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Briefing: Young Coastal Scientists and Engineers Conference 2013

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On 25–26 March 2013, 52 early career scientists and engineers, studying various aspects of coastal science, met at the University of Aberdeen for the ninth Young Coastal Scientists and Engineers Conference. The conference was jointly organised by the School of Engineering, University of Aberdeen, and Marine Scotland Science. Early-career scientists, researchers and practitioners presented 23 oral and 17 poster presentations over the 2-day meeting. The papers all had a coastal theme with a large diversity in the subjects covered, including waves, currents, tidal energy, coastal erosion, sediment transport, fluid mechanics and particle tracking. This briefing paper reports on the conference, and presents the keynote lecture and four papers voted to be of especially high quality by the panel of judges.

Notation

a	wave amplitude (m)
g	acceleration due to gravity (m/s)
k	wave number (m^{-1})
$S(\omega)$	wave energy spectrum (m^2/Hz)
t	time (s)
u	horizontal velocity (m/s)
v	vertical velocity (m/s)
x	horizontal coordinate (m)
y	vertical coordinate (m)
ε	wave steepness defined as $\varepsilon = ka$
η	free surface elevation (m)
λ_p	peak spectrum wave length (m)
μ	phase (rad)
T_p	peak spectrum wave period (s)
ϕ	velocity potential (m^2/s)
ϕ_s	velocity potential at the free surface (m^2/s)
ω	wave frequency (rad/s)

1. Introduction: Rory O'Hara Murray

The coastal zone is a dynamic and complex environment with physical changes occurring at a wide range of temporal and spatial scales. These developments are influenced by a large number of natural physical processes, but anthropogenic influences also play a key role. The UK has a strong maritime legacy and coastal regions have always been, and still are, important areas for industry and recreation. The seas and oceans have provided an essential food resource for millennia, and the offshore oil and gas industry has transformed the world's energy supply. The physical energy resource, such as offshore wind, wave and tidal energy, is also now starting to be utilised. Human developments in coastal regions, as well as further offshore, require harbours and ports along the coastline. The coastline has also historically been an main means of trade and communication, with large populations living in the coastal zone. For this reason it is often crucial to defend the coastline against natural changes. In order to design coastal defence schemes that work with nature, and to predict possible changes occurring due to any coastal engineering activities, it is incredibly important for coastal engineers to understand coastal processes in detail. The UK also has very diverse and culturally significant coastlines and coastal regions which are important to preserve for future generations.

For all these reasons it is essential to study coastal systems, in order to understand how they have changed in the past and will change in the future. This requires a multidisciplinary approach and for scientists from a variety of specialisms to use a large number of different tools. Opportunities arise for scientists working in a diverse range of specific fields such as acoustics, optics, fluid dynamics and computer modelling, as well as those studying specific coastal processes such as tides, waves and currents.

The UK has a strong coastal research community, and to encourage this further the Young Coastal Scientists and Engineers Conference (YCSEC) began in 2005 at Nottingham University. Every year YCSEC brings together early career researchers and practitioners, such as PhD students, post-doctoral researchers and recently qualified professionals, concerned with physical processes in the coastal environment. This year the keynote lecture was presented by Professor Peter Thorne, National Oceanography Centre Liverpool, summarising his work on sediment transport processes and the application of acoustic measurement techniques, and is presented here in Section 2. All the presentations were judged by a panel made up of the organising and steering committee and awards were given to the best oral and poster presentations. These papers and two other papers of particular merit have been selected for this publication. Next year the conference will be hosted by Cardiff University's School of Engineering (http://sites.cardiff.ac.uk/ycsec2014/).

2. Sediment transport; the triad, sound and a case study: Peter Thorne

Sediment dynamics in coastal waters has relevance to a broad spectrum of marine science ranging from the physical and chemical, to the biological and ecological. Sediment movement impacts on marine habitats, water quality, turbidity, biogeochemistry and morphology. Understanding these linkages is intellectually challenging and of great practical importance; hence sediment transport is studied globally.

2.1 The triad

The transport of sediments can be considered as arising from dynamic feedback interactions between the seabed, the hydrodynamics and the sediment movement. For example, flow separation and vortex generation due to flow over ripples on the seabed influences the suspension of sediment. Further, the shape of the ripples contributes to the overall flow resistance and the flow structure in the boundary layer. Yet the ripples themselves are a product of the local sediment transport. The term 'sediment triad' has been coined to describe these interactions.

2.2 Sound

Sound is a powerful tool for both measurement and the assessment of sediment transport models. It uniquely provides non-intrusive, collocated, high spatial-temporal resolution profiles of the flow, mobile sediments and bedforms; the dynamically interacting sediment triad. The concept of using acoustics for sediment transport studies is attractive and straightforward. A pulse of sound, typically in the range 0·5–5·0 MHz and millimetric in length, is transmitted from a downward-pointing directional sound source, usually mounted about a metre above the bed and the backscattered signal is gated into range bins and digitised. As the sound pulse travels towards the bed, sediments in suspension backscatter a proportion of the sound and the bed generally returns a strong echo. The former provides profiles of the suspended sediments and the flow, while the latter the time history of the bedforms. Acoustics has/is being developed to obtain such measurements, with sufficient spatial and temporal resolution, to allow the fundamental process of turbulence and intra-wave processes to be probed, while at the same time being non-intrusive.

2.3 A case study

To illustrate this application of acoustics, the problem of understanding sand transport over a rippled bed under waves is described. As waves propagate over a steeply rippled bed, vortex generation and shedding at flow reversal is considered to provide a mechanism capable of lifting sand into suspension to significant heights above the bed. The main prediction of the vortex concept is that sediment is carried up into the water column twice per wave cycle at flow reversal.

To investigate experimentally the concept of vortex entrainment of sediments, an experiment was conducted in a large wave flume (http://www.deltares.nl/en/facility/107939/delta-flume). The flume, one of the largest in the world (230 m long, 5 m wide and 7 m deep), allowed the waves and sediment transport to be studied at full scale. A paddle at one end of the flume generated waves that propagated along the flume over a sandy bed and dissipated on a beach at the opposite end. The bed was composed of coarse sand, which was located in a layer 0·5 m thick and 30 m long, approximately halfway along the flume.

To make the acoustic and other auxiliary measurements, an instrumented platform was deployed in the flume. Measurements were made of the bedforms, flow and suspended sediments; the interacting sediment triad. Using an acoustic sector scanner and a pencil beam acoustic ripple profiler, measurements of the bed were collected which showed the bed had vortex ripples. To obtain measurements of the flow, auxiliary current meters were used in conjunction with an acoustic 3-axis coherent Doppler velocity profiler. To obtain the third component of the sediment transport triad, the suspended sediments, a three-frequency acoustic backscatter system was used. All the measurements were synchronised so that patterns in the suspended sediment concentration, the near-bed oscillatory flow and the bedforms could be assessed concurrently.

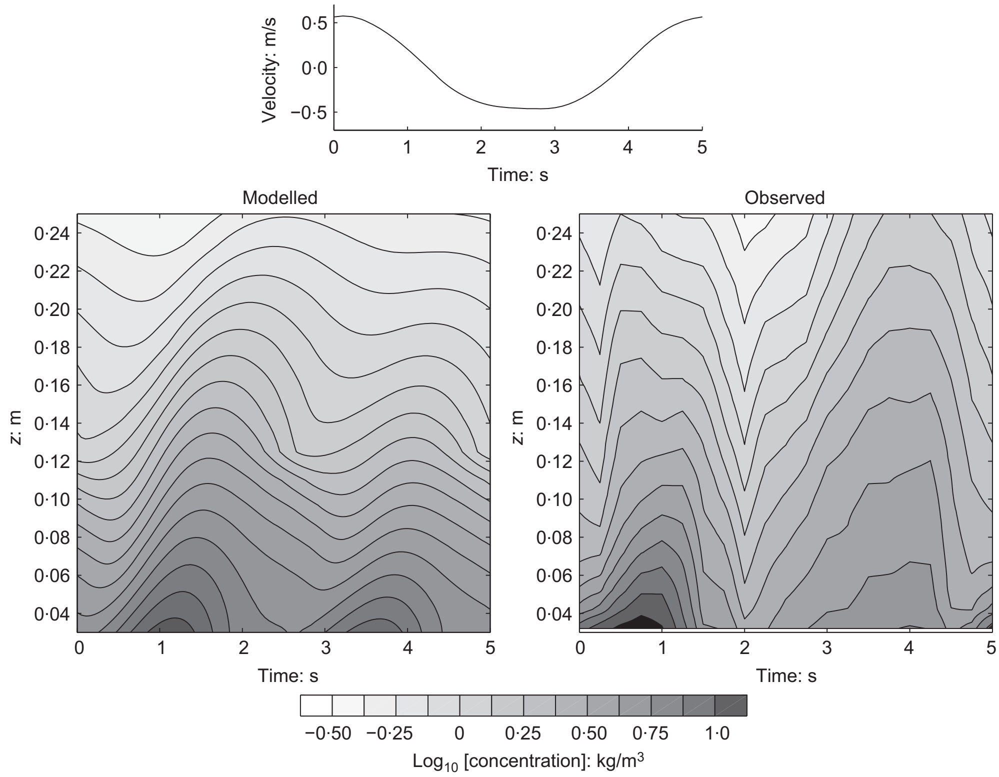

Figure 1. Measurement and modelling of suspended sediments with height z above a rippled bed under a 5 s period wave (Davies and Thorne, 2008)

Figure 1 shows acoustic measurements and a model, of the variation of the suspended sediments due to the passage of waves over the rippled bed. Focusing on the observed acoustic concentrations it can readily be seen that there are two periods of intense suspended sediment activity, at nominally 1 and 4 s, in the wave cycle. From the wave velocity plot it can be seen that the suspended sediment events lie close to the times of flow reversal. Apart from flow reversal, there are only low levels of suspended sediment concentration. These observations are consistent with the vortex entrainment description and support the model in Figure 1, which is based upon the generation of vortices as the primary mechanism for lifting sediment into suspension. These acoustic measurements represent some of the most detailed data collected to date on the interacting feedback sediment triad.

2.4 Conclusion

Over the past two decades the application of acoustics to the measurements of near-bed sediment transport processes has moved on from a qualitative tool, to being able to quantitatively measure detailed bedforms, flow and suspended sediments. The measurements can now be obtained with sufficient detail and accuracy, that emerging sediment transport models are being benchmarked against the acoustic observations, which are providing some of the most detailed measurements on sediment transport processes that have been obtained to date. And this is only the beginning! For further reading try the special issue of *Continental Shelf Research* (Thorne and Hay, 2012).

3. Particle paths due to Stokes drift by wave groups: Ton van den Bremer and Paul Taylor

3.1 Introduction

It is the photograph of the particle trajectories in plane periodic water waves by Wallet and Ruellan (1950) [reproduced in Van Dyke's 1982 publication, *An Album of Fluid Motion*] (Figure 2) that comes to mind when visually representing Stokes drift by surface gravity waves. The familiar result that particles undergo an elliptical orbit – becoming circular in deep water – which does not perfectly close due to a net drift in the direction of wave propagation has been known since its first systematic study by George Gabriel Stokes (1847).

Stokes drift is thought to play an important role in the physics of ocean surfaces and, hence, constitutes an important component

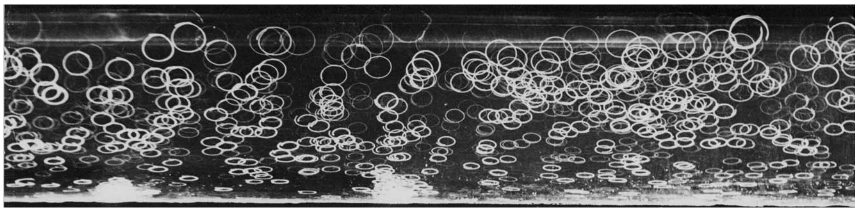

Figure 2. Particle trajectories underneath two-dimensional regular waves from Wallet and Ruellan (1950) [reproduced in the 1982 publication *An Album of Fluid Motion*].The waves are only moderately non-linear and the net horizontal drift is only visually apparent for a few orbits

of oceanic general circulation models (OGCMs) and, in particular, Langmuir circulation. In practice, the wave field on the open sea often has a group-like structure; it is composed of a spectrum of different frequencies and is therefore non-periodic. It is not a well-known result that Stokes drift by a wave group and Stokes drift by regular waves behave in a fundamentally different way. Second-order wave theories based on the interaction between waves of different frequencies predict an irrotational return flow at depth that is equal and opposite to flow associated with Stokes drift at the surface (Figure 3).

Herein, theoretical trajectories of neutrally buoyant particles at and below the surface of a focused wave group with an underlying JONSWAP spectrum are presented.

3.2 Calculating non-linear kinematics

A two-dimensional body of water of infinite depth and indefinite lateral extent is assumed with a coordinate system (x,y), where x denotes the horizontal coordinate and y the vertical coordinate measured from the undisturbed water level upwards. Inviscid, incompressible and irrotational flow is assumed and, as a result, the velocity vector can be defined as the gradient of the velocity potential $(u,v)=\nabla\phi$. The governing equation within the domain of the fluid is then Laplace and the

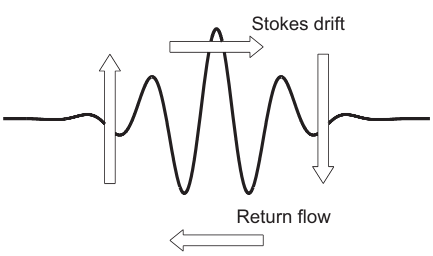

Figure 3. Illustration of the localised irrotational mass circulation moving with the passing wave group. The four mass fluxes (arrows) are equal

usual boundary conditions at the bottom and the free surface apply. A multi-chromatic wave solution to the governing equation and the boundary conditions that is linear in wave steepness $\varepsilon=ka$ takes the form

1.
$$\eta_{\mathrm{L}}(x,\ t)=\sum_{n=1}^{N}a_n\cos(k_nx-\omega_nt+\mu_n),$$
$$\phi_{\mathrm{L}}(x,\ y,\ t)=\sum_{n=1}^{N}a_n\omega_n\mathrm{e}^{k_ny}\sin(k_nx-\omega_nt+\mu_n)$$

where a_n, k_n, ω_n and μ_n are the amplitude, wave number, wave frequency and phase of the different Fourier terms. The wave number k_n and the wave frequency ω_n obey the linear deep-water dispersion equation $\omega_n^2=gk_n$.

In order to study the drift beneath large waves, the NewWave framework of Tromans *et al.* (1991) is adopted and each amplitude term is set to be proportional to its share in the total discretised wave energy spectrum $S(\omega)$

2.
$$a_n=a_{\mathrm{L}}\frac{S(\omega_n)}{\sum\limits_{n=1}^{N}S(\omega_n)}$$

so that the total maximum amplitude is a_{L}. In particular, a (discretised) Joint North Sea Wave Observation Project (JONSWAP) spectrum for fetch-limited seas (Hasselmann *et al.*, 1980) with a peak period $T_{\mathrm{p}}=12{\cdot}4$ s and a peak-enhancement $\gamma=3{\cdot}3$ is considered.

To capture the non-linearities that occur in large waves, use is made of the formulation of Creamer *et al.* (1989), who transform the surface elevation η and the surface potential ϕ_{s} into a new set of canonical variables. The nth Fourier component of the transformations of surface elevation η_n and surface potential $\phi_{\mathrm{s},n}$ are given by

3.
$$\eta_n = \frac{1}{|k_n|}\int_{-\infty}^{\infty}\left(\mathrm{e}^{\mathrm{i}k_n\tilde{\eta}_\mathrm{L}(x)}-1\right)\mathrm{e}^{-\mathrm{i}k_n x}\mathrm{d}x,$$
$$\phi_{\mathrm{s},n} = \frac{1}{|k_n|}\int_{-\infty}^{\infty}\mathrm{e}^{\mathrm{i}k_n\tilde{\eta}_\mathrm{L}(x)}\tilde{\phi}'_\mathrm{L}(x)\mathrm{e}^{-\mathrm{i}k_n x}\mathrm{d}x$$

where $\tilde{\eta}_\mathrm{L}(x)$ is the Hilbert transform of the linear free surface signal $\eta_\mathrm{L}(x)$ and $\tilde{\phi}'_\mathrm{L}(x)$ is the Hilbert transform of the spatial gradient of the linear velocity potential $\phi'_\mathrm{L}(x)$. These new variables exactly reproduce the second-order non-linear behaviour of surface waves and provide a good approximation to higher-order non-linearity. Having obtained the non-linear surface signals $\eta(x)$ and $\phi_\mathrm{s}(x)$ from Equation 3, the H-operator of Bateman *et al.* (2003) is then used to obtain subsurface kinematics. Finally, the horizontal and vertical velocity pair (u,v) is marched forward and backward in time to obtain the original and final position of a particle located at the focus point at the time of focus.

3.3 Particle trajectories in wave groups

Figure 4 illustrates the trajectories of four different particles located at and below the free surface at the focus point of a steep focussed crest. The particle located at the free surface undergoes the largest net motion in the direction of wave propagation. Its orbits are initially small and rapid, as the slowly travelling high-frequency waves travel past. The majority of the net horizontal transport is achieved by a few

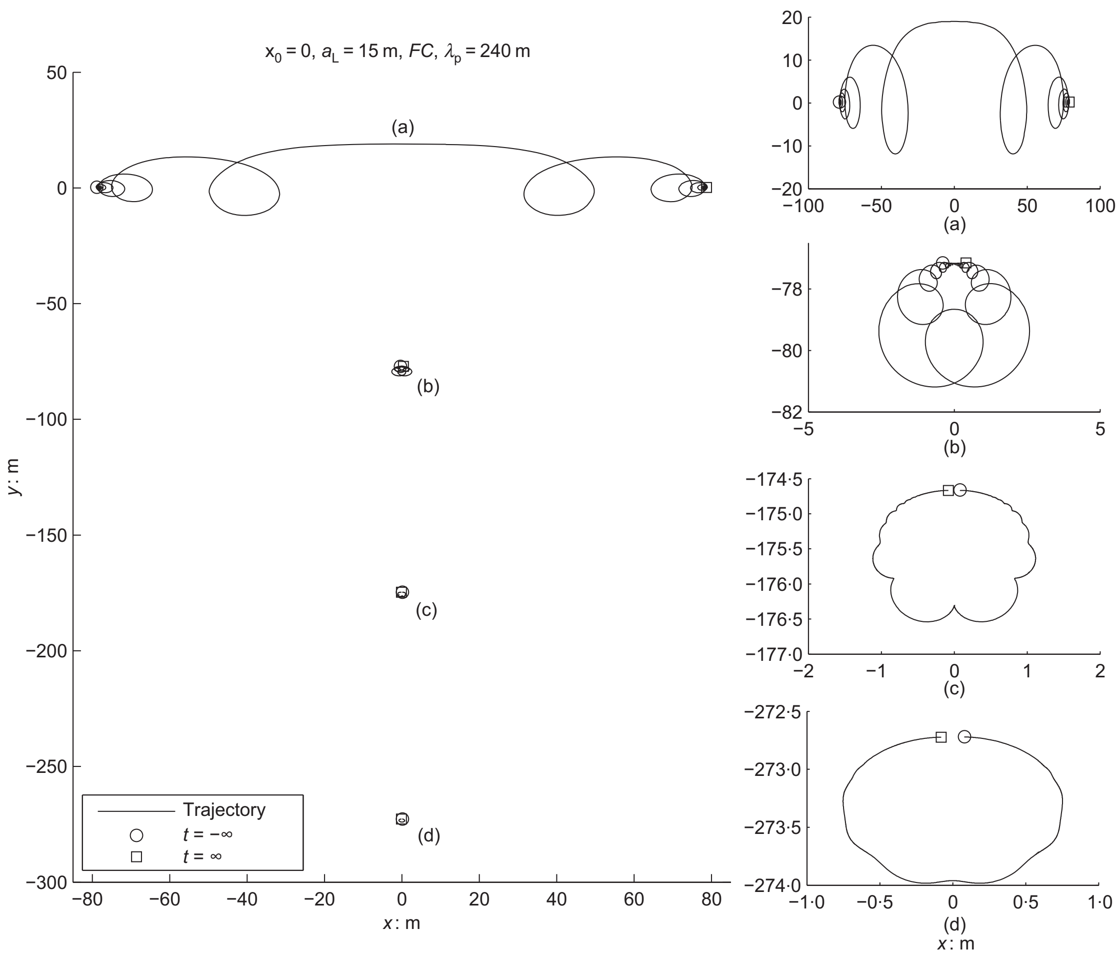

Figure 4. Particle trajectories of four particles located at and below the surface at the location of focus $x=0$ and the time of focus $t=0$ for a focused crest with a linear wave height of $a_\mathrm{L}=15$ m (steepness $\varepsilon_\mathrm{L}=k_\mathrm{p}a_\mathrm{L}=0{\cdot}4$)

large orbits when the wave group is at focus. The horseshoe-shaped return flow trajectory (Figures 4(b), (c) and (d)) only begins to dominate at depth. The effect of individual waves is still visible at intermediate depth, but only the horseshoe-shaped trajectory due to the return flow, which is reminiscent of the flow field of a dipole with a positive pole upstream of the wave group and a negative pole downstream of the wave group, remains deep in the fluid.

3.4 Conclusions

This contribution has examined the Stokes drift and return flow associated with a focused dispersive wave group by examining the trajectories of neutrally buoyant particles located at different depths below the surface. In the case of deep water, the large positive transport of a small number of particles in the near surface region is complemented by horshoe-shaped trajectories of small magnitude by a large number of particles at depth. In contrast to regular waves, a return flow at depth is an inseparable counterpart of Stokes drift by wave groups and ensures that the (irrotational) mass circulation associated with a wave group is a strongly localised feature that moves with the energy of the wave group.

4. What effect does high model resolution have on winds, and therefore the ocean?: Lucy Bricheno, Judith Wolf and Albert Soret

Accurate representation of wind forcing and mean sea level pressure is important for modelling waves and surges. This is especially important for complex coastal zone areas. The Weather Research and Forecasting (WRF) model was run at 12, 4 and 1·33 km resolution for a storm event over the Irish Sea. The outputs were used to force the Proudman Oceanographic Laboratory Coastal Ocean Modelling System (POLCOMS) hydrodynamic model at a range of frequencies and the effect on storm surge was assessed.

4.1 Introduction

Close to the coast the interaction between wind, waves and tides becomes most complex but also most critical. Storms are particularly important at the coast as these events can lead to high waves, storm surges, inundation and erosion in populated areas. The motivation for this research was to explore ways of improving coastal surge forecasting by improving the atmospheric forcing.The issue of atmospheric model resolution and forcing frequency is specifically examined herein.

4.2 Methods

Two well-established models were used: a three-dimensional (3D) tidal model, POLCOMS (Holt and James, 2001), and for the atmospheric modelling, a version of the Advanced Research Weather Research and Forecasting model ARW-WRF v3.2 (Michalakes *et al.*, 2004). The outputs from the meteorological model were used to drive the ocean model at a range of spatial and temporal resolutions.

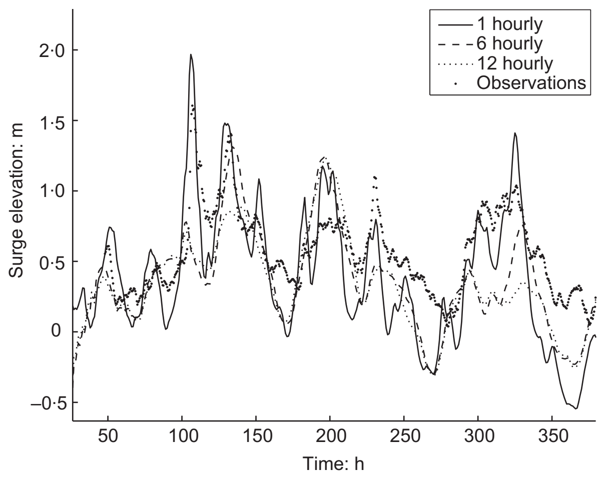

Figure 5. Surge elevation at Liverpool Bay, comparing POLCOMS modelled surge when driven by 1, 6 and 12 hourly meteorological forcing, with observations. Infrequent forcing means the model may miss important peaks in surge

4.3 Results

Surge model sensitivity to variable resolution meteorological forcing was tested, but little effect was seen: 12 and 4 km resolution forcing were compared, giving virtually identical modelled surges. This may be because the local water level is governed equally by incoming surge from the boundary and local atmospheric pressure, whereas the wave field is controlled by local winds. Forcing frequency had a much stronger impact (Figure 5) with hourly winds found to best capture the observed surge. A full analysis of the model results can be found in Bricheno *et al.* (2013).

4.4 Discussion

Modelled surge was found to be insensitive to spatial resolution, changing little when forced with higher resolution winds. This is thought to be due to the smoothly varying pressure field, as the inverse barometer effect is controlling the surge level. The temporal variability of surge was found to be very sensitive to forcing frequency, illustrating the importance of frequent atmospheric forcing in surge prediction.

4.5 Conclusion

Model skill is gained through forcing the ocean model with higher resolution wind and pressure fields. Modelled surge was found to be largely insensitive to spatial resolution (thought to be due to the smoothly varying pressure field), but very sensitive to forcing frequency.

5. Oscillatory flow over and within a permeable bed: Kathryn Sparrow, Dubravka Pokrajac and Dominic van der A

5.1 Introduction

Coastal sediment transport takes place in the near-shore environment where waves or currents introduce a significant shear stress on the bed causing the sediment to become mobile. Sediment transport is a particular concern within the field of coastal management and, as large areas of the UK coast are at risk from erosion, it is important to fully understand the physical process. This study aimed to further the understanding of sediment transport processes by investigating the interaction of flow above the bed with the flow within a permeable bed.

Several studies (Chen *et al.*, 2010; Liu *et al.*, 1996; Sparrow *et al.*, 2012) have proved that a permeable bed has a significant effect on the structure of the boundary layer above the bed with the horizontal velocities, turbulence and shear stress all being affected. However, the potential causes of this phenomenon have not been thoroughly investigated. A series of experiments were designed to allow for measurements both above and within a uniform permeable bed in an attempt to understand the mixing process of the flow between the two regions.

5.2 Experimental methodology

Boundary layer experiments were conducted in the Aberdeen oscillatory flow tunnel (AOFT). The tunnel is capable of generating oscillatory flow that is equivalent to the near-bed flow found under full-scale real waves. Within the test section a specially constructed test bed was placed. The test bed was constructed from five layers of cubically arranged uniform spheres that had a diameter of 12 mm, all overlaying a coarse-grained gravel bed. The total depth of the bed was 250 mm.

Velocity measurements were obtained using particle image velocimetry (PIV). The PIV system consisted of a double-pulsed laser, a timer box and a high-speed charge-coupled device (CCD) camera, all of which were software-controlled. During the experiments the laser was positioned above the AOFT and aligned so that the light sheet illuminated the tunnel centre line and passed into the bed through the aligned pore spaces. The camera was positioned at 90° to the laser plane and was focused on the measurement area. Five separate measurement areas were allocated to capture the flow above and within the bed.

5.3 Results and discussion

The results shown in Figure 6 are the phase-averaged horizontal velocity profiles at 30° phase intervals throughout the flow cycle. The free-stream conditions follow a sinusoidal motion with an orbital amplitude of 0·6 m, a period of 5 s and a maximum free-stream velocity of 0·75 m/s. The flow above the bed was considered first. For sinusoidal flow the profiles for equivalent phases were expected to be identical yet in this instance the profiles at 30° and at 210° possess a different velocity gradient close to the bed, with the profile at 30° having a higher velocity gradient, which will lead to a higher than expected bed shear stress at this phase in the flow cycle. Further investigation showed that the reason for this was an oscillating vertical exchange of flow. This vertical exchange of flow was induced by the ever-changing pressure gradient that occurs under these flow conditions, and so would be present under real wave conditions.

This study highlights the interaction and exchange of the flow between the two regions. This interaction could have a large impact on sediment transport as the additional forces from the vertical exchange of flow will also be significant. The vertical flow is known to alter the boundary layer flow by increasing or decreasing the drag force depending on the flow direction, but it will also have the effect of increasing or decreasing the effective weight of the sediment by creating a lift force on the individual grains in the bed. The two mechanisms have the opposite effect on the sediment entrainment and transport, so the net effect is likely to depend on the flow conditions, as well as on the bed permeability and porosity.

6. Long-term trends observed across the Scottish coastal monitoring sites: Jenny Wright, Sarah Hughes, Barbara Berx and Matt Geldart

6.1 Introduction

Marine Scotland Science (MSS) collects data at a number of monitoring stations around the coast of Scotland and further offshore. These data are useful in developing an understanding of the changing hydrographic conditions in Scottish waters and the associated ecosystem variability. Whereas some sites are maintained directly by MSS, others continue through the support of a network of volunteers and collaborating organisations around the Scottish coast.

Of the 12 coastal stations, a few of these sites were established over 20 years ago, with the oldest record dating back to 1909 in Millport (SMBA, 1909–1926), allowing the long-term trends in coastal waters to be observed. These data are very important in enabling additional understanding of the variability in Scottish waters and how it relates to changes in climate.

6.2 Methods

Temperature was recorded with the use of Vemco Minilog temperature sensors storing half-hourly data in data-loggers. At each station the sensors are located in different positions – in Millport the temperature sensor is suspended beneath a buoy close to the pier, thereby remaining at the same depth at all times, and in Fair Isle the sensor is attached to the pier at a

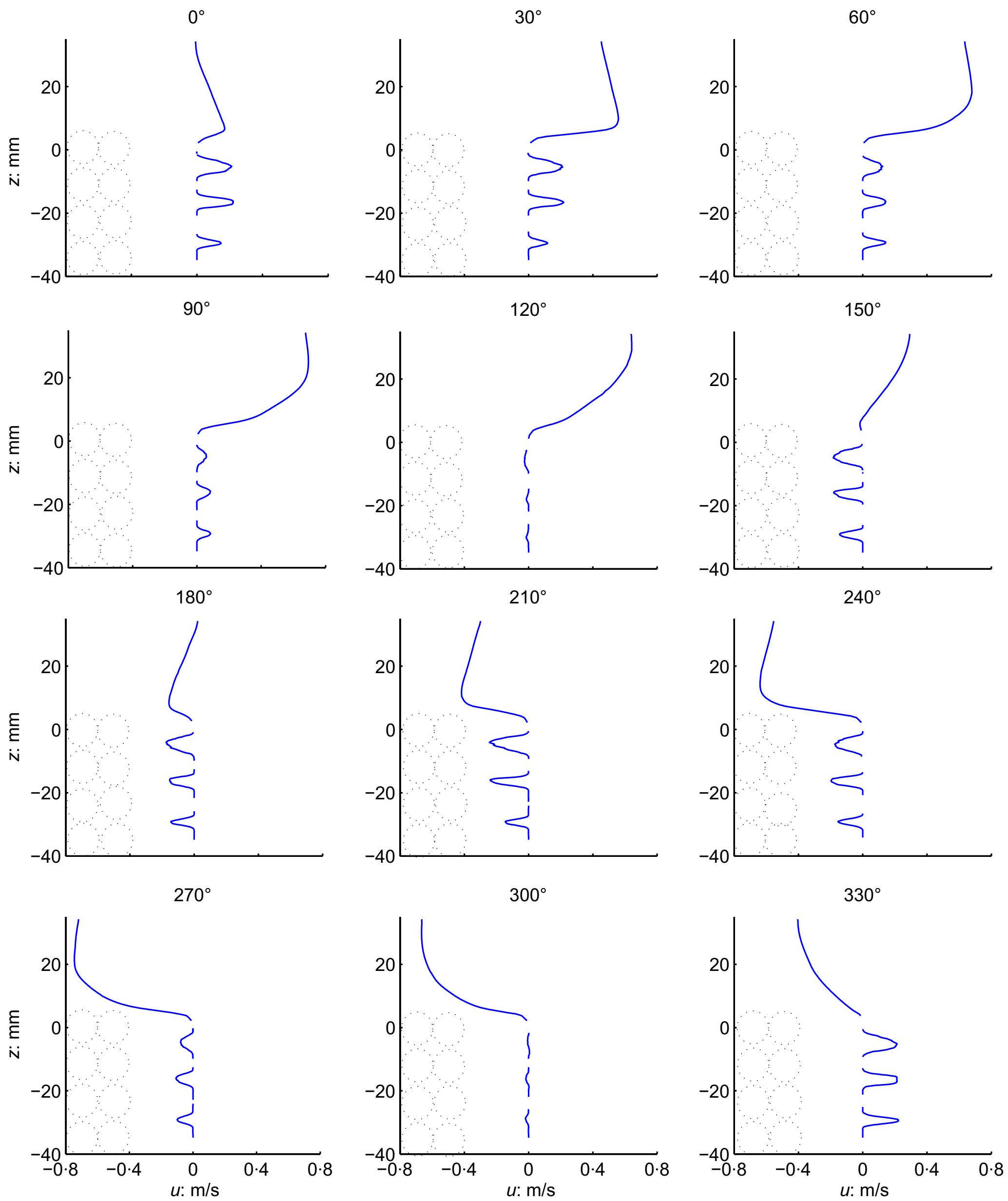

Figure 6. Horizontal velocity profiles obtained from the PIV measurements. Profiles shown are at 30° phase intervals throughout the flow cycle. The dashed circles indicate the *z*-position of the marbles

fixed depth. The earlier temperature measurements presented here were made by drawing up a bucket of seawater and using a thermometer to measure temperature.

6.3 Results and discussion

Figures 7(a) and (b) show the temperature time series and temperature anomalies at Millport, respectively. The temperature anomalies were calculated by removing the 1971–2000 average seasonal cycle, and the anomaly time series was filtered using a 3-year running mean and is shown in Figure 7(b).

The time series of sea surface temperature at Millport (Figure 7(a)) shows that there was a gradual temperature increase since the records began in 1909. An analysis of the

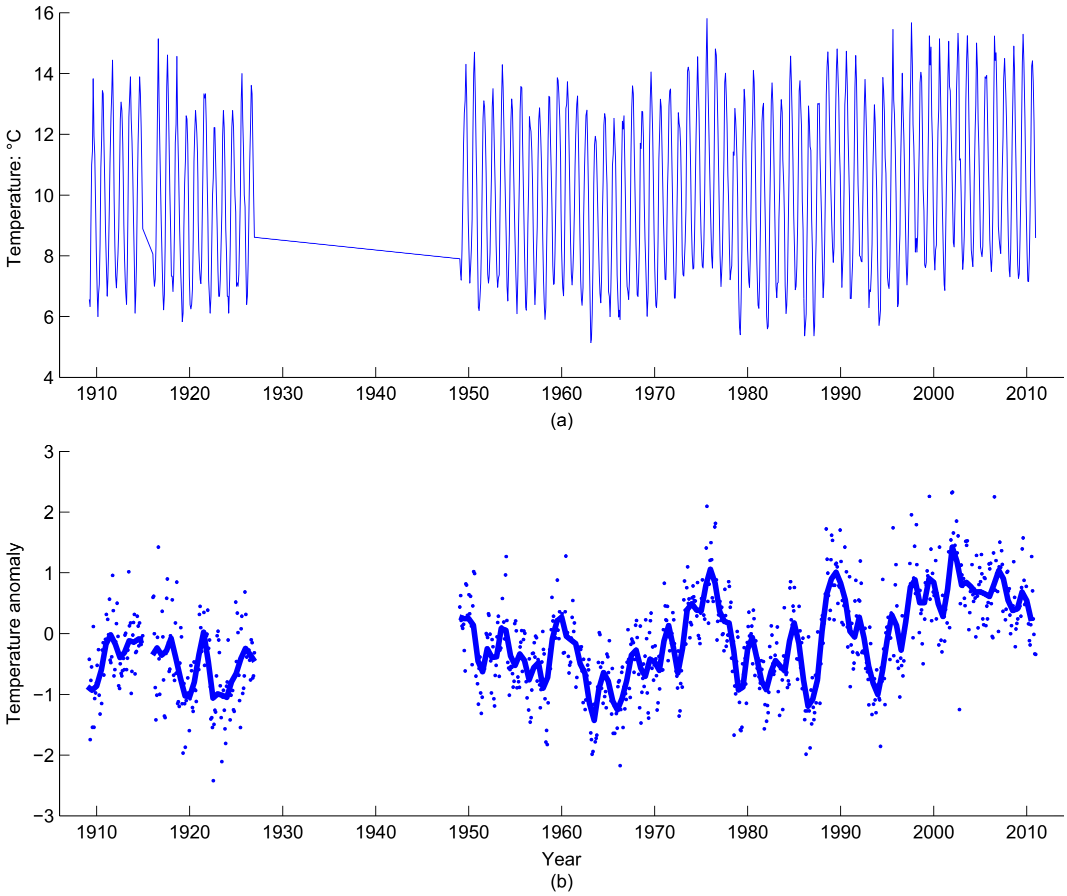

Figure 7. Millport data showing (a) temperature time-series and (b) temperature anomaly time-series with the line showing the filtered data

monthly averaged temperature anomalies showed that in the more recent years, since about 2000, the sea surface temperature at Millport has risen above the seasonal average, and this occurs throughout the year with warming occurring in almost every month of that time period. At Fair Isle, located north of Scotland, sea surface temperatures appear to have increased during the winter months, but there is a less marked change in the summer.

Heat can be gained and lost from the seas through either vertical heat transfer, such as incoming solar radiation, energy radiated back from the ocean, heat loss by evaporation or heat exchange by conduction across the air–sea interface; or horizontal heat transfer through advection in currents. In any given location the balance between these vertical and horizontal fluxes produces a net heat flux whereby there is either net heat gain into, or net heat loss from the seas. Figure 8 demonstrates how the net heat flux varies across Scottish waters with heat loss from the seas to the north and west, and with heat gain into the seas from the atmosphere in the North Sea and east coast. These data are from the NOCS Flux Dataset v2.0 derived from voluntary observing ships covering 1973 to 2006 (Berry and Kent, 2011). Despite daily and seasonal changes in the heat fluxes, on average there should be a heat balance. Therefore, when the sea surface temperature at the coastal stations increases or decreases over time it poses the question about how these changes are connected with changes in atmospheric and oceanographic conditions. A lot more work is required before these connections are fully understood.

At all sites temperature follows a seasonal cycle, with maxima occurring in the late summer and minima in the late winter. The west coast is strongly influenced by warm North Atlantic water, and this is evident by the warmer temperatures throughout the year in Millport in comparison with Peterhead.

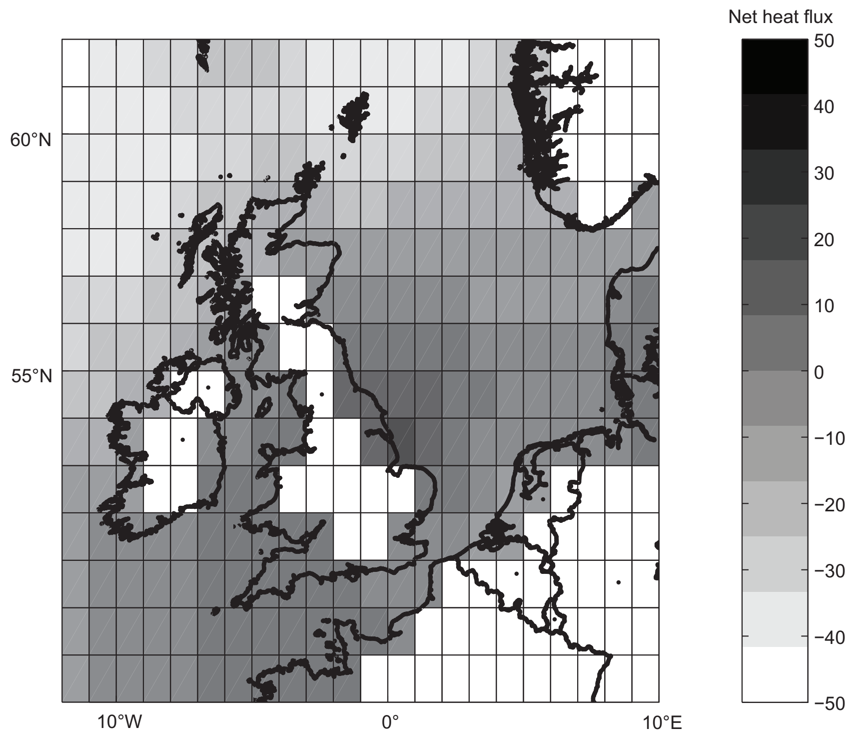

Figure 8. Net heat flux in the waters around the UK from the NOCS Flux Dataset v2.0 (Berry and Kent, 2011)

6.4 Conclusions

Temperature has been measured at the coastal monitoring stations for many years, with the oldest record dating back to 1909 in Millport. The temperature time series obtained from these stations can provide information on the effects of both vertical and horizontal heat exchange. Important information is also being gathered to help understand variability in coastal ecosystems.

Since the dataset began in Millport an overall increase in surface temperatures can be seen. This raises some important questions: why are these coastal waters warming? Is it due to atmospheric temperature increases, or is there a change in the waters flowing into the area? Further work includes determining how the changes that are being observed in the coastal temperatures are connected with changes in atmospheric and oceanographic conditions.

Acknowledgements

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