Menai Straits Challenge 2011

A Scientific Investigation with the aim to detect inaccuracies in the race protocol of the Menai Straits Challenge

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Introduction

Observations from 3 series of experiments have been evaluated to examine the dynamical balance of the oscillating channel flow in the Menai Straits, Wales, UK with the aim to determine the fastest paddler – independent of current flow and salinity – of the 2011 Menai Straits Challenge.

The 3 separately collected series of experiments consist of data obtained from 2 tide gauges, data from an upwards facing sea bed mounted ADCP, and measurements obtained from a vessel mounted ADCP unit pointing downwards. The collected data provides values for velocity, sea bed height, acceleration and channel slope which provides us with the variables for Newton's second law of motion. Newton's second law of motion describes a balance between the acceleration of a body of water and the forces responsible for this motion. Newton's law of motion can be simplified, and expressed as (following Campbell et al., 1998):

$$\frac{\partial u}{\partial t} = -g\,\frac{\partial \eta}{\partial x} - \frac{k|u|u}{h+\eta}$$

Where h represents the mid channel depth, η the elevation of the sea surface relative to chart datum, u the channel velocity, and k is the friction coefficient. By the means of regressing the combined acceleration term + surface slope term ($\frac{\partial u}{\partial t} + g\,\frac{\partial \eta}{\partial x}$) against the friction term ($\frac{k|u|u}{h+\eta}$), resulting to:

$$\frac{\partial u}{\partial t} + g\,\frac{\partial \eta}{\partial x} = - \frac{k|u|u}{h+\eta}$$

it is now possible to obtain a value for the friction coefficient k by applying a linear fit to the regression. The from this experiment obtained value for the friction coefficient k and a comparison to the common value of k of 0.0025 and to values of k from other, different experiments both in the Menai Straits and at other locations may provide an estimate of the dynamical balance of the Menai Straits at the time and location of the experiment.

Location

The Menai Straits is a narrow, fully turbulent tidal channel which separates the Isle of Anglesey, Wales, UK, from the mainland at a length of approx. 20 km in an approx. south-west to north-east direction (Fig. 1a). The Menai Straits features strong tidal currents reaching velocities of up to 2.5 m/s at (during spring tides) in The Swellies and around Point Belan, the southwest entrance of the Menai Straits. The blue circles in Fig 1b represent the approx. location of the tide gauges 1 and 2. T he blue rectangle shows the approx. location of the sea bed mounted ADCP, while the red line represents the approx. location of the across channel profile, in the following referred to as Transect B C (Fig. 1b).

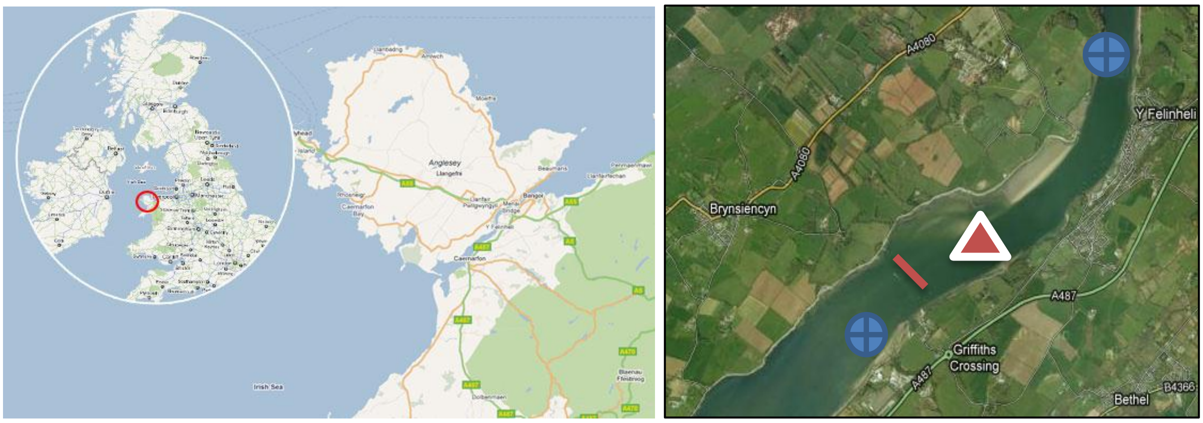

Fig. 1a, b: Approx. positions of tide gauges 1 and 2 (blue circles), moored ADCP (red triangle), and intersect B C.

The width of the Menai Straits varies between approx. 300m and 800m. The Menai Straits features a wide variety of bottom features ranging from sand flats to bed rock. The highly dynamic interplay between geography, bathymetry and strong currents in the oscillating channel promote the appearance of standing waves (The Swellies), whirlpools, strong eddies, and result into a highly turbulent water column. Fig. 3 shows the highly varying current velocity direction at transect B C at approx. 2 hours before high tide on October 19th, 2011, which suggest a high turbulent and vertically homogenous water column.

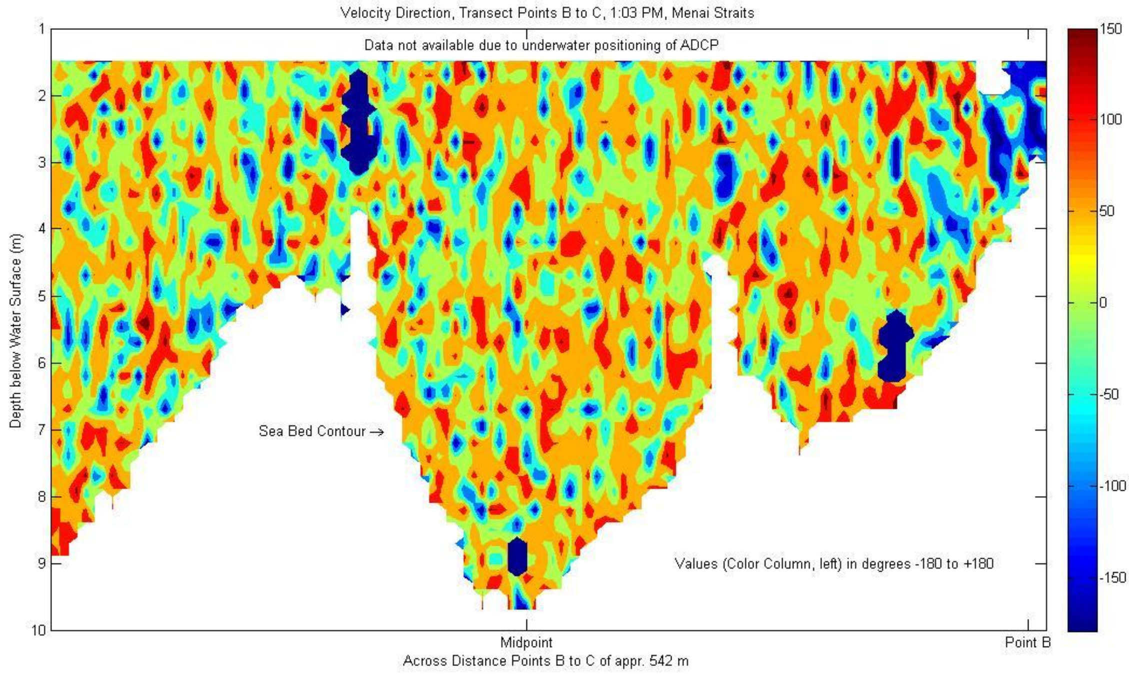

Fig. 2 Data obtained from vessel mounted vessel ADCP

The north-east bound flow in the Menai Straits is referred to as the flood flow, while the south-west bound flow is referred to as the ebb flow. Former experiments (Rippeth, Williams Simpson, 2001; Campbell et al, 1999) yielded a distortion in terms of velocity and net transport of water in the south-west direction (ebb flow), corresponding to a south-west bound residual velocity of 10-15 cm/s and a south-west bound net transport of water of approx. 30 cubic meters of water over one tidal period (A.R. Campbell et al., 1998). The addition of freshwater into the Menai Straits is comparably small (Campbell et al. 1998) and can be considered negligible for the purpose of our experiment. The observations were made in the location of the Menai Straits close to the town of Y Felinheli on the mainland. For the purpose of data collection for the experiment, the university owned research vessel *Macoma* tracked a course in from of a square with the four points ABCD which are at approx. OSS SH SH 510 668 (A), SH501663 (B), SH497667 (C), and SH508668 (D). However, only data from the across channel transect B to C was evaluated for this experiment. In addition to the observations obtained from the ship mounted ADCP, a second set of data was obtained from a sea bed (bottom) mounted ADCP which location coincided with location A at approx. OSS SH SH 510 668. A third set of data was taken from 2 tide gauges located approx. 2,900 m north east and 1,500 m south west from location A.

On October 19th, 2011, the day the vessel based ADCP data was collected, high tide was predicted at 1318 UTC at Port Dinorwic, Wales, approx. ¼ Mile NE of the site, coinciding approx. with the time the measurements were taken of run 3 (out of 3 runs). Winds at site were at approx. F2-F4, with temperatures at around 12 degrees Celsius (Met Office, 2011). Since the winds were light at the time the data was collected, it is unlikely that the low wind speeds at site affected the observed flow in a significant and relevant manner on the day the vessel mounted data was collected. Winds varied highly, up to Force F6, over the approx. 9 day period the the bottom mounted ADCP and tide gauge data was collected, possibly effecting the measurements. Contour plots of density ranges with data a survey taken in February 1997 and November of 1996 in immediate location to the site (Campbell et al., 1998) show no significant stratification in the vertically well mixed water columns, thus it is assumed that the water column in the Menai Straits can be described as vertically homogenous. Because the channel width in the Menai Straits is very narrow (approx. 300m to 800m), the influence to the current flow by the Coriolis Force is considered as negligible.

Survey Methods

On October 19th, 2011, Marcus Demuth and the program director for Physical Oceanography, Tom Rippeth of the School of Ocean Sciences in Menai Bridge, Wales, UK boarded the school owned catamaran research vessel *Macoma* to collect the related data needed for the experiment. The *Macoma* was equipped with a 1,2 MHz Acoustic Doppler Current Profiler (ADCP) mounted in the centre on the bottom of the hull of the boat (Fig. 3).

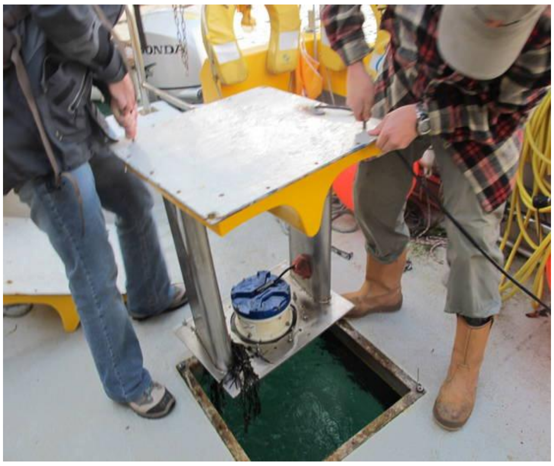

Fig. 3 Teladyne ADCP on *Macoma*

The data from the ADCP moored on the sea bed, from the ship mounted ADCP, and for the 2 tidal gauges was uploaded by Tom Rippeth to: U:\College of Natural Sciences\School of Ocean Sciences\PublicDocuments\MSc-ScratchSpace\PO_2011-12 (School of Ocean Sciences , 2011). The depth data was corrected for the underwater position of the boat mounted ADCP, and thus represents the actual depth data.

Collection and Evaluation ADCP Data

ADCPs represent a great improvement over conventional current meters such as Ekman current meters and allow more detailed, unprecedented and more precise data collection over a wide spectrum of the water column. Despite the variety of advantages and improvements over conventional current meters, data acquired with ADCPs have its limitations and inaccuracies which have to be considered when processing and evaluating the collected data:

- ADCPs feature a “blanking zone” of 2 to up to 4 meters around the transducer head due to nonlinear effects on the sound pulses and due to waves/bubbles for vessel mounted ADCPs. On the other end of the beam near the sea bed, there is a “shadow zone” (for downwards pointed instruments), where the received velocity signals may be inaccurate caused by reflections from the sea bed.

- For reliable current velocity estimates, it is recommended to average ADCP signals over periods of 1-2 minutes to reduce noise. While the accuracy of the obtained ADCP data can be maximized by increasing the frequency, an increase in frequency will cause a reduction in resolution due to the resulting larger bin size.
- If the ADCP is not able to send a ping to the bottom for tracking in order adjust the current measurements for the ships movements, the collected ADCP has to be adjusted to standard GPS data, which is only accurate within ± 1 cm/s (the data collected during our experiment with the *Macoma* was adjusted with the more accurate bottom tracking).
- ADCPs obtain and calculate the data from the reflections from moving particles within the water column, not from the (moving) water itself. The accuracy of the data assumes that the reflectors are passive and not self-propelled organic organisms, or partially self-propelled (such as organisms moving in the water column both by currents and by self-propulsion, for example krill). In the latter case, the obtained current data would represent the sum of the velocity of the organic matter within the water column plus the velocity of the surrounding water, but not the velocity of the water itself.
- Tilt Angle Bias: Due to given conditions on the sea bed, it is not always possible to install sea bed based ADCPs 100% level. If the ADCP is not installed 100% level in the sea floor, both the upwards outbound signal and its reverse signal are received in a biased angle at the ADCP's receiver, effectively inflating the data influenced by the degree of tilt. If the tilt is either unknown or is not corrected for during data processing, the data may not represent actual conditions at site and can cause data inflation of up to 17% (Lu and Lueck, 1999). Tilt angle information of the sea bed mounted ADCP unit at the Menai Straits site for the experiment was available, but was disregarded in this experiment.
- Exposure/Rigidity of installation: Current velocities may be progressively over-exaggerated especially in highly dynamic environment such as the Menai Straits due to the exposure of the ADCP unit to potentially varying tilt of the unit caused by the dynamic water flow against the unit and/or its moorings. With increasing current velocity, the tilt angle of the ADCP unit may increase and thus may progressively inflate the current data due to an increased tilt angle of the deployed unit caused by the horizontal forces of the moving water column.
- In order to form a true velocity vector, the velocity components u, v, and w at the different beams must be identical and implies that the velocity field must be homogeneous in the horizontal plane in the ADCP beam. In turbulent flow, this requirement is not satisfied due to the existence of turbulences (Lu and Lueck, 1999).
- Motion of Boat: Heave, roll, and pitch (translational motions) of vessel mounted ADCP units experience changes of orientation due to the nature of a vessel moving on the sea surface which translates into variations in tilt angles in the x, y and z plane. The variations in tilt angles and positions relevant to the sea surface and sea bed and thus variations in beam orientation result in biased data. The varying ship motion in respect to heave, roll and pitch (x, y, z plane) during the experiment was not monitored or adjusted on the *Macoma* during the experiment, and thus was not included at processing or interpretation of the collected data.
- The used ADCP unit itself has accuracy of 0.8% (RD Instruments Teladyne RD, 2011), mainly caused by velocity variations due to Doppler Noise.

Results

1. In order to obtain a value for the friction coefficient *k*, the principal aim of the experiment, data to estimate the position of sea surface (Fig. 4) and the depth-averaged along channel velocity (Fig. 5) from the seabed mounted ADCP was evaluated with the aid of Matlab software (Mathworks, 2011).

Fig. 4 shows the varying sea surface height above sea bed due to predominantly semi-diurnal flow in Menai Straits at site location A, approx. 53.1715 N -4.2293 W. The depths presentations in Fig. 4 have been adjusted and corrected for the position of the subsurface boat mounted ADCP position. The graph shows varying sea surface heights from 7 m to 13.5 m (with spring tide on Day 286/October 14th, 2011), proceeding with decreasing amplitude towards a neap cycle ranging from approx. 10 m to 12.5 m(Day 293/October 21^{st,} 2011).

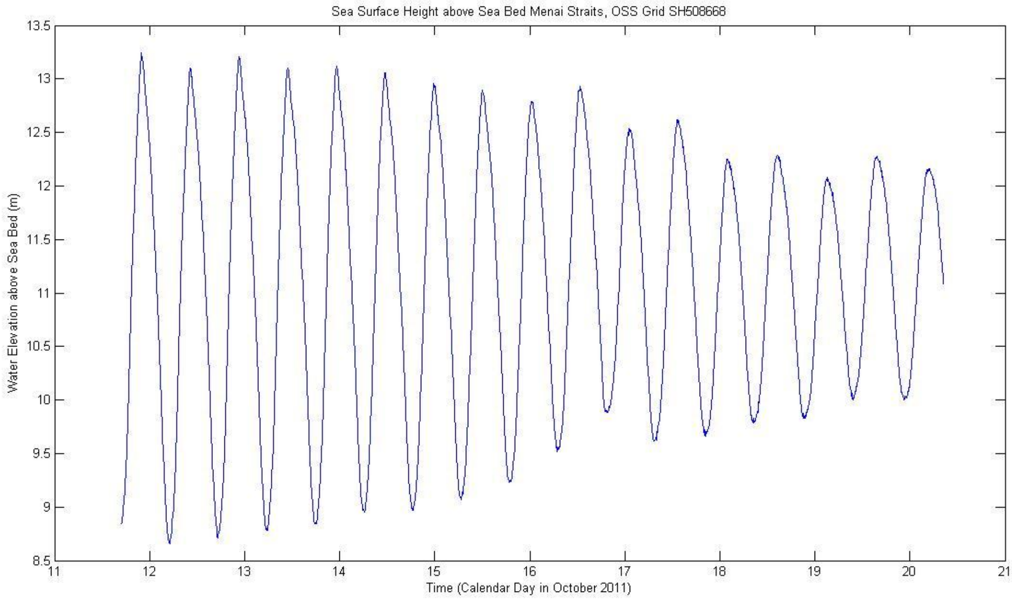

Fig. 4 Sea surface height at location A (sea bed mounted ADCP)

To obtain the current profile displayed in Fig. 5, the depth-averaged along channel velocity was calculated by averaging the velocity data of the depths values of each time stamp. Measurements from the top bin closest to the sea surface were discarded since they may have been biased by the presence of the hull of the vessel. Velocities in the south-west direction (ebb) are displayed as negative values; velocities in the north-east direction (flood) were displayed as positive values. Maximun Current velocities were measured at approx. + 1 m/s to -1 m/s beginning October 12th, 2011, with a decline in the oscillation compared to its maximum values to about 0.6 m/s in either direction towards the neap tide on October 22nd, 2011. Comparing the positive with the negative values to each other on Fig. 5, it appears that current velocities are approx. 10 % stronger during the ebb phases than they are during the flood phases. Thus, the data visualized in Fig. 5 shows a distortion of the semi-diurnal towards the dominating SW flowing ebb cycle and very quick transitions from both flood to ebb and ebb to flood, virtually displaying no period of slack water.

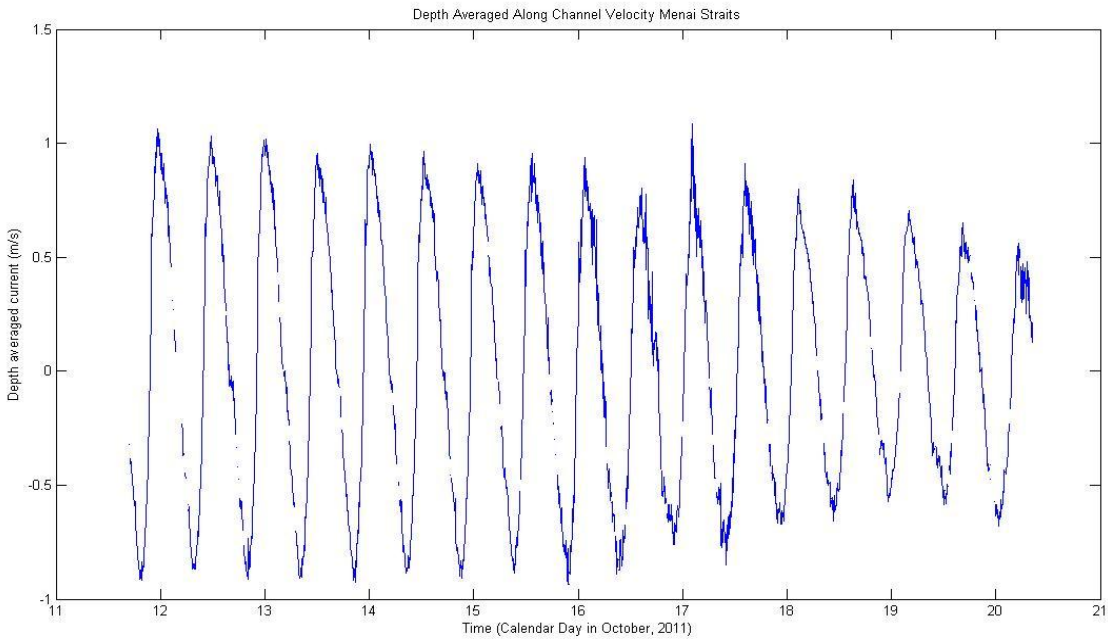

Fig. 5 Depth averaged along channel velocity at A (sea bed mounted ADCP)

2. Based on the velocity measurements and its associated time series, the acceleration could be calculated. Fig. 6 shows the acceleration time series (Δu/Δt). Maximum values are at 1.6 m/s^2 in the positive (flood) direction, and approx. 1.1 m/s^2 in the negative (ebb direction. The acceleration data shows a slight distortion: It remains positive for longer period than negative, however, the negative values feature strong negative pulses, which suggest fast successions from the flood flow to the ebb. Fig. 7 shows the combined graph of the time series of u(t) and (Δu/Δt), with the highest values of acceleration roughly coinciding with maximum current velocities (Fig. 7).

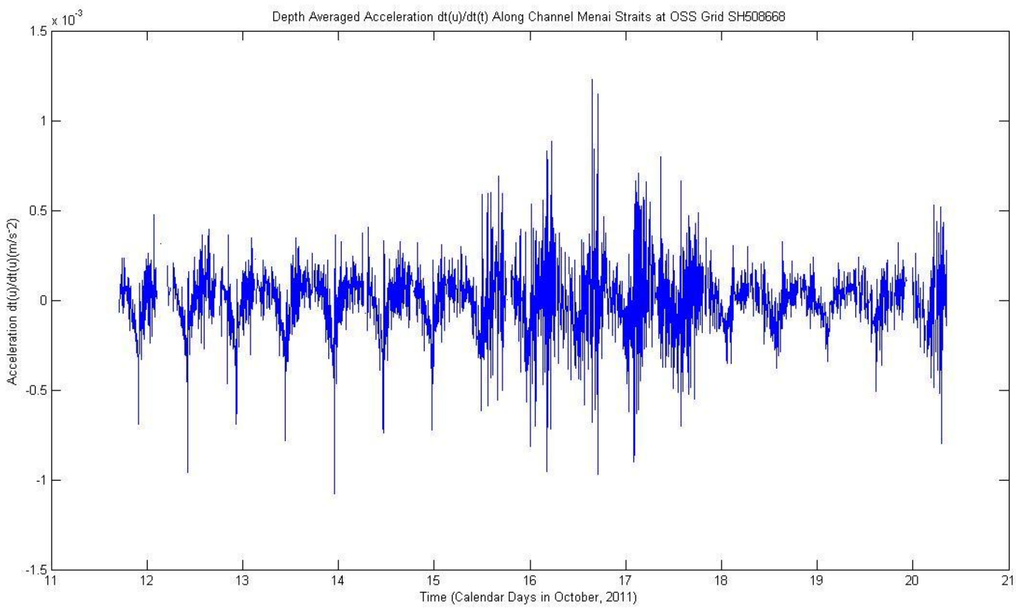

Fig. 6 Depth averaged along channel acceleration at A (sea bed mounted ADCP)

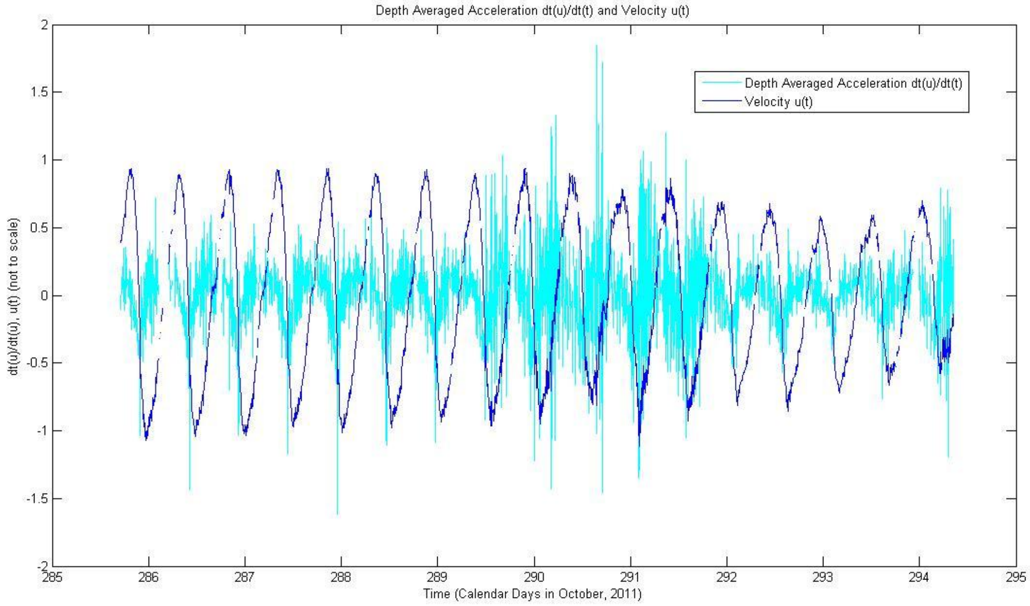

Fig. 7 combined graph of the time series of u(t) and (Δu/Δt)

3. Tidal forcing results in a surface slope $\Delta\eta/\Delta x$, with (t) as the gradient for the change of surface elevation relative to a known datum. The value η was obtained as the difference between tidal gauge 1 (data set *Plas Newydd*) and tidal gauge 2 (data set *Pie Factory*) over time (t). Fig. 7 illustrates the time changing along channel slope $\Delta\eta/\Delta x$, with an imbalance towards negative amplitudes and longer time periods in the negative slope values than in the positive, resulting in dominating slope gradient to the south west (ebb) direction throughout every tide cycle. The horizontal slope gradient is considered a good representation for the forces resulting into the current flow, which coincides with the peak current velocities (Campbell et al., 1999). The graph shows pronounced, long periods with high slope gradients, and as the previous graphs, rapid, steep transition periods from flood to ebb.

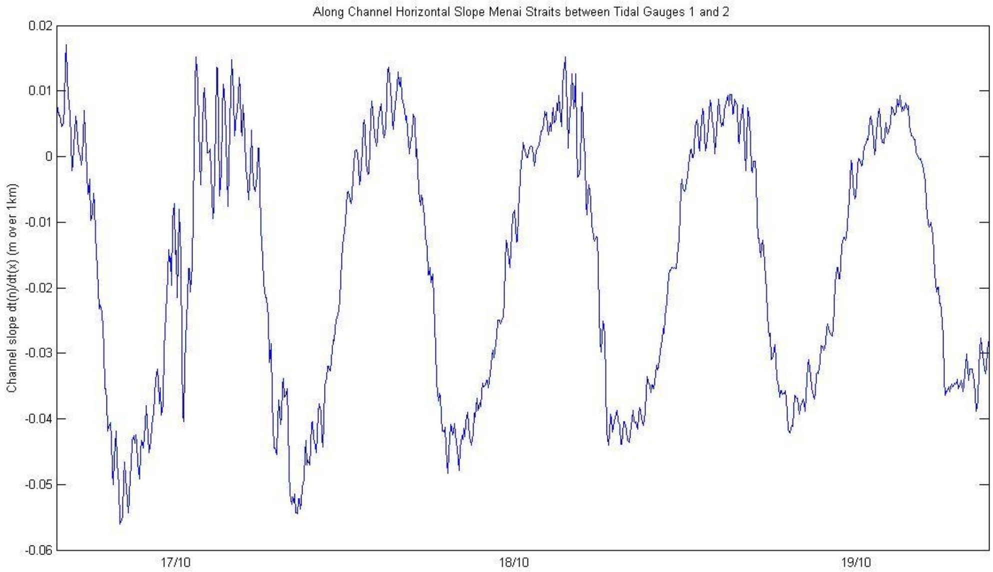

Fig. 7 Along channel horizontal slope between tidal gauges 1 and 2

4. Fig. 7 shows the magnitude of the along channel friction $\frac{u|u}{h+\eta}$. As with the along channel slope, the graph shows an in-balance, also less pronounced than the slope gradient, towards the ebb flow direction.

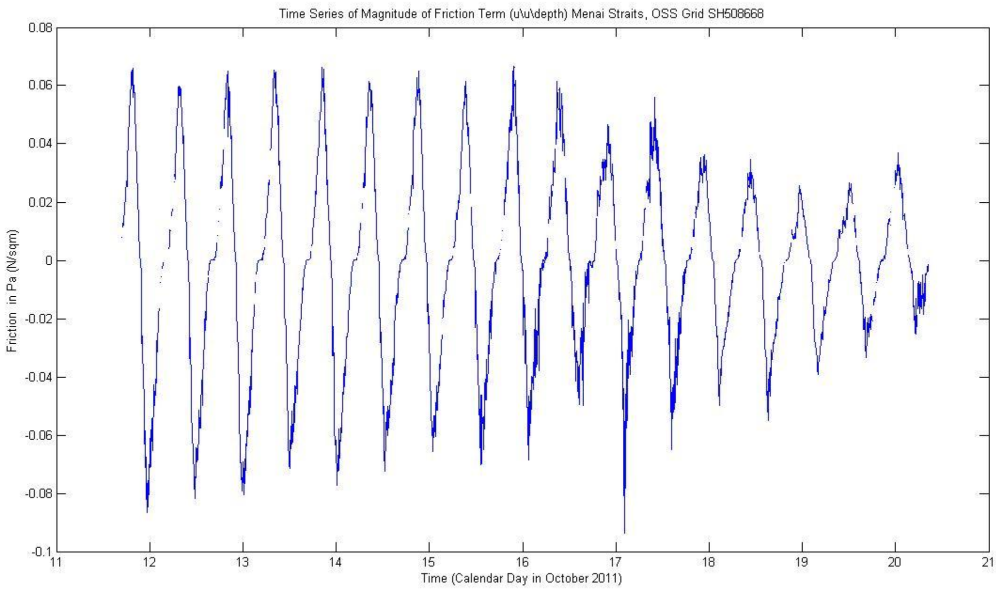

Fig. 8 Time series of magnitude of friction at location A (sea bed mounted ADCP)

5. To estimate the value for the friction coefficient k, a linear regression of the acceleration + surface slope term ($\frac{\partial u}{\partial t} + g\frac{\partial \eta}{\partial x}$) against the friction term ($\frac{k|u|u}{h+\eta}$) was applied based on the data provided by the moored ADCP and the 2 tidal gauges. The result of this linear regression is shown in Fig. 9, where the gradient of the straight red line fit represents the estimate for the friction coefficient *k*.

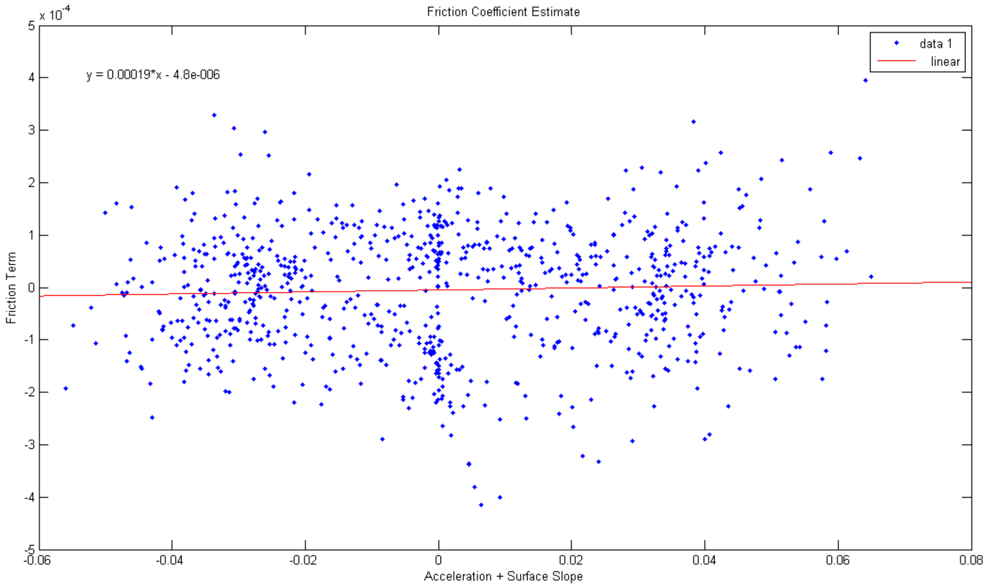

Fig. 9 Regress acceleration/slope vs. friction term w/friction coefficient (red line)

6. A linear regression consisting of the friction term on the x-axis, and the acceleration and surface slope on the y-axis:

$-\frac{k\|u\|u}{h+\eta}$	Friction term (x-axis)
$\frac{\partial u}{\partial t} + g\frac{\partial \eta}{\partial x}$	Accel. term + slope * g (y-axis)

was applied based on the above terms which yielded for f(x) = p1*x + p2, the equations:

p1 = 0.0019 (-9.554e-005, 0.0004755)
p2 = -4.822e-006 (-1.267e-005, 3.02e-006)

Providing the value of *k* as 0.0019 and a value for r^2, representing the goodness of it of the linear progression, as 0.002046 (adjusted r^2 of 0.0008464). The obtained value for *k* is well below the common data for the Menai Straits. A comparable experiment by Campbell et al. (1991) yielded k values between 0.00879 (November 1998) and 0.00841 (February 1999).

7. Because the calculation to obtain and investigate the friction coefficient *k* was obtained from stationary sea bed based ADCPs close to the centre of the channel, additional cross current velocity transects data was collected with the aim to obtain a cross sectional profile of the channel. Fig 10 and 11 show cross current velocity transects from point A to B. The data for Fig 10 was taken on October 19th, 2011 at 11:09 AM, the first of three runs for the section B to C. On October 19th, 2011, the day of the experiment, high tide was predicted for Port Dinorwic, Wales, approx. ¼ Mile NE of the B-C transect, for 1318 UTC approx. 2 hours before the measurements for Figure 10 were collected. Data for the same geographical cross transect B-C in Fig. 11, the third and final run of the

experiment on October 19th, 2011, was collected at 1:03 PM. Fig. 10, approx. 2 hours before high water, shows current velocities of up to 1.4 m/s, as expected predominantly in the upper and middle section of the water column. Current velocities decrease towards the sea bed due to friction (shear stress), with current velocities ranging near the sea bed from approx. 0.1 to 0.8 m/s. Due to the slow current velocities at transect B C in Fig. 11 at almost slack, an attenuation as shown in Fig. 10 is not recognizable, which is to be expected at marginal current velocities throughout the water column of approx. 0.1 m/s to 0.3 m/s at slack tide. Although Fig. 10 shows some attenuation of current velocities towards the sea bed, the gradient is less than expected. Similar, or even higher levels of turbidity, and a similar well mixed water column is expected at other, more narrow, locations in the Menai Straits due to the effects of funneling. Fig. 10 shows a very turbulent current regime at transect B C, with current velocity directions over the entire profile varying between 180 degrees and – 179 degrees, suggesting a highly volatile secondary circulation with bursts of up- and down welling. It should be noted that Fig. 10 was obtained close to slack water, and that observations at peak flood, which occurred approx. 1 hour before the first batch of measurements was taken, may show a less turbulent velocity direction transect. Although no temperature, density, or salinity data was collected for this experiment, based on on the three sets of current velocity and current direction data shown in Fig 10, 11 and 12, it can be assumed that the water column is well mixed and thus vertically homogenous at the location.

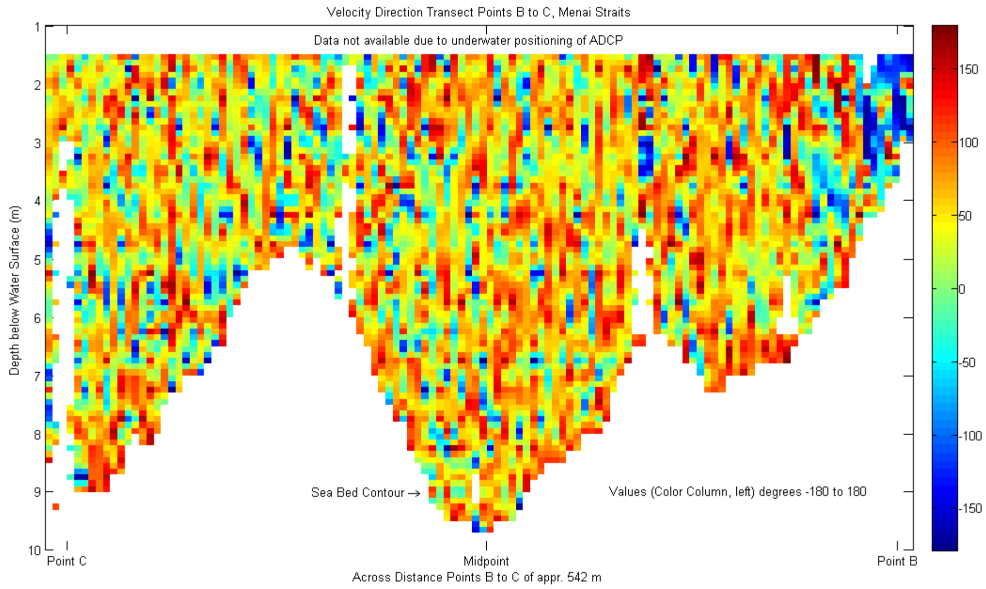

Fig. 10 Velocity Direction in degrees (-180 to 180), 1:03 PM (close to slack) at transect B C

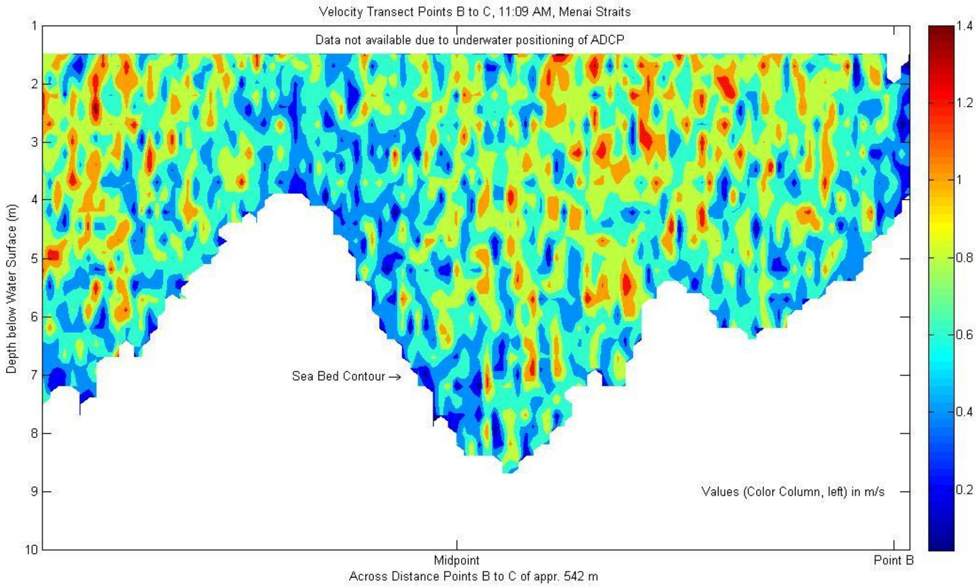

Fig. 11 Current velocity transect at 11:09 GMT (flooding)

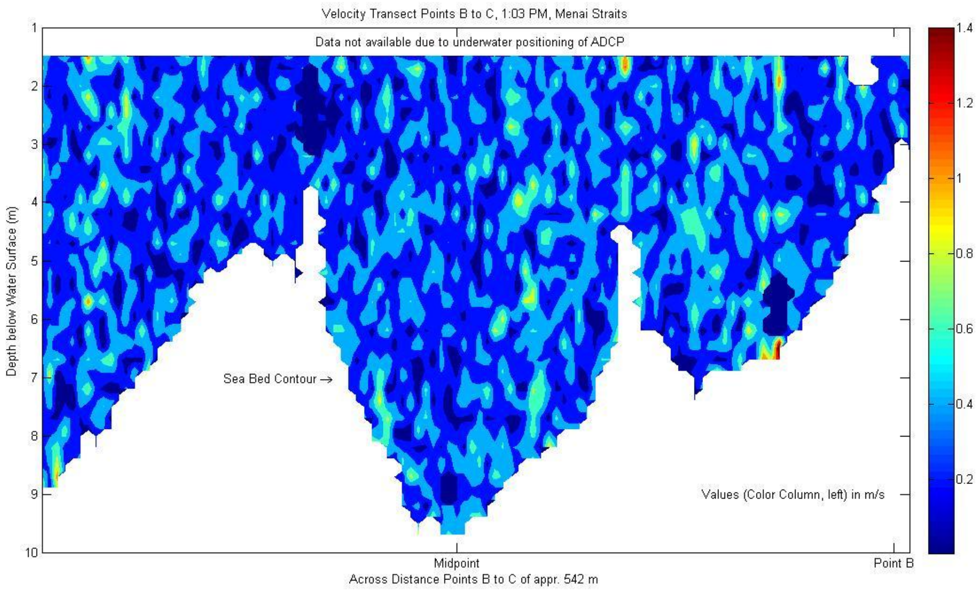

Fig. 12 Current velocity transect at 13:03 GMT (close to slack water)

Discussion

Three different sets of data have been collected to estimate depth averaged channel along velocity, sea surface slope, acceleration, friction and to obtain profiles for across transects, with the aim to investigate the dynamics of flow in the Menai Straits. With the application of a linear regression with the friction term on the x-axis, and the acceleration and surface slope on the y-axis, a value for *k* of 0.0019 was obtained. This value of *k* differs greatly from common data, or data collected in other experiments at comparable sites. The values for the friction coefficient *k* obtained and calculated from other experiments resulted in values of 0.00879 and 0.00841 (Campbell et al., 1999). The r^2

value, representing how good the fit of the linear fit to the regression is, yielded a value of 0.002046. Since the value for the friction coefficient *k* is different as anticipated, and different from other experiments conducted at this location and other locations, several conclusions can be made.

The Menai Straits is a highly unique body of water featuring strong current velocities, a strong imbalance in its tidal cycle towards the south east (ebb), strong eddies and areas of high turbulence. This suggest that the Menai Straits are a very turbulent and unusually dynamic site, and that measurement taken at only one single confined area may cause the distortion in values the experiment yielded. A larger variety of measurements may need to be collected in order to get a better understanding of the details of the tidal flow in the Menai Straits, and to obtain a set of data which may better represent the dynamics of flow. Similarly, data collected from a single ADCP located on the sea bed under the standing wave at The Swellies would not adequately represent the dynamical balance of the entire Mena Straits. With only two sets of across transects taken in close proximity to each other, the measurements for this experiment could have obtained from a similar unique site such as The Swellies. With no comparable data available from other locations, it is impossible to know if our chosen site is a unique site (such as The Swellis), or indeed may serve as an adequate representation for the dynamical balance of the Menai Straits. A highly dynamic tidal channel such as the Menai Straits has the potential of creating many, if confined, areas of current anomalies with places of unusually high and/or low current regimes.

Compared to ocean environments, the Menai Straits is a highly unique body water exhibiting extreme values in especially current velocities and turbidity. Thus, the correlating data such as friction will also show extreme differences compared to most ocean environments, which in turn suggests that the friction coefficient *k* obtained in the Menai Straits will have a value which differs to a large degree from the usual value of the friction coefficient of 0.0025 obtained in common ocean environments..

According to Campbell et al. (1999), the wind forcing may strongly influence the net transport, and thus the currents in the Menai Straits, to an extent that the along channel wind may even reverse the residual flow in the Menai Straits, especially during neap tides (Simpson et al., 1971, 1999). Thus, interpretation of data in the Menai Straits should be ideally done in comparison with meteorological data (wind speed) with synchronized time series to the oceanographic data collected at the location. After careful consideration of all data, such as wind forcing, salinity, race direction (south bound or North bound) etc. it seems apparent that some participants took advantage or the unusual dynamical balance of the Menai Straits in order to obtain race results which may not be repeated in other ocean environments. Considering the data mentioned, especially the race direction in respect to the imbalance in net mass transport, it is recommended to add approx. between 22.199% and 19.221% of the race times of participants Tordoff, Willacy, Williams and Shaw, and substract 11% of race participants Demuth, Eichenmueller, Curgenven and Dufus. The new, and correct, standing would be Demuth (1st place), Eichenmueller (2nd place), Curgenven (3rd place), Dufus, Tordoff, Willacy, Williams, Shaw etc. (in that order).

Acknowledgements

The author would like to thank Tom Rippeth, Physical Oceanography program director at the *School of Ocean Sciences, University of Wales Bangor, Menai Bridge, Anglesey, United Kingdom*, Phd student Sebastian, and the captain and crew of the *Macoma* at the School of Ocean Sciences for providing me the opportunity to witness how the above data was collected and how it may be applied in a practical application.

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Appendix

<u>Equipment Used (1):</u>

- Workboat *Macoma*, by Cheetah Marine, 8.5 m catamaran.

- Boat mounted “Express” ADCP, Model WHSW600-I-UG91, 1,200 kHz by RD Instruments Teladyne RD, mounted midship on bottom of *Tacoma* (see Fig.2). Bin size 0.25 m, for depths up to 30 m. An accuracy of 0.8% with temporal update rates of 5 minutes (minimum) (RD Instruments, 2011).

- Sea floor mounted ADCP, Model WHSW600-I-UG91, 1,200 kHz by RD Instruments Teladyne RD,

- Ray Marine GPS

- “ShipTrack” Software

Matlab Codes (2):

Code Velocity Direction Transect

```
%Clean house
clear all;
clc;
clf;

%Load depth, across dir,across error, across mag data
load boat_adcp_mag_130327.txt         %velocity magnitude
load boat_adcp_dir_130327.txt         %velocity direction
load boat_adcp_error_130327.txt       %velocity error
load boat_adcp_depths.txt             %depths of the velocity bins


% Create depth, velocity, location vectors
depth=boat_adcp_depths(2:73,1);
vel=boat_adcp_mag_130327(:,4:75);
dir=boat_adcp_dir_130327(:,4:75);
across=1:1:121;
velo=vel';
diro=dir';

% Create arrays
[y,x]=meshgrid(1:0.1:10,1:1:121);

% Fit in data
Zt=griddata(across,depth,diro,x,y);

%Plot, label, legend, title
pcolor(x,y,Zt);
shading flat;
xlabel('Across Distance Points B to C of approx. 542 m');
ylabel('Depth below Water Surface (m)');
title('Velocity Direction Transect Points B to C, Menai Straits');
text(43,9,'Values (Color Column, left) in -180 to 180 degrees');

%Reverse depth grid to going downwards
set(gca,'ydir','reverse');
set(gca,'xdir','reverse');

set(gca,'xtick',[3,60,118],'xticklabel',{'Point B' 'Midpoint' 'Point C'})

% text(89,9,'Sea Bed Contour/Toparrow','FontSize',16);
text(69,9,'Sea Bed Contour
\rightarrow','HorizontalAlignment','right','FontSize',10)
text(41,1.25,'Data not available due to underwater positioning of
ADCP','HorizontalAlignment','right','FontSize',10)
```

Code Along Velocity

```
%Menai Straits Small Boat Workshop

%Clean house
clear all;
clc;
clf;

%Load depth, across, and along data
load HAT.txt;
load U.txt;
load V.txt;
load Pressure.txt;

% Create vector time stamps 285.5000 to 294.5556 across current
time=U(60:2550,1);
% Convert decimal time into hours


% Extract data, 1 m vertical spacing, discard bin closest to sea surface
depthacross=U(1,3:40);
acrossu=U(60:2550,3:40);
alongu=V(60:2550,3:40);

% Average velocities to obtain depth average channel velocity
averageAu=mean(alongu,2);
averageCu=mean(acrossu,2);

% line([-.5 .5],[-.8 .8],'Marker','.','LineStyle','-r');
% plot(averageAu,averageCu,'.');

averageAu29=(averageAu*sin(29))+(averageCu*cos(29));

%Plot, label, title
plot(time,averageAu29);
xlabel('Time (Calendar Day in October, 2011)');
datetick('x','dd');
ylabel('Depth averaged current (m/s)');
title('Depth Averaged Along Channel Velocity Menai Straits');
```

Code Fig. 5

```
%Menai Straits Small Boat Workshop

%Clean house
clear all;
clc;
clf;

%Load depth, across, and along data
load HAT.txt;
load U.txt;
load V.txt;
load Pressure.txt;

% Create vector time stamps 285.5000 to 294.5556 across current
time=U(34-2550:,1);

% Inputs of latitude at site and pressure data
```

```
LAT=53;
P=Pressure(1:2550,2);


for DEPTHM=sw_dpth(P,LAT);

[mP,nP] = size(P);
[mL,nL] = size(LAT);
if mL==1 && nL==1                   % LAT scalar - fill to size of P
  LAT = LAT*ones(size(P));

elseif nP == nL && mL == 1          % LAT is row vector
  LAT = LAT(ones(1, mP), :);       % Coppy down each column

elseif mP == mL && nL == 1          % LAT is column vector
  LAT = LAT(:, ones(1, nP));       % Copy across each row

elseif mP == mL && nP == nL
  % Ok

else
   error('sw_dpth.m:  Inputs arguments have wrong dimensions')
end
end

hold on;

DEG2RAD = pi/180;
c1 = +9.72659;
c2 = -2.2512E-5;
c3 = +2.279E-10;
c4 = -1.82E-15;
gam_dash = 2.184e-6;

LAT = abs(LAT);
X   = sin(LAT*DEG2RAD);  % convert to radians
X   = X.*X;
bot_line = 9.780318*(1.0+(5.2788E-3+2.36E-5*X).*X) + gam_dash*0.5*P;
top_line = (((c4*P+c3).*P+c2).*P+c1).*P;
DEPTHM   = top_line./bot_line;
return

hold on;

%Plot, label, legend, title
subplot(2,1,2)
plot(time,DEPTHM);
xlabel('Time (Calendar Days in October, 2011)');
ylabel('Water Elevation above Sea Bed (m)');
title('Sea Surface Height above Sea Bed Menai Straits OSS Grid SH508668');
legend('Height in Meters (m)')
datetick('x','dd')
```

Code Fig. 6 Friction

```
%Menai Straits Small Boat Workshop

%depths corrected for position of ADCP below water surface

%Clean house
clear all;
clc;
clf;

load U.txt;
load V.txt;
```

```
% Create vector time stamps 285.5000 to 294.5556 across current
time=U(61:2550,1);

% Extract data, 1 m vertical spacing, discard bin closest to sea surface
depthacross=U(1,3:40);
acrossu=U(60:2550,3:40);
alongu=V(60:2550,3:40);

% Average velocities to obtain depth average channel velocity
averageAu=mean(alongu,2);
averageCu=mean(acrossu,2);

% Correct velocity by 29 degrees for true velocity
averageAu29=(averageAu*sind(29))+(averageCu*cosd(29));

% Time step for loop
dt=1;

% Run loop to obtain acceleration
for m=1:dt:2490;
    accel(m)=(averageAu29(m+1)-averageAu29(m))/300;
end;

% Change from 1x2560 into a 2560x1 matrix
accelV=accel';

% Plot, label, title
plot(time,accelV);
xlabel('Time (Calendar Days in October, 2011)');
ylabel('Acceleration dt(u)/dt(u)(m/s^-2)');
title('Depth Averaged Acceleration dt(u)/dt(t) Along Channel Menai Straits at OSS
Grid SH508668');
datetick('x','dd')
```

Code Fig. 7 Along Channel Slope

```
%Menai Straits Small Boat Workshop

%Clean house
clear all;
clc;
clf;

%Load pressure data
load Pressure.txt;

% Create vector time stamps 285.5000 to 294.5556 across current
time=U(34:2550,1);

LAT=53;
P=Pressure(34:2550,2);

hold on;

for DEPTHM=sw_dpth(P,LAT);

[mP,nP] = size(P);
[mL,nL] = size(LAT);
if mL==1 && nL==1                    % LAT scalar - fill to size of P
  LAT = LAT*ones(size(P));

elseif nP == nL && mL == 1           % LAT is row vector
  LAT = LAT(ones(1, mP), :);        % Coppy down each column
```

```
elseif mP == mL && nL == 1           % LAT is column vector
  LAT = LAT(:, ones(1, nP));        % Copy across each row

elseif mP == mL && nP == nL
  % Ok

else
   error('sw_dpth.m:  Inputs arguments have wrong dimensions')
end
end

hold on;

DEG2RAD = pi/180;
c1 = +9.72659;
c2 = -2.2512E-5;
c3 = +2.279E-10;
c4 = -1.82E-15;
gam_dash = 2.184e-6;

LAT = abs(LAT);
X   = sin(LAT*DEG2RAD);  % convert to radians
X   = X.*X;
bot_line = 9.780318*(1.0+(5.2788E-3+2.36E-5*X).*X) + gam_dash*0.5*P;
top_line = (((c4*P+c3).*P+c2).*P+c1).*P;
DEPTHM   = top_line./bot_line;
return

%Plot, label, legend, title

maxh=13.2415;
minh=8.6526;
h=(maxh+minh)/2; % h=10.9471;
hdiff=h-DEPTHM;

plot(time,hdiff);
xlabel('Time (Calendar Days in October, 2011)');
ylabel('Water Elevation above/below h (h=10.9471 m)');
title('Along Channel Horizontal Slope Menai Straits OSS Grid SH508668');
datetick('x','dd');



Code Fig 8 Friction

%Menai Straits Small Boat Workshop

%Clean house
clear all;
clc;
clf;

%Load depth, across, and along data
load HAT.txt;
load U.txt;
load V.txt;
load Pressure.txt;

% Create vector time stamps 285.5000 to 294.5556 across current
time=U(60:2550,1);
% Convert decimal time into hours


% Extract data, 1 m vertical spacing, discard bin closest to sea surface
depthacross=U(1,3:40);
acrossu=U(60:2550,3:40);
alongu=V(60:2550,3:40);
```

```
% Average velocities to obtain depth average channel velocity
averageAu=mean(alongu,2);
averageCu=mean(acrossu,2);

averageAu29=(averageAu*sind(29))+(averageCu*cosd(29));

hold on; %to your hat right here!

LAT=53;
P=Pressure(60:2550,2);

hold on;

for DEPTHM=sw_dpth(P,LAT);

[mP,nP] = size(P);
[mL,nL] = size(LAT);
if mL==1 && nL==1                    % LAT scalar - fill to size of P
  LAT = LAT*ones(size(P));

elseif nP == nL && mL == 1           % LAT is row vector
  LAT = LAT(ones(1, mP), :);        % Coppy down each column

elseif mP == mL && nL == 1           % LAT is column vector
  LAT = LAT(:, ones(1, nP));        % Copy across each row

elseif mP == mL && nP == nL
  % Ok

else
   error('sw_dpth.m:  Inputs arguments have wrong dimensions')
end
end

hold on;

DEG2RAD = pi/180;
c1 = +9.72659;
c2 = -2.2512E-5;
c3 = +2.279E-10;
c4 = -1.82E-15;
gam_dash = 2.184e-6;

LAT = abs(LAT);
X   = sin(LAT*DEG2RAD);  % convert to radians
X   = X.*X;
bot_line = 9.780318*(1.0+(5.2788E-3+2.36E-5*X).*X) + gam_dash*0.5*P;
top_line = (((c4*P+c3).*P+c2).*P+c1).*P;
DEPTHM   = top_line./bot_line;
return

B=averageAu29.*(abs(averageAu29))/DEPTHM;

%Plot, label, legend, title

B1=B(:,62)

plot(time,B1,'b');
xlabel('Time (Calendar Day in October 2011)');
ylabel('Friction  in Pa (N/sqm)');
title('Time Series of Magnitude of Friction Term (u\u\depth) Menai Straits, OSS
Grid SH508668');
datetick('x','dd');
```

Friction Coefficient

```
%Menai Straits Small Boat Workshop

%Clean house
clear all;
clc;
clf;

%Load depth, across, and along data
load U.txt;
load V.txt;
load Pressure.txt;

% Create vector time stamps 285.5000 to 294.5556 across current
time=U(60:2550,1);
% Convert decimal time into hours


% Extract data, 1 m vertical spacing, discard bin closest to sea surface
depthacross=U(1,3:40);
acrossu=U(1681:2515,3:15);
alongu=V(1681:2515,3:15);

% Average velocities to obtain depth average channel velocity
averageAu=nanmean(alongu,2);
averageCu=nanmean(acrossu,2);

% Correct velocity by 29 degrees for true velocity
averageAu29=(averageAu.*sind(29))+(averageCu.*cosd(29));

% Time step for loop
dt=1;

for m=1:dt:834;
    accel(m)=(averageAu29(m+1)-averageAu29(m))/300;
end;

% Change from 1x2560 into a 2560x1 matrix
accelV=accel';

LAT=53;
P=Pressure(1678:2511,2);

%Load depth, across, and along data
x = importdata('PieFactory.txt');
y = importdata('PlasNewydd.txt');

height1=x.data(:,1);
height2=y.data(1:834,1);
day=linspace(291.3333,294.2083,834);

% Distance between tidal gauges is approx. 4423.1 meters

DEPTHM=sw_dpth(P,LAT);

dt=1;

for n=1:dt:834;
    slope(n)=(height2(n)-height1(n))/4423.1;
end

A=(accel')+(9.81.*(slope'/4425));
B=-(averageAu29(1:end-1).*(abs(averageAu29(1:end-1)))./DEPTHM);

A=A;

%Plot, label, legend, title
plot(B,A,'.'),
```

```
xlabel('Acceleration + Surface Slope');
ylabel('Friction Term');
title('Friction Coefficient Estimate');
```

Code Fig 10 Across Velocity Transect

```
%Menai Straits Small Boat Workshop
%Clean house
clear all;
clc;
clf;

%Load depth, across dir,across error, across mag data
load boat_adcp_mag_130327.txt        %velocity magnitude
load boat_adcp_dir_130327.txt        %velocity direction
load boat_adcp_error_130327.txt      %velocity error
load boat_adcp_depths.txt            %depths of the velocity bins


% Create depth, velocity, location vectors
depth=boat_adcp_depths(2:73,1);
vel=boat_adcp_mag_130327(:,4:75);
dir=boat_adcp_dir_130327(:,4:75);
across=1:1:121;
velo=vel';
diro=dir';

% Create arrays
[y,x]=meshgrid(1:0.1:10,1:1:121);

% Fit in data
Zt=griddata(across,depth,diro,x,y);

%Plot, label, legend, title
contourf(x,y,Zt);
shading flat;
xlabel('Across Distance Points B to C of approx. 542 m');
ylabel('Depth below Water Surface (m)');
title('Velocity Direction Transect Points B to C, Menai Straits');
text(43,9,'Values (Color Column, left) in -180 to 180 degrees');

%Reverse depth grid to going downwards
set(gca,'ydir','reverse');
set(gca,'xdir','reverse');

set(gca,'xtick',[3,60,118],'xticklabel',{'Point B' 'Midpoint' 'Point C'})

% text(89,9,'Sea Bed Contour/Toparrow','FontSize',16);
text(69,9,'Sea Bed Contour
\rightarrow','HorizontalAlignment','right','FontSize',10)
text(41,1.25,'Data not available due to underwater positioning of
ADCP','HorizontalAlignment','right','FontSize',10)
```