Sediment in the Mississippi River (Courtesy Liam Gumley, University of Wisconsin-Madison/MODIS Science Team. Source: NASA, reproduced with the permission of the Lunar and Planetary Institute)

A walk down the 'water column'

Each year billions of tonnes of sediment are carried down rivers to the sea, and then fall down the 'water column' (a vertical stretch of sea) eventually to settle on the seabed – the Ganges alone transports 2000 million tonnes per anum. **Professor Tim Leighton** from the University of Southampton's Institute of Sound and Vibration Research (ISVR) looks at how, in following the same route, we can visualise the range of ways in which waves and communications are exploited for ocean exploration.

Vast quantities of suspended particles, many as small as a micron in diameter, rise from river beds. While gravity tends to make them settle out, turbulence, tidal action, and waves keep them in suspension. The flow over estuaries or seabeds can stir more particles into suspension. Professor John Chaplin and colleagues in the University of Southampton School of Civil Engineering and Environment have examined the way ripples on the seabed can disturb the flow of water over them.

Ripples on the seabed can trigger boundary layer instabilities that can ultimately lead to turbulence. These changes in turn affect the development of the ripples. The vortex structures can be visualised by injecting fluorescent dye into the bottom boundary layer.

The importance of such 'sediment in transport' has been recognised for thousands of years: its deposition during the annual flooding of the Nile determined the fertility of the land, a dominant feature in the religion, culture and politics of Egypt from 4500BC until the last century.

Today the presence of suspended sediment erodes beaches and forms new ones, and reduces the ability of active sonar systems to detect mines and torpedoes – the sonar equivalent of the effect of fog on car headlamps. Conversely, the acoustic scattering and absorption it produces can be used to monitor this environmentally important feature. In collaboration with QinetiQ at ISVR we have developed and validated the underlying science required for these applications. The Optoelectronics Research Centre (ORC) at the University has developed a biosensor which can simultaneously measure 32 different organic pollutants in real time. This is now in operation at several sites in Europe, monitoring pollution in rivers, side streams, estuaries and along coasts. ▶

Breaking waves

Breaking waves will play a key role in understanding climate change. They drive the exchange of momentum, heat and mass between the atmosphere and the ocean. More than 1000 million tonnes of atmospheric carbon transfers each year between the atmosphere and oceans. Also an understanding of the 'breaking' of the air/water interface can help to reduce the drag created at the bow of a ship, minimise some of the risks to river and marine life from flow around structures, improve coastal defences, and assist in many processing industries from water treatment to fermentation.

The team in the School of Civil Engineering and the Environment has a wave flume in which water can be made to break in a highly repeatable way. The roles of bubbles and splashes are looked at by using probes that record the presence of gas or liquid at the tip of 10 micrometre diameter optical fibres. The sensor measures light internally reflected by the liquid and, with a resolution in time of much less than one microsecond, the tiny probes have a very small effect on the wave breaking events they are measuring. The wave breaking is so repeatable that the probes can be scanned throughout the volume during repeated wave breaks to build up a map of the bubble distribution. From this it's possible to calculate the proportion of energy loss in the breaking wave associated with the formation of bubbles and splashes, and can also estimate at any instant the total area of the liquid/gas interface across which air/sea exchanges can take place. This dovetails with ISVR's measurements at sea of bubble production beneath oceanic breaking waves using nonlinear acoustics.

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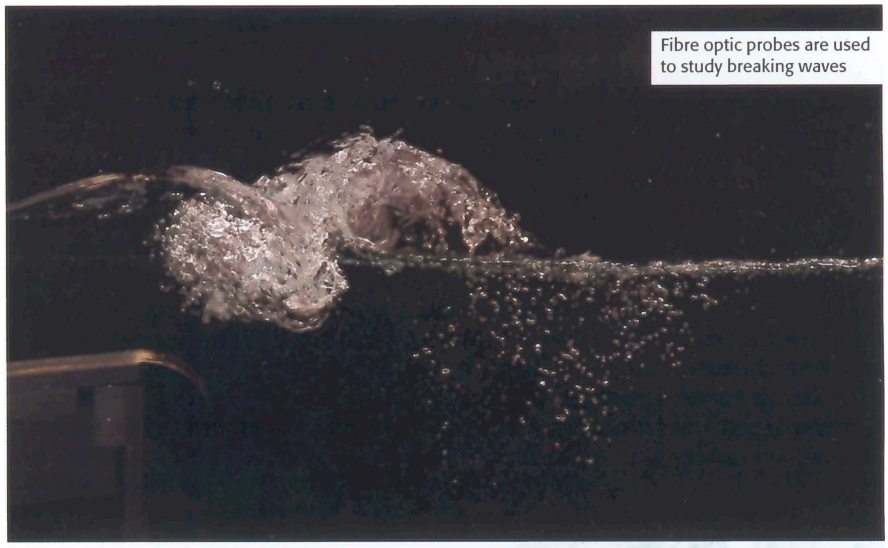
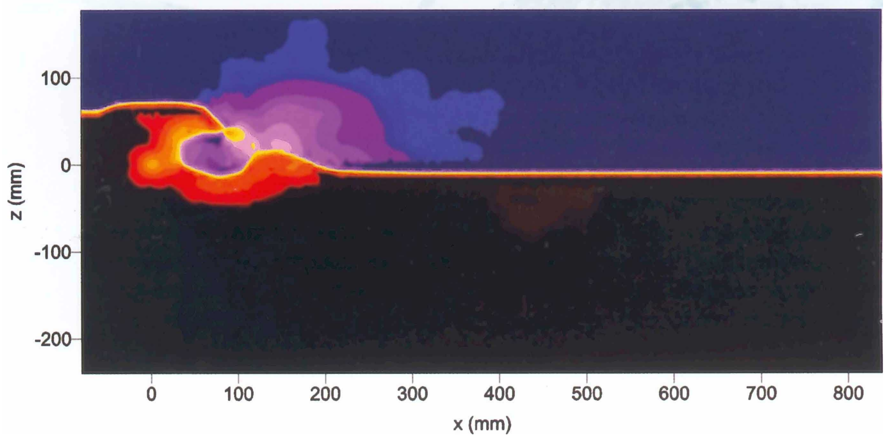

Fibre optic probes are used to study breaking waves



Whale acoustics

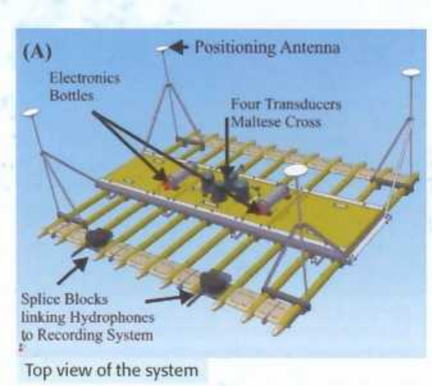
Sound plays a key role in the life of marine mammals living in the oceans allowing them to communicate, locate food and explore their environment. Man's exploitation of the oceans has had an adverse impact. The ecological stresses caused by our activities range from direct hunting, which has led to the near extinction of several species, through the killing and injury of animals in collision with ships, to acoustic disturbance caused by the expanding use of ship traffic and the ever-increasing use of acoustic devices, such as sonar. To understand the impact of these activities we need to be able to study the behaviour of marine mammals, and acoustics is a powerful tool. When justifying the impact of an activity we need to be able to determine the presence of marine mammals within an area; again acoustics is key. Collaborative work with Professor Paul White in ISVR and Dr Andrew Williams at the National Oceanography Centre, Southampton has examined a wide range of whale behaviour and acoustics, including developing methods for using acoustics to track marine mammals at sea and automatically to detect and analyse their calls.

For example, sperm whales *(Physeter macrocephalus)* dive to great depths (up to 2 km) to hunt for squid. During the dive they emit a series of regular clicks, used for locating prey. The unusual anatomy of sperm whales means that each click has a complex structure, and by analysing the structure of the clicks we are able to determine the size of an animal. By deploying an array of hydrophones (underwater microphones) the animal's path can be followed during the dive, providing marine biologists with insights into their social behaviour. This type of analysis is not restricted to sperm whales and can be applied to other deep diving marine mammals.

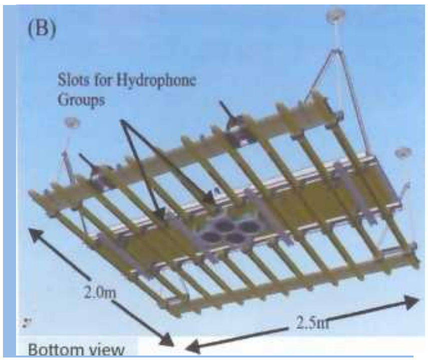
Particularly interesting are studies of beaked whales. Beaked whales are particularly sensitive to disturbance by high-powered sonar sources – there are examples of beaked whales being killed by interacting with military sonar systems. The mechanism of death is not well understood, and beaked whales remain mysterious creatures. Analysis of the vocalisations of a particular beaked whale species – the northern bottlenose whale *(Hyperoodon ampullatus)* – has revealed interesting structures in their sounds. In addition, the previous issue of *New Boundaries'* described the ways in which acoustics could be used by marine mammals to enhance the effectiveness of their hunting strategies.

3D chirp system in west Solent

"The system has been tested over a range of sites, including buried archaeological wrecks, and to survey the seabed prior to planned civil engineering constructions."



Top view of the system



Bottom view

"Not only does it offer the customer the first true 3D sub-bottom sonar images, but its attractive design features include the fact that it is small and easily deployable."

The world's first true 3D sub-bottom sonar

A collaborative team from the University (Dr Jon Bull, Dr Justin Dix, Dr Martin Gutowski and Dr Tim Henstock from the School of Ocean and Earth Sciences; and ISVR has worked with a GeoAcoustics Ltd to produce the world's first true 3D sub-bottom profiler – sub-bottom sonar has traditionally produced 2D images. However, enhancing sub-bottom sonar to 3D should be beneficial in areas as diverse as marine archaeology, mineral exploration and extraction, geology, and military applications. The device was designed to contain an array of 240 hydrophones, slotted into the 1 1 thin ' longitudinal section' arms.

A rising chirp sound – typically in the range 1–24kHz – is emitted from four sound sources (transducers) arranged in a Maltese Cross. The data give resolution of objects on scales of around 10–30cm in the top 20–30m of unconsolidated seabed. To survey an area, the device is towed behind a ship. For good results it is vital to know the positions and orientations of all the transducers and hydrophones the entire time the device is operational, and four positioning antenna use global positioning systems (GPS) to establish the position and orientation of the device.

The system has been tested over a range of sites, including buried archaeological wrecks, and to survey the seabed prior to planned civil engineering constructions. The system was recently been deployed in the sea with conditions up to a Force 4 and the optimal towing speed through the water was found to be $2ms^{-1}$. Seismic data was acquired within the west Solent over an area known to contain dipping and faulted limestones and mudstones. An area 75m wide by 750m long was surveyed. Data is currently being processed from a survey of the Invincible – a French ship which was captured by the British. She was refitted and about to go into battle against the French when, in 1757, she ran aground as she was being taken back to Portsmouth. Despite efforts to lighten her by removing the cannons and even the masts, she could not be re-floated, and sank in subsequent storms. The data should produce the world's first 3D sonar maps of a wreck buried in the seabed.The 3D Chirp system was licensed to GeoAcoustics Ltd in December 2004 to enable commercialisation. Likely commercial customers include companies in the oil and gas sector, defence industry, and large civil engineering projects. Not only does it offer the customer the first true 3D sub-bottom sonar images, but its attractive design features include the fact that it is small and easily deployable. As a result, it could be put on a plane and be anywhere in the world within 24 hours, and be towed by whatever boats are available on site. This quick-response option is far cheaper than sending a full survey ship on a journey of weeks or months. NB

1. New Boundaries, 1, 22-25, April 2005

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