a bank of UV LEDs on the inside of the window to penetrate to the outside surface and provide anti-biofouling control. The USB port on the camera interfaces over Ethernet to the control computer in the L2L PLUTO shore station. The camera streams jpeg images at a rate of 20 Hz to the control computer on the island allowing users in the PLUTO control room to see the live feed and interactively control the camera system.

The PLUTO website has a variety of controls for moving the camera. The public can view the last image captured along with a diagram illustrating where the camera is pointing. The camera controls are password protected and used by scientists for interactive viewing and setting up experiments.



Figure 3. Pan and tilt camera installed at the PLUTO observatory. Note fish condos on the bottom right being observed by the camera. Water visibility during this time of year (April) was poor due to high levels of plankton. A red tide started blooming on April 8, 2008

Clicking on any of the up/down/left/right arrows provides motion in the desired direction in 10 degree increments. Clicking on the 'H' will move the camera to the home position, which points to the PLUTO observatory. There are currently eight preset positions defined (P1-P8) to observe specific ongoing experiments.

Ground cable- The ground cable has 3 single mode fibers, 3 20 gauge conductors, with 0.68 inch diameter, triple steel armor, manufactured by Rochester Cable, Inc. The cable is terminated at the node through a pressure compensated junction box with through hull penetrators for the fibers and conductors.

The 2 km cable travels along the seafloor to a seawall on shore where it is housed in a conduit for approximately 100 m before exiting into the shore station laboratory. On station the cable is mechanically terminated and the fibers connected to a matched media converter to provide the surface LAN. Power is provided by a 2 kw UPS, which can provide up to 6 hours back up supply in the event of generator failure. Total power consumption depends on which sensors are active but typically does not exceed 1.5 A.

Shore control lab- All data are logged on shore by three computers, one running Linux as the main data logger and webserver, one running Windows XP to communicate with the ADCP and temperature string, and a third running Linux to control the pan and tilt camera and conduct image processing on the images. Since LJI is located on a fairly remote island, communications to the mainland are by satellite. Data are synchronized to a server at the Woods Hole Oceanographic Institution via rsync where the public website is located.

Public website- The public website provides access to both real-time data streaming from PLUTO and to archived data through dropdown menu selection boxes (<http://4dgeo.whoi.edu/panama>).

Bathymetry- An extensive bathymetry survey was conducted of the area to evaluate seafloor conditions before deciding on a final location. Depth ranged between 10 and 40 m with sandy bottom between the seawall and final location of the node.

Installation- The cable route was chosen to avoid rocks and coral reefs. The cable and node were deployed from a 60' landing craft by hand from shore to final location at a depth of approximately 20m. The cable was wound into the landing craft in a figure eight and deployed as the vessel traveled at approximately 3 kts. At the final location, the node was lowered by hand to rest in approximately 20m. Divers then attached air bags to the node and positioned it at the edge of a reef in the vicinity of a highly diverse corals and fish species. Although no attempt was made to bury the cable, diver inspection 24 months following deployment shows that ca 80% of the cable had self buried. Two locations were noted when the cable lay over rock outcroppings and was suspended ~1m off the seafloor. No apparent damage to the cable was noted with the exception of the first 5m of cable exiting the seawall and entering the water where the entire triple steel armor had rusted away.

Operation and Maintenance- Operation of the observatory is automated but can be over ridden remotely. Data for each sensor are recorded into daily files at a rate of about 10 kb to 10MB/day depending on the instrument. Images from the camera are taken at 1 min intervals and stored locally. The data is then regularly synchronized (every minute) to a WHOI server through the satellite link and made available to the public via the website.

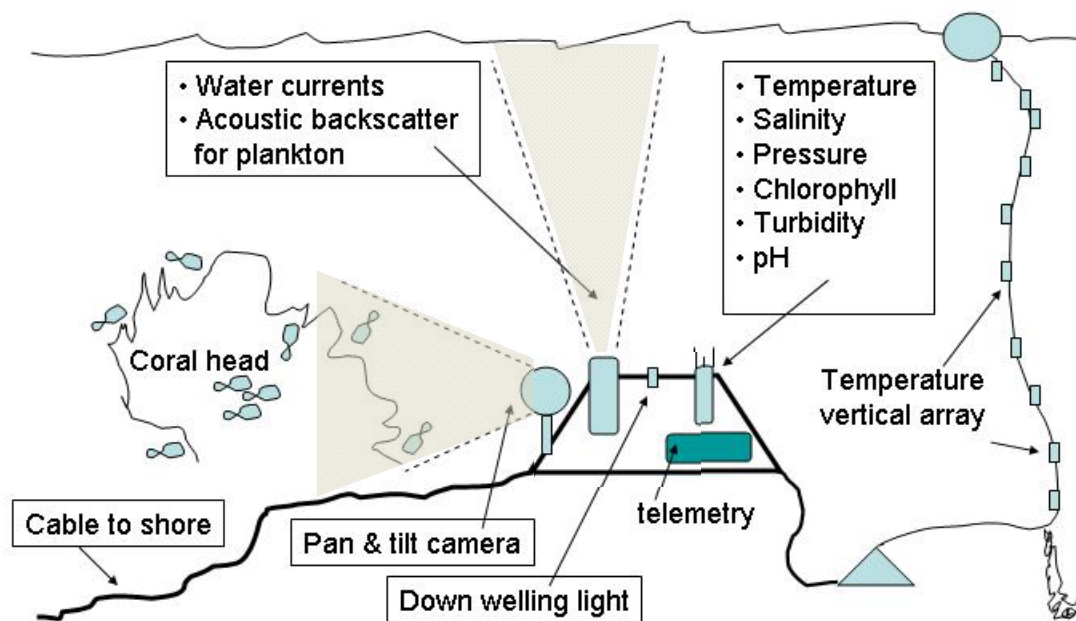


Figure 4. Cartoon of PLUTO observatory assets.

As expected, there are two major challenges with operation of PLUTO: obtaining continuous power and biofouling of the sensors. The laboratory runs alternately on two generators but often shuts down to conserve fuel overnight. The PLUTO UPS then needs to handle the load for five to six hours before the generators are restarted. This has resulted in several instances where data are lost for hours to days at a time because of generator or UPS failure. Biofouling of the sensors and camera is substantial within several weeks, particularly during the dry season when nutrients are high (see below). Although on continuously, the UV LEDs have not provided full coverage of the window. This could be improved by adding more and higher power LEDs on future systems. For the most part, copper sheeting is used with good success as covering on sensor bodies to minimize fouling. Ultimately, divers need to scrub the sensors and camera window once every few weeks to ensure high quality performance.

While removing or adding new sensors, divers unplug and re-plug the Subconn microcircular connectors without failure. This was an unexpected benefit relieving the need to constantly bring the node to the surface for sensor replacement.

RESULTS AND DISCUSSION

PLUTO has now been in operation more or less continuously since January 2006 providing high resolution time series on critical variables modulating local physical, biological and chemical processes. The most striking observation has been the presence of an internal tide on the order of 12h and associated internal waves, which travel over the thermocline with a wave period of about 10 min.

Seafloor temperature at 20m over a 2 year period shows a distinct seasonal pattern (Fig. 5). Temperature was stable between 27-28°C during the wet season (June–December) but decreased with large fluctuations in the dry seasons (January-May) with temperature ranging from 25-15°C. Rainfall ranged from 0 to 100 mm/h during the wet seasons and dropped to near zero in the dry seasons. The seasonal evolution of temperature-salinity (TS) properties indicate large swings in T during the dry season followed by a period of relative quiescence, a period of swings in both T and S, and a period of warm T with little variation in S (Fig 6).

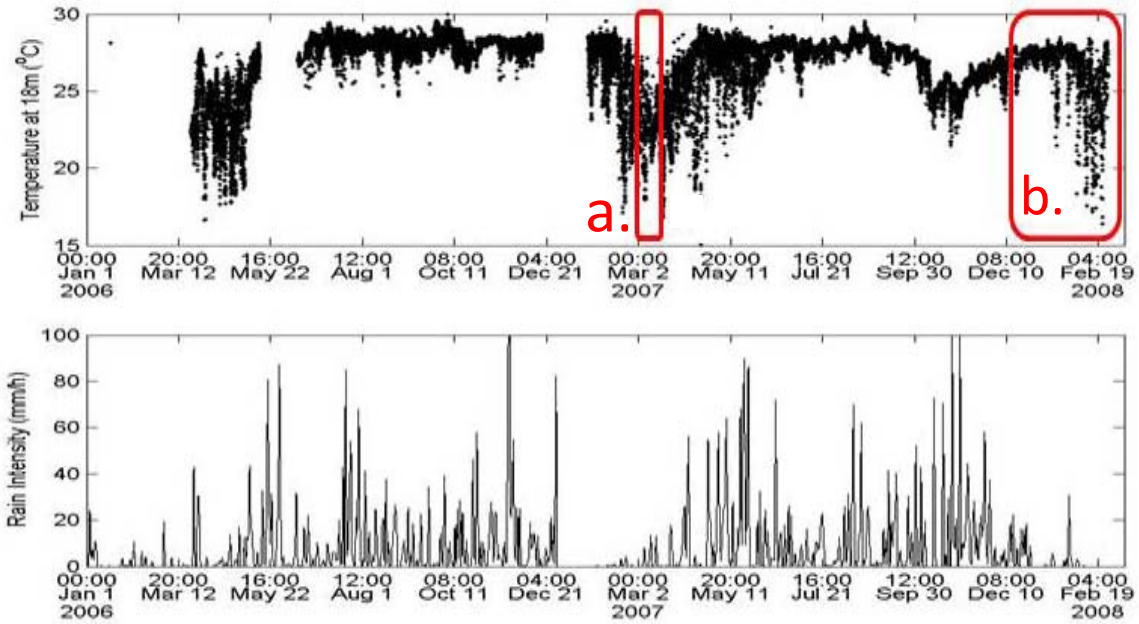


Figure 5. Two year long record of temperature at the PLUTO node resting on the bottom at a nominal depth of 20m (top) and rainfall intensity (bottom). The two highlighted regions in the top panel indicate when cold, salty, nutrient rich water is upwelling onto the shelf. Region b is enlarged in Figure 5.

December marks a transition from warm, isothermal conditions to upwelling of cold, salty water typically beginning in January (Fig. 7). Upwelled water is nearly devoid of oxygen with values ranging from 1 to 3 μM oxygen. Turbidity and chlorophyll levels increase as the dry season and upwelling progress.

As an example of a very common occurrence during the dry season, a nine hour record from the temperature string and uplooking ADCP on April 10, 2007 show high frequency internal waves impacting the PLUTO site (Fig. 8). The warmest temperature at the surface is 30°C and the coolest at the bottom is 14°C. The internal wave period was 10 min with transitions from 30 to 10°C within one minute. ADCP velocities show discontinuities during passage of internal waves while water column backscatter intensified will cool water intrusions.

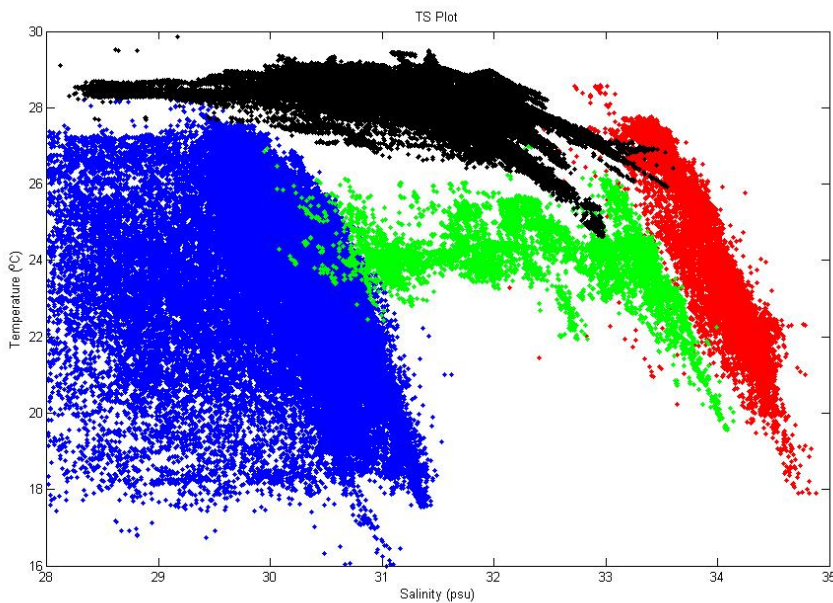


Fig 6. Seasonal changes in TS relationships for 2006-2007 color coded by time. red: Jan-Feb; green March; blue: April, black: July-Dec.

A species of dinoflagellate causing Red Tide events *Cochlodinium polykrikoides* has bloomed for the past three years during April. Water samples taken for the analysis of nutrients (nitrate) indicate that surface waters are depleted in nutrients but upwelled, cold water have highly elevated levels ranging from 18-24 μM nitrate. The combination of strong insolation, high PAR, high vertical mixing from internal waves and high nitrate in cool, upwelled water probably provides a unique environment for Red Tide organisms to flourish rapidly.

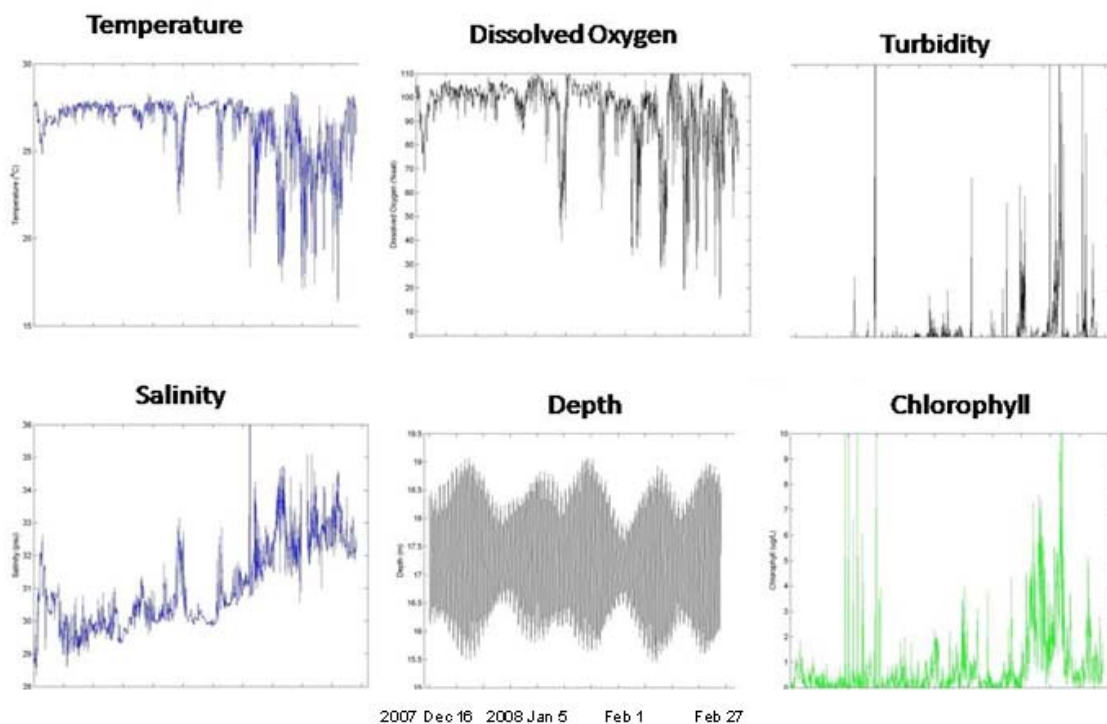


Figure 8. Three month long record beginning in December 2007.

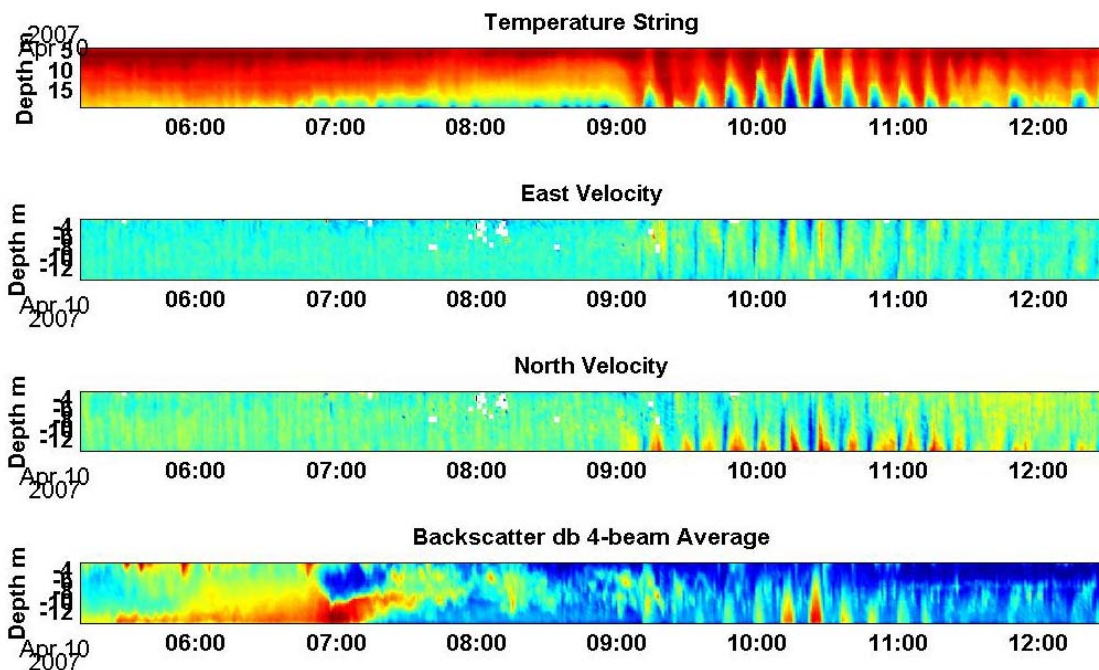


Figure 9. Nine hour record on 10 April 2007 of (a) vertical temperature structure, (b) current velocity from the east (ADCP), (c) velocity from the north, and (d) acoustic backscatter at 1.2 MHz. Note high frequency (10 min) depressions of the thermocline coincident with high backscatter contained in cooler water at depth.

Pan and Tilt Camera- Twelve camera targets mounted on poles at various distances from the camera allow positioning the camera at known locations and for determining water quality based on turbidity at known distances. The targets also allow auto pre-focusing if the need should arise. From the website, clicking on any of the presets will move the camera to that location in about 30 seconds to 1 minute depending on the distance traveled from the current location. Experiments have been established to automatically move the camera at preset intervals and take a sequence of pictures thereby establishing a time-series at multiple locations.

Experiments underway and being observed by the camera include the following:

1) Fish condos - both transparent and opaque PVC tubes were installed in clusters around the camera to provide fish nesting sites, specifically for the beaubrummel Damsel fish (*Stegastes flavilatus*). PVC tubes are a common tool used to study Damsel fish breeding activity. Any clutches laid within the tubes can be monitored with the camera to study spawning times, clutch size, parental care, egg cannibalism, and territoriality. Differences in damselfish behavior between the opaque and transparent tubes should be a function of sensitivity to visual predators.

2) Fouling panels - glass, aluminum and wooden panels have been coated with several antifouling materials to determine

efficacy as a function of substrate. The camera can be positioned to view each of these panels.

3) The home position of the camera is the PLUTO node as mentioned above (Plate 1). When the camera is not being used to scan the water column, pictures are being taken at 1 minute intervals to establish a time series of fish community structure. One of the primary reasons for establishing this time series is to determine the effect of internal waves on fish and invertebrate communities. One of the questions we have is whether the internal waves are allowing warm water fish to expand their foraging range as the thermocline is depressed. We see strong changes in fish community structure as the waves travel by, but a detailed, inter-seasonal, and inter-annual analysis will be necessary to describe their effect on local communities. To date 52 species of reef fish have been identified using the PLUTO camera.



Plate 1. Home position of the pan and tilt camera looking at the PLUTO node in the background. Foreground contains a school of creolefish (*Paranthias colonus*), a Mexican hogfish (*Bodianus diplotaenia*), and a barberfish (*Johnrandallia nigrirostris*).

CONCLUSIONS

PLUTO is an example of a relatively inexpensive fiber optic underwater observatory (Plate 2) deployed on a remote tropical island, that is providing unique, high frequency, long term observations of events, which would otherwise go undetected. PLUTO is being used to address factors controlling terrestrial runoff and transport of freshwater, particulates, nutrients, and plankton. Mixing of these materials into the upper mixed layer and the influence of these processes on primary (photosynthesis) and secondary (zooplankton) production and fish community structure can now be resolved on scales of seconds to years.

Upwelling of cool, salty, nutrient rich water was not thought to occur to the west for panama basin since no thermal signature is usually detected from sea surface temperature satellite imagery [7]. However, data from PLUTO clearly show upwelled intrusions in very shallow water. Most likely the impact of upwelling in the Gulf of Chiriqui is an elevation of the thermocline, which then oscillates vertically as internal waves are generated by the receding internal tide. Only under extreme conditions will a thermal signature be observed at the surface. How these very large thermal fluctuations and lack of oxygen impact coastal benthic, planktonic and pelagic communities in the region is unknown.

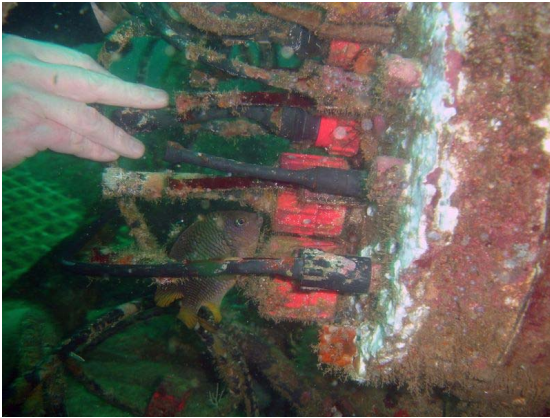


Plate 2. PLUTO node being readied for deployment (top left). Fiber optic ground cable being deployed from barge (top right). Connectors on node after 2 years in water (bottom left). Diver (A D York) cleaning the ADCP (bottom right).

Acknowledgements

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