Smart sensors – a new paradigm for marine management: an example from the Great Barrier Reef.

S. J. Bainbridge, D. Eggeling and G.W. Page
Australian Institute of Marine Science
PMB 3 MC, Townsville Qld 4810 Australia.

***Abstract* - The development and deployment of smart sensors represents a new opportunity for how we measure and monitor maine systems. The linking in of large amounts of real time data into modeling and visualization systems linked in turn to web based knowledge systems will deliver new ways of engaging and interacting with environmental data. One key component of this is allowing the user to decide how they will engage and what products they require and how they want the information to be delivered. The types of environmental futures envisaged by many marine scientists will require new approaches, new ideas and new technologies. The smart sensor systems currently being deployed on the Great Barrier Reef are a start to realizing this new paradigm for the management of marine systems.**

I. INTRODUCTION

The management of marine ecosystems in the face of a range of stresses, including predicted climate change, has become one of the major challenges for marine science [1].

To manage you need to monitor or measure. For marine systems this traditionally has meant using a number of separate approaches such as monitoring programs using field personnel (such as the Great Barrier Reef Long Term Monitoring Project [2] or the Long Term Ecological Research Network (LTER) program [3]), base line monitoring using sensors such as remote sensing, oceanographic moorings and field stations [4] and targeted studies [5]. Each of these components has their strengths and weaknesses but each by themselves does not represent a complete monitoring system with often poor integration between the components.

Sensor networks or smart sampling combine parts of each of these approaches but importantly links this into a knowledge infrastructure (so called 'knowledge fabric') which in turn allows for a new range of outcomes and responses. This linkage, between in-situ systems and back end information and knowledge systems represents a new paradigm for marine monitoring.

II. SENSOR NETWORK COMPONENTS

A series of sensor networks are currently being deployed on the Great Barrier Reef under a broader Facility for the Automated Intelligent Monitoring of Marine Systems (FAIMMS) which is part of the Great Barrier Reef Ocean Observing System (GBROOS) which in turn is a geographic node of the Australian Integrated Marine Observing System or IMOS project [6].

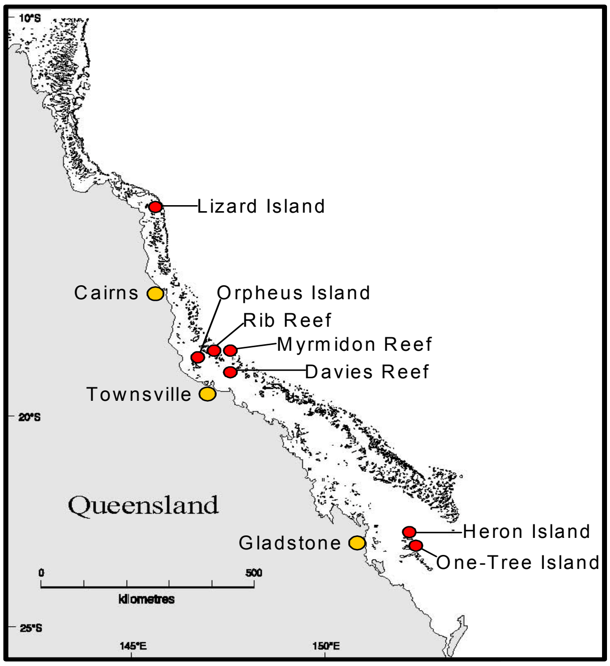

Figure One. Location of the sensor network sites.

The FAIMMS / GBROOS project has installed sensor networks at four locations along the Great Barrier Reef (GBR) with another three to be completed by mid 2010. This will give installations at Heron and One Tree Islands in the south through to Orpheus Island, Davies, Rib and Myrmidon Reefs in the central Great Barrier Reef (GBR) to Lizard Island in the north (Fig. 1). Data flows from each site in real time using a range of communication systems including 3G phone systems, line of sight microwave links and a novel 'over the horizon' surface ducted microwave [7]. These systems deliver two-way megabit per second speed IP based links to locations more than 70 kilometres off shore.

At each site an above water wireless network is created into which wireless sensors are deployed using buoys or small towers. The sensors are deployed on the buoys or towers connected using smart controllers. The controllers register with the network and push a small SensorML [11] packet back to a central data centre which registers the sensor with the central database, enables data retrieval, configures the monitoring system and automatically generates a metadata record for the sensors attached to the controller. An example deployment from One Tree Island is shown in Fig. Two.

978-1-4244-5222-4/10/$26.00 ©2010 CROWN

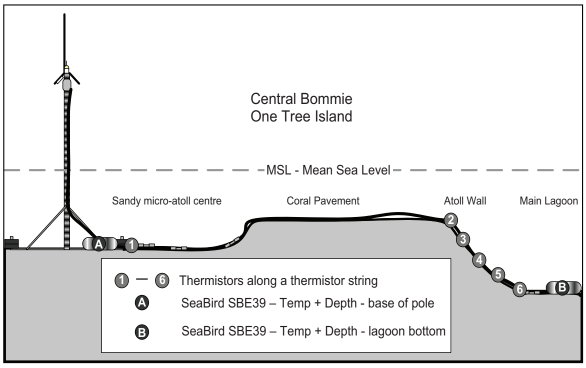

Figure Two. Sensor deployment diagram for One Tree Island.

Traditional 'dumb' oceanographic sensors and instruments (such as SeaBird SBE39's and SBE37's, Nortek ADCP's, LI-COR light sensors and Vaisala weather stations) are used coupled with smart controllers to provide real-time two way communications for data retrieval, health monitoring and to allow the sensors to be re-programmed remotely either through pushing updates or through automatic 'smart' event driven adaptive updates.

The system is unique in mixing 'smart' controllers and traditional oceanographic sensors giving data that has the required robustness with the new set of capabilities that the smart controllers and high speed two-way communications bring. The system has recorded events such as tropical cyclone 'Hamish' which passed Heron and One Tree Islands in March 2009, the warming of the GBR in the lead up to the 2009/10 summer as well as small scale circulation patterns with the lagoons of the reefs. As of early 2010 some 7.4 million observations have been recorded from over 160 data streams from the operational sites.

III. WHY REAL TIME MATTERS

Part of the design for sensor networks is the ability to collect data in real time. This not only gives information about processes and events as they occur but provides data for input into predictive models to improve the accuracy of forecasting. Products such as the NOAA Coral Reef Watch bleaching forecasts [8] are using the FAIMMS real time data to seed models of potential coral bleaching,

The real time data also allows for adaptive sampling where, using a rules based system, the sampling regime (such as sampling rates, calibrations, which sensors are active and which are in sleep mode) can be altered to deliver an adaptive sampling capacity. For example battery life can be extended by decreasing sampling rates during times when the data is less interesting or short term events can be sampled by increasing sampling. This allows the infrastructure to be 'tuned' to better capture events of interest.

The infrastructure also support high data rate sensors such as video and audio that can provide additional types of data. There are a number of applications where real-time video data is of interest from simple monitoring to the management of human activities such as fishing. Audio information can give passive records of particular species or, via active tags, fine scale information on individual species movements.

The final aim is to link the real time data with an event detection system to enable events of interest to be detected in the data streams. This would allow a manager to input the set of conditions that are of interest and then only be alerted when the conditions are met. This could be events such as upwelling, periods of high temperature and high light, low salinity events that are associated with floods and so on. By linking into event detection systems managers are able to identify periods or events of interest from the masses of data being collected.

The real time data also acts to focus additional studies. If the real time data shows potential bleaching conditions then it becomes possible to undertake detailed studies to investigate the biochemical responses of organisms to the conditions.

Figure Three shows real time data from Heron and One Tree Islands with a characteristic 'saw-tooth' pattern of temperature rise and fall in the lagoons of these reefs

IV. DATA MANAGEMENT

The collection and management of large amounts of real-time data has its own issues. The first issue is that of quality control. Traditionally logged data is subjected to intensive quality control and correction before being released often months after the data was collected. Real time data does not allow this luxury, the data needs to be released as soon as possible so only limited quality control is possible. The project is dealing with this issue by releasing a number of data products including the 'raw' real time data and a delayed mode processed product.

The Quality Control framework is based on a series of levels. Level-0 is the raw data as it comes from the instruments, Level-1 leaves the data intact but implements a series of simple range checks and other automated tests to identify data that is missing (no value collected), wrong (values are illegal) or illogical (values do not make sense). The data is again unaltered but flagged using the IOC/IODE quality control flags [9]. Importantly Level-1 does not alter the data; it just flags it as good or otherwise.

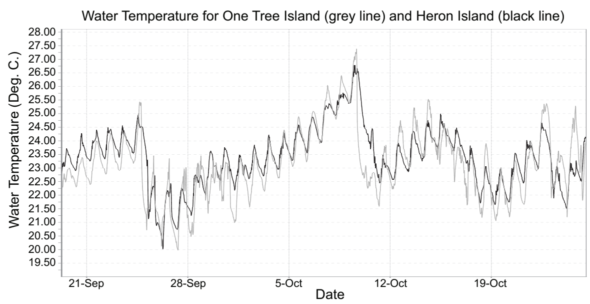

Figure Three. Temperature from late September to October 2008 from Heron Island (black line) and One Tree Island (gray line) showing a 'saw-tooth' pattern in temperature.

Above Level-1 are various processed data products which typically do involve altering or processing the raw data into more usable products. Typical processing includes de-trending to correct for sensor drift and calibration changes, interpolating to fill in missing values and adjusting against other sensors if these are available.

The data are stored in a relational database within a database schema that includes the data itself, the quality control information, deployment data, instrument, calibration and service history data as well as access rights and project level details. Metadata is provided to the level of each sensor in ISO-19115 format [10], instrument level metadata is provided as a SensorML record [11].

V. DATA EXCHANGE AND ACCESS

The project is adopting the Open GIS Consortium (OGC) Sensor Web Enablement (SWE) [12] set of protocols to give access to the data. The data is also made available via a Ocean Data Portal being developed as part of the IMOS project [13] which combines metadata searching with data presentation in a web environment.

Another form of access is provided using the Data Turbine middleware software [14] which in turn provides access to a number of users either through dedicated Data Turbine clients or through integration into other Data Turbine servers. This latter approach is being used to deliver data into the Coral Reef Environmental Observatory Network (CREON) project that is integrating data from a number of coral reef sensor networks into a single data platform[15].

The data is also fed into a sensor data 'broker' system called Pachube [16]. The Pachube system beings together data providers and data users, data is fed into the infrastructure as a series of data feeds which can then be combined into new data products. All of the data is free to use and so totally new data products can be made from the 'Lego' blocks of the services that are fed into the system. One delivery mechanism for these outputs is an iPhone application called 'PachubeMon' and the data from the project is currently available via this application.

VI. PARADIGMS

Do the type of capabilities that sensor networks provide really constitute a new paradigm for marine monitoring and management? It does in one significant way; it links many of the disparate monitoring activities into a single system and then links this into the 'knowledge fabric' that more and more underlies our lives. The linkage of the real time multi-variant data into mainstream information systems is the paradigm shift in that it allows for targeted information and knowledge products to be developed by the users somewhat independently of the data collectors. While this carries some risk it represents a new way that people can engage with, interact with, and work to preserve marine environments.

At the sensor end we now have high speed IP based two way communication with the deployed devices. This allows for high data rate sensors such as video, audio and intensive samplers such as Acoustic Doppler Current Profilers (ADCP's) and high precision wave recorders. It also allows for the instruments to be fully controlled remotely using standard IP based tools (such as terminal sessions and remote desktop tools) allowing for sophisticated instrumentation to be deployed and remotely operated and controlled. Finally it allows for these systems to be monitored as to their availability and health (such as battery life) so that they can be serviced and maintained as required. All of this is done using standard computing equipment and infrastructure.

At the user end the data is available using the myriad of ways that users choose to view and interact with information. This could be via smart phones, via the internet or via value added services that they receive via other channels such as television, SMS or Instant Messaging (IM). What is new is that the user can choose how they wish to interact with the system - at what level, at what frequency and by what channel.

The final component is the realization that the future internet will not be about connecting people but about connecting devices and computers. This so called 'Internet of Things' (IoT) [17], as exampled by the Pachube system [16], allows data sources and users to be easily mixed and for a level of 'intelligence' to be applied to the data collected.

The vision is that people will engage with the data much as people now do with weather data either as raw information about how warm or wet it is or as processed products such as forecasts and seasonal trends.

VII. CONCLUSION

The development and deployment of smart sensors for the monitoring of marine environments, by linking the environmental data with the developing knowledge fabric that includes the Web 2.0, smart phones and other media, has the potential to deliver a new way that marine systems are managed. The linking of real time data, modeling and visualization systems and user based event detection systems delivers a powerful set of tools for managers. In the same way GIS promised new understandings so the new information infrastructure offers completely new ways of viewing, engaging and interacting with data with the promise that, in so doing, it will deliver new understandings and subsequently new environmental outcomes.

The FAIMMS Sensor Network project shows some of this future with a range of real time data coming in from a series of sites along the Great Barrier Reef. The infrastructure is open to any interested party with a plug and play design dramatically lowering the cost of deploying instrumentation. The data management and access systems being built look to hook into the knowledge fabric with event detection and visualization systems under construction.

The vision of a 'digital skin' that lies over ecosystems and which records and monitors them is no longer science fiction but one that is coming into reality. The FAIMMS project, along with a number around the world, is looking to develop these ideas into operational systems that provide a new set of data and knowledge about how these systems operate and how they respond to changes, both natural and human induced. As the world becomes increasingly impacted by change they will form an essential component to how we monitor and measure and, through this, how we manage these systems.

Acknowledgment

The GBROOS Project and the FAIMMS Facility are part of the Australian Integrated Marine Observing System (IMOS) project and are funded by the Queensland State Government and the Australian Federal Government through the National Collaborative Research Infrastructure Strategy (NCRIS). The authors also acknowledge the help of the Tropical Marine Network (TMN) that co-ordinates the island research stations along the Great Barrier Reef as well as the staff on the AIMS research vessels and the AIMS workshops.

References

[1] Johnson JE, Marshall PA (eds) *Climate Change and the Great Barrier Reef. A Vulnerability Assessment*. Great Barrier Reef Marine Park Authority and Australian Greenhouse Office, Australia, pp 51-74. 2006.

[2] AIMS 2010 *AIMS Long Term Monitoring Program (LTMP)* http://www.aims.gov.au/docs/research/monitoring/reef/reef-monitoring.html

[3] LTER 2010. *Long Term Ecological Research (LTER) Network* http://www.lternet.edu/

[4] NOAA 2010. *NOAA Coral Reef Watch* http://coralreefwatch.noaa.gov/satellite/index.html

[5] GBRMPA 2010. *Reef Water Quality Protection Plan* http://www.reefplan.qld.gov.au/

[6] IMOS 2010. *Australia's Integrated Marine Observing System* http://www.imos.org.au

[7] Palazzi C, Woods G, Atkinson I, Kininmonth S *High speed over ocean radio link to Great Barrier Reef.* Tencon 2005-2005 IEEE Region 10, Melbourne, Australia, 21-24 November 2005.

[8] NOAA 2010. *NOAA Coral Reef Watch* http://coralreefwatch.noaa.gov/satellite/baa/index.html

[9] UNESCO/IOC/IODE & MAST, 1993. *Manual of Quality Control Procedures for validation of Oceanographic Data* - UNESCO Manuals and Guides 26

[10] ISO, 2003. *Geographic Information – metadata*. http://www.iso.org/iso/iso_catalogue/catalogue_tc/catalogue_detail.htm?csnumber=26020

[11] OGC, 2010. *OpenGIS Sensor Model Language (SensorML)* http://www.opengeospatial.org/standards/sensorml

[12] OGC, 2010. *Sensor Web Enablement Working Group.* http://www.opengeospatial.org/projects/groups/sensorweb

[13] IMOS 2010. *IMOS Ocean Portal* http://imos.aodn.org.au/webportal/

[14] DataTurbine, 2010. *Data Turbine*. http://www.dataturbine.org/

[15] CREON 2010. *Coral Reef Environmental Observatory Network* http://www.coralreefeon.org/

[16] Pachube 2010. *Pachube* http://www.pachube.com/

[17] Wikipedia 2010. *Internet of Things* http://en.wikipedia.org/wiki/Internet_of_Things