Reviews & Papers

From the Technical Editor

By the end of September 2010, followers of high performance sailing will have heard what has been decided for the 34th America's Cup. This event has always been an interesting mix of technology, funding and rules since it was initiated in 1851, when the American yacht did the proverbial horizon job on the best that the British Yachting establishment of the time had to offer. From then until 1983, the Americans held on to the Cup by either skill and superior technology or clever interpretation of the rules, depending on which side you were on.

My closest encounter with the America's Cup was in 1983, the last year that the Cup was held in Newport, Rhode Island. It was impressive to see the stately 12 metre class yachts in and out of the water. That was the year when Australia II beat the Americans with the revolutionary 'winged keel.' It was a clever adaptation of hydrodynamic technology to a class of yacht with a measurement rule originally written in 1907. The rule gave designers a chance to introduce new technology for hull shape, construction materials, sails and rigging, while allowing yachts to compete on a level playing field. The purpose of the 12 metre rule was to allow scope for performance trade-offs and technology development, while on the other hand preventing sudden (and expensive) changes making older boats obsolete.

In 1958, 12 metres class yachts were picked as a way of reviving the America's Cup after the Second World War, when even the very rich could not afford to race the magnificent J Class yachts of the pre-war era.

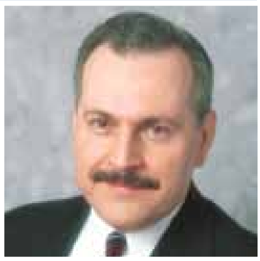
This remained the case until 1992, when the America's Cup Class was introduced. These boats were bigger and lighter and as a result much faster than the 12 metre class, but also much more expensive. The new America's Cup Class was a no holds barred return to the large budgets and glamour, suitable for an event such as the America's Cup.

There have been two notable incidents when the Cup has flirted with multi-hull yachts. The first was in 1988 when Dennis Connor's catamaran beat a New Zealand challenge sailing a 90 foot long mono-hull. The latest was the 33rd America's Cup in 2009 where both teams used multi-hulls. With the 33rd Cup over, we can now look forward to the 34th and the opportunity for a new America's Cup Class, which should represent the pinnacle of sailing technology, which of course comes with a very big budgets and the need for very rich sailors. Plus ca change…

Dr. David Molyneux
Technical Editor

A far smarter bay

P.J. Gaughan



H.R. Kolar

Gaughan and Kolar describe efforts to develop an information system for marine and coastal monitoring in Galway Bay, Ireland.

Who should read this paper?

The SmartBay Galway project is an example of how a foundational cyberinfrastructure for the marine environment can be designed and implemented to act as a focal point for research and development into technologies that can be applied to monitoring and analysis. The paper will be of interest to ocean energy developers, aquaculturists, technologists, and those interested in sensor research and development and its applications in the marine environment. Government agencies and groups tasked with the implementation of environmental monitoring regulations in the oceans and the coastal zones should also read this paper.

Why is it important?

The implementation of SmartBay Galway on the west coast of Ireland provides the ocean community with a highly integrated cyberinfrastructure to perform research and development of environmental monitoring technologies as well as a functioning coastal observatory providing data about the marine environment to a broad range of users in the bay area. The advanced analytical and visualization technologies being applied to the marine datasets will make the analysis and interpretation of the huge amounts of data collected easier, more intelligent, and faster. At the core of the system is a real time sensor data warehouse that supports multi-parameter and multi-scale sensor feeds

To date the SmartBay project has seen the deployment of a number of environmental sentinel platforms and the integration of existing sensors and information sources into a data and information environment with an innovative human interface with advanced visualization capabilities supporting multidisciplinary users. This has been done to a large part through use of technologies developed for monitoring in the industrial sector and applying these to the marine environment.

About the authors

Paul J. Gaughan is the Project Coordinator for SmartBay Galway and has worked at the Irish Marine Institute since 2002. Paul received his MSc in Applied Geophysics from the National University of Ireland in 1993 and subsequently worked in the offshore oil industry for 5 years. He is particularly interested in advanced visualization of marine data sets.

Harry R. Kolar is a Distinguished Engineer in IBM Research and is the lead information technology architect for the SmartBay Galway project. He holds a BS and MS in Physics and a PhD in the Science and Engineering of Materials and is currently focused on distributed intelligent cyberinfrastructures for environmental applications. He is an Adjunct Professor of Physics at Arizona State University in the US.

IMPLEMENTING A SMARTBAY ON THE WEST COAST OF IRELAND

P.J. Gaughan[1] and H.R. Kolar[2]

[1] *The Marine Institute of Ireland, Rinville, Oranmore, Co. Galway, Ireland*
www.marine.ie

[2] *IBM Corporation, Yorktown Heights, NY, USA*
www.ibm.com/green/water

ABSTRACT

The aim of SmartBay Galway is the development of a strategically positioned marine research platform, with a reputation for the development of leading-edge technologies for global markets and for the development of innovative solutions to address important environmental issues. The SmartBay project has seen the deployment of a number of environmental sentinel platforms and the integration of existing sensors and information sources into a data and information environment with an innovative human interface with advanced visualization capabilities supporting multidisciplinary users. SmartBay Galway has, at its core, a real time sensor data warehouse that supports multiparameter and multiscale sensor feeds. One of the key goals of the project is to mobilize research skills and expertise based in Ireland in fields such as microelectronics, sensors, advanced materials, and communications involving scientists, technologists, and the corporate sector. The innovative aspects of the project are broad in that a robust open, yet flexible, foundational infrastructure has been demonstrated which can quickly adapt to support new projects, sensors, input data streams, and users, providing numerous benefits to a diverse research community.

INTRODUCTION

Water resource management (the activity of planning, developing, distributing, and optimizing the use of water resources), renewable energy development, and climate change mitigation are some of the key global issues facing the planet over the next generation. Ireland's location, at the eastern end of the Gulf Stream and the southernmost temperature limits of many commercially important fishery species such as salmon and cod, coupled with one of the world's best wave energy resources, makes Ireland an ideal observatory and natural laboratory for the development and testing of the advanced marine technologies of tomorrow. The SmartBay project reflects an exciting intersection between knowledge, technology, and the ocean: it offers Ireland a major niche and competitive opportunity in the global market for smart technologies.

BACKGROUND ON THE MARINE INSTITUTE AND SMARTBAY

The Irish Marine Institute (MI) is a state body with a national remit to coordinate, undertake, promote, and assist marine research and development that will promote economic development, create employment, and protect the marine environment. The

Irish Marine Institute is an internationally respected science body with almost 250 staff (including scientists, IT specialists, and technicians) and a €50M state-of-the-art headquarters with 54 laboratories on the shore of Galway Bay. The Technical Support Base in Galway is an operational facility to support specialist research infrastructure of relevance to SmartBay including a remotely operated vehicle, offshore buoys, tide gauges, and the national equipment pool. The Institute operates a wave energy test site in Galway Bay and two purpose-built research vessels: RV *Celtic Voyager* and RV *Celtic Explorer* (65 m and 31 m, respectively). Marine Institute research and development and monitoring programs include marine food safety, fish stock assessment, fish health, marine chemistry, aquaculture, climate change, climate scenario modeling, ocean modeling, deep sea research, seabed mapping, and oceanography. The Institute is an active partner in a number of international ocean observing initiatives, including the European Multidisciplinary Seafloor Observatory, and the European Seafloor Observatory Network, and has a number of collaborative research agreements in place with prominent international research groups in the area of ocean observation.

The background to SmartBay lies in the long-standing mission of the Irish Marine Institute to develop new commercial activities to realize the full potential of Ireland's marine resources/sector, which is tied to Ireland's 890,000 km^2 of underwater territory. In 2004 the Institute initiated a linked suite of research and capacity-building projects in the field of advanced marine/environmental technologies. These sought to build upon research skills and expertise that had been developed in Ireland in fields such as microelectronics, sensors, materials, and communications. Initiatives such as SmartBay on Canada's east coast, a user driven ocean observing system driven by the specific information needs of the users of Placentia Bay, Newfoundland [Carter, 2008], have influenced the evolution of the SmartBay Galway concept.

From a scientific perspective, Ireland already has an internationally recognized capability in sensor and communications technologies, marine ecosystems, and environmental research. However, this capacity cannot be fully realized without the appropriate supporting infrastructure.

MULTISTAKEHOLDER ASPECTS

The SmartBay Galway initiative acts as a catalyst for integration of existing research capabilities and strengthening synergies at the institutional, regional, and national levels. SmartBay does not replicate institutional research efforts; rather, it acts as a vital focus for the integration of the multidisciplinary research effort that is needed to provide the next generation marine science and informatics services. It is at the interface of multidisciplinary research that new discoveries and innovations are most often found. The consequence of convergence is the creation of a portfolio of commercial opportunities that may include new products, devices, solutions,demonstration projects, software applications, or services.

Internal Marine Institute users include personnel involved with meeting legal water monitoring obligations at a national and international level and those working operationally in the area (e.g. research vessel support, seabed mapping support through the provision of local weather, water level information, etc.). External users and direct beneficiaries of the SmartBay system include local aquaculture, fishing and coastal industries, the general public, third level educational institutions, tourism, and municipal authorities.

DESCRIPTION OF THE PROJECT/ DEMONSTRATOR

The current SmartBay Galway infrastructure includes eight wireless sensor nodes at key locations around Galway Bay. The sensor nodes include three moored monitoring platforms containing an array of instrumentation and sensors, three tide gauges, and two wave monitoring buoys (Figure 1).

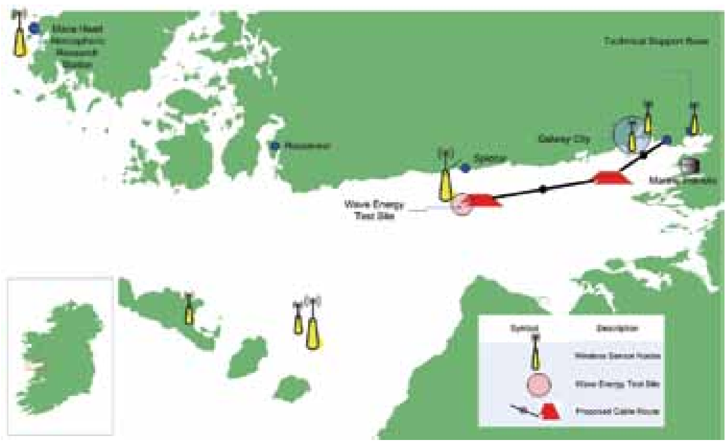


Figure 1: The SmartBay Galway infrastructure.

Data from the two wave monitoring buoys is transmitted via high frequency radio as a constant stream of three dimensional coordinates + time (x, y, z, t) for recording and display. The buoy outputs processed data of compressed wave spectra along with general housekeeping information plus data on buoy inclination, orientation, sea temperature, battery consumption/life remaining, and GPS Lat/Long position at regular intervals.

The SmartBay tide gauges transmit water level information along with weather parameters via GSM telemetry to a base station located at the Marine Institute where this information is processed. A flow gauge sensor is installed in the Corrib River to provide an indication of the volumes of freshwater entering the bay area.

The three SmartBay Sentinel buoys utilize the Mobilis DB8000 databuoy platform (Figure 2). Key design features of the platforms that influenced their selection include robust construction, modular design, interchangeable components, modular solar power systems, single, bridle, or multipoint moorings through the hull compartment, high stability in operation, and ease of transport.

Each Sentinel buoy consists of a 3 m diameter doughnut-shaped flotation collar in the centre of which is located a moon pool with a 0.9 m diameter pipe extending downwards to a water depth of approximately 2.3 m. Located at the bottom of the pipe is a retrievable frame which contains an assortment of water quality sensors. The flotation collar has a 2.6 m high octagonal shaped superstructure bolted to its deck. This superstructure has eight 16 W solar panels attached to supply the power, and internally there are batteries for power storage, a power monitoring and control system, a data acquisition system, and a wireless data transmission system.

The buoy telemetry system uses GPRS to transmit the collected data to the MI at regular

Figure 2: SmartBay Galway Sentinel buoy.

intervals and this data is processed and output as a text file. Data from the platforms is collected and stored in a database after being processed by the SmartBay data acquisition software developed in-house by the Marine Institute.

The platforms contain a combination of the following instrumentation and sensors:

- Meteorology array
- Acoustic Doppler Current Profiler (ADCP)
- Spectral harmonic wave sensor
- CO_2 sensor
- Coloured dissolved organic matter sensor
- Nitrate sensor
- Water sample carousel
- Moored conductivity, temperature, and depth sensors
- Water Quality Monitor: measuring temperature, depth, salinity, dissolved oxygen, chlorophyll fluorescence, and turbidity.

As part of the development of the SmartBay cyberinfrastructure, a web-based environmental monitoring portal was created to address the requirements to deliver a system that could present an integrated view of the bay while at the same time, distribute customized data sets for specific stakeholder groups. The system also had to be modular and flexible to cater to changing needs and to provide a foundation upon which expansion and enhancements could be built upon over time.

The portal demonstrator was developed using IBM WebSphere Portal technology (Figure 3), a software platform designed to help users access the information, applications, and people they need to productively manage their tasks by combining multiple features and capabilities in a unified environment. The portal hosts *portlets*, which are user interface components providing different functionality. With a rich, responsive user interface that includes Web 2.0 features, users can organize, manage, and share their content and encourage collaboration and innovation among employees, partners, customers, researchers, and the general public. The open standards-based software is interoperable with a wide range of technologies, allowing the Irish Marine Institute to maintain required security levels and support a service-oriented architecture approach. The portal software has a myriad of features designed to improve the end user's web navigation experience. Part of the challenge of designing the SmartBay web portal was targeting the features of the portal which could be developed and enhanced to improve the display of marine information for Galway Bay. To facilitate the multistakeholder aspects in relation to the visualization and dissemination of data collected as part of the SmartBay Galway infrastructure, direct consultations were held with the various stakeholders on what data and information they would like to see displayed.

The modular portal technology provides a number of services which are available to users and are easily configurable. The system assures consistent responsiveness to user requirements in that many of the components are directly accessible to users themselves. An example of such functionality is alarm services: all users can actively monitor changes in any sensor parameters within the system. Alarms

Figure 3: The SmartBay Galway portal.

may be set at any level and in an escalating manner to notify of trends and the alarms will be visible on the user's SmartBay system or can send notifications via e-mail or SMS (text messaging) to a mobile phone. Prior to this, monitoring was manual in that the user would need to access data (which was not available in real time) to monitor environmental variables.

Additional common services are also included in SmartBay such as multilayer mapping and bulletin boards. Mapping services show all sensors within the cyberinfrastructure, their exact geographic position, device characteristics (type, manufacturer, model, image, operational parameters), operational state, and current data values. Bulletin board services are available and provide operational updates as well as specific feeds from other Marine Institute applications such as harmful algal blooms alerts that are issued after detailed laboratory-based toxicology testing on shellfish samples. The bulletin board functions may be enabled by subscription for particular user groups and they also accept input from users via various methods such as direct via the SmartBay portal, e-mail, or by SMS/text message from mobile phones.

While the SmartBay portal provides a consistent user interface framework, it is supported by an additional layer of analytical technology (IBM Alphabox), which carries it beyond a conventional "dashboard" construct. Advanced analytics were developed that support the application of specific algorithms for marine applications and interfaces to specialized external systems and services. One example of this was the development of a floating hazard drift portlet, which was developed for commercial fisherman in conjunction with the Ireland-based forecasting company Nowcasting and U.S.-based Applied Science Associates. The pilot application allows commercial fisherman to report floating objects via a browser-based mapping interface on their onboard computers or via SMS/text messaging from their mobile phones. In less than one minute, a graphical 24-hour predicted path (with uncertainty) of the hazard based on forecasted sea and weather conditions is calculated and displayed in SmartBay. Met service forecasting interfaces also support a coastal flood monitoring application portlet for Galway Harbour.

The SmartBay Galway sensor data warehouse (IBM DB2 technology) is supported by sensor feeds that operate at various time scales (dependent on requirements) to handle the import and preprocessing of multiscale, multiparameter sensor data from various telemetry sources, a number of which have been mentioned previously (Figure 4). The warehouse utilizes the Marine Institute's metadata standards, which are critical to

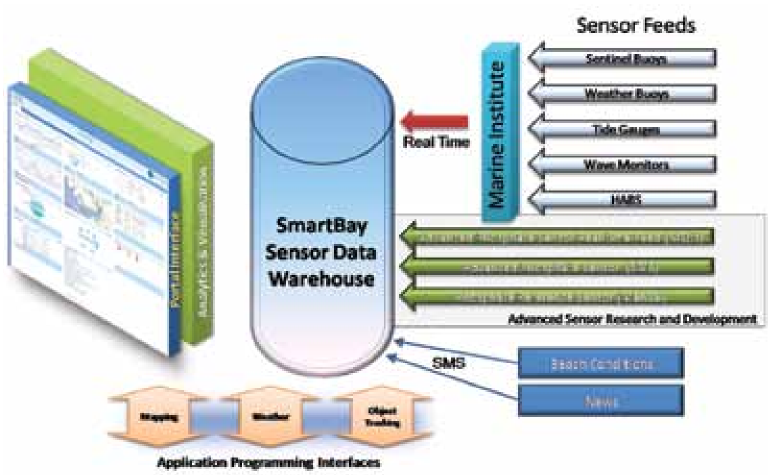


Figure 4: High-level system schematic of SmartBay Galway.

ensure maximum effectiveness of SmartBay in terms of integration and interoperability with other systems and subsystems both internal and external to the Marine Institute. Real time data access removes latencies that could delay alerts, response/corrective measures, or remediation (e.g. pollution events). Communications and integration are handled with standardized middleware including high integrity messaging services supported by an enterprise services bus architecture, able to extend to specific devices using the IBM WebSphere technology. SmartBay also makes use of a "Cloud Computing" model whereby computing resources such as processing, storage, networking, and applications are accessible as services through networks. Cloud environments provide a number of benefits in areas such as rapid deployment, scalability, and parallelism.

SmartBay was also designed to support the development and testing of advanced sensors such as those being developed by the National Centre for Sensor Research (NCSR) at Dublin City University [McGraw et al., 2007]. IBM middleware components provide an end-to-end high integrity environment for remote monitoring using two different telemetry methods. An embedded computing platform was designed for a NCSR prototype phosphate sensor which extends a common programming model to the actual sensor. This provides not only tighter integration, but also allows a uniform programming tool set to be used across the system. This end-to-end consistency ensures the same Java programming skills are applicable for the embedded platform as are used throughout the overall system. The embedded platform also adds new functionality in terms of remote device management using an embedded software stack hosted on IBM's J9 Java Virtual Machine platform on a Linux operating system. This has successfully demonstrated the applicability and value of an embedded Java environment in a true end-to-end solution for a sensor which monitors an important environmental pollutant. The platform also hosts agent technology for advanced functions using the open source Agent Factory originally developed by the PRISM Laboratory in the School of Computer Science and Informatics at University College Dublin [O'Hare et al., 1998].

Key benefits of the SmartBay web portal include:

- Data across various stakeholders/systems in the marine environment can be integrated to yield information to an extended stakeholder base for the most beneficial use of the environment.
- A consistent theme in the feedback gathered from consultations with the various different stakeholders was the value in presenting a broad range of marine related data on the same screen.
- The ability of the portal, with its large number of views of the marine environment, to aid a diverse set of users in their decision making processes.
- Novel environmental monitoring tool: the approach of integrating disparate datasets and presenting the data at different levels of detail to a broad range of stakeholders ranging from the recreational to the highly scientific is novel in a marine environmental monitoring context.
- The portal alarm functionality gives users the capability to react more quickly to events such as platforms moving off-station, high tides, flooding, and pollution events.

Thematic area	Key scientific and technological questions
Climate Variability and Ocean Circulation	• How much CO_2 is in solution in the ocean waters and can this be quantified as part of the global carbon cycle? • What are the implications of climate change on CO_2 levels in seawater?
Water Quality	• Do human activities have an impact on marine ecosystems? • Can technology support European Water Framework Directive monitoring requirements? • What conditions trigger harmful algal blooms in Galway Bay? • Can satellite information be used to "ground truth" *in situ* water quality measurements?
Modeling	• What are the marine processes that determine the transport of nutrients, plankton, and suspended sediment? • How can ocean modeling accuracy be improved and how are large regional ocean models affected by proximity to the coast?
Offshore Aquaculture	• Is offshore aquaculture a feasible option in Galway Bay? • What are the oceanographic conditions that a successful offshore aquaculture industry will need to withstand?
Ocean Energy	• How well are ocean energy prototype devices operating relative to the wave climate at the Ocean Energy Test Site in Galway Bay? • How can wave energy be harnessed to generate renewable electricity?
Technology Research and Development	• What issues are involved in transferring new sensor developments from the laboratory to field testing in the marine environment? • How can the analysis and interpretation of large marine datasets be aided by the development of real time analytics and advanced data visualization tools?

Table 1: Key scientific and technologicial questions that Smartbay Galway is helping to address.

- A user-friendly interface using state-of-the-art Web 2.0 technologies provides rich functionality and significant potential for integration into a range of education and outreach programs.
- It allows the Irish Marine Institute the capability to offer a user specific service to a broad range of different user groups without a large application development overhead. Previously, application development in house was carried out on a "per project" data basis with conflicts often arising between different user groups' requirements; the SmartBay Web Portal provides a flexible framework to support a diverse set of users and a rapid prototyping and development environment.

IMPORTANT ONGOING RESEARCH INITIATIVES ENABLED BY SMARTBAY GALWAY

Specific scientific research themes have been identified as key drivers for SmartBay Galway and are presented in Table 1. The deployed infrastructure has facilitated and enabled a number of research initiatives and developments related to these thematic areas. These initiatives have contributed in addressing some important scientific and technological questions directly linked to processes in Galway Bay as well as making a contribution to answering some of the larger global questions relating to our understanding of ocean processes.

MODELING AND FORECASTING

To understand the influence of human activities on the oceans, we must understand ocean physics, chemistry, geology, and biology interactions over local and global scales, and over long and continuous time periods. SmartBay Galway is collecting spatial and temporal data over a range of scales which are used by modelers to drive oceanographic models.

A hydrodynamic model has been created as part of the SmartBay Galway project for a domain that covers Galway Bay at a resolution of 200 m with 20 vertical levels. This enables the modeling team to model the temperature, salinity, currents, and tidal heights for Galway Bay in hindcast and forecast mode. The Regional Ocean Modeling System hydrodynamic model, a free-surface, hydrostatic, primitive equation ocean model is employed [Shchepetkin and McWilliams, 2005]. Bathymetry of the model domain is interpolated from high resolution datasets of multibeam and LIDAR data collected under the INFOMAR (INtegrated Mapping FOr the Sustainable Development of Ireland's MArine Resource) program. The model domain is embedded in an existing 2.5 km NE Atlantic model[1] so as to reflect fluctuations in the ocean climate. The model uses NCEP GFS[2] atmospheric forcing, and tidal forcing at the boundary is obtained using OTIS, the Oregon State University Tidal Data Inversion Software[3]. Included in the model also is discharge from the main freshwater source into Galway Bay: the Corrib River, a very significant driver for the hydrodynamics in Galway Bay. In particular, the freshwater plume exerts a major influence on the surface salinity and current structure in the inner bay and on the north shore.

REMOTE SENSING "GROUND-TRUTHING"

Changes in sea surface temperature of coastal waters can be used as an indicator of water quality. *In situ* sensors are increasingly being used as a mechanism to automate this process; however, these sensors are subject to harsh environmental conditions and are subject to possible failure or inaccurate data. They have limited spatial resolution as they are, in effect, single point sensors. Although a network of *in situ* sensors deployed in the SmartBay system can provide detailed information on a specific region such as Galway Bay, to obtain a more complete picture, satellite remote sensing can be used to provide improved spatial coverage at good temporal scales. However, *in situ* sensors have a richer temporal scale for a particular point of interest. Satellite sources can provide information on larger regions, but this is limited by factors such as cloud cover and frequency of overpass; therefore, a combination of these sensing mechanisms is beneficial for water quality monitoring.

Sea surface temperature data is available from a variety of satellite sensors: Advanced Along Track Scanning Radiometer (AATSR) [Llewellyn-Jones et al., 2001] and Advanced Very High Resolution Radiometer [Townshend, 1994] work carried out in Galway Bay by researchers on the west coast of Ireland has combined data from multiple satellite sources and *in situ* sensors and investigated the benefits

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1 www.marine.ie/home/services/operational/oceanography/OceanForecast.htm
2 www.nco.ncep.noaa.gov/pmb/nwprod/analysis/
3 www.coas.oregonstate.edu/research/po/research/tide/index.html

and drawbacks of using multiple sensing modalities for monitoring a coastal location.

CLIMATE VARIABILITY AND OCEAN CIRCULATION

The SmartBay monitoring platforms are also contributing to a climate change research program being undertaken by the Marine Institute and the School of Physics, National University of Ireland (NUI) Galway.

Carbon dioxide, when dissolved in water, produces carbonic acid. Seawater, which contains hundreds of chemicals acting together in a chemical "ecosystem" to create an ongoing balance between acidity and alkalinity, is buffered to withstand a certain amount of this gas. Indeed, the tiny plants living in the ocean rely on carbon dioxide and sunlight to produce life-giving oxygen.

Theoretically, if the oceans continue to absorb carbon dioxide at rates described for the past century, the elevated acidity of the seawater might affect the plankton communities and reduce their productivity.

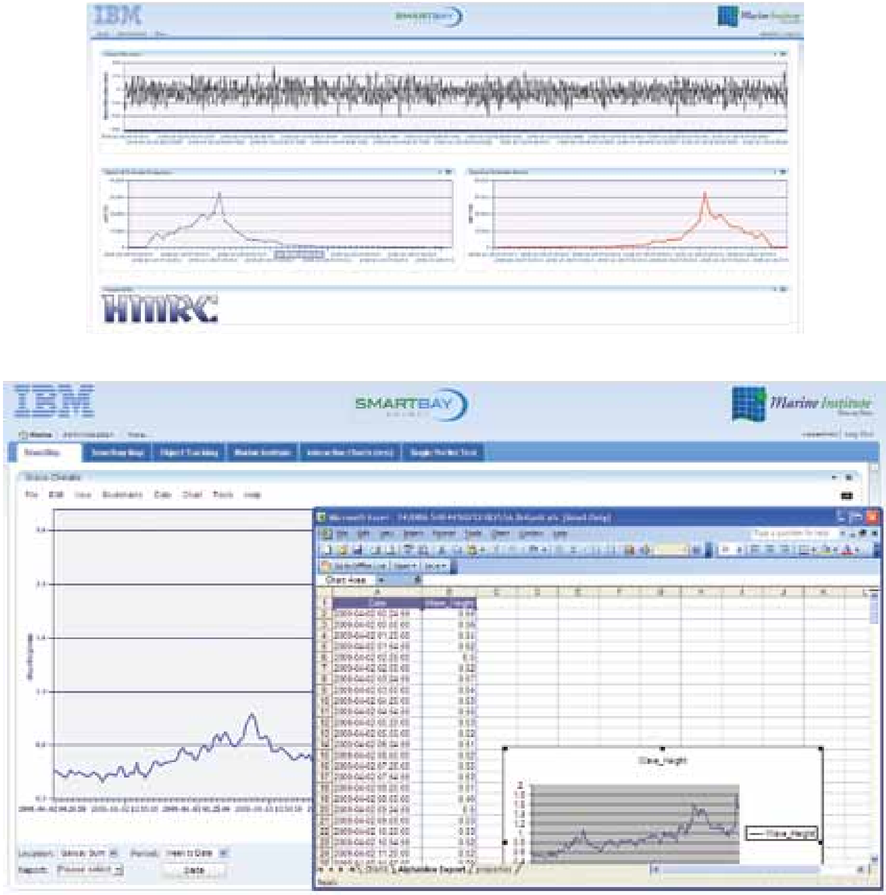
There are two components to the CO_2 program: the first is to quantify the flux of carbon dioxide between the atmosphere and the ocean and its impact on carbon dioxide concentrations in the sea; the second component is to quantify the impact of carbon dioxide concentrations in seawater on the carbonate chemistry system, total alkalinity, and ultimately, ocean acidification.

The flux study involves continuous measurements of carbon dioxide flux both at NUI Galway's land-based Mace Head Research Station on the west coast, supported by a Marine Institute SmartBay buoy moored a couple of kilometres offshore, and on board the research vessel RV *Celtic Explorer*. This program is initially enabling capacity within Ireland to conduct such studies and will provide a basis for longer-term assessment of changes in the carbonate system and the level of ocean acidification ultimately required to predict risk to marine ecosystems.

The Smart Bay platform at Mace Head has a PSI CO_2 sensor that measures the concentration of carbon dioxide in the seawater and also supplies information on meteorology, current, and wave characteristics. At the land-based Mace Head research facility, a LI-COR 7500 and a McGill sonic anemometer measure the air concentration of carbon dioxide and wind speed. The CO_2 flux in the atmosphere is calculated using the "eddy covariance technique," which is the standard for surface layer gas flux measurements as it is a direct computation of the covariance of the gas concentration with the air vertical velocity at the height of measurement [McGillis et al., 2001]. The gas transfer velocity ("k-value" in cm/hr) of carbon dioxide across the air-sea boundary can be calculated using these data.

OCEAN ENERGY

Marine energy extraction is a complex process of which there are many facets and a greater knowledge of a device's working environment is required over the oceanographic standard of summary statistics. This means that near instantaneous measurement of the impacting sea state is necessary to understand the reaction of wave or tidal current energy conversion devices. The primary objective



Figures 5a (top) and 5b (bottom): Real time wave climate display: (a) wave height with spectral data and (b) raw data access.

is to quantify the power produced, which is pneumatic, mechanical, and electrical. Of equal importance is the survival of these machines in severe storm conditions.

At the benign wave energy test site in Galway Bay operated by the Irish Marine Institute, two medium scale wave energy devices have been deployed for extensive testing periods with the requirement that there would be concurrent measurement of the sea state for correlation with the measured outputs of the devices. Data analysis is performed in both the frequency and time domain. One of the intricacies of wave energy extraction from the ocean environment is that for similar summary statistics over a thirty minute period, there can exist largely differing distributions of energy in the frequency domain [Barrett et al., 2008]. The effect of this on a device can be excessive in some cases, where the power output can reduce to just 5% of the expected return from the stated summary statistics.

The SmartBay Galway monitoring infrastructure not only provides the required level of detailed wave measurement and reporting in real time (Figure 5), but also the additional information of local environmental conditions and the infrastructure for high capacity data transmission. Marine energy consists of teams of multiple disciplines, including naval architects, electrical engineers, and financial experts. The SmartBay Project provides the added value of presenting the various data streams in an ocean energy standard, which can quickly and easily be understood by interested parties ranging from the device development team to the electrical grid operator.

AUTONOMOUS WATER QUALITY MONITORING

The requirement for coastal and transitional *in situ* water quality monitoring systems that collect high frequency data is self evident given that such water bodies are often highly dynamic and it is difficult to capture episodic events such as phytoplankton blooms using conventional spot sampling [O'Donnell et al., 2008]. Such real time monitoring of water quality is a key element of the SmartBay monitoring capability. Environmental and water quality monitoring are key to measuring and understanding the chemical and biological quality of water and for taking reactive and remedial action [Regan et al., 2009]. Each SmartBay Sentinel buoy monitors a broad range of water quality parameters and data is collected and transmitted at a high frequency enabling scientists to view changes in the water quality as they occur. Currently data is correlated against samples collected in the field by technicians on service visits to the buoys, but it is intended to strengthen the sampling collection process by the deployment of automatic water samplers on the buoy platforms in the near future. The samples are collected for subsequent laboratory nutrient analysis and phytoplankton speciation at the Marine Institute laboratories.

PLANNED DEVELOPMENT

As an ongoing system and development test bed, a number of enhancements are planned for SmartBay. Continued improvements in the area of metadata and data federation are an imperative in terms of the effective use and management of data and information for a diverse and growing user community. Federation also helps preserve and better exploit the Marine Institute's investment in data in that the entire body of scientific data is known and accessible to a wide variety of users. Advanced visualization technologies are also under evaluation for integration within the SmartBay portal framework; this will be especially useful in the case of multidimensional complex, dense, and dynamic data sets and the integration of various data sets from MI modeling groups.

The analytical capabilities of SmartBay will also expand with the addition of new technologies such as streaming analytics, which provide the ability to apply complex analyses in real time on large volumes of real time streaming data from sources such as acoustic (e.g. hydrophones, sonar, ADCP, etc.) and video feeds [O'Hare et al., 2007]. Applications in these areas may be very complex in that data volumes are high, natural and artificial (anthropogenic) noise levels are often time and environment dependent, and signal features intricate. The real time abilities of such technologies are desirable for applications such as marine mammal (cetacean) monitoring and protection as well as improving our ability to observe and understand short-lived events within the ecosystem. We are utilizing a technology from IBM Research known as "System S," which not only performs complex analytical processing in real time, but can do so in a distributed fashion, essentially spreading the application over a number of computing platforms as needed for load balancing. System S also contains a knowledge management component which enables the system to operate intelligently in an autonomous fashion. An example of this would be the dynamic response of the system to cross correlate sensor data in real time across a geographic area to confirm that a deviation from normal baseline values of a particular pollutant is real and then to ramp up the sampling rate of various distributed sensors in hopes of better understanding the dispersion and movement of the plume in the system. Real time intelligent monitoring and analytics such as this provides benefits in terms of improving our knowledge of these events as well as provides us with information critical to emergency response or remediation. These approaches fall within a number of current research domains such as sensor web technologies, the semantic sensor web, and adaptive sensing environments [Hayes et al., 2009A and 2009B; O'Hare et al., 2009].

SmartBay will continue to extend the capabilities of the Marine Institute's cyberinfrastructure by moving analytical capabilities closer to the actual data sources (sensors) through the incorporation of embedded intelligence. As in the case of the phosphate sensor demonstrator, this design philosophy is especially relevant for remote monitoring in that latencies in the system may be considerably reduced or eliminated in the case of early warning of significant events. This approach also helps establish a "data-driven" operational model in conjunction with a hypothesis-driven regime where scientists work with data which are collected on a centralized host server via a "backhaul" network.

A significant enhancement to SmartBay Galway is also planned with the addition of a sub sea floor cabled extension of 20 km in length to support two undersea research nodes with 400 V power and high speed communications via ten pairs of optical fibres (see Figure 1 for the deployment location). The research nodes will host a complement of sensors including flood lit high definition cameras and complex acoustic arrays as well as docking ports for autonomous underwater vehicles.

SUSTAINABILITY

The real value of systems such as SmartBay Galway will only be realized over time to allow a significant time series of data to be recorded – so the sustainability of the infrastructure is a key objective of the project. The Marine Institute is actively involved in a number of initiatives involving the industrial and research sectors in Ireland along with state industrial development and enterprise agencies. These initiatives are developing a pipeline of industrial research and development projects based around SmartBay Galway to generate income which will help sustain the SmartBay infrastructure into the future.

SUMMARY

The SmartBay Galway infrastructure enables basic and applied research in sensor and systems development and marine/environmental science: its purpose is to act as a catalyst to bring together researchers with different skills and experience enabling world class marine research. This in turn is facilitating the conversion of research, development, and innovation into economic, social, and environmental benefits. SmartBay will continue to evolve to better meet the needs of the global marine research and development community through the application of leading edge technologies and approaches from multiple disciplines following a "best practices" philosophy.

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