Analysis of Complex Sand Waves in Raccoon Strait, San Francisco Bay

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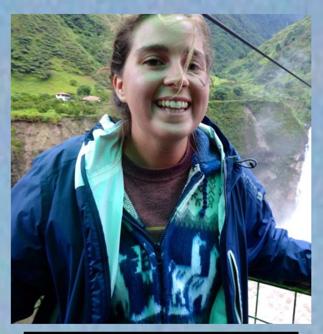

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ABSTRACT

College of Charleston BEAMS (BEnthic Acoustic Mapping and Survey) students sailed aboard the eTrac, Inc. vessel *S/V Pulse* in December 2014 as part of a multibeam survey of Raccoon Strait, the channel separating Point Tiburon and Angel Island in San Francisco Bay. Multibeam data were processed using CARIS HIPS 9.0, revealing complex and dynamic bathymetry of Raccoon Strait, consisting of sand waves varying significantly in length, height, and orientation. Water depths within the strait range from 8 to 65 m, and sand waves range in length from less than 5 m to more than 500 m, with several having heights exceeding 30 m. These sand waves were classified by their geomorphology. Wave symmetry, dimensions, and orientation were used to compare the relative ebb and flood tidal energy flowing through the channel. Raccoon Strait is known to have some of the strongest tidal currents in the San Francisco Bay, due to both the narrow 1 km channel width and its proximity to the bay's mouth. The Strait's southern margin sand waves are oriented eastward towards the inside of the bay and northern margin sand waves are oriented westward towards the bay mouth indicating forceful tidal currents in both ebb and flood directions. The distinctly different flow paths may be the result of Coriolis influence within this large estuarine bay. This study shows how high resolution bathymetry and backscatter can be used to study dynamic inshore sites. Repeated surveys of this area could be used to document migration of these large sand bodies.

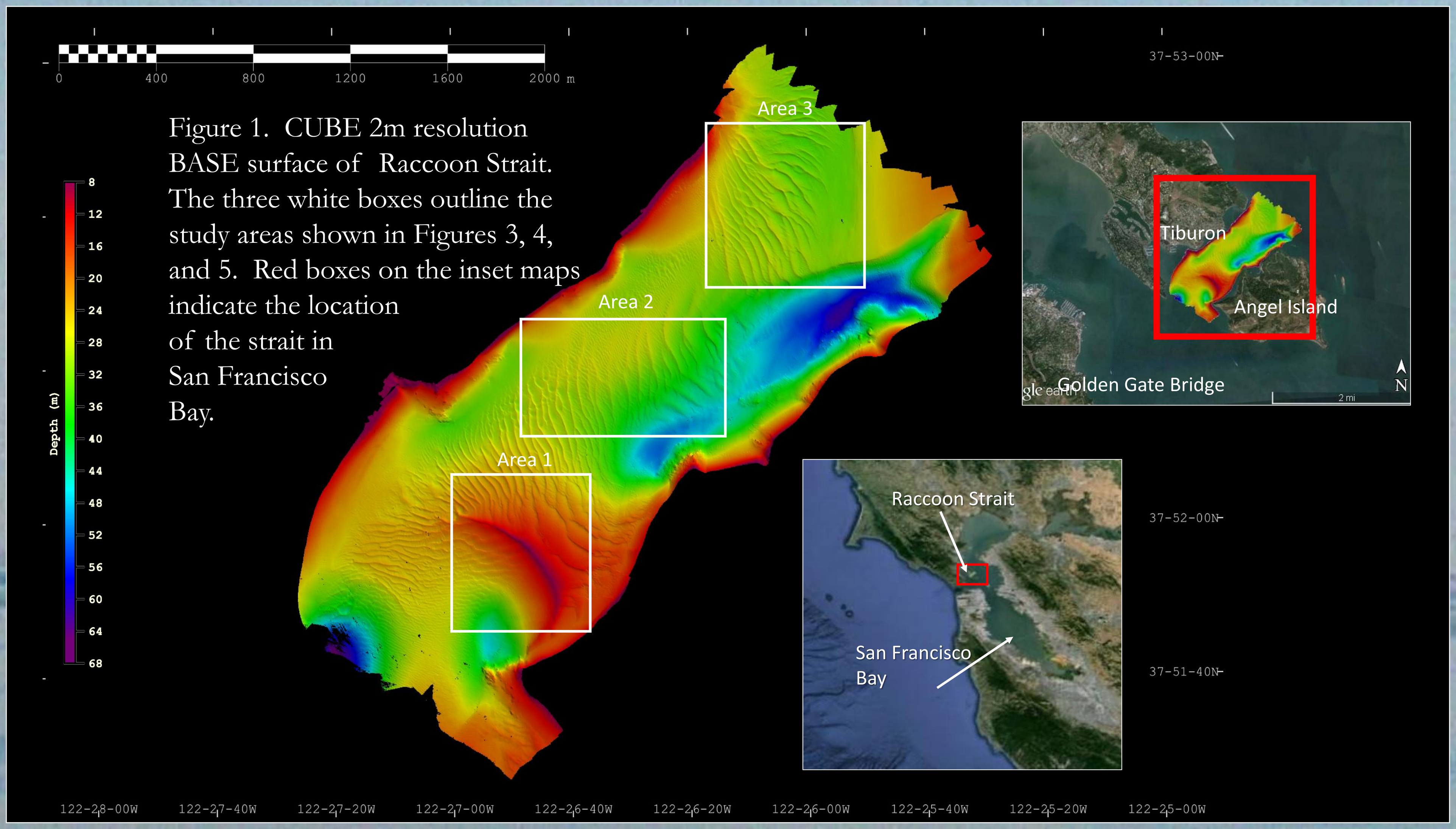


Figure 1. CUBE 2m resolution BASE surface of Raccoon Strait. The three white boxes outline the study areas shown in Figures 3, 4, and 5. Red boxes on the inset maps indicate the location of the strait in San Francisco Bay.

METHODS

- Data were acquired by College of Charleston students aboard the Etrac, Inc. survey vessel, *S/V Pulse* in Fall, 2014 with an R2 Sonic 20/24 multibeam sonar.
- Bathymetry data were processed with CARIS HIPS 9.0 at 2m CUBE BASE surface resolution.
- BASE Editor 4.1 was used to generate a slope surface.
- Sand wave morphology and orientation were determined by measuring the wave length from trough to trough, and then the wave height from the crest. The length from the base of each sand wave to the crest determined the orientation since the slip face side of a sand wave is shortest (Figure 2, Table 1).

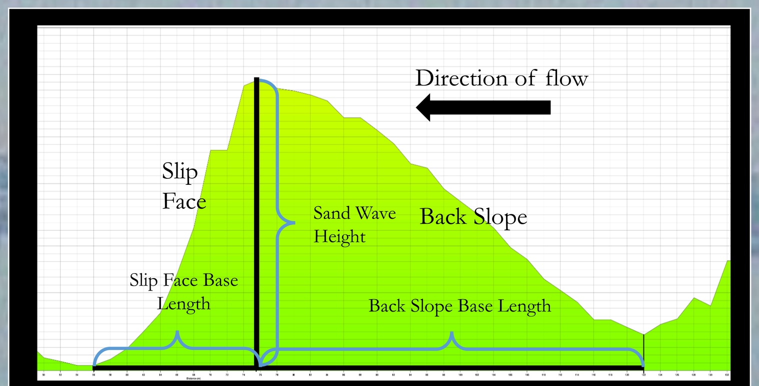
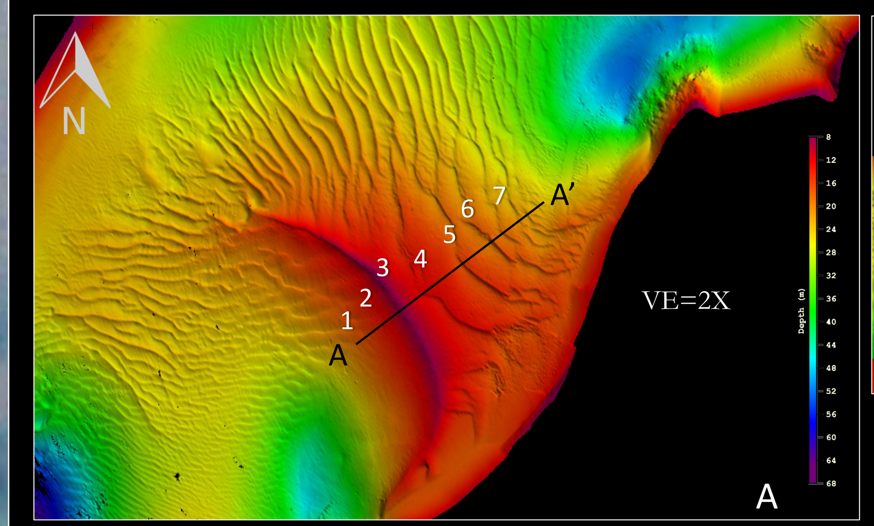
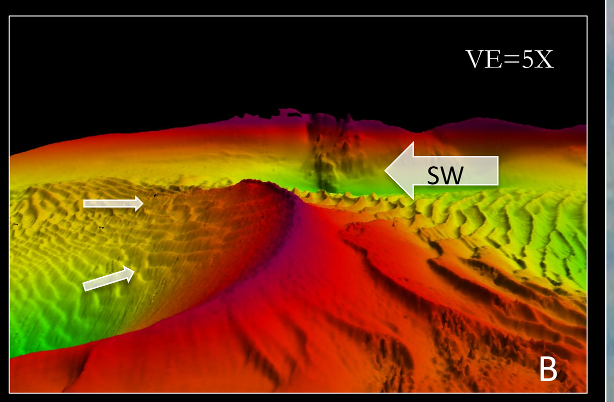


Figure 2. Example of how the direction of flow for each sand wave was determined

Area 1





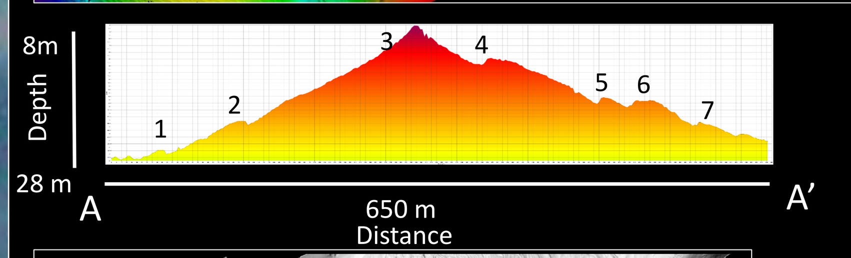


Figure 3A-B. Profile A-A' shows the largest sand wave in Raccoon Strait, oriented southwestward towards the mouth of San Francisco Bay, indicating net ebb tidal flow. However, smaller sand waves on its slip face are oriented northeastward towards the interior of the bay, indicating influence by a weaker flood tide current.

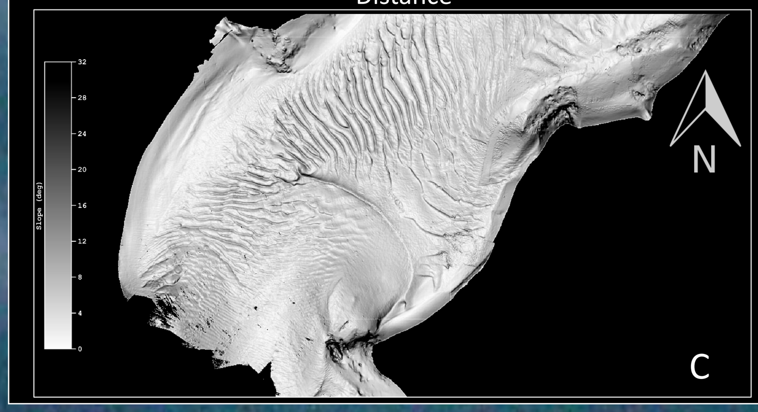
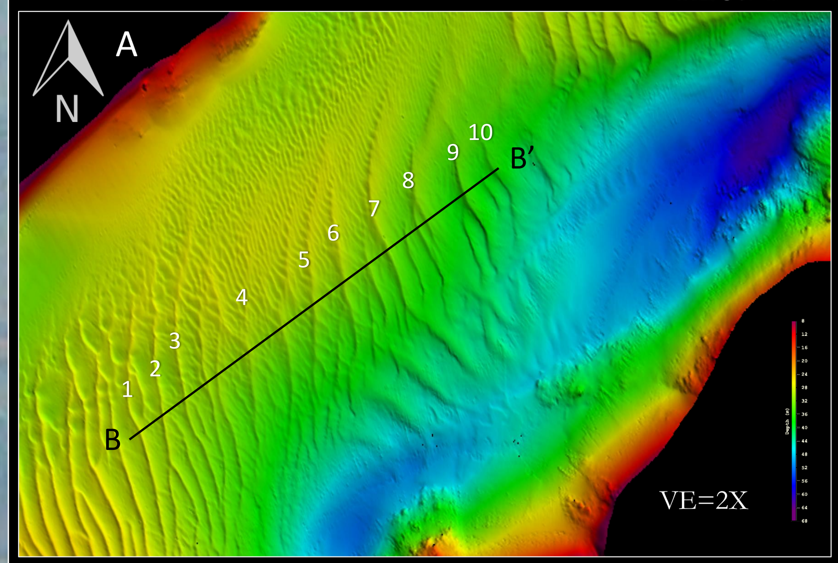


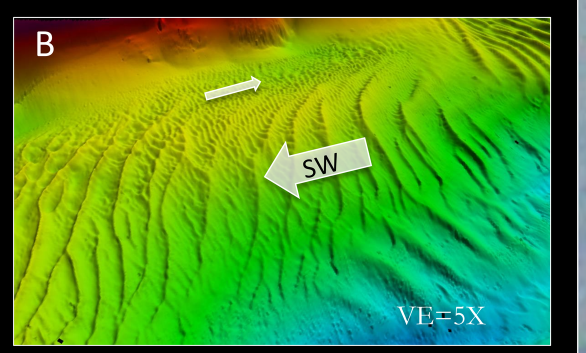
Figure 3C. In the slope-calculated surface of Area 1, the slip face of each sand wave is indicated by darker shading since it is steeper than the back slope.

BACKGROUND

Raccoon Strait is located just north of the mouth of San Francisco Bay between Angel Island and Point Tiburon in California (Figure 1). San Francisco Bay is fed by the San Joaquin and Sacramento River systems making it the second largest estuary on the west coast of the United States. The rivers deposit huge quantities of sand originating from the eroding Sierra Nevada mountain range, resulting in large fields of sand waves in the bay, particularly in and around the mouth (Elias and Hansen 2013). The waves are shaped by strong tidal currents and therefore indicate the force and direction of tidal flow throughout the bay. In fact, the sand waves on the north edge of the bay's mouth beneath the Golden Gate Bridge are oriented with the crest facing towards the ocean indicating net ebb tidal currents while those on the south edge are oriented with the crest facing towards the bay indicating net flood tidal currents (Barnard et al., 2006). Similarly, the sand waves in Raccoon Strait are distinctly associated with ebb or flood tides depending on their location within the channel.

Area 2





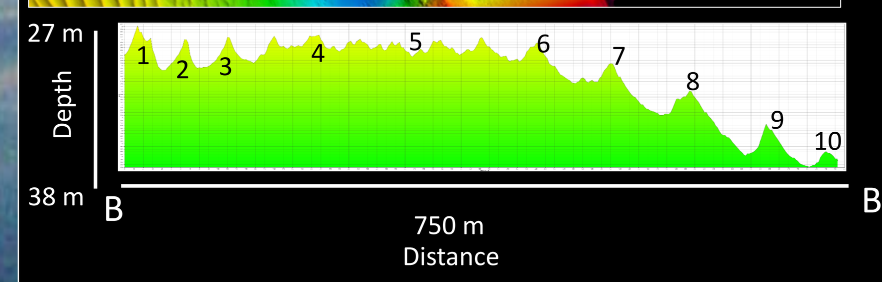


Figure 4A and 4B and Profile B-B'. Sand waves in the center of Raccoon Strait are dominantly oriented towards bay's mouth, however smaller northeast-oriented waves are superimposed on these larger waves (see waves 4-6). Overall, the areas shows a net ebb tidal flow.

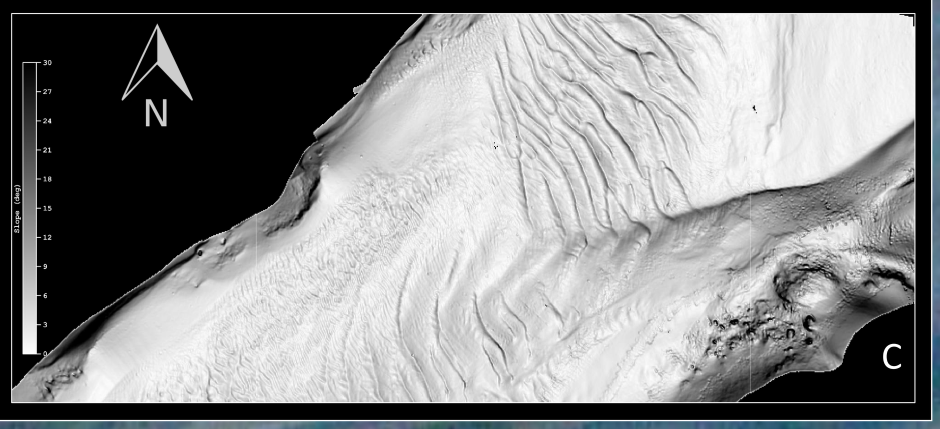
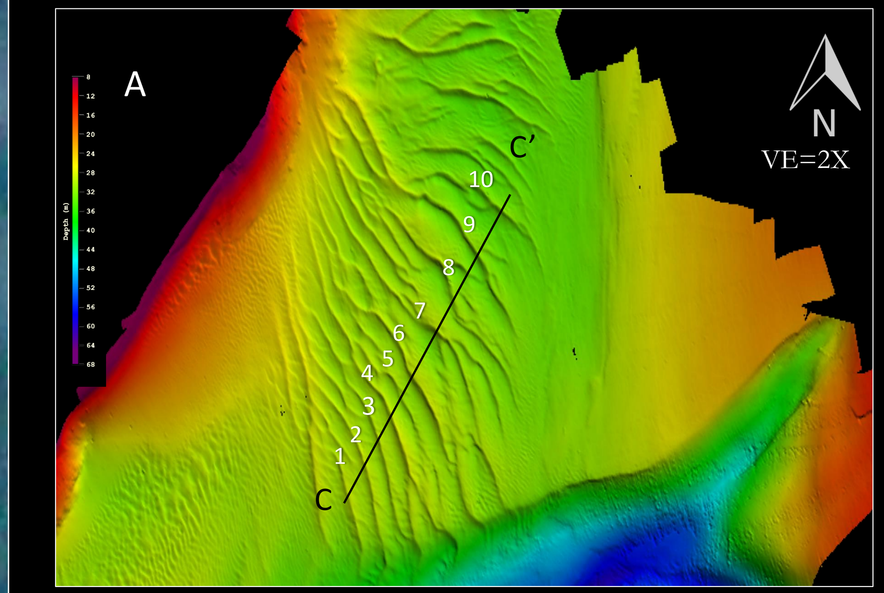


Figure 4C. Variations in Area 2 slope show that sand wave slip faces (darker areas), are primarily oriented toward the southwest, indicating an ebb-oriented current flow.

Area 3



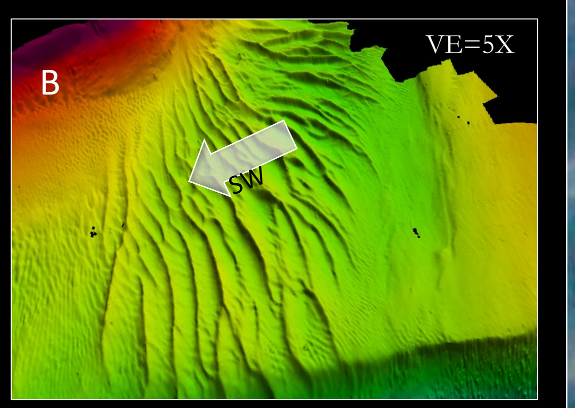
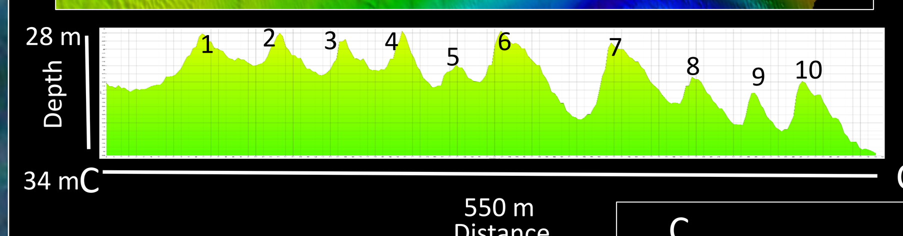


Figure 5A, 5B and Profile C-C' show sand waves at the northern portion of Raccoon Strait. These waves are all oriented westward towards the bay's mouth, indicating a net ebb tidal current.



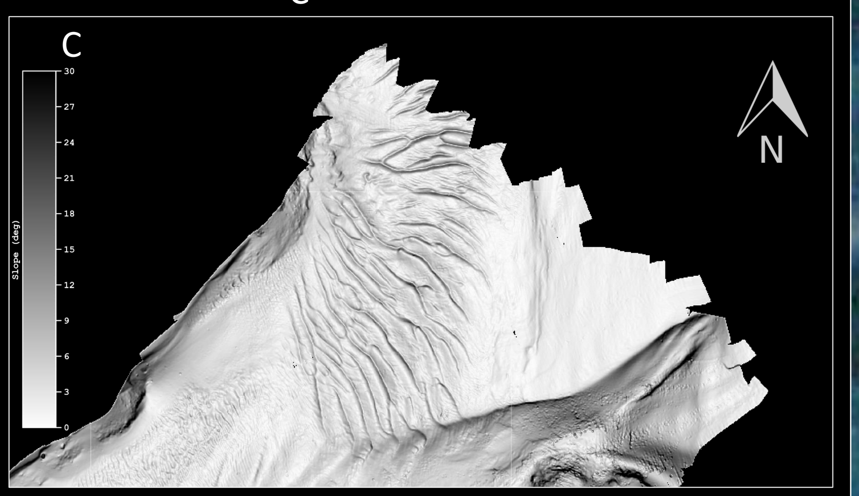


Figure 5C. The variations in slope of Area 3 show that the slip faces of the waves, shown as darker colors, are all on the west face of the sand wave indicating a westward current flow.

RESULTS

Area 1: With 5 of the measured waves pointing southwest towards the mouth of the bay and only two pointing east towards the inside of the bay, Area 1 has net ebb flow (Figure 2). Also, the largest sand wave in Raccoon Strait (over 300 m wide and 30 m tall) is facing southwest indicating high velocity ebb flow.

Area 2: The smallest waves in Raccoon Strait are in Area 2 and are facing both northeast and southwest (Figure 3). Waves facing northeast are concentrated in the southwestern portion of Area 2 while waves facing southwest are more towards the northeast. Symmetrical waves in the area indicate bidirectional flow.

Area 3: All of the measured waves in Area 3 are facing southwest displaying a strong net ebb tide in the northern portion of Raccoon Strait (Figure 4). Waves in Area 3 are steeper than in the other areas of study so the tide may be stronger there.

Summary: Raccoon Strait as a whole exhibits net ebb tidal currents since the majority of the waves face southwest towards the mouth of San Francisco Bay. However, waves facing northeast in parts of the strait are evidence of a significant, but weaker flood tidal current. Peakedness describes how high a sand wave rises over the wavelength measured trough to trough (Table 1). When plotted against sand wave symmetry there is no correlation (Chart 1) so the peakedness of a wave does not influence symmetry, however the current velocity and direction through the channel influences both variables.

Area 1

Area 1 waves	Height (m)	Back Slope Length (m)	Slip Face Length (m)	Peakedness	Symmetry	Flow Direction and Tide
1	1.4	16.0	4.0	0.10	0.25	norhteast-flood
2	0.4	8.0	4.0	0.01	0.50	norhteast-flood
3	33.6	317.0	63.0	2.97	0.20	southwest-ebb
4	4.4	65.2	6.8	0.27	0.10	southwest-ebb
5	3.9	53.8	10.5	0.24	0.20	southwest-ebb
6	2.2	18.0	6.0	0.19	0.33	southwest-ebb
7	4.9	30.0	8.0	0.62	0.27	southwest-ebb

Area 2

Area 2 waves	Height (m)	Back Slope Length (m)	Slip Face Length (m)	Peakedness	Symmetry	Flow Direction and Tide
1	2.0	19.0	8.0	0.15	0.42	northeast-flood
2	2.3	9.0	6.0	0.35	0.67	northeast-flood
3	1.6	9.8	8.2	0.15	0.84	northeast-flood
4	0.4	3.2	2.9	0.02	0.90	southwest-ebb
5	0.5	6.0	6.0	0.02	1.00	symmetrical
6	2.5	40.0	14.0	0.12	0.35	southwest-ebb
7	1.6	10.0	8.0	0.14	0.80	southwest-ebb
8	0.9	8.0	8.0	0.05	1.00	symmetrical
9	2.3	25.6	14.3	0.13	0.56	southwest-ebb
10	1.1	22.1	5.9	0.04	0.27	southwest-ebb

Area 3

Area 3 waves	Height (m)	Back Slope Length (m)	Slip Face Length (m)	Peakedness	Symmetry	Flow Direction and Tide
1	0.7	11.4	4.6	0.03	0.40	southwest-ebb
2	1.5	12.0	11.0	0.10	0.92	southwest-ebb
3	0.4	10.0	4.0	0.01	0.40	southwest-ebb
4	2.5	18.0	4.0	0.28	0.22	southwest-ebb
5	0.7	7.0	5.0	0.04	0.71	southwest-ebb
6	3.8	23.0	15.0	0.37	0.65	southwest-ebb
7	3.1	40.0	20.0	0.16	0.50	southwest-ebb
8	3.4	47.7	19.0	0.17	0.40	southwest-ebb
9	2.3	40.5	9.5	0.11	0.23	southwest-ebb
10	1.3	23.0	7.5	0.06	0.33	southwest-ebb

Table 1. Each sand wave was measured as shown in Figure 2. Peakedness is measured by dividing the height of the sand wave by the sum of the slip face and back slope lengths. Higher numbers indicate greater peakedness. Symmetry is measured by dividing slip face length by back slope length, so that numbers closer to 1 indicate more symmetric forms.

This poster was generated as part of the College of Charleston BEnthic Acoustic Mapping and Survey (BEAMS) Program. For more information, contact Dr. Leslie Sautter (SautterL@cofc.edu).

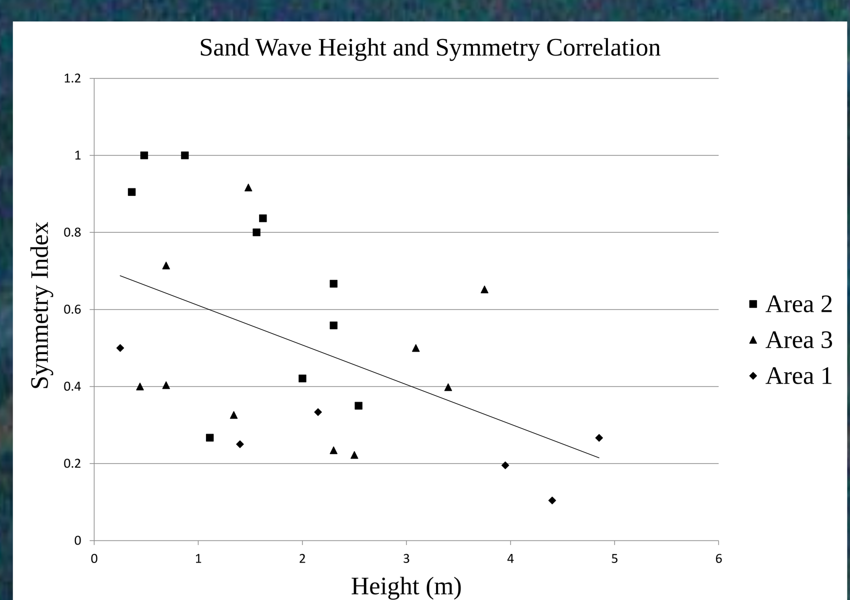


Figure 5 (right). Sand wave symmetry correlated with height shows that sand wave symmetry decreases with height ($R^2 = 0.3$).

DISCUSSION AND CONCLUSIONS

Ebb tidal flow clearly dominates Raccoon Strait based on the consistent orientation of the larger sand waves oriented southwest towards the mouth of the San Francisco Bay, although some of the smaller waves are oriented northeastward, facing the inside of the bay due to the flood tide. The net ebb flow in Raccoon Strait can be attributed to the tendency of incoming tides, which, due to Coriolis hug the right (southern) side of a lagoon (i.e., San Francisco Bay) and continue to flow counterclockwise, exiting on the lagoon's northern side (Li et al., 2013). Raccoon Strait's location directly north of San Francisco Bay's narrow mouth and close to the western edge (Figure 1) puts it in line with the outgoing, or ebb tide after it has flowed counterclockwise around the bay. However, Raccoon Strait's proximity to the bay's mouth allows for some of the flood tidal current to generate smaller sand waves oriented towards the interior of the bay. These conflicting ebb and flood currents create the nearly-symmetrical sand waves in Area 2 (Figure 3), as well as the smaller waves superimposed on larger waves. The larger waves in Areas 1 and 3 that are oriented towards the bay's mouth are produced by dominant ebb tidal currents on the west edge of San Francisco Bay. Further studies performed on the bay's eastern edge or on the other side of the mouth from Raccoon Strait may show bed forms that are produced by a stronger flood tide and therefore have a net orientation towards the inside of the bay.

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