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The Great Barrier Reef Sensor Network

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Abstract

The Australian Institute of Marine Science has a long history of monitoring the marine environment and associated biota. Data from seven autonomous weather stations are augmented with submerged temperature loggers and automatically quality checked and stored in the data centre. However collecting real-time data at appropriate temporal and spatial scales is critical to understanding complex marine processes. The emerging generation of 'smart' sensors opens up a range of opportunities for automated intelligent monitoring of marine systems. However development of these sensors is beyond the capacity of AIMS and requires the involvement of national and international collaborations. The Coral Reef Environmental Observing Network provides a mechanism to develop sensor networks for the Great Barrier Reef(GBR). Comprised of marine groups across the world this group is active in assisting members to monitor the coral reef environment. For the GBR, we are extending the existing monitoring infrastructure by placing of a number of environmental sensors, measuring temperature, salinity and light, at Davies Reef, Magnetic Island and Heron Island in North Queensland. Utilising standard computer network protocols, the sensors will be IP based, spatially aware and able to adapt to conditions they are monitoring. This will give us a better understanding of the relationship between various environmental parameters, the impact of temperature changes on coral reefs and the impact of global warming on the GBR system. Critical to the success of this project will be the early involvement of marine managers in the design and functionality of the entire system.

Introduction

The environmental dynamics of marine systems such as the Great Barrier Reef (GBR) are complex yet require our understanding in order to manage anthropogenic stresses effectively. With over 3,200 reefs extended over 280,000 km^2 (Furnas 2003) the scale of the fluctuations range from kilometre oceanic mixing to millimetre inter-skeletal currents. Scientific institutions, like the Australian Institute of Marine Science (AIMS) need to collect environmental data that matches the questions being addressed. Clearly many parts of the GBR will remain under sampled as a result of economically viability, but the extension of scientific understanding does not require complete sampling coverage in both time and space. The critical aspects of environmental monitoring are the strategic and opportunistic collection of data at a range of scales that provide supporting evidence for a given hypothesis (Borsuk, et al. 2002).

Given the potentially catastrophic thermal stress that might impact on the GBR over the next 100 years (Hoegh-Guldberg 1999) we need to understand the patterns of temperature and response (Berkelmans, et al. 2004) in order to alleviate anthropogenic stress. Modelling environmental patterns at this early stage of global climate change leads to high levels of uncertainty given the paucity of the evidence (Wooldridge, Done 2003). Collecting environmental information is the only way to develop more robust models, the challenge is to be able to collect data across the required spatial and temporal scales in a cost and time effective manner. AIMS has extensive experience in collecting large scale reef environmental data using a range of resources. For example, routine surveys of the coral and fish assemblages (Sweatman, et al. 2001) are augmented by the acquisition of satellite imagery, weather station measurements and opportunistic field surveys. Of particular note are the data loggers that are placed in the field for extended periods before being recovered. Although this system has provided many valuable datasets the recent demands of state of the art modelling require a more targeted set of data. Scientific institutions around the world are now examining the possibility of using emerging technologies to remotely monitor the environment.

In particular the Monterey Ocean Observing System (Graybeal, et al. 2003), Moorea LTER (Schmitt, et al. 2004) and Taiwan's EcoGrid (Lin 2004) are examples of sensor network implementations in marine environments. The most advanced is the network implemented by Monterey Bay Aquarium Research Institute where extensive undersea cabling has enabled sophisticated autonomous underwater vehicles to combine with stationary observing platforms (Graybeal, et al. 2003). Despite these advances the deployment of sensors on a scale of the GBR or even just the reefs off Townsville remains a significant challenge. AIMS lacks the expertise to develop such sophisticated sensor networks however collaborations with national and international institutions can leverage the extensive infrastructure on the iconic GBR.

Formed from a meeting at Scripps Institute of Oceanography in 2005 the Coral Reef Environmental Observing Network (CREON) involves active members from around the world (see www.lakemetabolism.org). The focal activity of the group is to develop four pilot sensor networks at the coral reefs located at Taiwan, Moorea, Florida Keys and GBR. When the technical obstacles for these sites are overcome, we intend on making available the expertise and technology available cheaply to interested organisations around the world.

What is meant by the term 'sensor network'? This particular term is used to describe the latest trend in electronic monitoring. In previous designs the sensor simply recorded the information ready for downloading. In some cases the downloading is instantaneous and another system handles the storage. With 'smart' sensors it becomes possible to program or control them to alter their sampling and measuring characteristics based on a pre-set condition (such as a temperature threshold or event detection), on what other sensors are doing (such as upstream sensors) and from the central land based control system. This allows them to be both reactive and pro-active to best measure and record events of interest. The emerging technologies of wireless networking, compact but fast digital processors, solar and wind power generation and extended data storage across the internet have facilitated an approach previously only described in science fiction novels.

In a sensor network, each sensor contains a small computer that 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 and broadcast into the network, typically via wireless transmission. This means that if the sensor is unable to directly contact the target computer the data can be rerouted to the target via other sensors (ad hoc network establishment). The network of sensors can be deployed at varying scales allowing an integrated mix of widely dispersed sensors for large scale processes and small scale sensors for smaller processes. For example it becomes possible to fully integrate sensors measuring kilometre scale temperature patterns with a smaller network of sensors around a single coral colony.

With an array of sensors in the field the additional data storage and interpretation requirements increase considerably (Graybeal, et al. 2003). Development of middleware such as Storage Resource Broker (http://www.sdsc.edu/dice/SRB/index.html), which broker access to heterogenous databases, enable researchers around the world to utilise the data collected and are critical in supporting collaboration. Automatic real-time spatial analysis optimises the capacity of the system to address environmental imperatives.

The emerging generation of 'smart' sensors opens up a range of opportunities for automated intelligent monitoring of marine and coastal systems by providing management critical information in real time. The development of aquatic sensor networks monitoring platforms in the GBR region will not only improve scientific understanding of environmental process, but also allow the verification of data acquired from other platforms, such as remote sensing satellites.

The challenge is to be able to collect the right data at appropriate spatial and temporal scales in a cost and time effective manner and deliver it in a format that can be used by management. Scientific data provided by new technologies often does not fit the needs or interest of managers and decision makers or they are not presented in a way that can be used in a management framework (Olsen, 2001). In this sense, a dynamic and adapative approach is required.

Adaptive Management (AM) provides a framework that enables communication and collaborative learning in the decision making process (Holling, 1978). AM is characterized as an iterative and flexible process for continually improving management policies and practices by learning from the outcomes of operational programs. By both perceiving management interventions as tools for learning and by enabling continuous feedback between availability of scientific data and policy requirements, AM represents an effective interface to manage water quality and ecosystem health in the GBR system.

This paper describes the proposed transition from the existing automated systems to a sensor network for the GBR.

Method

Implementing a sensor network is not yet at the plug-and-work stage and considerable development is required to align all the components in to a functioning system. We intend on installing a pilot system that will fit into the existing environmental monitoring structure with minimal disruption. The existing real-time environmental monitoring system comprises of an array of sensor instruments feeding into central processing units that transmit back to AIMS and display directly via the web.

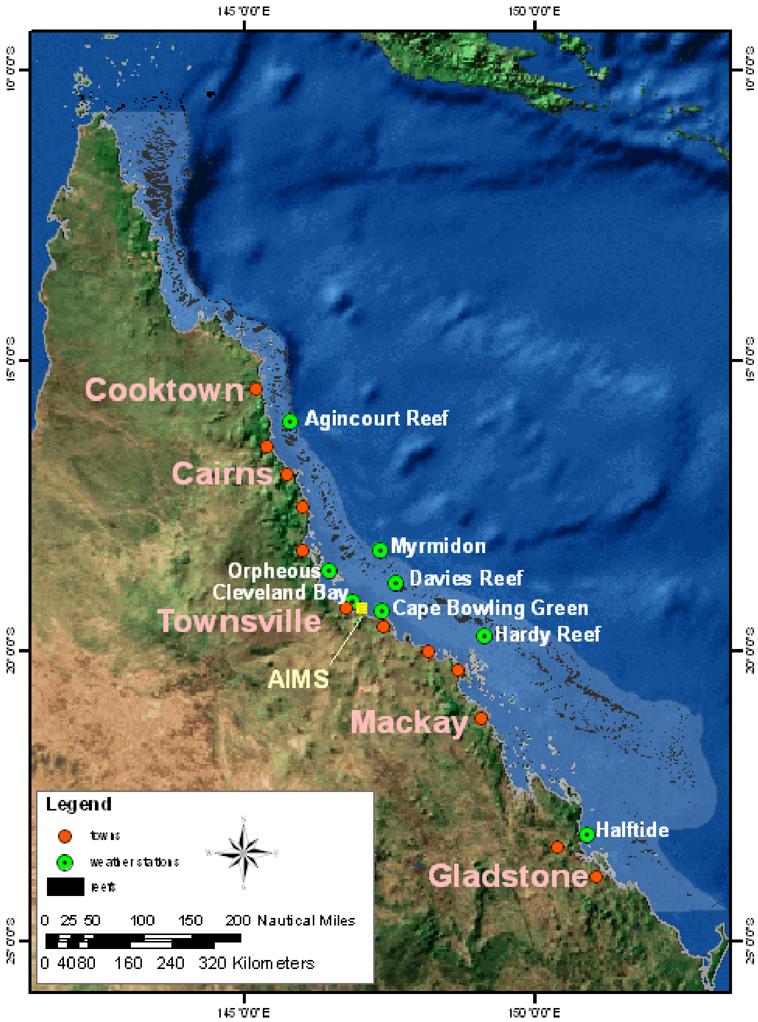

Figure 1. Map of weather stations operated by AIMS in the GBR

The sensor network being constructed will focus on three sites; Davies Reef located 70 nautical miles from AIMS, Magnetic Island and Heron Island. Davies Reef is approximately 7 by 3 kilometres and has a new weather station that was erected in October 2005 to replace the existing structure (figure 2).

Figure 2. The old Davies Reef Weather station

The considerable distance between Davies reef and AIMS (78km) demands some novel engineering to get the data ashore. The existing HF radio while economical lacks the bandwidth that sensor networks require. An alternative method involves the use of a 10.4 GHz microwave radio link that employs humidity ducts in the first few metres above the ocean (figure 3) to act as a waveguide and wrap the radio waves across the ocean surface (Kerans, et al. 2002a, Kerans, et al. 2002b). An experimental link deployed in December 2004 showed the viability of this approach. The graph in Figure 4 shows measured amplitude readings on the 21-22nd December 2004 indicating an acceptable signal level over the test period.
Concurrently, we are developing wireless sensors that contain an array of measuring devices deployed at a variety of depths (figure 4). To complement the increased data complexity and volume of data that will be collected, the data storage structures have been upgraded to implement both the object ring buffer (ORB) and the storage resource broker (SRB) software deployed by ROADnet (Withers, Meentemeyer 1999).

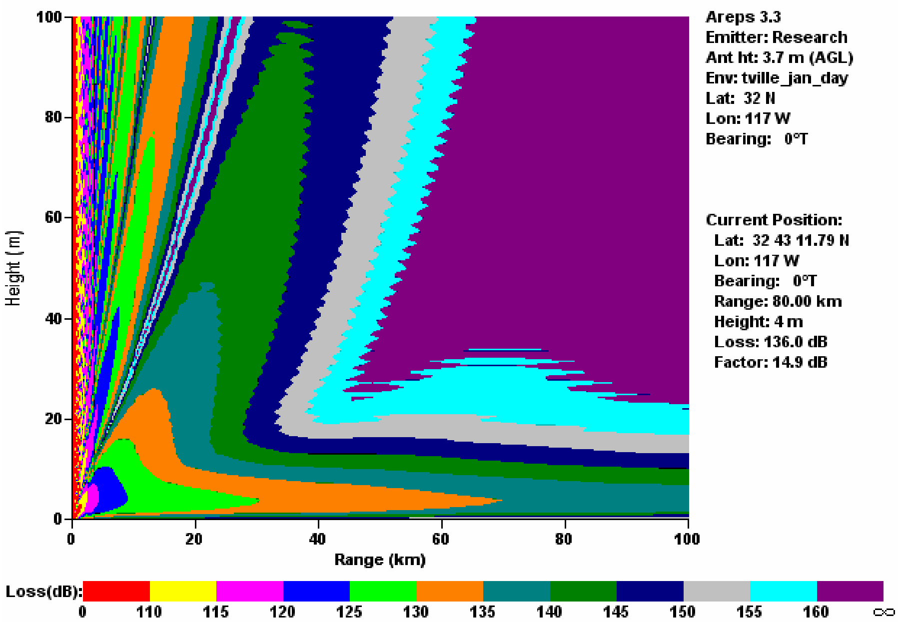

Figure 3. Transmission propagation for 10.4 Ghz microwave link showing how the waves at low height are able to travel long distances with acceptable loss.

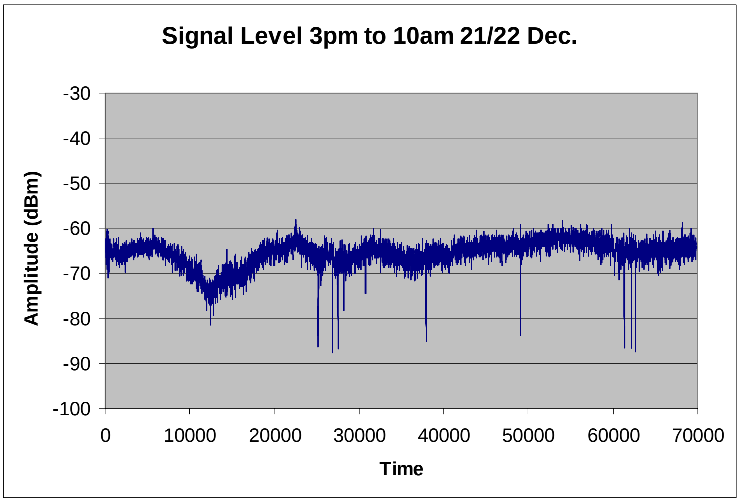

Figure 4 . Received signal Amplitude of IF signal versus time.

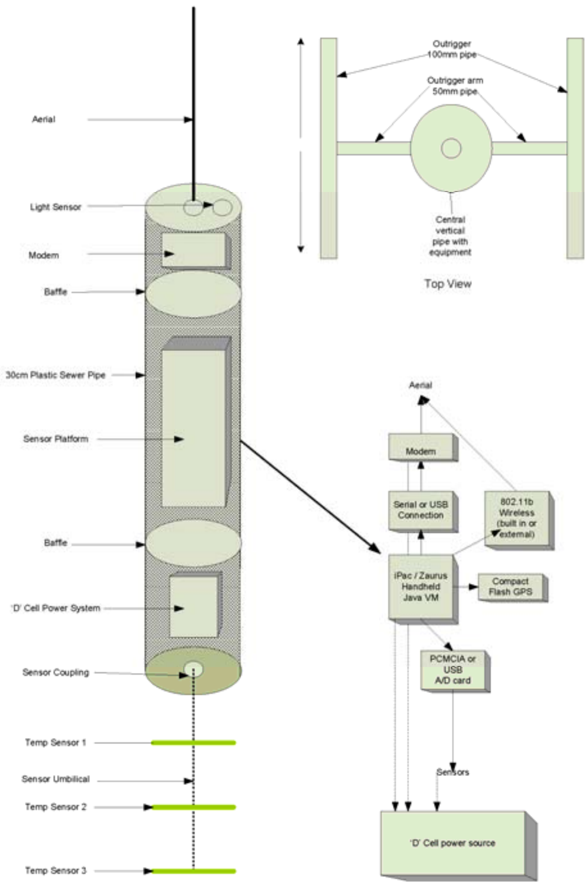

Figure 4. Schematic of a possible sensor design

The data will arrive at AIMS as an IP stream to a Sun server and then into our existing database (Oracle 10g which is grid enabled). A series of mathematical models (running on the grid enabled software) will then forecast future trends and produce a simple index of the likelihood of coral bleaching taking place (which is related to time above a set temperature stress point) (Hoegh-Guldberg 1999). This index will then be made available to key researchers at the Great Barrier Reef Marine Park

Authority, AIMS and the general public. We will develop grid based visualisation software systems to visualise the results of the models and of the historical data, allowing for trends and patterns within the data to be seen. The goal being to determine the environmental response by the corals to the physical processes and the temperature changes. Hind casting will then be used to fine-tune the models in real time to generate improved predictions.

Challenges ahead

There are still many challenges to overcome to achieve our objectives. A short list includes the following:

- Combating marine fouling so that maintenance costs are minimised is perhaps the most difficult of challenges. Copper enhanced housings for the sensors would appear to be a solution with a cleaning time of 6 months being potentially possible.
- With the cost of diving prohibiting extensive exposure to the reef the opportunities that are presented by streaming video are enticing. If this video can be made available to the public via a web site then many educational and promotional packages can be developed. Additionally, the potential for using camera arrays to provide 3D-tracking data for behaviour monitoring in small areas (2x2x2 metres) is being explored.
- Exploring the variety of data transmission media available. While we are starting with a microwave based system other technologies include: CDMA-X1 mobile phone data networks, acoustic modems for under water signalling and satellite direct and satellite phone networks. As well as the transport layer, there is work to be done in developing network protocols that are better suited to sensor networks. In particular 'ad hoc' networks require rapid protocol negotiation, efficient transport and routing independence.
- Maintaining power supply to the sensor network via solar and wind generation. While the extra power consumption for the sensor network will be minimised the application of wind generators will be necessary to boost the solar capacity. An underlying engineering restriction is the wind loading that solar panels create.
- Optimising the technical collaborations that presently exist around the world will require money and time. High profile products that can be used for marketing will be sought to maintain these collaborations. There is probably no other project that demands inter-disciplinary contribution like sensor networks. A 'basic' team is comprised of ecologists, web designers, electronic engineers, information technologists, database engineers, spatial modellers and chemists.
- Aligning the development of new technologies to the demand of scientists and marine managers will require additional consultation and understanding. To address this specific issue we are researching the adaptive management framework required to implement a high technology monitoring system.

Discussion

Understanding the processes that impact reefs, such as temperature, requires high quality data at a range of spatial scales on a regular basis. Autonomous smart sensor based systems provide one way to obtain this data from the scale of oceans to the scale of individual corals. The development of a suite of technologies to deliver a robust, simple but effective technology platform to support sensor webs has become a high priority for a number of marine and environmental agencies. This project looks to take this goal forward for the Great Barrier Reef using the existing AIMS weather station infra-structure as its base and extending this using a number of technologies and a number of partners. In particular the CREON collaboration will enable us to gather the expertise from all the participating organisations. Only in this way can a cost effective system be made available for marine scientists around the world.

Some of the technical obstacles are similar for any marine based monitoring system and mainly revolve around fouling, powering equipment and the general problems of maintaining equipment in a remote and hostile (at least to electronics) environment.

There are, however, a number of new challenges that need to be addressed. This include being able to store and deal with the large amounts of data that the system will generate (which may include video feeds), the integration of the data into modelling and visualisation systems and the ability to manage and maintain a system that is inherently more complex than the simple passive systems deployed currently. Individually most of these issues have been addressed by other groups, and so the goal of this project is to combine collaborations in order to implement a system that will deliver knowledge level products to help understand and manage the Great Barrier Reef system. We hope our efforts will create a valuable technology knowledge base for the further deployment of reef monitoring systems in remote environment.

Clearly there are many advantages to sensor network arrays. The capacity to constantly ‘ping’ a sensor and ensure it is functioning within calibration in real time overcomes many of the reliability problems that conventional data logged sensors are burdened with. Additionally, the prospect emerges of introducing sensors that are responsive to their environment. For example, a multi-sensors array that only sample at times when their results are required, remaining dormant and saving power until their data will be of value. This type of interactive sensor array is particular appealing when monitoring dynamic, near shore and estuarine environments.

Another concern is the cost of sensor networks. While the individual elements are not expensive, systems of this type will realise their true potential if they are replicated in large numbers. We are as far as possible employing off the shelf or simple to fabricate hardware and software solutions. There is considerable potential to reduce the costs and even consider mass production of the component sensors.

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