International Workshop on Environmental Multimedia Retrieval 2014
EMR 2014, April 1st, Glasgow, UK. In Conjunction with ACM Conference on Multimedia Retrieval (ICMR) 2014

Remote Monitoring of our Environment: A Data Fusion Problem

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Summary

- I will present an overview of basic sensing
- I will introduce sensors as a data deluge of errorsome, unreliable data
- I will highlight the importance of sensors in environmental monitoring for scalability
- I will present some deployments from our work
- I will show the problems in sensing for environment have a lot of similarities with work in multimedia fusion but it has even more challenges

Insight Centre for Data Analytics

- Newly formed research centre with focus on data analytics for the discovery economy and connected health
- +200 researchers across 4 Universities

Insight

Insight Centre for Data Analytics

- Develop analytics on data from any sources … sensors, online, transactional, web, personal sensing, and environmental

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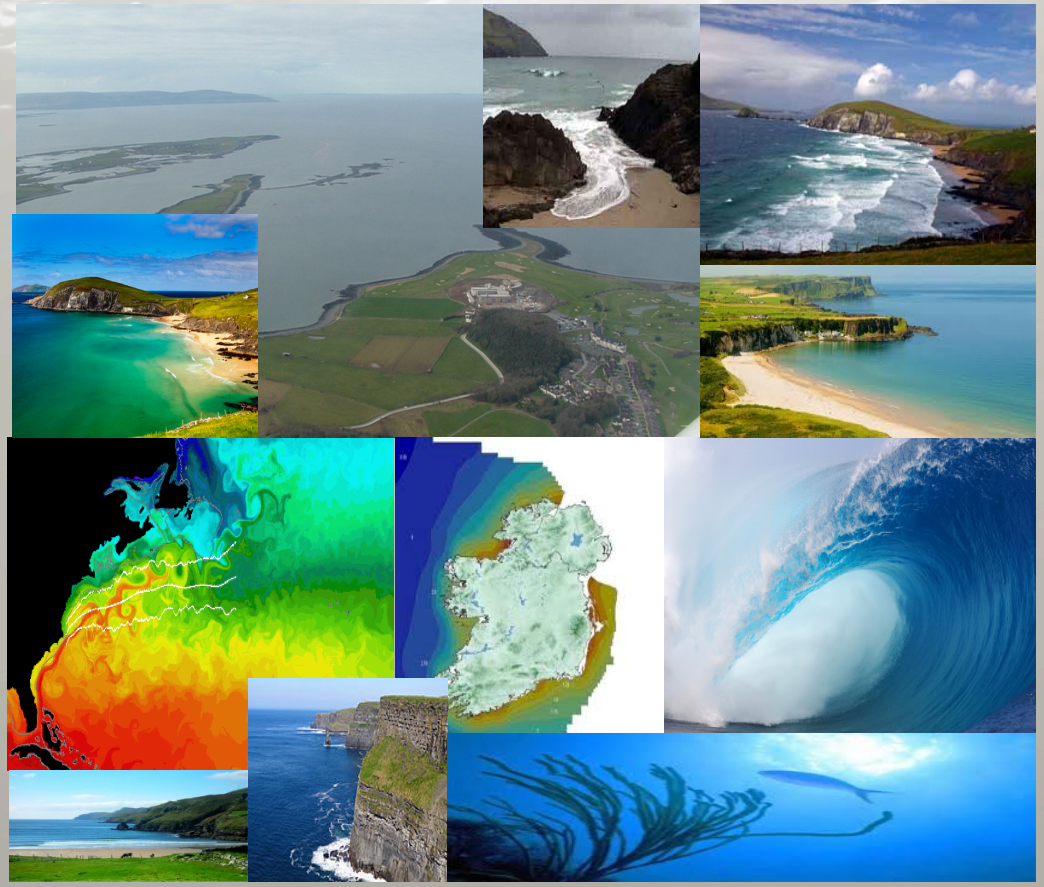
Ocean Wealth

Marine and freshwater environments - vital assets on many levels

Huge economic opportunity that remains unexploited

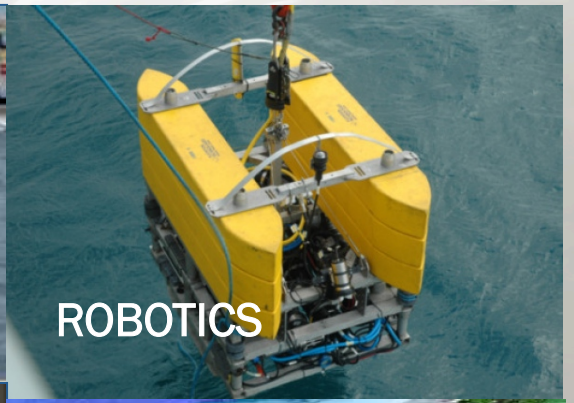
A responsibility to understand the effects of various developments

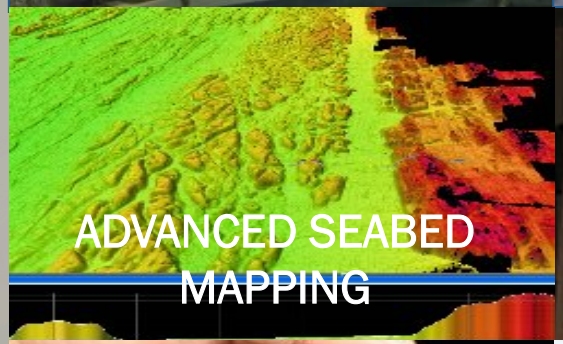
Modelling and understanding of environmental processes essential

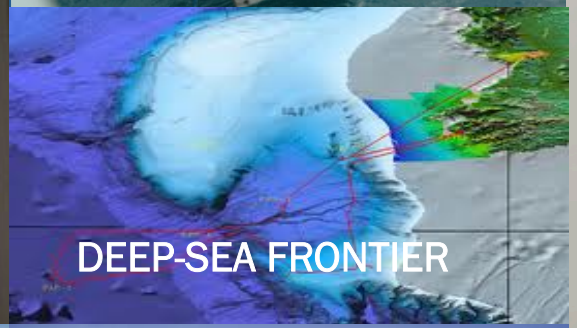


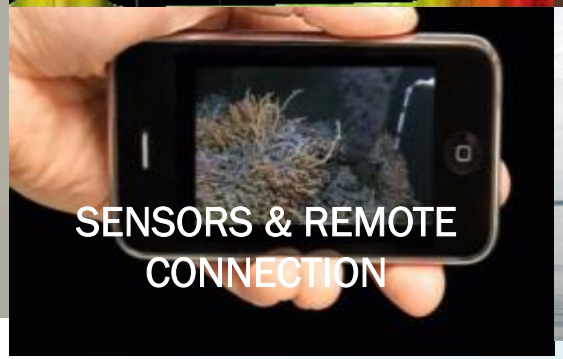
Insight

Harness Marine Resources in New Ways









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Ireland's Marine Resource

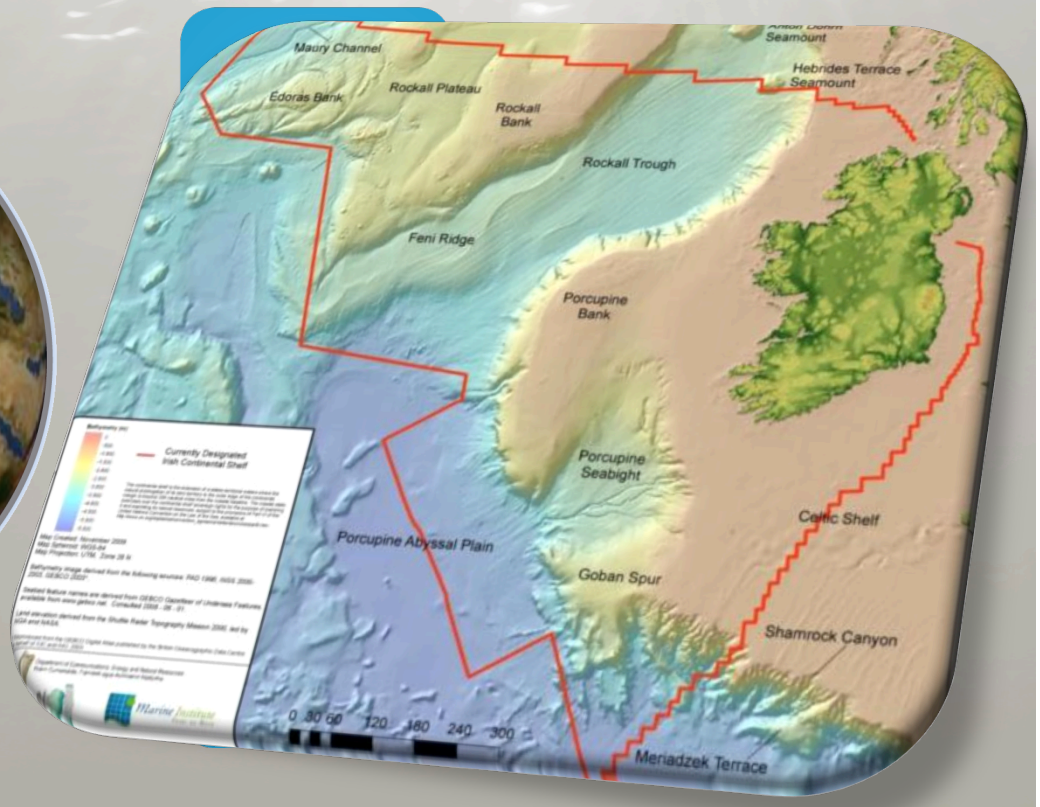
Our Ocean Wealth

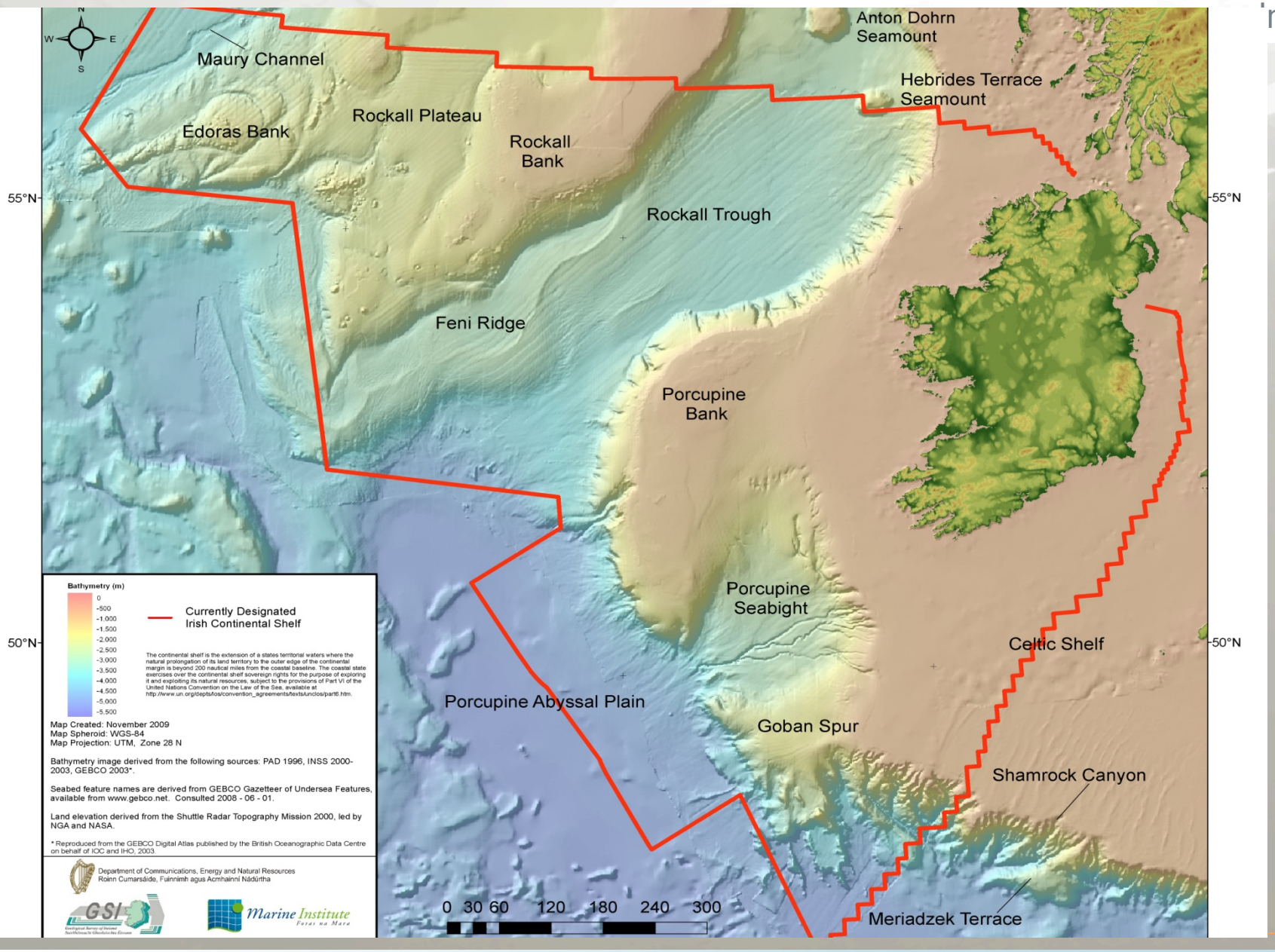
Size
0.9m km²
(90% of Ireland)

Value
€2.4bn
(direct and indirect Gross Value Added)

1%
of GDP

Global Ocean Wealth





Real Map of Ireland

Insight

Harnessing Our Ocean Wealth:
An Integrated Marine Plan for Ireland

As Taoiseach, I want to see us reconnect to the sea in a way that harnesses the ideas, innovation and knowledge of all our people, at home and abroad. I want to see us setting out to secure for ourselves and our children the social, cultural and economic benefits that our marine assets can deliver.

Taoiseach, Enda Kenny, TD
February 2012.

New Ways – New Approaches – New Thinking

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An Integrated Marine Plan for Ireland: Harnessing Our Ocean Wealth (July 2012)

New Ways – New Approaches – New Thinking

Action Plan
July 2012

www.OurOceanWealth.ie

European Union Strategy for the Atlantic (2011)

Atlantic Action Plan (2013)

An Integrated Maritime Policy for the European Union (2007) and its associated Sea Basin Strategies

Five EU Member States and their maritime territories including the waters surrounding the Azores and Madeira (Portugal) and the Canary Islands (Spain)

Insight

Capacity Development in Marine ICT

SmartOcean: a Marine Institute initiative to establish Ireland as a leader in the development of smart, knowledge-based, high value-added products and services in the ICT & the Sea sector.

Main objectives :

1. Explore new ways of building Ireland's marine technology sector to access regional and global markets

2. Review recent policy developments and funding opportunities

3. Establish international networks and partnerships

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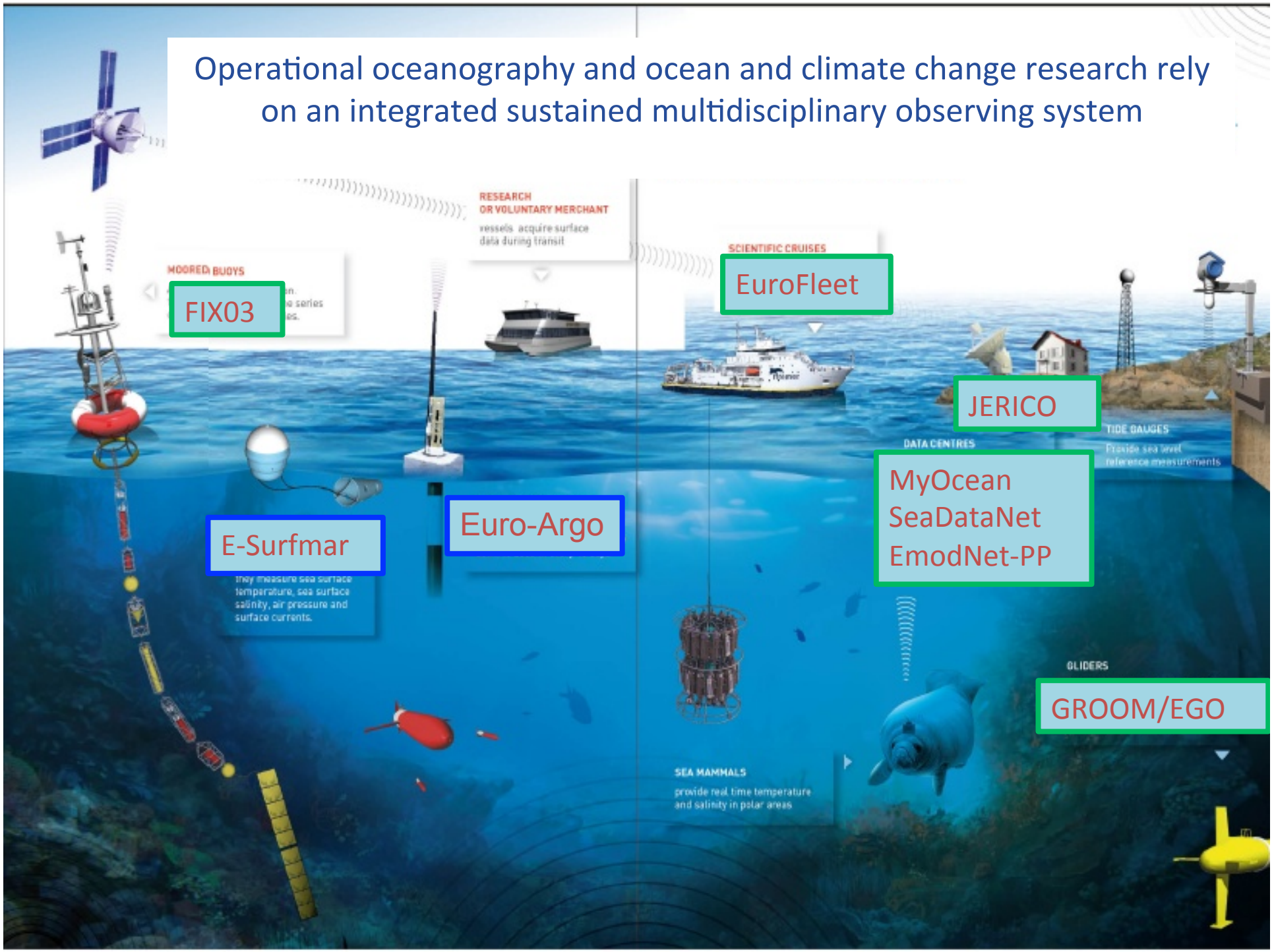
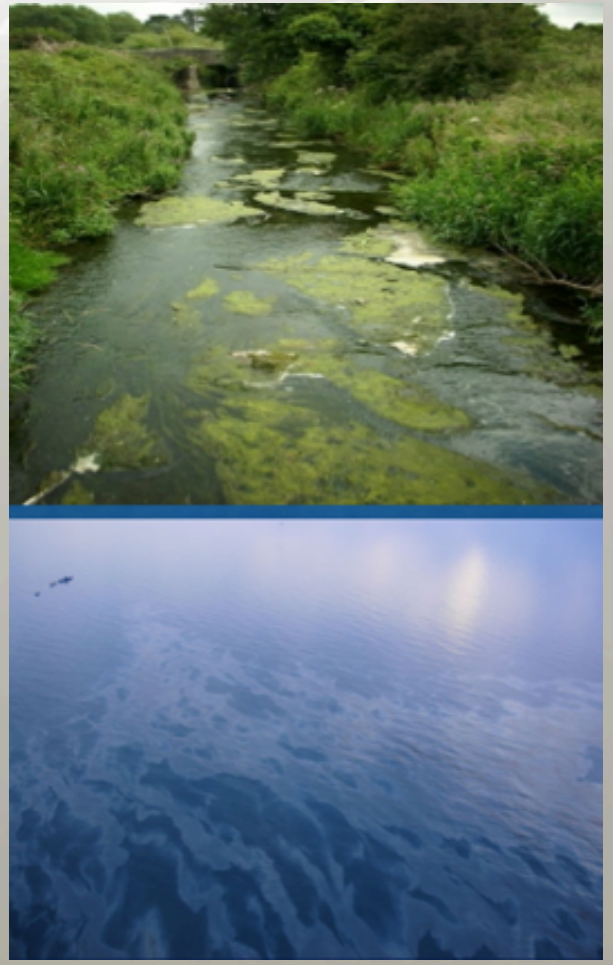
Operational oceanography and ocean and climate change research rely on an integrated sustained multidisciplinary observing system



Typical Pressures on Inland Waters

- Agricultural runoff
- Inputs from domestic and industrial treatment plants
- Algal blooms – an explosive increase in the density of phytoplankton within an area
- Oil spills
- River pollution from runoff from urban streets and septic tanks



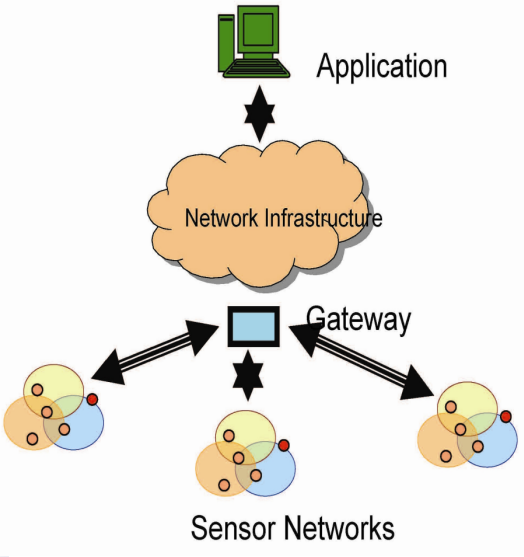
Implications

- Human health
- Quality of bathing waters
  - Contamination of food
  - Plant and animal life
- Local businesses
  - Fisheries and aquaculture
  - Port operation
  - Leisure and tourism
  - Wider economy

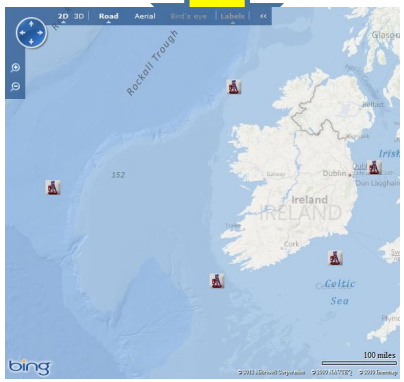
Issues

Dynamic environments – need to be monitored and protected, better understanding of environmental processes allows us to create models, make predictions and better manage our environment.

Wireless Sensor Networks



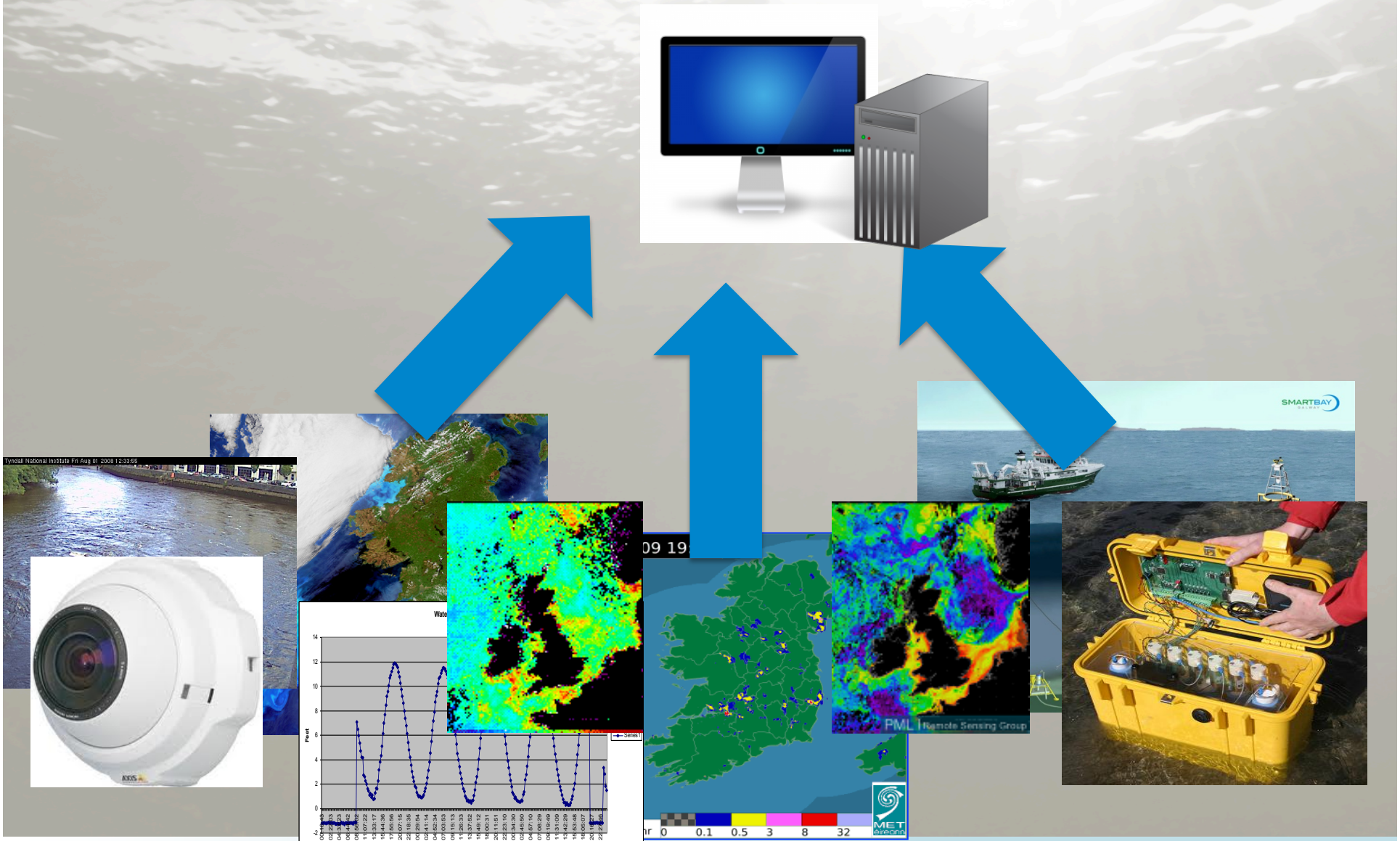
Issues in relation to
-Scalability
-Reliability



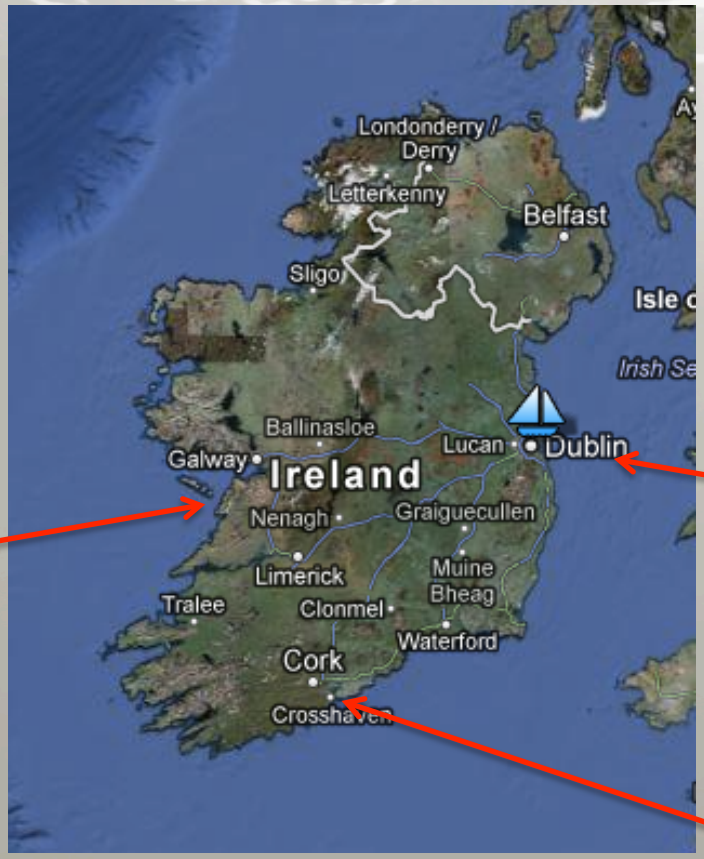
However …

- Sensors are exposed to harsh conditions and biofouling
- Limited spatial resolution
- Difficult to monitor large areas over long periods
- Unsuitable for some environments and realtime detection of some events
- Very costly
- How can we use these devices more intelligently ?

Multi-**Modal** Sensor Network



We have Three Test Sites we worked on

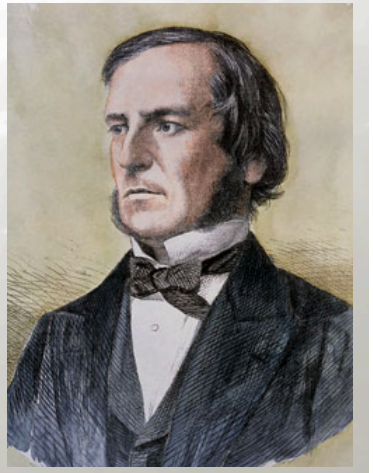


Galway Bay

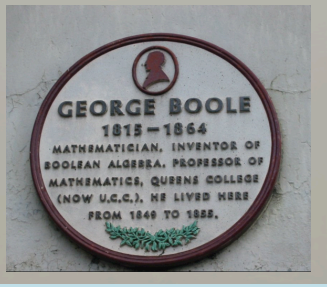
Poolbeg Marina

River Lee

River Lee



- River Lee in Cork City … interesting from an environmental perspective, challenging to monitor
- Historically significant … George Boole in 1853 illustrated how to combine probabilities of independent events
- *"Opposite the window of the room in which I work is a field, liable to be overflowed from two sources, distinct, but capable of being combined, viz., floods from the upper sources of the River Lee and tides from the ocean."*



River Lee

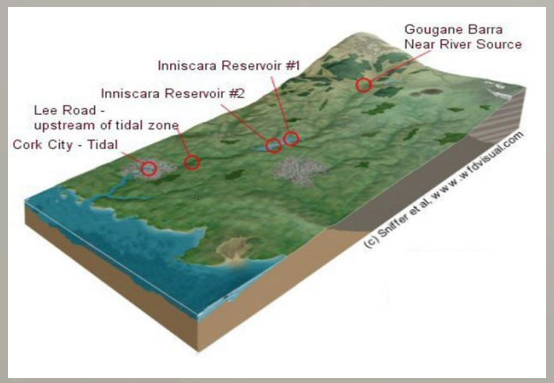
- Big problem with River Lee is algal bloom caused by increased phosphates and nitrates which are runoff from fertilisation of upstream farmland
- How to detect, track back, locate, prosecute, deter and prevent ?
- Need a phosphate / nitrate detector

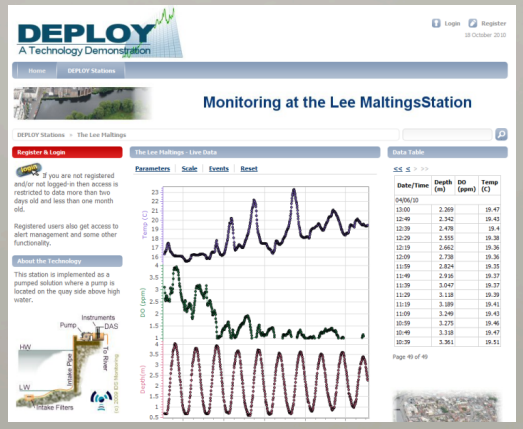
Insight

Existing DEPLOY Sensor Network

DEPLOY
A Technology Demonstration

DEPLOY is a technology demonstration project which aims to show how state of the art technology can be implemented for cost effective, continuous, real-time monitoring of a river catchment.





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pH sensing – wasn't that solved by Nikolskii in the 1930's?

EVENT	DATE
Launch (San Francisco)	September 2013
PHASE 1: Innovation Phase	
Registration opens	January 1, 2014
Early-bird Registration deadline	March 2014
OA Solutions Fair and Kick-Off Event	March 2014

OVERVIEW

Overview

Competition Guidelines

Competition Schedule

Registration Process

The Challenge: Improve Our Understanding of Ocean Acidification

The Wendy Schmidt Ocean Health XPRIZE is a $2 million global competition that challenges teams of engineers, scientists and innovators from all over the world to create pH sensor technology that will affordably, accurately and efficiently measure ocean chemistry from its shallowest waters… to its deepest depths.

There are two prize purses available (teams may compete for, and win, both purses):

A. $1,000,000 Accuracy award – Performance focused ($750,000 First Place, $250,000 Second Place): To the teams that navigate the entire competition to produce the most accurate, stable and precise pH sensors under a variety of tests.

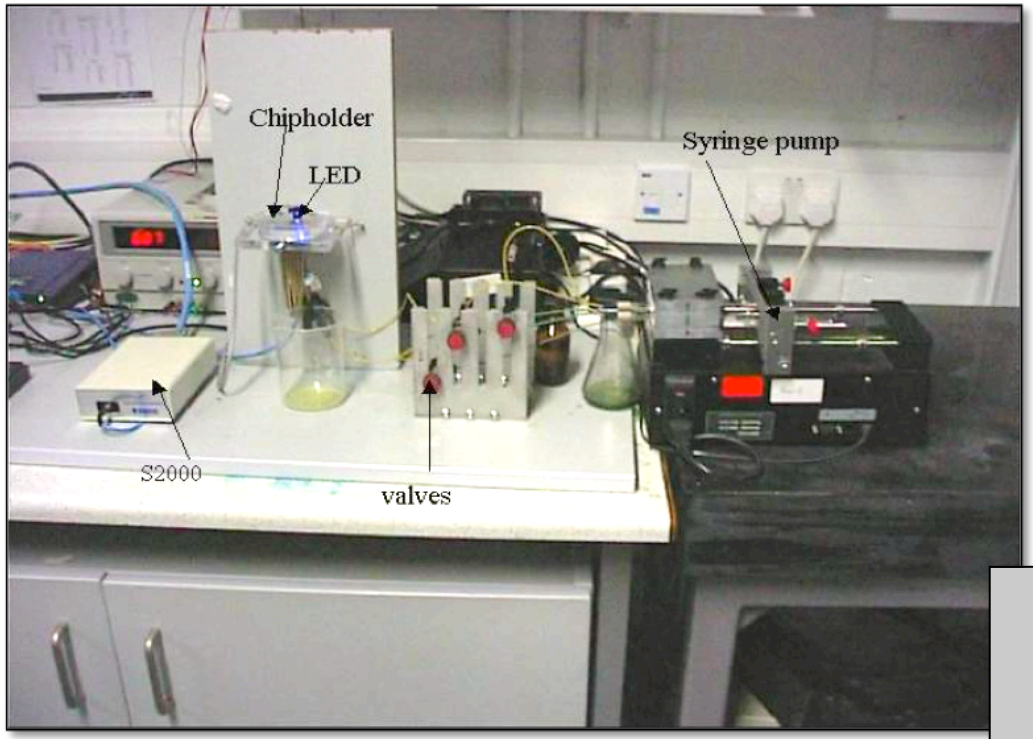
The Wendy Schmidt Ocean Health XPRIZE on acidification of the ocean

$2,000,000 up for grabs!

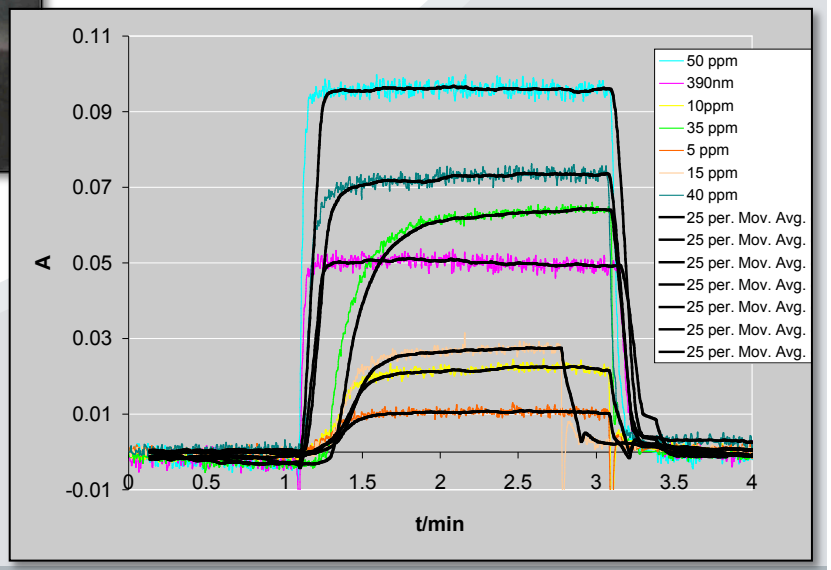
Challenge is to provide a way to do reliable measurements of pH in the ocean environment

The winner will almost certainly be a reagent based platform, not a conventional chemical sensor

Reagent based Nutrient Analyser

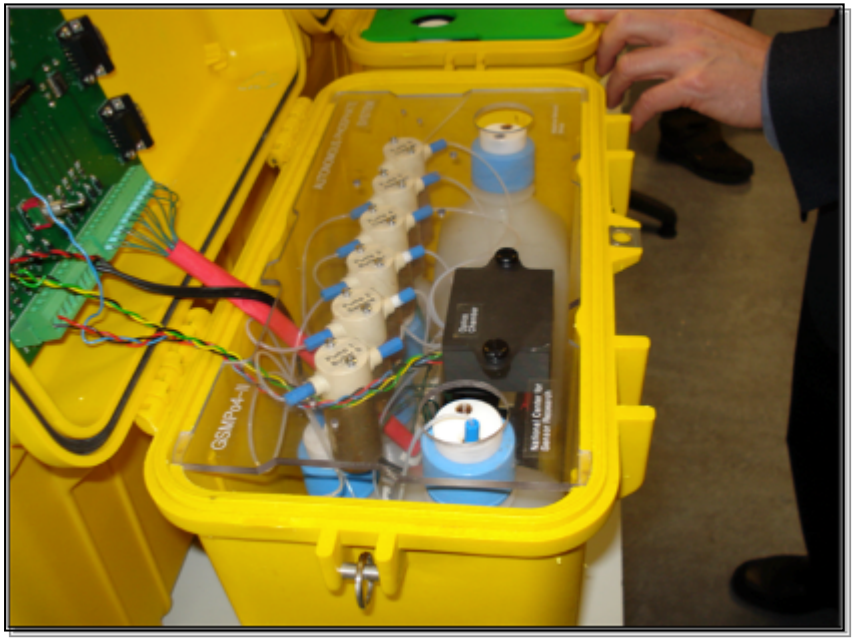


- Setup ca. 1999
- Worked well but not an integrated system



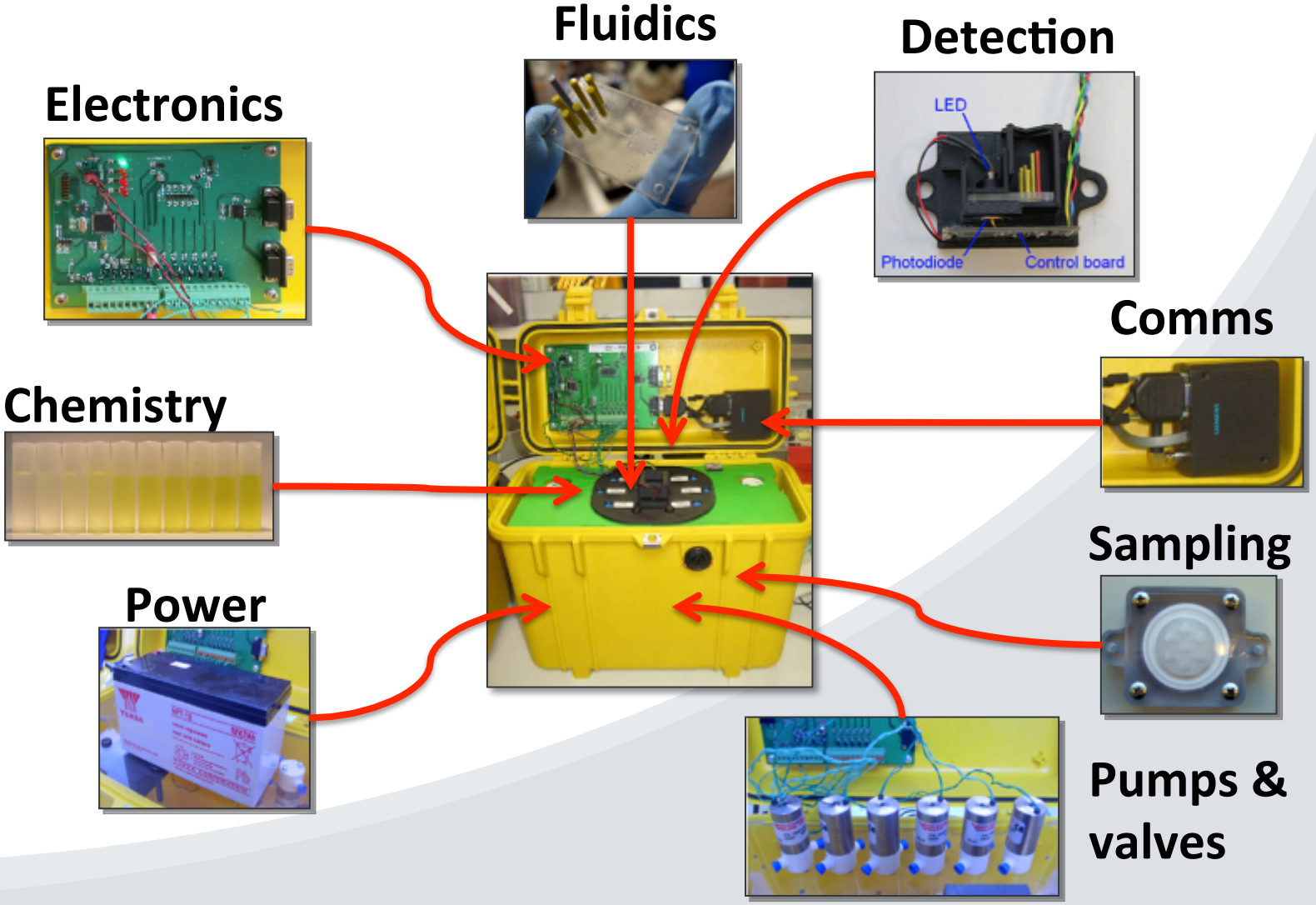
Chemical Sensing using an Integrated uFluidic System based on Colorimetrics: A Comparative Kinetic Study of the Bertholet Reaction for Ammonia Determination in Microfluidic and Spectrophotometric Systems, A Daridon, M Sequiera, G. Pennarun-Thomas, J Lichtenberg, E Verpoorte, D Diamond and NF de Rooij, Sensors and Actuators B, 76/1-3, (2001) 235-243.

Autonomous Reagent-based Nutrient Analyser (ca. 2008)



Complex system integrated into a robust platform: component cost ca. €2,000

Analyser Platform

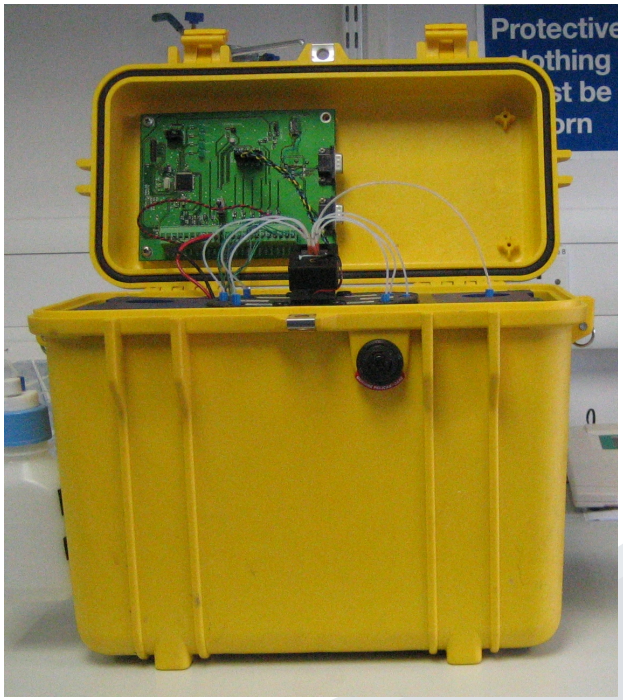


Evolutionary Improvements

Microlab

>€20,000 per unit

1st Gen System (2008)



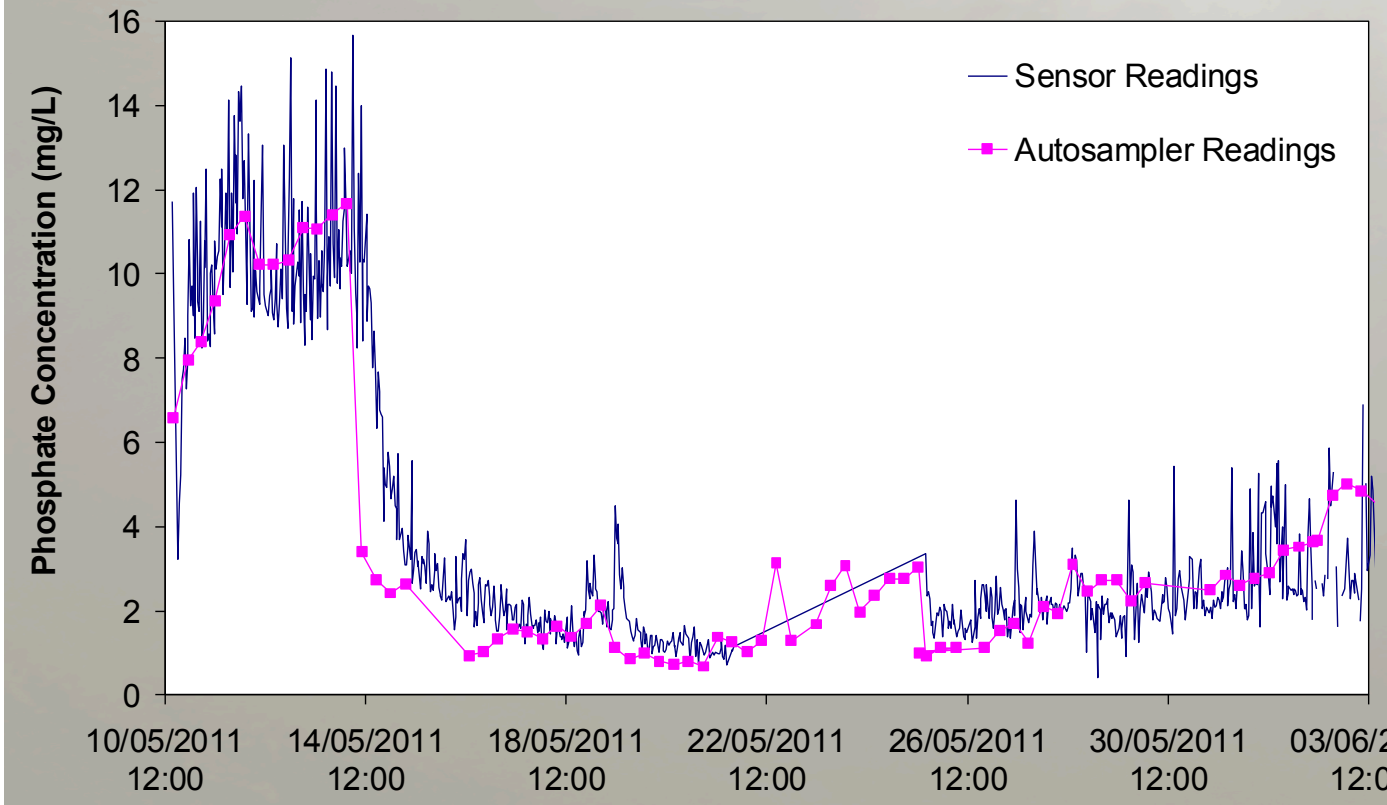
11 Deployments, almost 10,000 measurements

2nd Gen System (now)

Built 10 systems in our lab

Waste water treatment plant calibration

- ✓ Monitoring phosphate levels in effluent outflow
- ✓ Sensor performs hourly measurements
- ✓ Validation samples collected with an autosampler



Nutrient Sampler

- Problem with nutrient sampler is it is reagent-based .. requires sample of river water mixed with reagents to trigger colorometric reaction then storage of waste
- Microfluidics reduces sensor size and extends lifetime but every sample costs, so how to we sample *intelligently ?*
- We use multiple sensing modalities

Lee Maltings, River Lee

- Dynamic
- Tidal
- Dam upstream
- Located at Tyndall National Institute = network and power for the camera deployment
- SmartCoast sensors deployed until January 2009
- Deploy sensors deployed since April 2009
- … Temp, Turbidity, Depth, Conductivity, Dissolved Oxygen, pH, Nutrients

River Lee – Deploy Project Sites

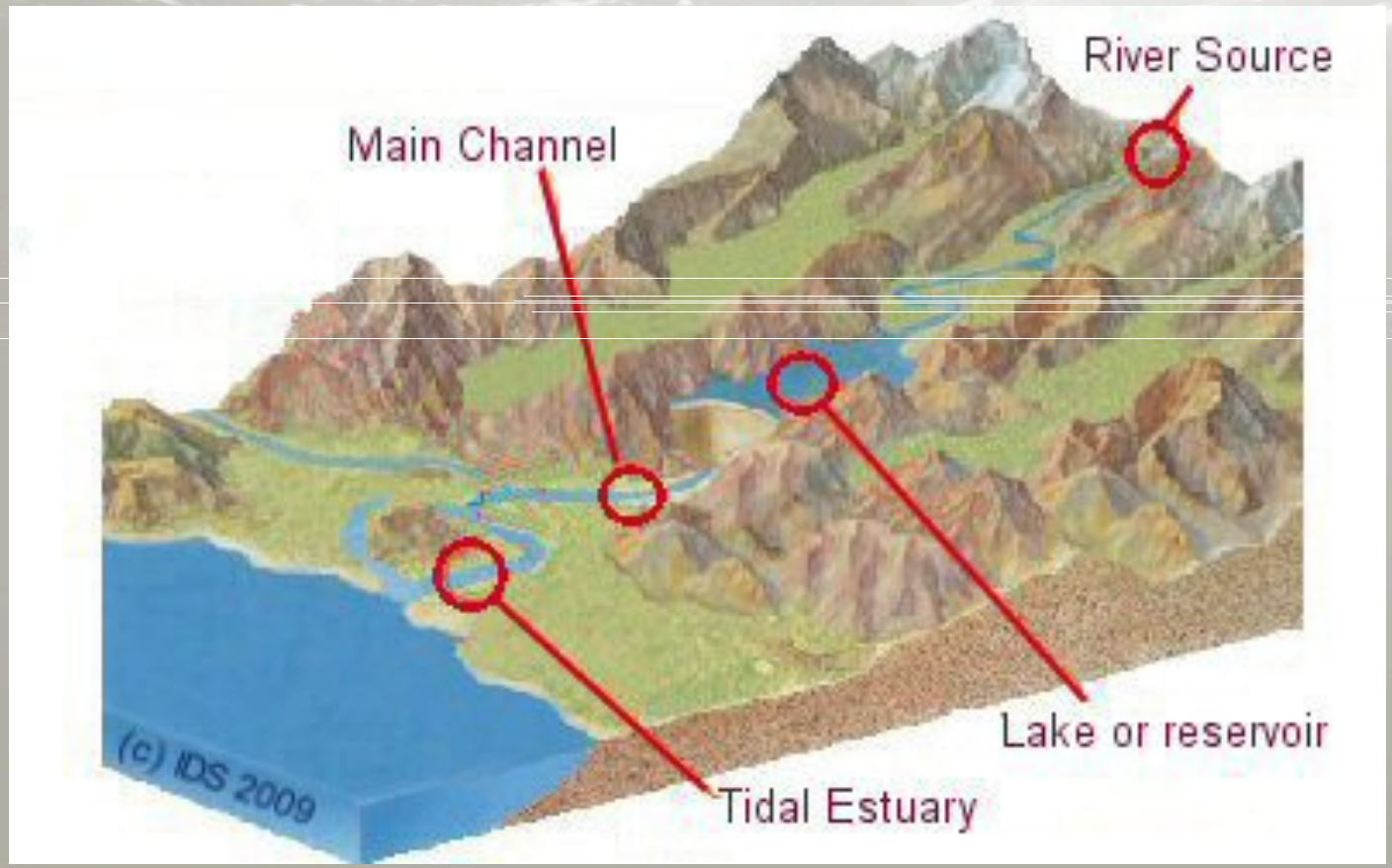


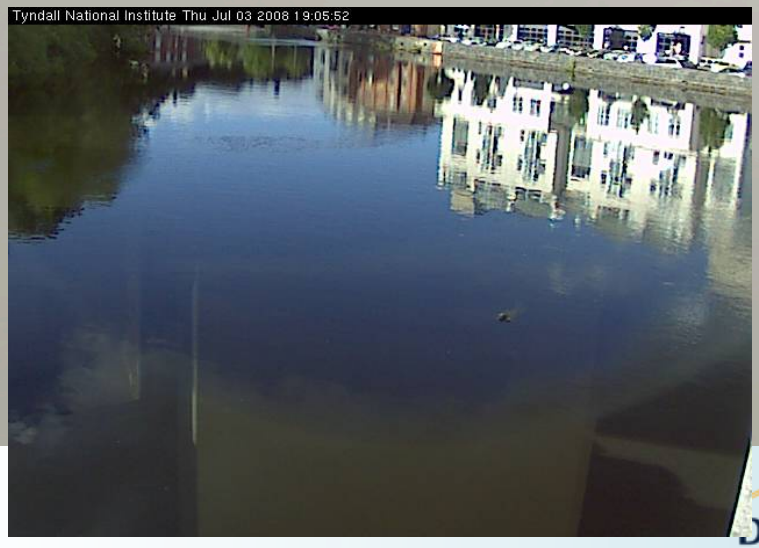
Image: www.deploy.ie (IDS: Intelligent Data Systems)

River Lee Visual Sensor

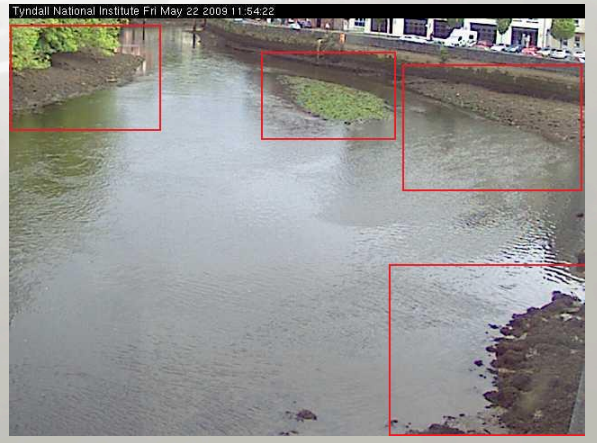
- AXIS 212 PTZ Network camera
- Low cost, low maintainance
- Act as “eyes” on the water to either dispute or validate the readings from in-situ sensors
- May be also used to detect other types of events such as biofouling
- Act as a back-up sensing mechanism if the in-situ sensor goes offline
- Alert if something of interest seems to be happening for adaptive sampling

Camera Angles

Challenging Variable Conditions



Water Depth Pilot Study



- To investigate potential benefits from the use of multiple sensing signals to monitor ➔ detection of water level.
- Investigates the complementary use of the in-situ SmartCoast / Deploy water depth sensor and the on-site camera in monitoring the level of water at the river location.
- The singular use of either sensing mechanism has potential drawbacks in environmental monitoring, however when used in unison, some of these potential issues may be compensated for.

Water level estimation from image data

None

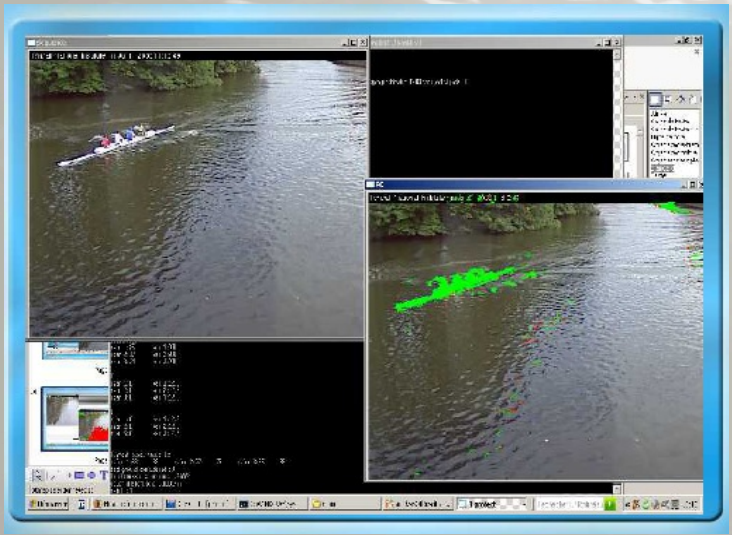
Low

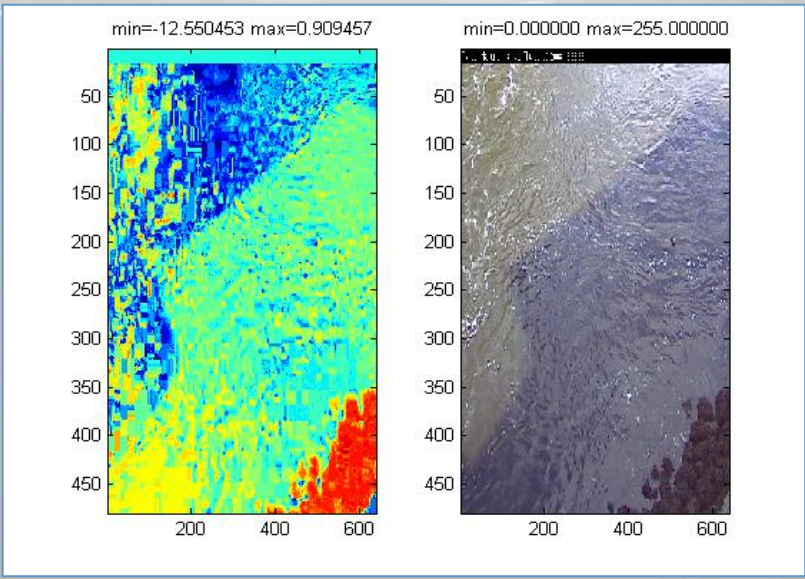
Medium-Low

Medium-High

High

We built an Image Classification System for depth estimation





Results: Overall Accuracy vs. Sensor

Approach was to train a machine learning algorithm to learn depth from the groundtruth of the depth sensor.

Input is low-level features from images, algorithm (automatically) uses the most appropriate features. We tried several classification approaches

	C_1	C_2	C_3
Class Distance Error	0.642	0.537	0.302
Classification Rate	0.467	0.732	0.750

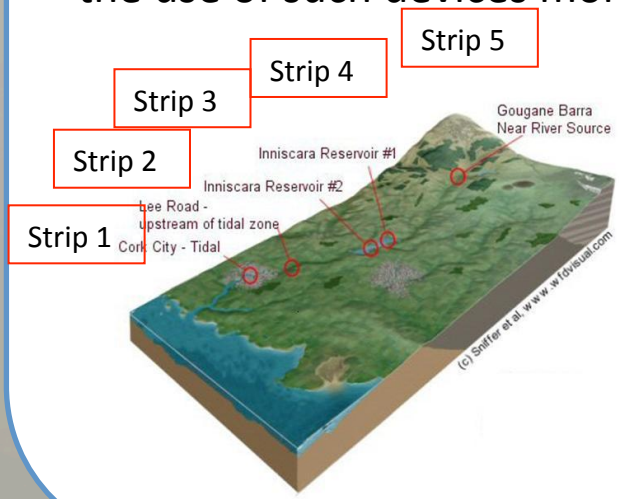
The best performing classifier classified 75% of the images correctly.

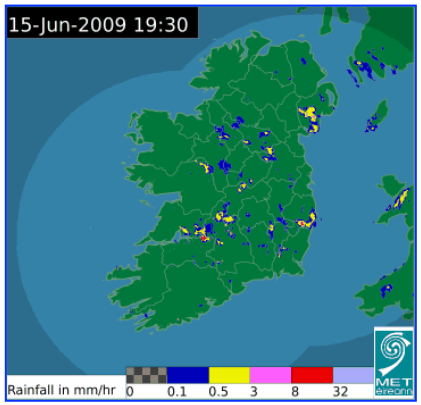
Future … more sophisticated algorithims for classification of visual features and examine correlations between in-situ sensor readings and image features.

Multimodal Sensing in Lee Maltings

Investigation of the incorporation of **rainfall radar image data** and **in-situ depth data** into an **artificial neural network (ANN)** for predicting average freshwater levels.

Objective: Provide context information to control the operation of an expensive, limited sampling in-situ phosphate sensor at the Lee Maltings site, hence making the use of such devices more **efficient** and **scalable**.





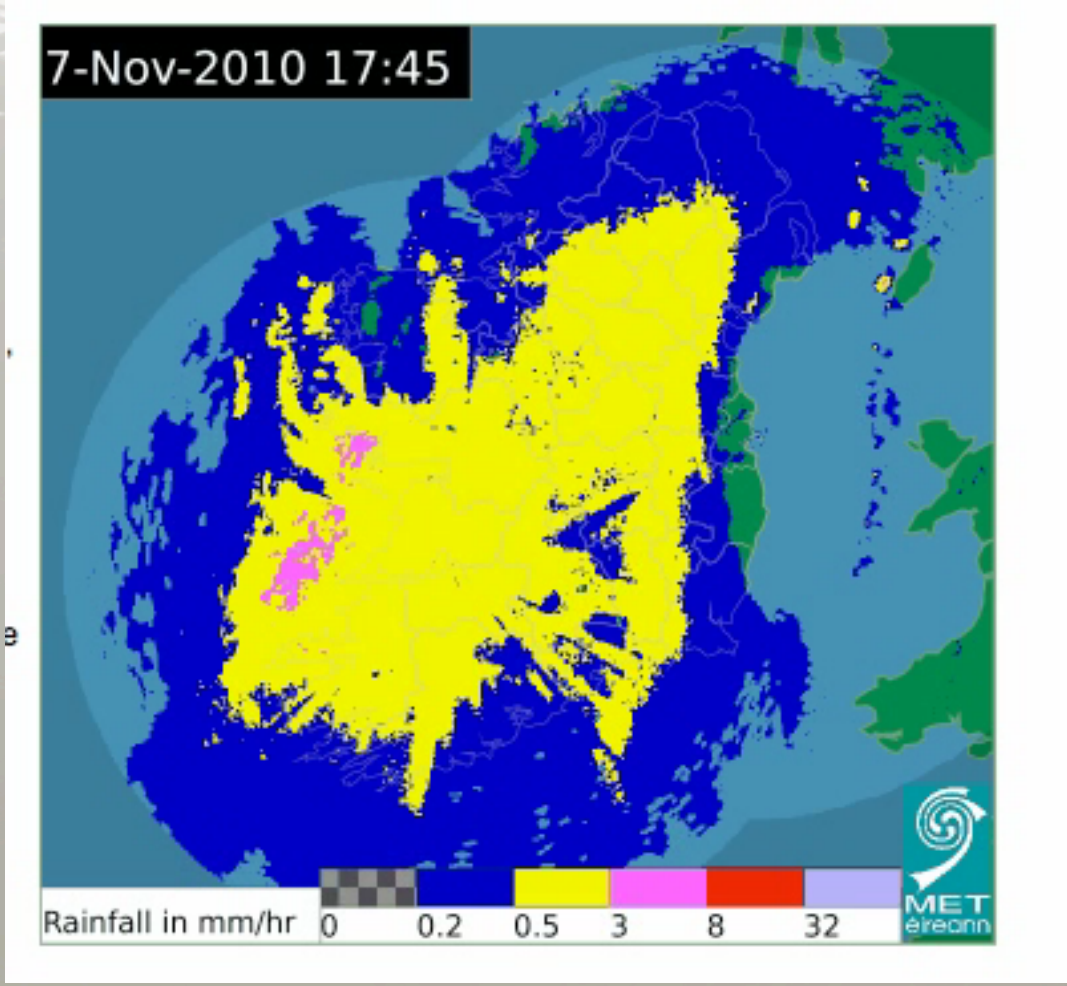
Rainfall radar

Two radar stations in Ireland, fused

1km^2 resolution, 5 levels

Updated every 15 minutes

Poor resolution close to radar stations



RR to control Nutrient Sampling

- The most significant indicators of nutrients in river, are time of year, and rainfall runoff upstream *c.f.* city street pollution
- Use RR to predict freshwater level at Lee Maltings, then detect nutrients
- We extended the lifetime of nutrient sampler by *intelligent sampling*
- Fusion of multi-modal sensor sources gives enriched picture, more informed decision-making

Unreliable Sensing

- For Lee Maltings and other sites, faced with issue of unreliable sensors when aggregating heterogeneous sensor types.
- We integrated a trust and reputation framework – RFSN, a software integration tool – into both, to handle this issue

Examined different application scenarios for RFSN:

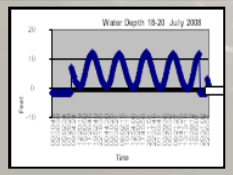
1. Determining the most reliable model for the prediction of in-situ parameters at the Lee Maltings
2. Determine the most reliable SST remote for Galway Bay

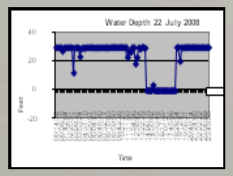
Reputation-Based Framework for High Integrity Sensor Network (RFSN)

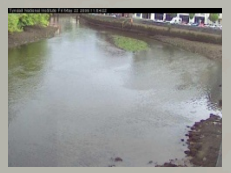
- The main challenges of a reputation system are:
  - The representation of reputation
  - How the reputation is built and updated
  - How the ratings of others are considered and integrated
- RFSN builds trust and reputation for each node, continuously refined
- RFSN employs a Bayesian formulation, specifically a beta reputation system, for the iterative steps of reputation representation, update, integration and trust evolution
- The two key components of RFSN are *Watchdog* and *Reputation*
- Designed to counter arbitrary misbehaviour of nodes in a WSN

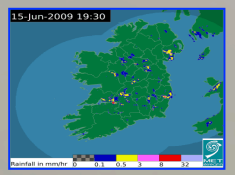
Insight

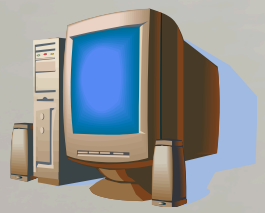
Application of a reputation and trust based framework – Example Water Level Detection











RFSN

WATCHDOG

REPUTATION SYSTEM

Input - Trust metrics for each of the nodes when requested

Event Detection System

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Trust and Reputation

What is meant by TRUST and REPUTATION of nodes in a network?

- when a node is *trusted*, it implicitly means that the probability that it will perform an action that is beneficial or at least not detrimental in the network is high enough to consider engaging in some form of cooperation with the node. (Gambetta, 1988)
- Reputation is the trustworthiness of a node; the opinion of one node about another node, and it is a confidence that evolves over time

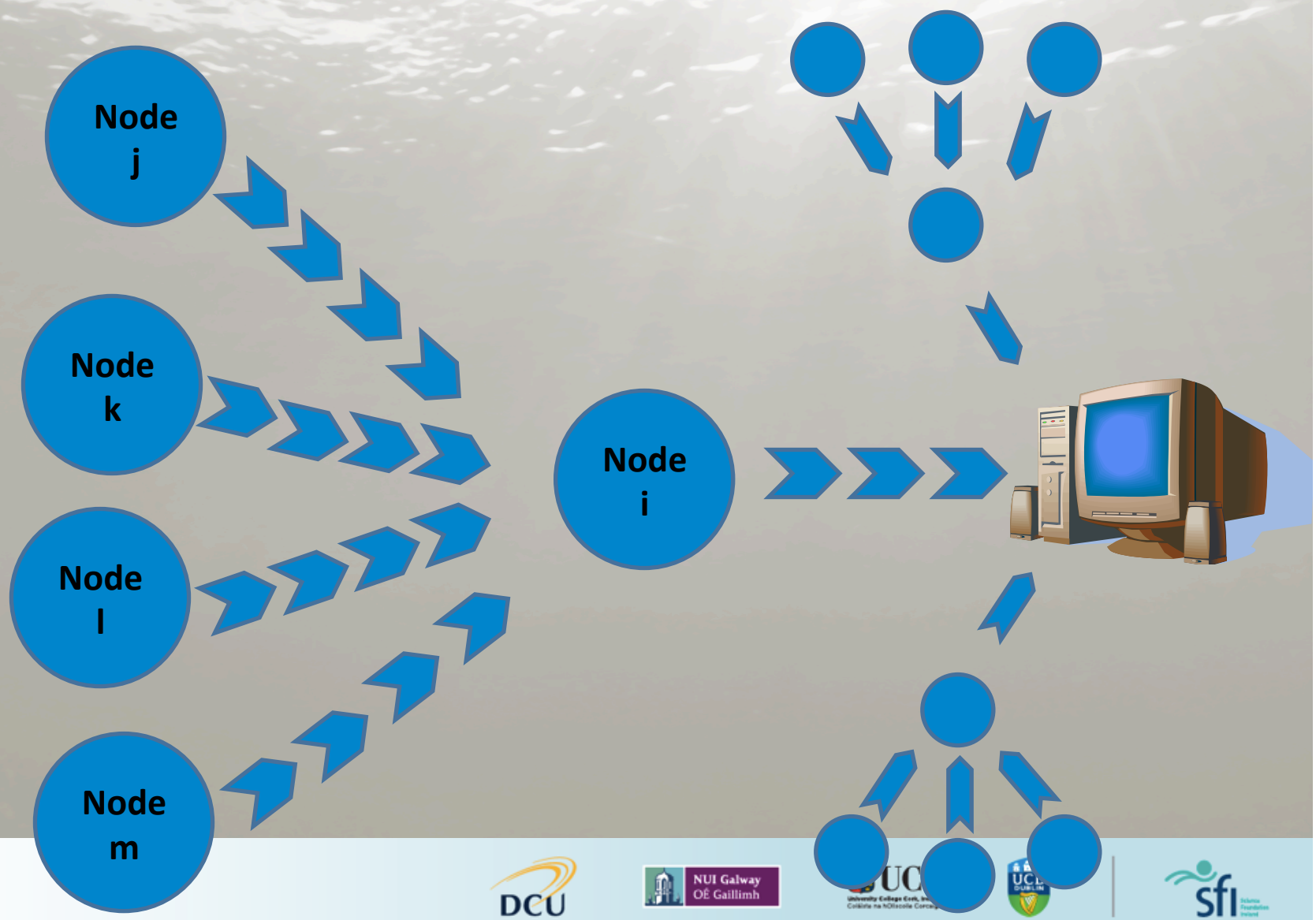
Reputation-Based Framework for High Integrity Sensor Network (RFSN)

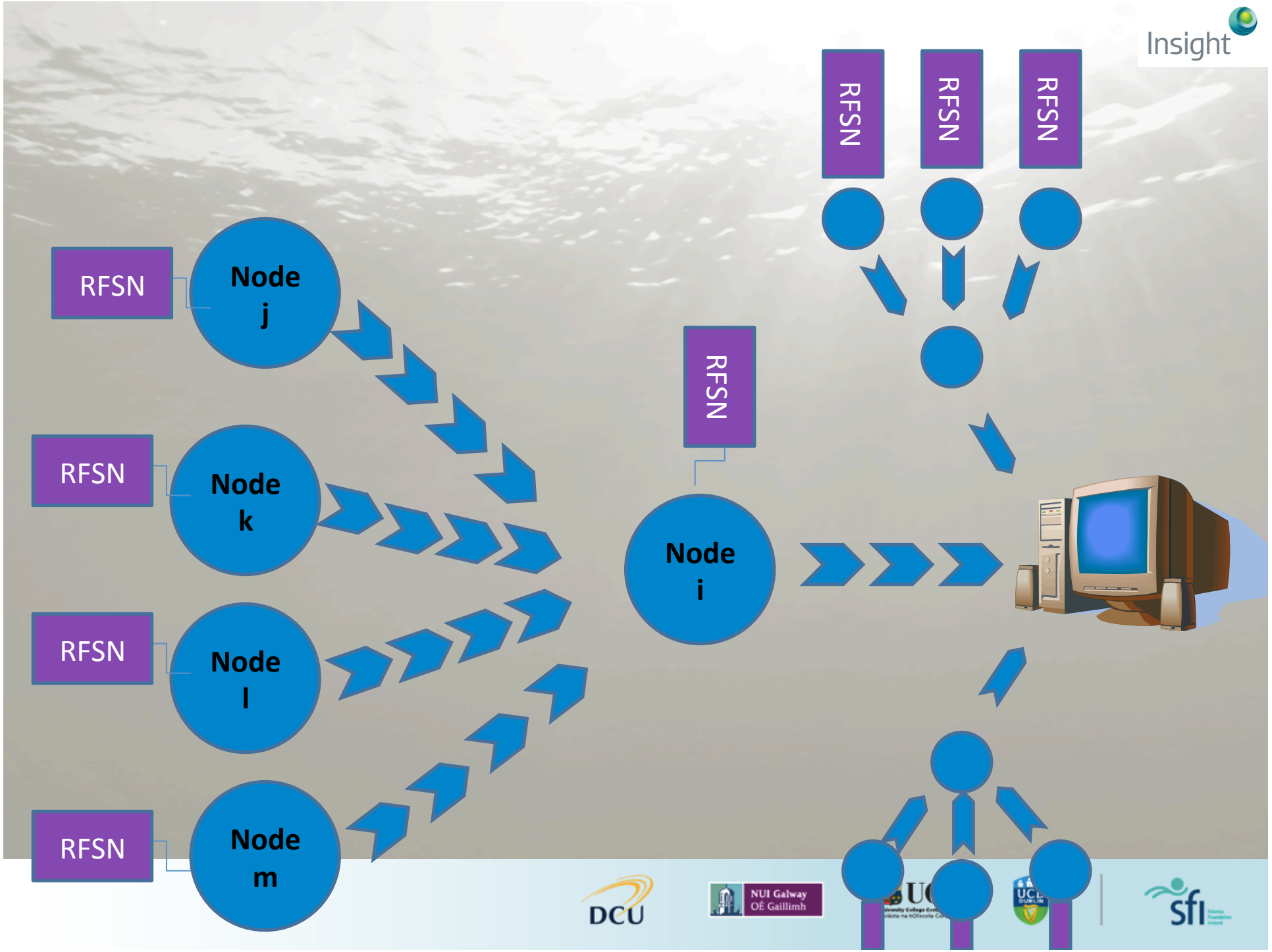
- **The main properties of a reputation system are:**
  - The **representation** of reputation
  - How the reputation is **built** and **updated**
  - How the **ratings of others** are considered and **integrated**

- **RFSN** employs a **Bayesian formulation**, specifically a **beta reputation system**, for the algorithm steps of **reputation representation**, **updates**, and **integration** and **trust evolution**.

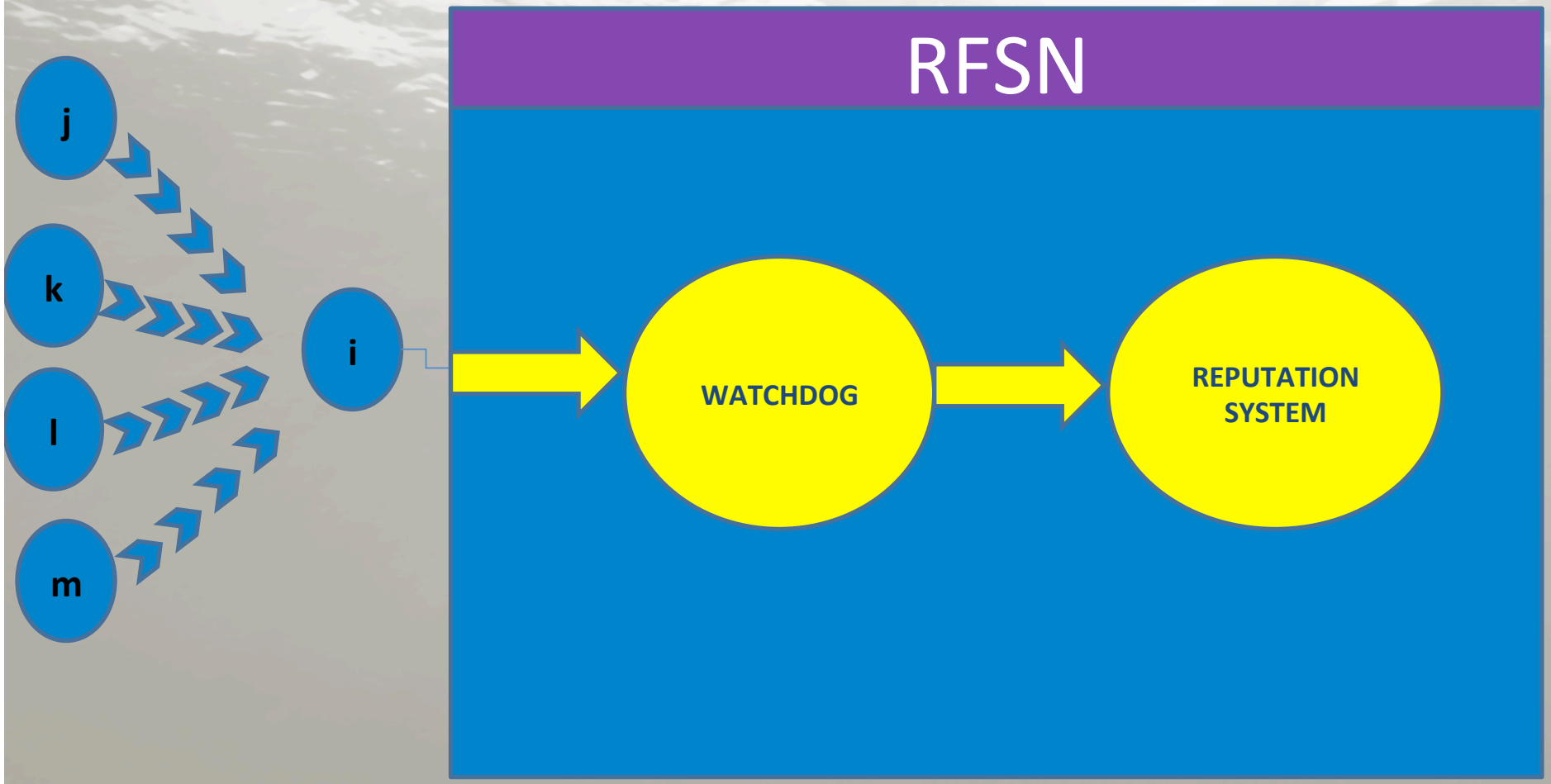
- Our **adaptation of this model** helps to **provide information** about the **data accuracy** in a **multi-modal sensor network**

Community of Sensor Nodes

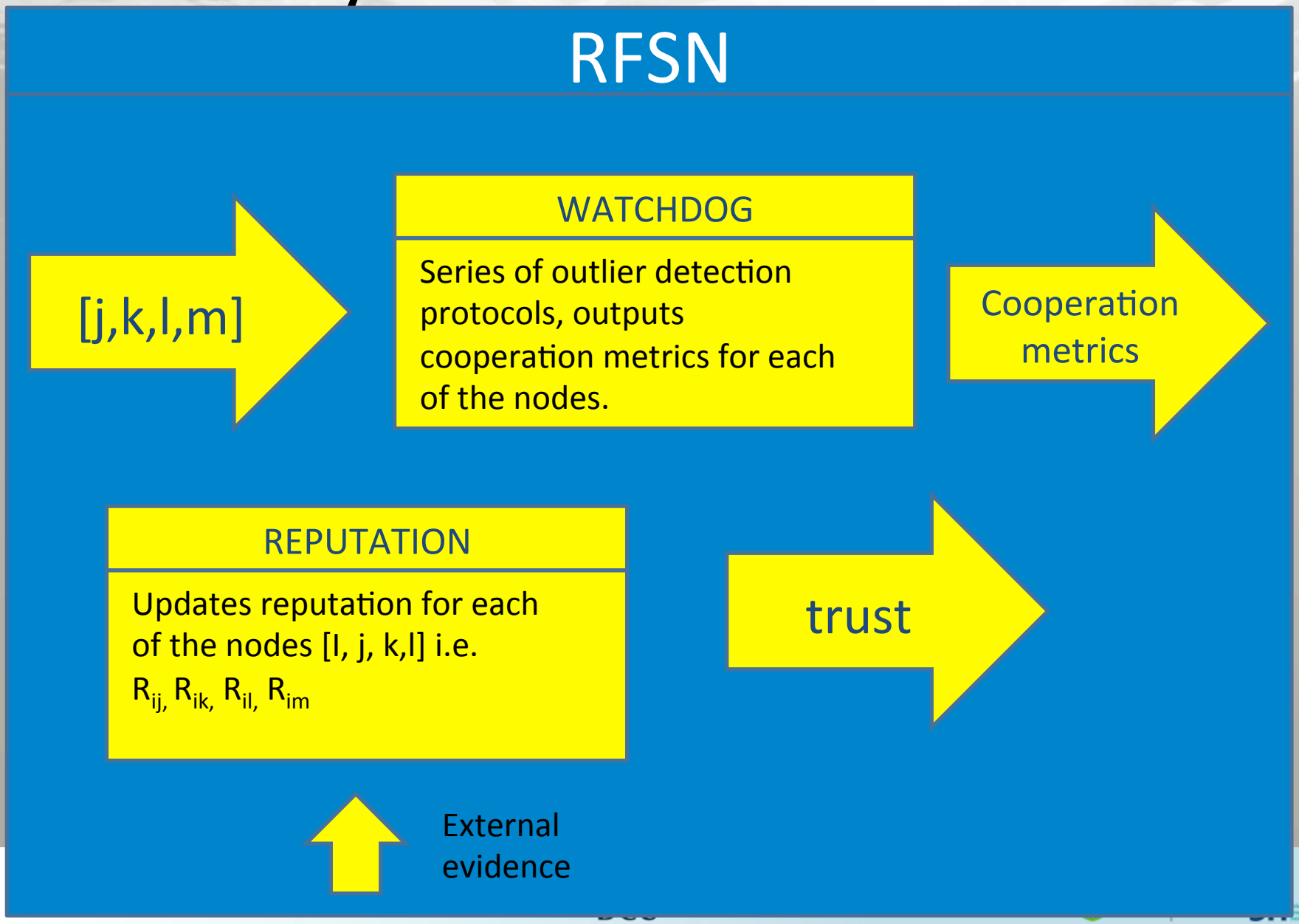



Insight
RFSN
RFSN
RFSN
RFSN
Node j
RFSN
Node k
RFSN
Node i
RFSN
Node l
RFSN
Node m
DCU
NUI Galway
OÉ Gaillimh
UCD
SFI

Community of Sensor Nodes



Community of Sensor Nodes



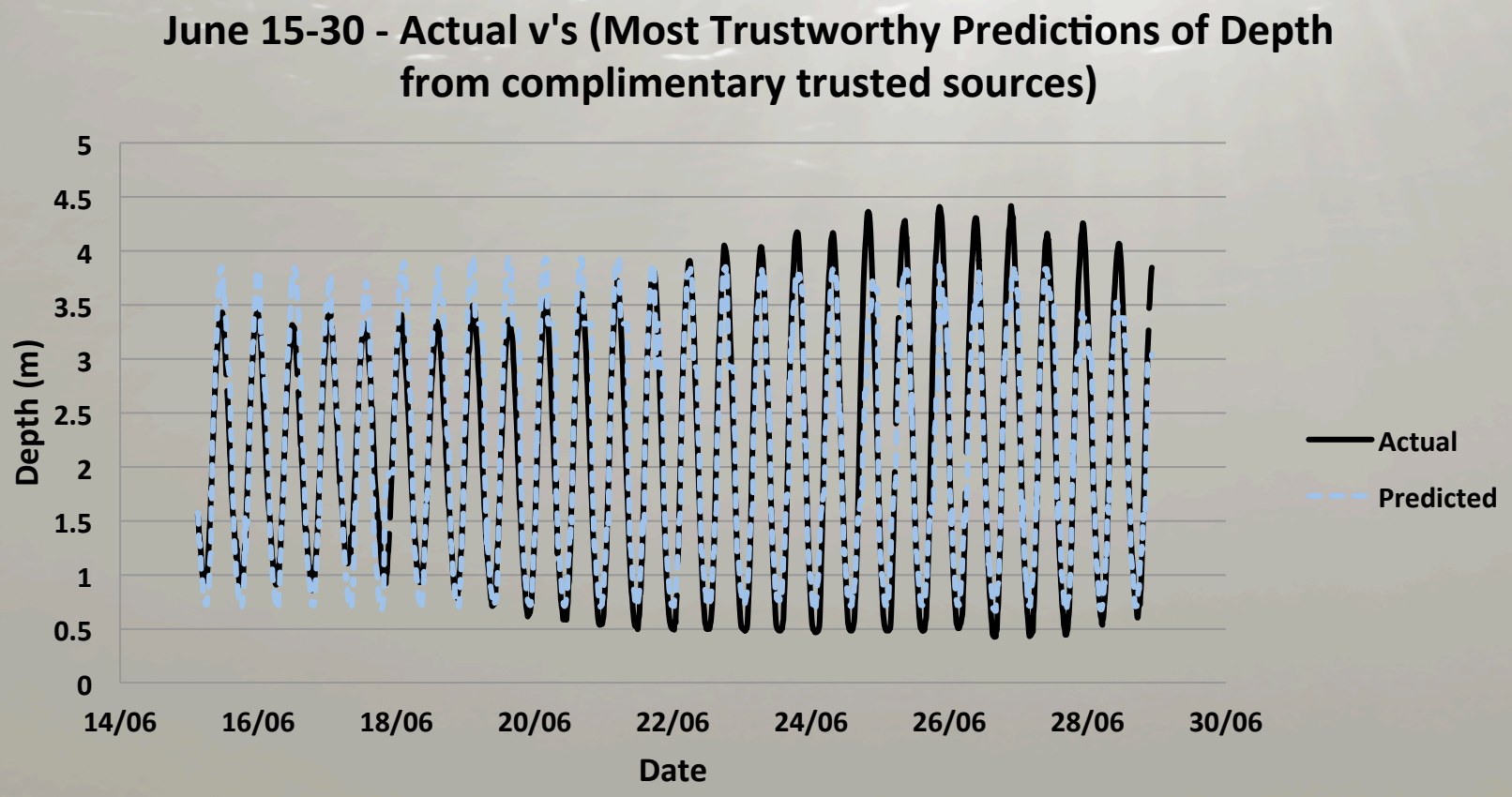
Adaptation of RFSN to multi-modal sensor networks

- Why RFSN?
  - Strong foundation in **statistics**
  - Can **counter any arbitrary misbehaviour** of nodes
  - Directly addresses the issues of **data quality**
  - Outlines a **detailed framework of application,** developed as a middleware service on motes
  - Other trust frameworks in the literature **address issues that are not relevant in the context of this research** e.g.
    - *An Architecture for Dynamic Trust Monitoring in Mobile Networks –**DDDAS*** **(Onolaja , 2009)**
    - Trust Management problem in Distributed Wireless Sensor Networks - **GTMS (Shaikh, et al, 2006, 2009)**
    - *Event-based trust framework model in Wireless Sensor Networks **(Chen et al 2008)***
    - *Behaviour-Based Trust in Wireless Sensor Networks* **(Huang et al, 2006)**

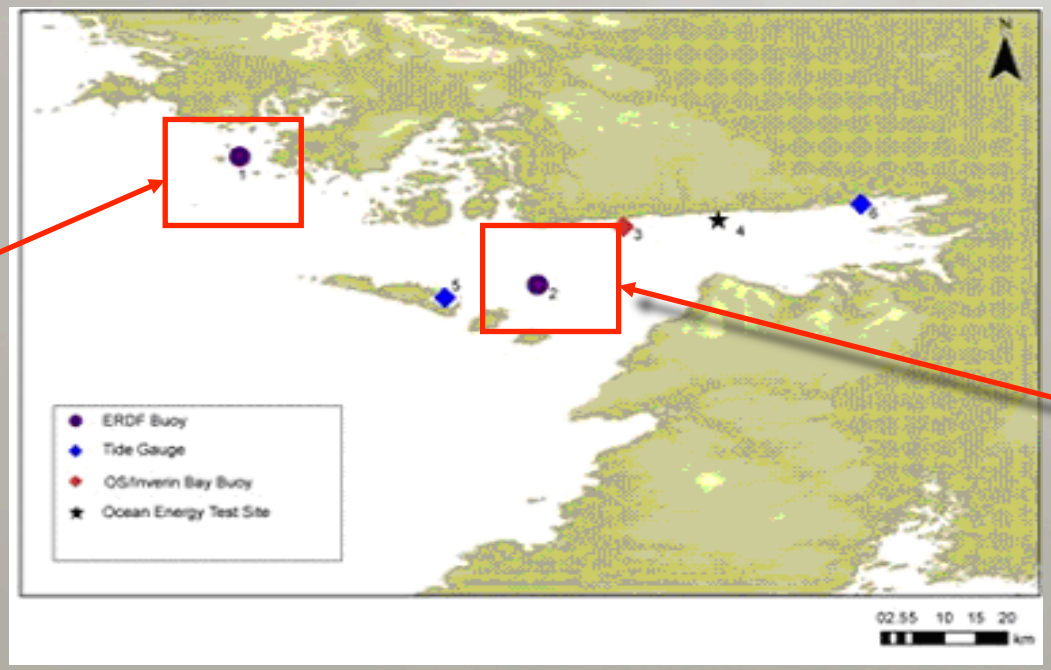
RFSN and Sensor Fusion

- Incorporating RFSN to account for calibration drift, errors, missing data, we compute sensor values for missing or mis-behaving sensors, from combinations of inter-dependent others
- RFSN manages the data quality

RELIABILITY



Also did SST Estimation in Galway Bay



Mace Head SmartBuoy

MidBay SmartBuoy

Multimodal sensor fusion

- Fusion of multiple sensors as presented here is non-trivial because streams have errors
- Analogous to multi-modal retrieval in multimedia, where concept detectors have differing **but consistent** reliability
- Imagine using a concept detector for video retrieval whose accuracy varied with … the time of day !
- Underlying the fusion, and similar to any wireless sensor network data fusion, we have built and use a trust and reputation framework

Conclusions and Contributions

- From our work at Lee Maltings, Galway bay, Dublin port … combination of diverse heterogeneous information sources gives a more complete picture of what is happening.
- At Lee Maltings, from in-situ sensors, we gain information at a *greater temporal resolution* for *specific points* on the river, however the image data provides *greater coverage* of the area at a *coarser resolution.*
- At Lee Maltings, image data provides a useful tool for observing overall trends in the river and correlates well with the in-situ data.
- Similar findings for Galway Bay and Dublin port

Conclusions and Contributions

- … if the in-situ sensor goes offline, the satellite data provides a back-up sensing mechanism and reduces the possibility of missed marine events.
- … if the depth sensor goes offline, the visual sensor provides a back-up sensing mechanism which reduces the possibility of missed river events.
- … if the in-situ sensors detect a change, it is possible to validate that change through information from an alternative sensing modality, subsequently constituted as representing a real event and not just the result of problems with the in-situ sensor.
- Greater understanding of phenomena along with increased information for better decision making.

Summary

- I have presented an overview of basic sensing
- I have introduced sensors as a data deluge of errorsome, unreliable data
- I have highlighted the importance of sensors in environmental monitoring for scalability
- I have presented some deployments from our work
- I have shown the problems in sensing for environment have a lot of similarities with work in multimedia fusion but it has even more challenges

Acknowledgements

- Based on research funded by the Dept. of Communications, Marine & Natural Resources under the Strategy for Science, Technology and Innovation (2006-2013) and by Science Foundation Ireland under grants 07/CE/I1147 and 12/RC/2289.