

Underwater Sensor Networks, Oceanography and Plankton Assemblages.

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ABSTRACT

The Great Barrier Reef Australia (GBR) is affected by cold water intrusions originating in the Coral Sea and upwelled on the reef. Therefore biological interest in GBR upwellings has been driven by the view that upwelled waters rich in nutrients boost plankton production and overall productivity of the GBR system. We propose to employ a Wireless Sensor Network (WSN) for in situ monitoring of upwellings. Temperature is a good proxy for upwellings however 3D dense spatial data is required to describe upwellings and their impact on plankton abundance. The array of underwater sensors was deployed at various depths on the coral reef in Nelly Bay, Magnetic Island, GBR. We propose that the temperature data is communicated real time using RF signal to the on-shore base station. WSN has capability to communicate temperature data in real time thus offering the opportunity for rapid response times to measure the biological impact of upwellings on reef assemblages. This permits us to collect the plankton data in real-time synchronized to the temperature changes. This paper outlines the methods of the deployment of WSN for ecological research. It also describes preliminary results.

1. INTRODUCTION

In Great Barrier Reef Australia, cold water intrusions come from the Coral Sea bringing nutrients into GBR waters [1]. Biological interest in GBR upwellings has been driven by the view that upwelled waters are rich in nutrients and contribute significantly to the overall productivity of the GBR system [1]. Moreover, Furnas and Mitchell [1] found strong correlation between temperature and concentrations of phosphate, nitrate and silicate in upwelled regions of GBR. The ocean fluctuations in nutrients result in variations in the growth of marine organisms such as phytoplankton [2-4]. Understanding the plankton abundance and composition within the complex GBR ecosystem is essential to understanding the GBR food chain.

Plankton is considered to be some of the most important organisms on Earth since it is a primary food producer for most aquatic life. Based on the trophic level, plankton could be divided into three broad groups: phytoplankton (producer),

zooplankton (consumer) and bacterioplankton (recycler) [5]. Understanding the phytoplankton productivity in the world ocean has recently become a major concern because of its role in CO₂ recycling and therefore the effect on global climate change [6]. In addition to making a significant contribution in removing carbon dioxide from the atmosphere the phytoplankton create the foundation of the ocean food chain.

Phytoplankton biomass can fluctuate significantly depending on the availability of inorganic nutrients [2]. Plankton species can move up and down the water column [7], thus plankton abundance should be estimated with respect to depth and appropriate 3D sampling design is important. Phytoplankton blooms, defined as rapid growth, take place when upwelled waters bring nitrate, phosphate and silicate nutrients into euphotic surface zones [2].

Upwelling is an oceanographic process where deep, cold and usually nutrient-rich water moves towards the ocean surface, replacing the warmer, usually nutrient-depleted surface water. The upwelling can be caused by various dynamic processes in the ocean including wind, topography and tidal movements. Large scale coastal upwellings are generally driven by wind force. This type of upwellings occur when alongshore winds generate Ekman transport causing the surface waters to move offshore and be replaced by deeper nutrient-rich water that upwells close to shore [8]. Thomson and Wolanski [9] established that strong tidal currents can pump nutrient-rich water from below the mixing layer through the reef passages onto the shelf. High frequency coastal upwellings can also be associated with tidal jets, internal tides, internal waves and internal tidal bores [10]. The temporal and spatial variability in upwellings near coral reefs contribute greatly to temperature variability and input of food to coral reef assemblages [11].

The GBR upwellings allow the cross-shelf intrusions of Coral Sea water through the reef matrix [12]. Andrews [13] used temperature to trace cross-shelf transport which in open stratified water produces a marked bottom- temperature signal. The temperature was found to mark the upwelling intrusions adequately [13]. Furnas and Mitchell [1] found that nitrate, phosphate and silicate concentrations are strongly correlated with water temperatures.

We hypothesize that changes of sea water temperature impact the abundance of plankton and therefore propose to set up real-time monitoring of high frequency temperature changes. To be able to trace the effect of high frequency temperature changes due to daily tides and upwellings with sufficient tolerance we propose to monitor on a relatively small spatial scale compared to previous studies. We hypothesize that daily tides have similar effect on plankton abundance as previously documented upwellings but with smaller magnitude. Thus the aim of this study is to understand the effect of high frequency changes in the sea water temperature due to tidal fluctuations on plankton distribution and abundance on 3D scale at Nelly Bay, Magnetic Island, Australia.

We employed a Wireless Sensor Network (WSN) for in situ monitoring of temperature on 3D scale with real time data transmission capabilities. We outlined how the temperature data is communicated real time using RF signal to the on-shore base station. This solution permits us to collect biological data (plankton) synchronized to the physical changes in the ocean temperature. This paper describes the design and first effort at implementation of WSN for real time temperature monitoring in the marine environment.

2. Methods

A. Sensor Array

The array of sensors was deployed on 3 dimensional spatial scale with horizontal coordinates spaced out along the reef crest and reef flat and at various depths. In this study we used temperature monitoring solution based on 1-Wire devices DS18B20 from Dallas Semiconductor. The DS18B20 communicates over a 1-Wire bus that by definition requires only one data line (and ground) for communication with a central microprocessor. Each DS18B20 has a unique 64-bit serial code, which allows multiple DS18B20s to function on the same 1-Wire bus; thus, it is simple to use one microprocessor to control many DS18B20s. The resolution of the temperature sensor is user-configurable to 9, 10, 11, or 12 bits, corresponding to increments of 0.5°C, 0.25°C, 0.125°C, and 0.0625°C, respectively. In this study the sensors were programmed to record temperature every 5 minutes with maximum resolution of +/-0.0625 °C. Multiple DS18B20 sensors were connected using Dallas 1-Wire protocol to a processing unit called Unode supplied by Ambient Systems (Figure 1). The Unode has integrated RF networking capabilities to communicate with other Unodes and the base station using Lightweight Medium Access Protocol (LMAC) designed by University of Twente in Holland [14, 15]. Simulations showed that LMAC protocol is more energy-efficient compared to SMAC and EMACs [14].

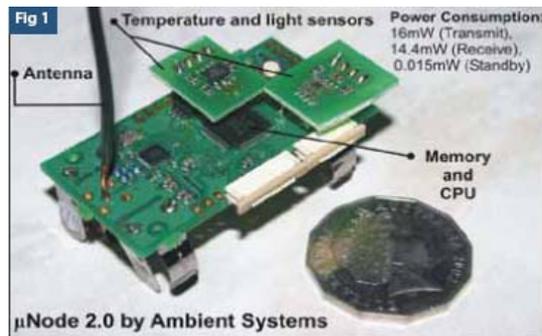


Figure 1: Unode supplied by Ambient Systems | 15 |

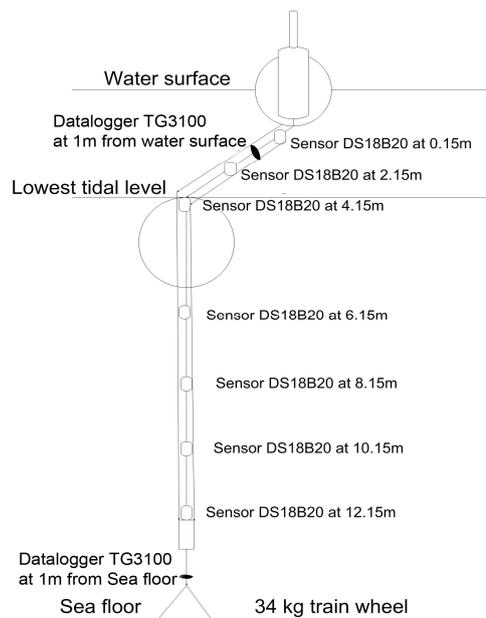


Figure 2: Diagram of the sensor buoy with seven DS18B20 digital thermistors and two data loggers TG3100.

Each string of temperature sensors was connected to a Unode (Figure 2) and positioned underwater inside of a hydraulic cable at various depths (2 meters apart). We also installed 2 data loggers TG3100 outside of hydraulics cable containing DS18B20 sensors for the purpose of comparison to the DS18B20 sensor data and calibration. The data loggers were supplied in water proof package and were placed outside of hydraulic cable therefore able to provide data about possible temperature off set caused by the hydraulic cable itself. The laboratory experiments conducted previously showed no significant off set in temperature but slight delay in response to temperature change (up to 5minutes).

The data loggers were placed under water on 05/09/07 and retrieved on 25/09/07. TG3100 were synchronized and programmed to record temperature every 10 minutes with accuracy of +/-0.2 °C.



Figure 3: Study site at Nelly Bay, Magnetic Island, Australia. The sensor network consisted of 4 moorings (1-2, 3-4, 5-6 and 7-8). Each mooring has 7 sensors deployed on vertical scale 2 meters apart and 2 data loggers (Figure 2). Each data logger has a number on the map 1-8. The temperature surfaces were extrapolated from the data loggers point data recorded on 17/09/07 (for the illustration purpose only).

We deployed a sensor network consisting of 4 moorings (Figure 3). Each mooring has a sensor string attached to the Unode and multiple Unodes form wireless sensor network (WSN). WSN offers several advantages over historical monitoring techniques by streamlining the data collection process, potentially minimizing human errors and time delays, reducing overall cost of data collection, and significantly increasing the quantity and quality of data on temporal and spatial scales [16]. Wireless sensor networks allow fine grained interface between the virtual and physical worlds and thus represent the future for environmental monitoring [17].

In a sensor network, each node is able to manage the collection of environmental data. This management includes interacting with other sensors to determine the data collection rates and electronic system status. The environmental data is then packaged up using standard networking protocols to broadcast into the network. This means that if the node is unable to directly contact the target base station the data can be rerouted to the target via other sensors (multi-hop network). There is no hierarchy between the nodes and they can be spaced out randomly to form multi-hop mesh as long as the distances are within the signal reach. The sensors communicate unique identification number and thus the data can be tagged with three dimensional attributes (x, y and depth). The transmitting frequency band of 900 MHz was chosen as the most suitable compromise between board rate, humid environment and commercial availability of transmitters.

B. Study site

The data on temperature and plankton was collected at Nelly Bay (146° 51' 9" E 19° 9' 52" S), Magnetic Island, Australia. Magnetic Island is situated about 7 km off Townsville (Figure 3); it is bordered by a number of sheltered bays with fringing reefs. Nelly Bay's 1800m-wide sand and rubble intertidal reef crest and slope area was used for data collection (Figure 3). The temperature sensors were spaced out along Nelly Bay reef crest and reef flat at various depths.

C. Plankton data collection

The discrete water samples were collected using Niskin bottles. Niskin bottles are a common technique for plankton sampling; they are cylinders able to remove columns of water of known diameter and depth [18]. The abundance of some phytoplankton species, for example *Trichodesmium* cyanobacteria, have been difficult to quantify because the colonies are easily damaged or destroyed during collection [19]. Thus the Niskin bottle method is preferred for this study over collection with plankton net because it minimizes trauma and enhances the survival of taxa that are easily damaged or killed when they come into contact with the mesh of plankton net. The water samples were collected next to each temperature station at 2 depth levels (1 meter from the sea surface and 1m from the sea floor). We originally planned to collect plankton samples at the time of high and low tides during spring tides (high tide of ≥ 3.4 meters) and when the event of cold water intrusion is detected. It was our intention to use the threshold of 1 °C for the event to be considered as

cold water intrusion. It was planned that temperature data would be transmitted by WSN and be available on the internet. Therefore the plankton collection was to be triggered by email if the observed difference in temperature value from underwater sensors reached 1 °C ($\Delta T = T_x - T_i \geq 1 \text{ }^\circ\text{C}$).

3. Preliminary results

Preliminary study results showed that the concept of WSN with underwater temperature sensors is a feasible solution to the small scale temperature monitoring of the reefs. However some adjustments had to be made to the original concept. We found that RF capabilities of the Unodes with small antennas (0.2m) could not reach (multi-hop) desired distance to the on-shore base station (500 meters). We therefore integrated into our network a more powerful RF repeater – RF 401 available from Cambell Scientific Inc.

We also established that the max range was highly affected by the height of the antennas from the ground plane as described by Bullington’s [20] equation. We increased the size of the antennas on all Unodes. We also placed RF401 repeater on the cardinal navigation marker which elevated the tranceiver (sink) by about 15 meters from the ground level. With such adjustments we successfully received temperature data from one sensor string on 21/09/07 (Figure 4). Due to unforeseen failure of hydraulic cables the underwater temperature sensors got wet and we could not collect data from other strings. (Expected by December 2007)

The data loggers were not affected by the hydraulic cables failure because they were supplied in water proof package by the original manufacturer. Based on temperature data from the data loggers there were a number of cold water intrusions detected during the observation period from 5/09/2007 till 25/09/2007 (Figure 5). We confirmed that temperature threshold of 1°C was adequate to mark cold water intrusions for Nelly Bay study side.

The maximum temperature variance detected between the sea surface and the sea floor data loggers was 1.2 °C on 06/09/07 at 13:40 (Figure 5); the TG3100 were in 7 meters of water and 5 meters apart on vertical scale (Figure 2). The plankton samples were collected on 06/09/07 at high tide (18:40) 5 hours after the event. Another event of significant temperature differences between the same data loggers was recorded on 17/09/07 (Figure 3; Figure 5). However since there was no significant difference between high and low tides (neap tide) on 17/09 and the real time wireless communication was not available to trigger plankton collection, the plankton samples were not collected for this event. Thus during the observation period from 5/09/2007 till 25/09/2007 only one event of possible cold water intrusion was followed by plankton collection. It is therefore not possible to verify our hypothesis that the changes of sea water temperature impact the abundance of plankton with statistical confidence.

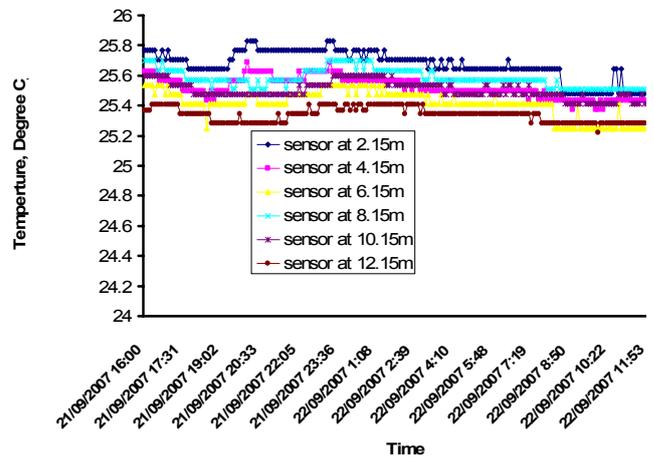


Figure 4: Graph of temperature variation for the period 21st to 22nd of September 2007 in Nelly Bay, Magnetic Island. The data was obtained from six digital sensors DS18B20 deployed at different depth on sensor string 3-4 (Figure 3).

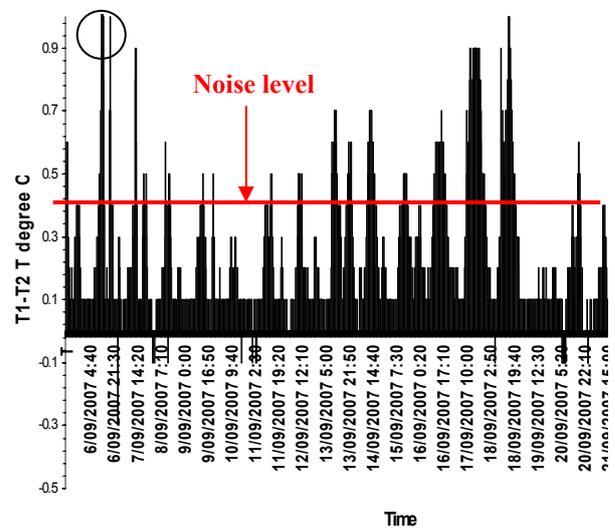


Figure 5: Graph of temperature variation between temperature data T1 from data logger 1 (surface) and T2 from data logger 2 (sea floor) (Figure 3). The horizontal red line represents noise level of 0.4 °C due to calibration of the data loggers (+/-0.2).

4. Discussion

The data obtained from the data loggers placed in Nelly Bay confirmed our predictions that the water temperature can vary by 1 °C on a small spatial scale. We also established that such temperature variations were not always influenced by tides but other oceanographic processes, possibly upwellings, could be the reason for the temperature variations in Nelly Bay, Magnetic Island. However due to system implementation problems with WSN we could not collect high spatial resolution data to fully analyze observed events. The temperature data obtained from the data loggers showed that spring tides did not always produce significant variation in sea water temperature and that the events of significant

temperature variations were not always connected to high variations in tides.

Our study highlights the fact that under water data loggers do not provide necessary information on time to measure physical aspects of high frequency upwellings and biological consequence of physical change. The underwater temperature data loggers have been successfully used to measure the impact of temperature variations on coral growth [21] and to predict return times for cold water upwellings [11]. In 2003, Leichter et al. [22] deployed the Benthic Oceanographic Array on Conch Reef off Florida Keys to provide an understanding of interaction between cold water intrusions generated by internal waves and 3-D reef bathymetry. Benthic Oceanographic Array consisted of 100 temperature sensors arranged in 10 arrays of 10 elements and capable of synchronized, high precision, autonomous sampling [23]. Such sophisticated temperature arrays allow in-situ high frequency analysis on 3-D scale of the run-up of internal waves on a complex surface of coral reef [22]. However such models have limitations when it comes to requirements of ecological researchers to obtain real time biological samples of dynamic marine organisms at particular temperature regimes.

Our study confirms the importance of WSN for ecological research of marine organisms. This method allows to correlate temperature changes with a highly dynamic organism such as plankton by reactive sampling. The phytoplankton growth is generally determined by two parameters: light and nutrient levels [3] and in favorable conditions can double the biomass in one day. Growth and aggregation of phytoplankton is influenced by water dynamics on spatial and temporal scales ranging from meters and minutes to kilometers and seasonal changes [4]. Thus in-situ measuring techniques with high frequency real time communication ability are required to correlate the effect of tidal changes and upwellings on plankton species.

The deployment of WSN with underwater sensors in Nelly Bay, Magnetic Island, provided valuable information about the challenges that the marine environment creates for electronic equipment. The sea water is a very aggressive medium when it comes to electronic equipment placed under or above water. The challenges we faced during WSN deployment highlights the importance of field trials. We suggest that primary parameters such as maximum range of transmission and power consumption of WSN should be established by trials in real physical air especially when intending to use in harsh environments such as in marine applications.

While we are still dealing with some of the challenges, we are able to confirm that existing design of underwater sensor string based on DS18B20 and Ambient RF Unodes is a feasible solution. Our future focus will be on getting a stable performance from the WSN with 16 strings (112 sensors) over a period of 2 months to be able to collect high resolution spatial data for 3D visualization of cold water intrusions. For future research we also suggest to collect multiple plankton samples: 1 hour, 2 hours and 5 hours after the detected event to establish the speed of biological response to cold water intrusions.

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