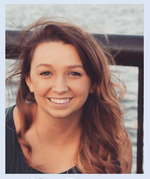
Geomorphological Analysis of Complex Sediment Waves in Southeastern Ireland



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ABSTRACT

During July and August of 2009, hydrographers with the Geological Survey of Ireland and Marine Institute of Ireland conducted two multibeam sonar surveys aboard the R/V *Celtic Voyager* on the southeast coast of Ireland approximately 7 km east of Wexford Harbour (Figure 1). Surrounding the harbour and to the southwest off of Kilturk Bank, bathymetric analysis revealed a complex system of sediment waves with depths that range from 12 to 80 m, with east-west crests measuring ~14 km and wavelengths ranging from ~100 to 1100 m. The purpose of this study is to quantify the sediment wave geomorphology, including length, width, height, sinuosity, peakedness, and orientation in order to approximate variability in the water current velocity and heading for this area. Based on data collected from the Army Corp of Engineers (Levin and Lillycrop, 1992), velocities in the Irish Sea range from 0.3 to 1.0 m/sec. However, using average wavelength data from the sediment waves, sites within both study areas were shown to range in predicted current velocity from approximately 0.1 to 4.0 m/sec (Figure 4). The sediment waves in all study sites vary in size, wavelength, and orientation making the southeast coast as a whole an intricate and convoluted tidal area with hazardous changes in current directions and velocities. The varying current directions indicate areas of uni- and bi-directional flow, relating to St. Georges Channel currents and nearshore tidal flows, respectively. These quantitative analyses of sediment wave geomorphology using multi-beam sonar is useful for determining the current strength and direction in shallow waters where safe navigation is key. Comparative results of the two regions will be presented.

METHODS

- The Geological Survey of Ireland and Marine Institute of Ireland sailed aboard the R/V *Celtic Voyager* in 2009 and collected multibeam sonar data using a Kongsberg EM3002 multibeam echosounder.
- CARIS 9.1 and 10.4 were used to create CUBE BASE surfaces with a 2 m resolution (Fig. 3).
- Five sites (A-E) were identified based on the difference in sediment wave characteristics surrounding the Lucifer Bank and Long Bank (Fig. 4)
- Seven sites (KB-S, KB-I 1, 2, KB-D 1, 2, 3, 4) were chosen based on the differences in characteristics and their placement within shallow, intermediate, and deep waters (Fig. 7)
- Measurements were made from south-to-north profiles to determine the crest to crest wavelengths in both study areas. Individual sediment waves were measured for their base length (on both the north and south sides), and height. (Fig. 4, 7).
- **Symmetry** was determined by dividing the South base length by the North base length, where a value of 1.0 indicates sediment wave symmetry. Values greater than 1.0 indicate asymmetry with a current flowing northward, whereas values less than 1.0 indicate asymmetry with a southward-flowing current (Fig. 2).
- **Peakedness** was calculated by dividing height by total base length (Fig. 4). Values greater than 0.05 and above represent higher peakedness (Fig. 2).
- **Velocity** was calculated from the US Army Corps of Engineers from the Irish Sea. Based on this data, a scale was created to determine the velocities correlating with the data in this study (Fig. 2).

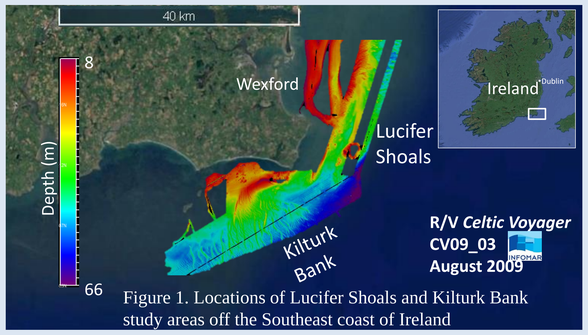


Figure 1. Locations of Lucifer Shoals and Kilturk Bank study areas off the Southeast coast of Ireland

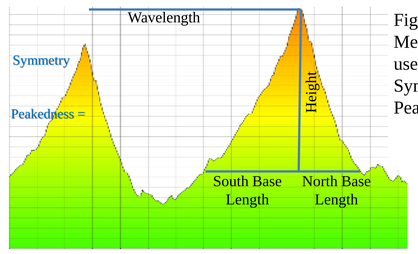
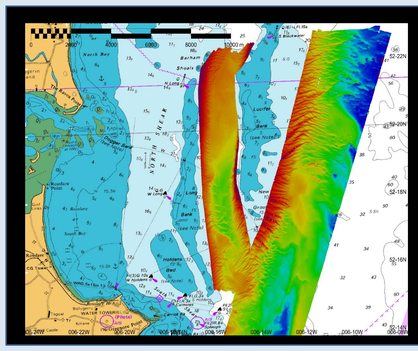


Figure 2: Measurements used to calculate Symmetry and Peakedness.

BACKGROUND

In the summer of 2009, hydrographers with the Geological Survey of Ireland and the Marine Institute of Ireland conducted multibeam sonar surveys off the southeast coast of Ireland aboard the R/V *Celtic Voyager* as part of the INtegrated Mapping FOr the Sustainable Development of Ireland's MArine Resource (INFOMAR) Program. A complex suite of giant bedforms here referred to as sediment waves was mapped in two adjacent regions: Lucifer Shoals east of Wexford Harbour, and Kilturk Bank southwest of Lucifer and east of Ballyteige Bay. Normal tidal current direction is from the south to the north (Kinahan, 1875) and the tidal range is approximately 1.5 m (Wexford Harbour Tide Times, 2017). However, in these areas, the current is known to be powerful, and requires careful navigation. Rosslare Harbour, which lies to the southwest of Lucifer Bank and Long Bank, is a major ferry port with service from Wexford to the UK and France. There is a significant tidal current leaving Rosslare Harbour and entering the area surrounding both Lucifer and Long Banks. Ships and ferries traveling through the channel have to be mindful of the tide. Even though the current poses a significant hazard to traffic at sea, the waters are navigable, as the Harbour is well marked with buoys and hazard markers and the ships' captains are well briefed on tidal currents (D. Rowan, Personal Communication). However, in some cases, the current directions switch suddenly and oppose each other, creating risky waters. The current directions and winds are meeting each other at particular times in the tide, creating the potential for standing waves (V. Quinlan, Personal Communication). While surveying this area, Quinlan observed that the sediment waves were dynamically changing within one tidal cycle in one day. The purpose of this study is to discover the dominant directions and relative strengths of localized currents by using sediment wave orientation, symmetry, and wavelength. Each site is strikingly different in sediment wave geomorphology, which give clues to current velocity and heading. Current velocities are directly related to sediment wave wavelength, whereas sediment wave symmetry and peakedness are estimated to be indicative of current direction and velocity, respectively. Based on prior data collected by the U.S. Army Corps of Engineers (Levin and Lillycrop, 1992), velocities in the Irish Sea were documented to range from 0.3 to 1.0 m/sec.

Lucifer Shoals



Lucifer Shoals

Figure 3. Admiralty chart with a 2m CUBE BASE surface

Table 1: Average wavelength, symmetry, height, peakedness, and average velocity for sediment waves at each site.

Site	Average Wavelength (m)	Average Symmetry	Average Height (m)	Average Peakedness	Predicted Average Velocity (m/sec)
A	252.68	1.075	6.500	0.060	1.6
B	148.09	0.952	3.500	0.038	0.5
C East	105.626	3.181	6.486	0.043	0.1
C West	215.09	1.239	4.429	0.048	1.2
D	92.08	1.626	2.500	0.034	0.5
E	153.4	0.322	3.091	0.026	0.6

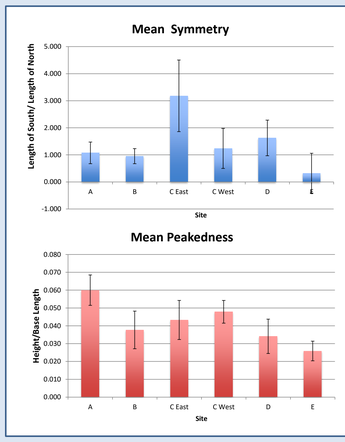
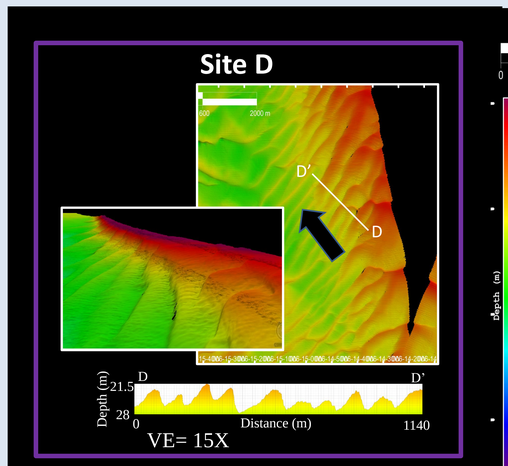


Figure 6: Mean symmetry and mean peakedness for sediment waves at each site, measured along profiles.



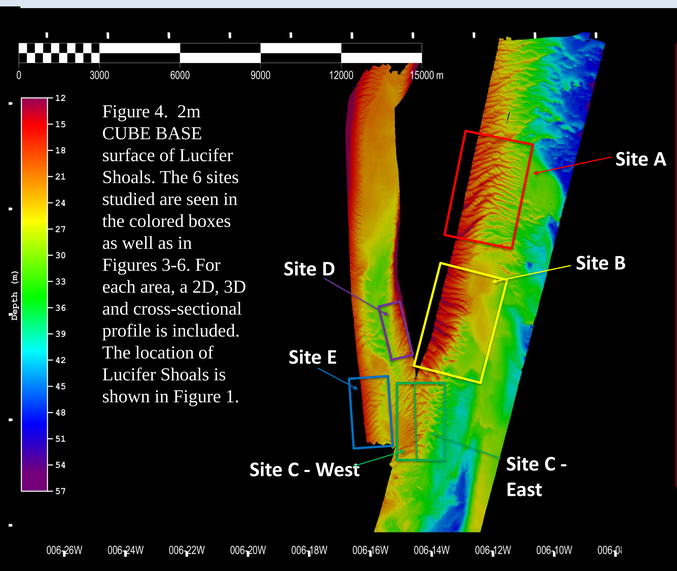
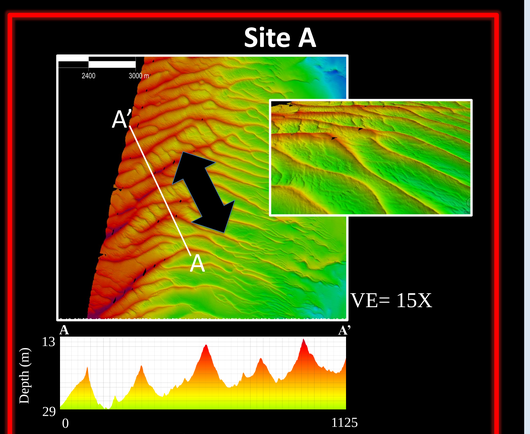
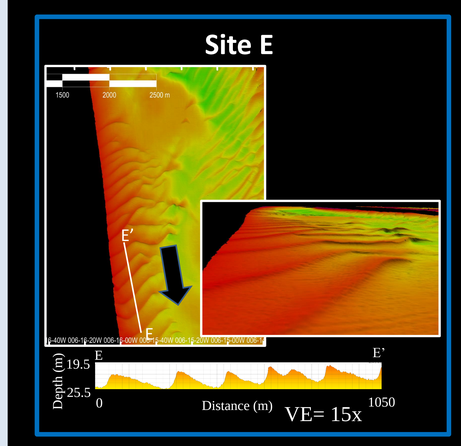
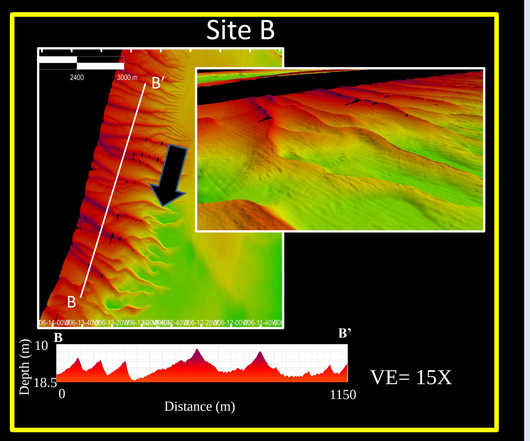


Figure 4. 2m CUBE BASE surface of Lucifer Shoals. The 6 sites studied are seen in the colored boxes as well as in Figures 3-6. For each area, a 2D, 3D and cross-sectional profile is included. The location of Lucifer Shoals is shown in Figure 1.







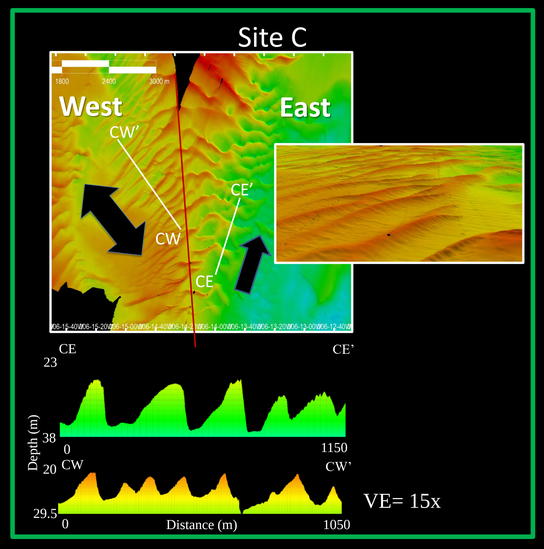


Figure 4A-E and Profiles A-E- 2D and 3D surface with profiles drawn to show the 1st order sediment waves. The current direction for each site is shown with an arrow on the 2D surface.

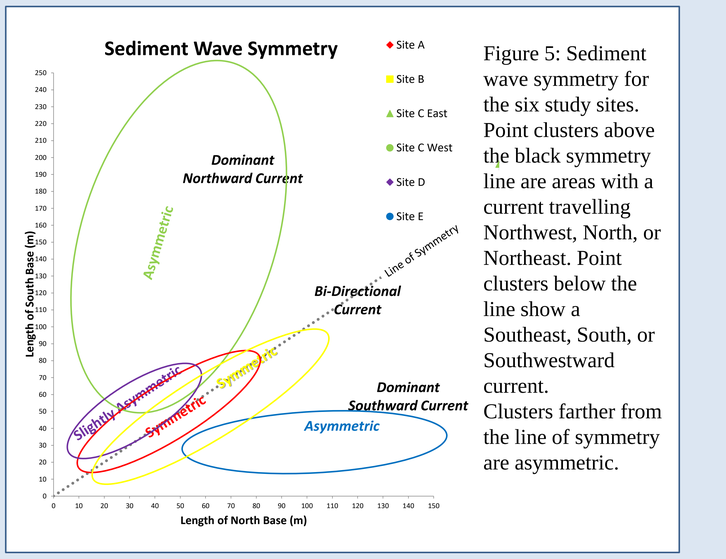


Figure 5: Sediment wave symmetry for the six study sites. Point clusters above the black symmetry line are areas with a current travelling Northwest, North, or Northeast. Point clusters below the line show a Southeast, South, or Southwestward current. Clusters farther from the line of symmetry are asymmetric.

RESULTS: LUCIFER SHOALS

Results are graphically illustrated in Figures 4 and 5. Data are from Table 1.

Site A - sediment waves in this area are close to symmetrical although some waves indicate a Southward and some show a Northward current. The velocity of the current in this area is predicted to be 1.6 m/sec.

Site B - These sediment waves are close to being symmetric, however the majority of the North side base lengths are longer than the South base lengths, indicating a Southward current. Velocity was predicted to be around 0.5 m/sec.

Site C East - Nearly all sediment waves show strong asymmetry with a Northward current direction.

Site C West - The average symmetry in this area shows symmetry, which means that there is a Northward and Southward current present.

Site D - The sediment waves in this area lie close to the line of symmetry, however there is a moderate Northward current.

Site E - The sediment waves for this site are very much asymmetrical and have a dominant Southward current direction.