Environmental Monitoring of Galway Bay: Fusing Data from Remote and In-Situ Sources

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ABSTRACT

Changes in sea surface temperature can be used as an indicator of water quality. In-situ sensors are being used for continuous autonomous monitoring. However these sensors have limited spatial resolution as they are in effect single point sensors. Satellite remote sensing can be used to provide better spatial coverage at good temporal scales. However in-situ sensors have a richer temporal scale for a particular point of interest. Work carried out in Galway Bay has combined data from multiple satellite sources and in-situ sensors and investigated the benefits and drawbacks of using multiple sensing modalities for monitoring a marine location.

Keywords: multi-modal sensor networks, sea surface temperature, remote sensing

1. INTRODUCTION

Sensor networks are a logical extension of the greater 'networked world'. They provide a gateway through which the 'digital' world can sense and respond to changes in the real world [1]. In recent years the concept of wireless sensor networks has been the focus of intense research. Due to their potential to facilitate data acquisition at a scale and resolution not previously possible, they have excited a range of scientific communities. The concept is relatively new and involves a diverse range of technologies and disciplines while impacting a wide variety of application sectors [2]. The Wireless Sensor Network (WSN) concept "envisages a world in which the status of the real world is monitored by large numbers of distributed sensors, forming a sensor 'mesh', that continuously feeds data into integration hubs, where it is aggregated, correlations identified, information extracted, and feedback loops used to take appropriate action" [2]. It envisages a world of ubiquitous sensing through large scale deployments of self-sustaining WSNs, linked to digital communications continuously monitoring our environment and instantly detecting and reporting changes in the quality of our environment.

In its ultimate manifestation, the realisation of multiple wireless sensor networks collaboratively monitoring an array of diverse events in the 'physical' or 'real' world happens at 'internet-scale' with sensors functioning as nodes in local-area networks that are themselves linked into wide area networks, through existing communications infrastructure [1]. These diverse data streams are aggregated at web-based integration hubs that subsequently identify and classify significant events and return personalised information back to the relevant destination [3]. This has led to the emergence of the 'sensor web' concept whereby sensor technologies will serve as new peripherals for the internet and bring a whole new world of data concerning our physical environment to the wider web where it will be automatically interpreted, integrated, and transformed for human interaction, querying and mining [4].

However there lie many challenges in the realisation of the vision outlined above in the area of environmental monitoring. The current state of the art in wireless sensor networks poses many drawbacks and challenges for environmental monitoring applications. This research proposes that inland and coastal marine environmental monitoring networks would strongly benefit from the use of a multi-modal sensor network utilising visual sensors and other sensed information alongside the more traditional in-situ wireless sensor networks. The analysis presented here forms part of ongoing research which is investigating the use of visual sensors - including digital cameras and satellite imagers - and context information alongside a traditional in-situ wireless sensor network for improved event detection in coastal and inland marine environments [18 19].

This paper focuses on environmental sensing in a coastal marine environment. It provides an analysis of Sea Surface Temperature (SST) data from both an in-situ sensor network and satellite remote sensors. The in-situ data is retrieved from the SmartBay Environmental Monitoring System recently installed in Galway Bay, Ireland and the satellite data is retrieved from a High Resolution Diagnostic Data Set (see section 4). It demonstrates the underlying issues with the singular use of either of these modalities in an environmental event detection network and subsequently reinforces the need for their complementary use for reliable monitoring of events in a marine environment.

The rest of this paper is organised as follows. The use of WSNs for water quality monitoring applications and the problems incurred are outlined in section 2. In section 3, applications involving SST observations and their importance, along with satellite technologies used to carry out these measurements are briefly described. The area of observation and the datasets and technologies employed at this location are described in section 4. Finally section 5 presents an analysis of the in-situ and satellite SST observations retrieved at this location over approximately a two month period. This analysis demonstrates the underlying issues with the singular use of either of these technologies for reliable event detection in an environmental sensor network.

2. WIRELESS SENSOR NETWORKS FOR WATER QUALITY MONITORING

The implementation of the Water Framework Directive (WFD) [20] is increasing the need for advanced technologies to manage water quality. All EU Member states must achieve good status in all waters by 2015 and maintain that status. The establishment of this directive has lead to the need for water managers to adopt a new approach to managing their waters. They are under increasing pressure to continuously monitor inland waters and coastal zones in relation to a variety of water quality variables.

For many years water managers relied on field measurements for water quality evaluation. This involved costly, time and labour –intensive on-site sampling and data collection, and subsequent transportation to laboratories for evaluation. This type of sampling is too limited on temporal and spatial scales to adequately monitor the quality of various water bodies on a long-term basis and to address the development of events such as harmful algal blooms and fish kills. It also introduced various data quality issues through inadequate quality-control and quality assurance protocols such as extended holding times before analysis and the use of non-standardised methodologies [5]. These methods were also ineffective in capturing dynamic marine events essential for increased knowledge and better decision making in relation to our coastal and inland marine environments.

New technologies are enabling the collection of more data from more places, and more cost-effectively than in the past. In recent years, the use of in-situ wireless sensor networks (WSNs) for marine environmental monitoring has been investigated to allow continuous real-time remote monitoring of the marine environment at greater temporal and spatial scales. Reliable instrumentation of natural spaces with numerous of these networked sensors can enable long-term data collection at scales and resolutions that are difficult and sometimes impossible to obtain otherwise. They provide an intimate connection with the immediate physical environment that enables localised measurements and the abstraction of information that is difficult to obtain with traditional instrumentation.

In situ WSNs are used to allow important indicators of water quality to be continuously monitored and to provide early warning information of the onset of events such as harmful algal blooms, coastal erosion, dangerous bathing/sea conditions etc. to allow appropriate action to be taken by decision makers. The data collection process is streamlined with a minimisation of human errors and time delays increasing the quantity and quality of data on temporal and spatial scales with a possibility of real-time "alert notifications" of harmful marine events [5]. Data can be accessed remotely which negates the need for data collection in sometimes hazardous or hard to reach environments.

As previously outlined, the WSN concept envisages a world of ubiquitous sensing through large scale deployments of self-sustaining WSNs linked to digital communications continuously monitoring our environment and instantly detecting and reporting changes our environment. The ultimate goal of an environmental sensor network is the realisation of an adaptive environment – one that senses and rapidly adapts to potential incidents in order to minimise their impact. However there are many issues with the current state of the art in in-situ wireless sensor networks for the realisation of this vision.

2.1 Problems with in-situ WSNs in environmental monitoring

The range of analytical devices used in wireless sensor networks (WSNs) can be layered into a hierarchy in terms of sophistication, capabilities, operational costs and degree of autonomy [1]. Generally the more sophisticated of these devices are chemo-bio sensors. These sensors are currently not at the stage whereby they can operate autonomously for long periods of time [2]. They have a limited deployment lifetime (i.e. number of samples) before they begin to experience signal drift and require maintenance. They are also high in cost and require significantly more energy than their less sophisticated counterparts [3]. These factors render the current state of the art in this technology unsuitable for large-scale deployments. The analytical sciences community is looking at the development of less reliable but lower-cost devices that could be deployed in large numbers. Subsequently future investigations will focus on how to use the more sophisticated devices more efficiently along with investigating how we can best manipulate large numbers of the less-reliable devices.

The majority of low power wireless network research (LPWN) is currently dominated by transducer based activities (e.g. thermistors, photodetectors, vibration/movement sensors). However even without the added complexity of chemo/bio sensing there are considerable issues in terms of the supporting infrastructure to enable large-scale wireless sensor network deployments involving many thousands of devices [3]. Sensors deployed most notably in the marine environment are often subject to harsh conditions. This can result in sensor failure and unwarranted gaps in the data. Sensors are often subject to the problem of bio-fouling. This is the unwanted accumulation of biological material on man-made surfaces. Biofouling results in unreliable and noisy data and sensors that are not maintained on a regular basis can prove problematic and result in inaccurate data. In certain scenarios it may be unclear whether events detected in the data are due to problems with the sensor or if they actually constitute real events. Also, in-situ sensors can improve the scale of sensing but only up to a point. They have limited spatial resolution as they are in effect single point sensors and often the region of interest in a marine environment may be quite vast. Furthermore, due to the expense and logistical difficulties often associated with the deployment of an in-situ sensor network in certain marine environments, it may be difficult to monitor a wide area over long periods of time**.** Certain environments or events may not even be suited to monitoring by an in-situ WSN, for example, the turbulent nature of the surf zone often makes it difficult to successfully maintain in-situ instrumentation for certain coastal monitoring applications. Finally certain events may occur that may not necessarily be immediately detected by in-situ instrumentation. For example if there is pollution floating on our water, water managers may not be automatically alerted by readings from the in-situ observations. However it may be vital that this is attended to immediately. This work proposes that the use of alternative sensing modalities and context information along-side an in-situ wireless sensor network can help to overcome some of these problems. This paper provides an analysis of SST measurements retrieved from an in-situ sensor network deployed in Galway Bay, and concurrent satellite measurements for the same region. It demonstrates the necessity for both information sources in an environmental sensor network for reliable event detection and sufficient monitoring of a coastal marine environment.

3. SEA SURFACE TEMPERATURE – APPLICATIONS AND REMOTE SENSING TECHNOLOGIES

3.1 Applications of SST

SST Measurements are fundamentally important to a number of studies and applications including ocean forecasting, weather forecasting, climate and seasonal forecasting, tourism and fisheries research etc. Ocean forecasting systems provide forecasts of currents and other environmental variables for use in a wide variety of applications such as environmental monitoring, oil spill drift forecasts, tide predictions, ship routing, search and rescue operations, estuary management, and operational wave forecasting. Ocean models are highly dependent on sea surface temperature data and require data to be available in near real time, to have a high accuracy (better than .4k), and have a spatial (<10 km) and temporal (6-12 hours) resolution [6]. An example of an operational ocean forecast system is that of the UK National Centre for Ocean Forecasting (NCOF) [21] which provides a variety of operational ocean model services through the operational FOAM and shelf sea model systems.

Sea surface temperature measurements also play an important role in weather forecasting systems. SST influences the atmosphere and subsequently can play a role in determining its behaviour [7]. Daily analyses of SST and sea-ice are required by my many operational numerical weather prediction (NWP) systems to ensure an accurate forecast. SST can influence the formation of showers, thunderstorms, sea fog and sea breezes, tropical cyclones etc. It is also an extremely important climate variable [8] and is incorporated into climate and seasonal forecasting studies. However for incorporation into climate models it is extremely important that SST measurements are of extremely high accuracy and free of bias.

SST is extremely important in operational coastal monitoring applications. Operational oceanography provides real-time information and forecasts for marine environmental conditions in order to support a variety of marine activities [9]. Water temperature can have a large effect on eco-system function. Changes in water temperature can result in increased algal growth in the water and changes in the solubility of oxygen. It can also influence the extent to which metal contaminants are assimilated by physiological processes [10], viral persistence [11], the conductivity and pH of the water column etc. It is important for management and monitoring of fisheries [12] and thus needs to be routinely monitored for variation or events. Changes in SST may also be indicative of changes in the amount of freshwater flow, or discharges of 'cooling' waters from power plants or industrial effluent.

3.2 Satellite Sensors for SST Observation

Global ocean measurements of SST collected through satellite measurements have made a major contribution to climate research [13]. Satellite observations are essential for the construction of global SST fields due to the sparse coverage of in-situ measurements of SST from ships and buoys. Spaceborne sensors can improve SST measurement capability through their high spatial and radiometric resolution and regular sampling [13].

For over two decades SST has been routinely observed using thermal infrared data from space borne sensors [14]. Satellite instruments such as Advanced Very High Resolution Radiometer (AVHRR), the Moderate Resolution Imaging Spectroradiometer (MODIS) and the Along-Track Scanning Radiometer (ATSR) have the ability to derive satellite SST measurements with accuracies of a few tenths of a Kelvin [14]. As previously mentioned high accuracy SST measurements are essential for climate research and other studies. The ATSR radiometers were designed with these requirements in mind [14]. The first ATSR, an experiment instrument, was launched on board ERS-1 in 1991. In 1995 ATSR-2 was launched onboard ERS-2. These were followed by the Advanced ATSR (AATSR) launched onboard Envisat in March 2002. Together this series of instruments will lead to a > 15 year record of data that can be used to monitor long-term changes of SST [14]. This enables a detailed investigation of previously unobservable ocean processes including those that govern the spatial and temporal dynamics of the lower atmosphere and upper ocean [13]. Historically SST measurements have been provided from AVHRR operational on NOAA satellites since 1981 [7]. The latest version is AVHRR/3, first carried onboard NOAA-15 launched in May 1998. However, IR measurements of SST can only be obtained during cloud free conditions which can prove problematic for many applications. They can also be affected by aerosols from volcanic eruptions and dust storms [7]. Microwave remote sensing has the potential to eliminate some of these problems as clouds and aerosols are essentially transparent to microwave radiation at frequencies below 12 GHz [7]. The Tropical Rainfall Measuring Mission (TRMM) Microwave Imager was one of the first to produce high-quality microwave SST data. However these observations have a footprint size of approximately 46 km and an accuracy of approximately 0.5°C [7]. This is quite large considering the 1km resolution of satellite IR observations. However these measurements are available in all non-raining conditions. Other limitations of this instrument included inability to measure SST near land, the low inclination of the TRMM orbit which restricts measurements to the latitude band of 40°S – 40°N, and degraded accuracy of TMI retrievals of SST below 10 degrees C approx [7]. AMSR-E which orbits the earth on the EOS Aqua satellite addresses some of these limitations including the restricted latitudinal sampling and the degraded estimates at low SST. This sensor began sampling the global ocean in June 2002 with 89% coverage each day and 98% coverage every two days. Again the resolution of this instrument would not be as high as some of the IR sensors, however it leads to improved global sampling though greater coverage [7]. The launch of WindSat on the Coriolis satellite in January 2003 brought about a new generation of satellite remote sensing instruments [15]. This is a satellite-based polarimetric microwave radiometer designed to demonstrate the capability of polarimetric microwave geometry to measure the ocean surface wind vector from space. In addition to proving the US Navy with these measurements it also measures other environmental parameters including SST [16]. Despite all of this, microwaves are several orders of magnitude larger in wavelength than the visible portions of the spectrum. Thus the spatial resolution of typical microwave radiometer observations is coarse. They have limited capabilities for monitoring coastal regions, and precipitation in the atmosphere can severely limit the retrieval of certain geophysical parameters [15].

Satellite-derived SST products are normally validated through the use of in-situ instrumentation e.g. from weather buoys, in-situ radiometers mounted on research vessels etc. Collectively, these provide robust and valuable validation data but, due to the often limited geographic and temporal coverage of individual campaigns, the cost and difficulty of maintaining instrumentation, this approach falls short of a continuing global satellite SST validation strategy [13]. Validation of satellite observations is an ongoing process to continuously validate measurements throughout the lifetime of the sensor as well as for validation of new algorithms and models. Scientists are investigating the best combination of tools from (satellite observations, in-situ measurements, and numerical models) for global SST analysis[13]. It seeks to build on the complementary aspects of various satellite instruments by merging data to provide data of increased quality and resolution. The Global Ocean Data Assimilation Experiment initiated a project along these lines to develop high spatial and temporal resolution SST data products. Details of this project – GHRSST-PP [6] - are provided in Section 4.

4. STUDY AREA AND INSTRUMENTATION

Figure 1: Map of Ireland showing Galway Bay, Image: Marine Institute, Ireland

This section describes the area under consideration, along with the in-situ and remote sensing systems employed for the analysis.

4.1 SmartBay

Galway Bay is a large bay on the west coast of Ireland. It is approximately 50 km long (30 miles) and from 10 to 30 km (7-20 miles) in breadth (see Figure 1). The Aran islands are to the west of the of the bay and there are other small islands within the bay. SmartBay [22] is a national research project seeking to establish a network of buoys, seafloor cables and other infrastructure, supporting a range of sensors, information systems, telemetry and other communications technology for real time in-situ oceanographic monitoring of Galway Bay. It is essentially a next-generation water management system. The SmartBay pilot project has been successfully established by the Irish Marine Institute and includes the deployment of environmental monitoring buoys, and wave monitoring instrumentation. The Marine Institute also operate two tide gauges in this region monitoring water depth, water temperature and atmospheric pressure. There are a number of parameters currently under observation by the SmartBay instrumentation including temperature, salinity, fluorescence, dissolved oxygen, particulate CO_2, waves and currents. A web-portal is currently under development to provide access to the data and novel methods of viewing the information.

The SmartBay Pilot project [22] incorporates environmental and oceanographic information from the following sources which can be seen in Figure 2 below:

- Environmental Monitoring Buoy at Mace Head
- Environmental Monitoring Buoy, deployed at Mid-Bay location off Inis Meáin
- Directional Wave Rider deployed and operational at the Ocean Energy Test Site
- Tide Gauges deployed and operational in Galway Harbour and Inis Mór

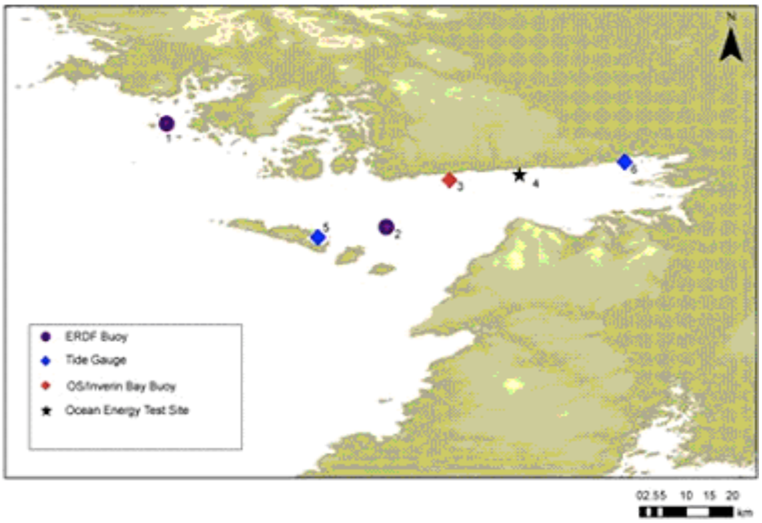

Figure 2: SmartBay Galway Pilot Project Infrastructure, Image: Marine Institute, Ireland

4.2 Other Instrumentation in Use in Galway Bay

The Marine Institute also operates two purpose built research vessels *RV Celtic Explorer* and *RV Celtic Voyager* [23]. These are multipurpose research vessels fully equipped with state-of-the-art scientific instrumentation, laboratories and IT equipment. The *RV Celtic Explorer* is designed for undertaking offshore and deep-sea survey operations. The *RV Celtic Voyager* is more suited to coastal research and offshore survey operations. These vessels are used for a variety of applications including environmental monitoring, fisheries research, seabed mapping, oceanology, and seismic surveys. Oceanographic models for Galway Bay have also been completed. A 200m resolution ROMS hydrodynamic model and SWAN wave model, based on the latest bathymetry are in use for monitoring and forecasting activities in the region.

4.3 HRDDS data

There exists a number of European and international projects aimed at improving the interoperability of satellite sensor data; an example of such a project is the Global High resolution Sea Surface Temperature pilot project (GHRSST-PP) which was initiated by GODAE – Global Ocean Data Assimilation Experiment [24]. GODAE identified that numerical ocean forecasting models require a near real-time supply of SST data, sampled often enough to resolve the diurnal cycle, along with an accuracy better than .2k and a spatial resolution better than 10 km which is only possible by combining the best capabilities of different types of sensors. In 2002 it initiated GHRSST-PP [6 17].

The data products that are available from GHRSST –PP include L2P data products. These data products provide satellite SST observations from various satellite sensors in a common format (netCDF) together with a measure of uncertainty for each observation. This means that all satellite SST data are presented in a common format and the user doesn't have to re-code for the ingestion of different satellite data. The ancillary data provided allows the user to filter data based on the criteria outlined to their specific application. L4 products are also provided with the aim of providing the best available estimate of SST to the user. A combined analysis of all available SST data is carried out enabling the benefits of using in situ, microwave satellite SST and infra-red satellite SST in synergy. Diagnostic datasets are also produced for a number of sites around the globe. This is where all available L2P and L4 data for a number of small areas are gathered and subsequently re-sampled onto a common grid to assist inter-comparison and characterisation of the various input data streams. Two diagnostic data set sites were established in December 2008 by David Poulter at the National Oceanography Centre Southampton, UK- one at Galway Bay and the other at Dublin Bay [25]. We hope to establish more sites further away from the coastline alongside the weather buoys in the future.

5. ANALYSIS

In our analysis we demonstrate the benefits of incorporating heterogeneous information sources in a multi-modal event detection system for coastal marine monitoring. For this initial analysis we look at data from the HRDDS site for Galway Bay and SST data from two SmartBuoys provided by the Marine Institute. Other ongoing work incorporates alternative modalities such as cameras, rainfall radar, water quality sensor data etc [18 19].

One of the SmartBuoys is situated at Mace Head (Mace Head buoy) which is close to the coast while the other buoy is situated in the middle of the Bay (MidBay buoy). These are both situated within the region of the HRDDS site. Both of the SmartBuoys are measuring SST along with other water quality parameters such as salinity, fluorescence, dissolved oxygen etc. However for the purposes of this analysis only SST is considered here. For the analysis, 65 days worth of data was downloaded (to match the same days covered by the SmartBuoy data) from the HRDDS for Galway Bay. For each day the HRDDS data set provides up to 14 different data products. Two of these data products, AVHRR (NCDC-L4LR) and UKMO-L4HRfnd-GLOB were chosen as they have a relatively good resolution for Galway bay compared to the other products. For each of the chosen data products the Java BEAM API (developed by Brockmann-consult) was used to select the pixel that best represented the location of both SmartBuoys. The neighbouring pixels to these sites of interest were also selected however only the pixels that best represented the location of both SmartBuoys was used for the subsequent analysis. The HRDDS provides daily data products with a range of spatial resolutions. The spatial resolution of UKMO-L4HRfnd-GLOB is 0.05 degrees, with AVHRR (NCDC-L4LR) having a poorer resolution of 6km.

In Figure 3, the overall SST for both buoy sites is displayed. Up to 48 readings are taken each day but in the time period we examined, the buoys were also offline for a number of days. The number of readings per day is reflected in the size of the columns which represents the range of SST values sampled during that day. On average 44.55 readings are taken per day for Mace Head and 40.69 are taken for Mid Bay by the SmartBuoys. Around the 2nd of June there was a large shift in SST which here reflects a brief increase in air temperature. The gap in data demonstrates that even the current-state-of the-art in in-situ monitoring devices are subject to failure. This may lead to missed events or inaccurate scientific analysis. Thus it may be beneficial to incorporate diverse sources of information in an environmental sensor network for more reliable event monitoring.

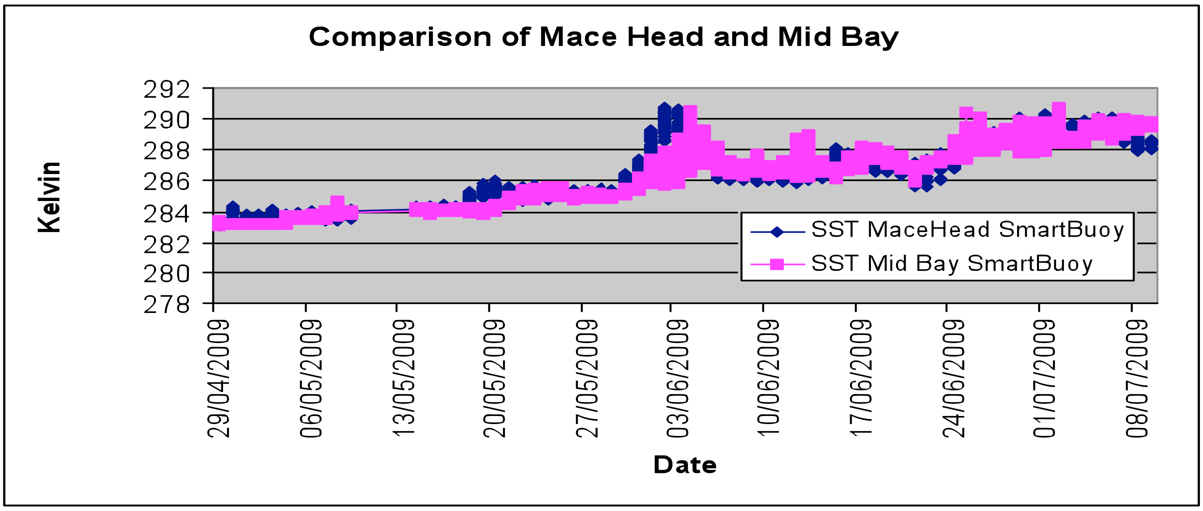

Figure 3 – In-situ SST readings from sea-based buoys. Note that for a number of days both buoys were offline.

In the next stage of our analysis, we compared the data products, AVHRR (NCDC-L4LR) and UKMO-L4HRfnd-GLOB with SST data from the SmartBuoys. Our initial analysis found that there was 100% agreement between AVHRR and UKMO data products for Mid Bay and for Mace Head sites. Thus, Mace Head SST for data product 1 (AVHRR) is the same as Mace Head SST for data product 2 (UKMO) and Mid Bay SST for data product 1 is the same as Mid Bay SST for data product 2. However, Mace Head SST from data product 1 and from data product 2 is not the same as Mid Bay SST from data product 1 and from data product 2. Therefore we can distinguish between both sites. Thus in Figure 4 we display the overall AVHRR and UKMO SST scores for both sites. These scores are the mean SST values associated with the sites of interest, i.e., Mid Bay and Mace Head, taken from each data product. A simple JAVA program was written to process this data and it extracted the associated data from each pixel in the data product(s). Only those mean SST scores which relate to the sites of interest are shown. Both data products show that the rise in SST for Mace Head and Mid Bay is not identical but they both show a similar overall trend. The spatial resolution of the HRDDS products therefore is good enough for us to distinguish between both sites.

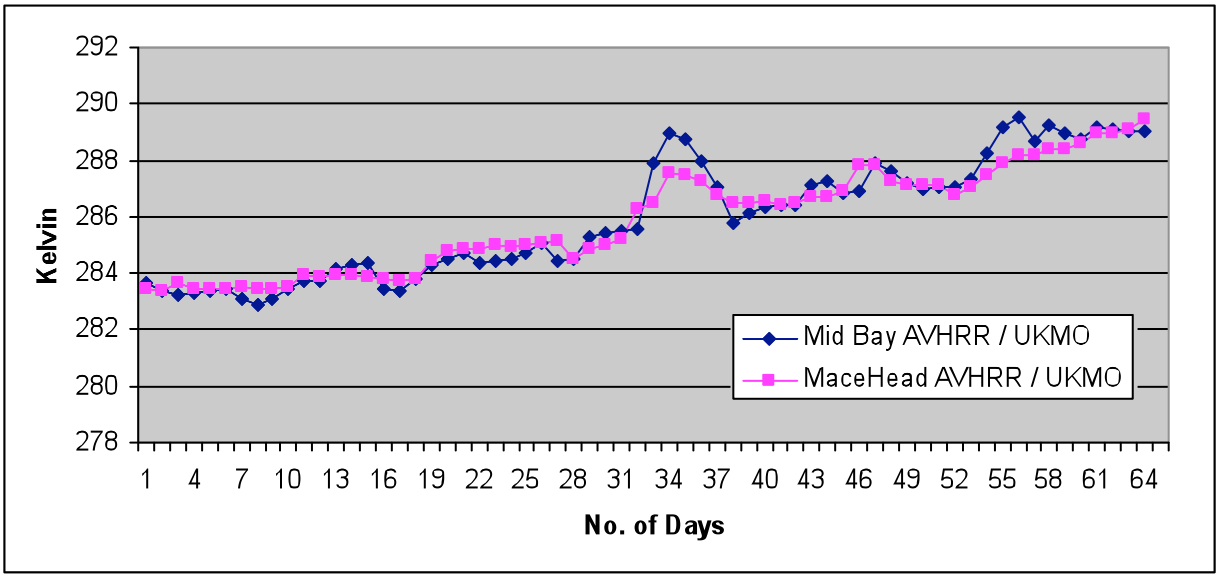

Figure 4 – The overall mean SST values from AVHRR (NCDC-L4LR) and UKMO-L4HRfnd-GLOB for the MaceHead and MidBay locations

Given the variation between both sources of data we are left with one fundamental question - which of the two sources is closest to the in-situ data for each site? To answer this question we aligned the AVHRR (NCDC-L4LR) and UKMO-L4HRfnd-GLOB data with the in-situ data. However, it should be noted that there are in theory up to 48 readings per day for each SmartBuoy as they sample every 30 minutes. In practice the number of readings per day does not always reach 48 readings. To compensate for this and as a relatively straightforward way of comparing both sets of data the average in-situ mean SST for each day was extracted. These daily averages for both SmartBuoy sites were correlated with the SST values associated with the pixels that best represented the location of both SmartBuoys in the AVHRR (NCDC-L4LR) and UKMO-L4HRfnd-GLOB data products for Galway Bay. These correlations are given in Table 1.

Table 1 – Correlation between daily averages of Mean SST from the MidBay and MaceHead SmartBuoys and the AVHRR (NCDC-L4LR) and UKMO-L4HRfnd-GLOB data products for Galway Bay

	AVHRR	UKMO
MidBay	0.973109	0.976541
MaceHead	0.926728	0.941454

From Table 1 it is clear that both remote sensing sources are a better match for MidBay than MaceHead (which is closer to the coast). But overall the UKMO-L4HRfnd-GLOB data product seems a closer match for both the SmartBuoys sites. Overall, the HRDDS data correlates very well with the in-situ data. Thus if the in-situ sensor fails, it represents a 'back-up' sensing modality. It can also be used to validate events detected by the in-situ sensors and subsequently examine overall trends in the greater spatial area of the bay. The data from which the correlations were found is shown in Figure 5a and Figure 5b. Those days where SmartBuoys recorded no data, i.e. were not online, were not used when the correlations were found.

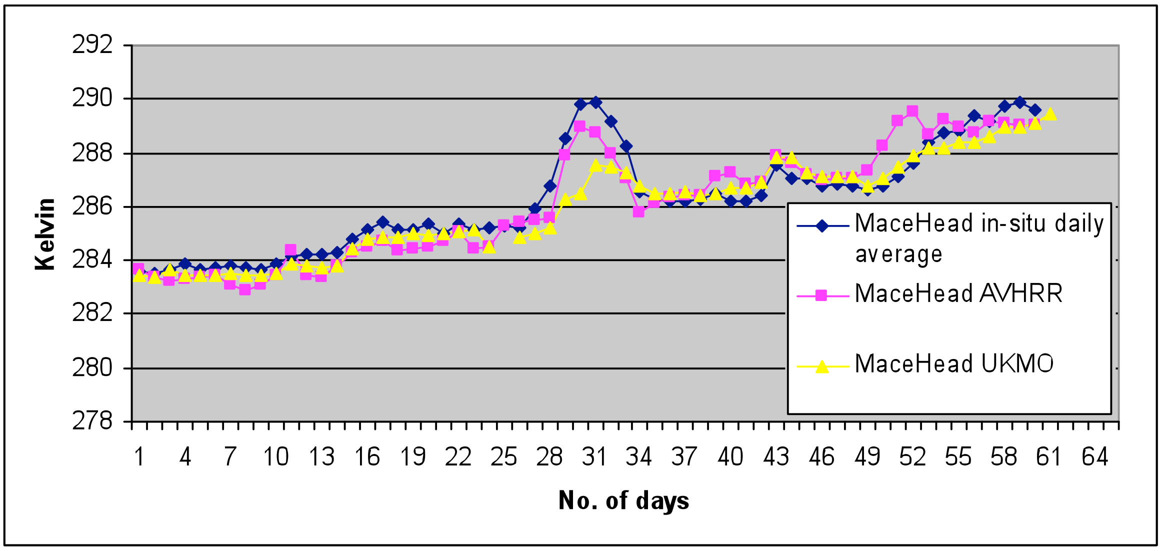

Figure 5a – Comparison between daily averages of Mean SST from the MaceHead SmartBuoy and the AVHRR (NCDC-L4LR) and UKMO-L4HRfnd-GLOB data products for Galway Bay. Days where the SmartBuoy recorded no data, are not displayed.

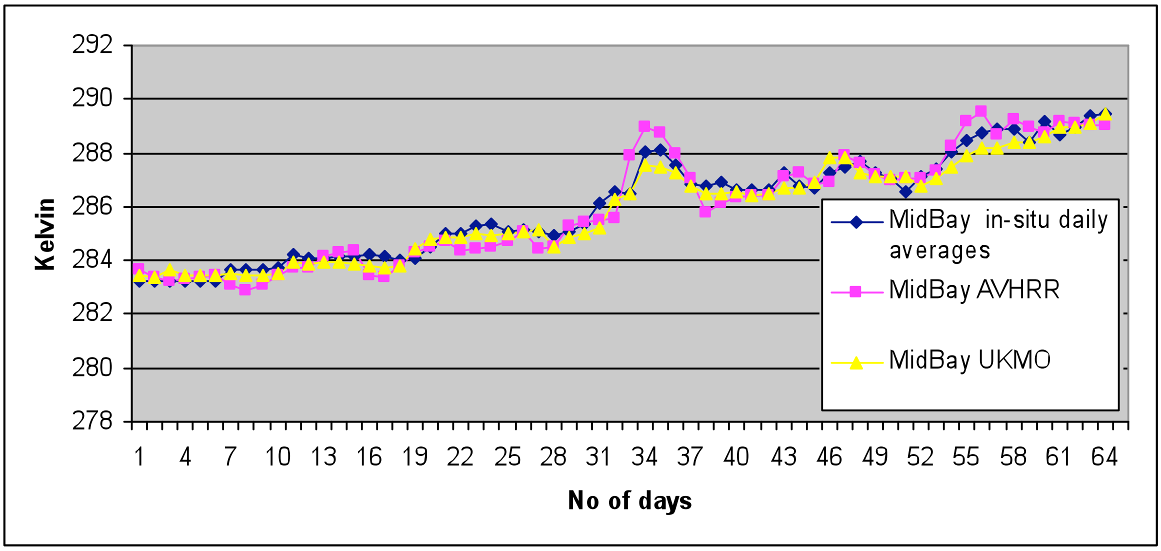

Figure 5b – Comparison between daily averages of Mean SST from the MidBay SmartBuoy and the AVHRR (NCDC-L4LR) and UKMO-L4HRfnd-GLOB data products for Galway Bay. Days where the SmartBuoy recorded no data, are not displayed.

The in-situ sensors have greater temporal resolution that the HRDDS data. Thus we can gain information on daily events and trends e.g. diurnal trends in SST (see Figure 6), with the in-situ data and resolve this for specific points in the region rather that obtaining a more coarse analysis of events in the area. However, the in-situ data only allows us to observe this information for a very limited number of points in the bay. The HRDDS data provides information for a large area of the bay, however, at a coarser resolution than that of the in-situ data.

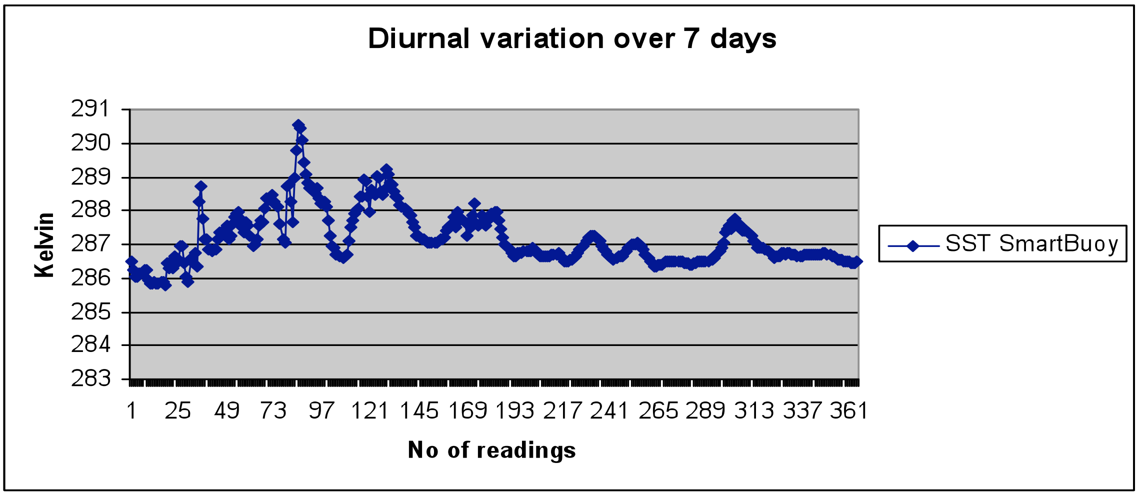

Figure 6 – Diurnal variation in SST over 7 days.

6. CONCLUSION

From the analysis, it is clear that a combination of diverse heterogeneous information sources can give us a more complete picture of what is happening in a region. From in-situ sensors, such as the SmartBuoys, we can gain information at a greater temporal resolution for specific points of the bay; however the HRDDS data provides greater coverage of the area at a coarser resolution. The incorporation of each of these sensing modalities into an environmental sensing system will thus provide increased information on coastal marine events.

The HRDDS data provides a useful tool for observing overall trends in the bay and correlates well with the in-situ data. Thus if the in-situ sensor goes offline, the HRDDS data provides a back-up sensing mechanism and reduces the possibility of missed marine events. If the in-situ sensors detect a change, it is also possible to validate that change through information from an alternative sensing modality. This change can subsequently be constituted as representing a real event and not just the result of problems with the in-situ sensor. The in-situ data, with greater temporal resolution, can be used to alert a significant marine event, the HRDDS data then may be consulted to examine trends throughout the Bay around this period. This allows greater understanding of phenomena along with increased information for better decision making.

This initial analysis forms part of ongoing work which is investigating the use of multiple sensor modalities for improved monitoring and event detection in coastal and inland marine environments. This analysis concentrates on SST, however our research is considering a number of environmental features and variables. It seeks to demonstrate the use of multiple heterogeneous information sources for improved event monitoring on a number of levels in an environmental sensor network. As well as improved event detection, these information sources can also be used in a complementary fashion to increase efficiency in a resource-constrained network and provide early warning information on the onset of significant events. A limited number of sophisticated devices may be used more efficiently and it will ultimately lead to an adaptive environment – one that senses, detects and reacts.

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