OBSERVATION OF TIDAL EXCHANGE DYNAMICS FROM SURFACE CURRENT MEASUREMENTS USING UNMANNED AIRCRAFT SYSTEMS

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INTRODUCTION

Coastal transport processes are fundamental to oceanic biogeochemical cycles, sediment dynamics, and pollution management. Surface-associated material transport in coastal settings, including the fate of floating marine contaminants such as oil spills and harmful algal blooms, is heavily controlled by ocean surface currents, together with wave action. During tidal exchange, ocean currents are one of the key parameters that affect whether these surface pollutants may be transported in or out of the bay and estuary through tidal inlets. Thus, practical measurements of ocean surface currents are important to predict many coastal transport processes effectively. However, observation of these transport processes requires large-scale current mapping in the spatial domain to fully resolve the governing mechanisms.

In the present study, we utilize an unmanned aircraft systems (UAS) wave-based current mapping technique introduced by Streßer et al., 2017 to visualize the flow structures of the tidal exchange through the Galveston Bay inlets, TX, in high spatial resolution, using a consumer-grade UAS for imaging the ocean surface. The wave-based current mapping method is based on a 2D space plus time (3D) Fourier transform of UAS imagery with the Doppler-shifted, linear wave dispersion relation fitted to the 3D spectral data to estimate surface currents. We assess the adequacy of the wave-based current mapping method by comparing it with traditional image-based techniques, including Particle Image Velocimetry (PIV) and Optical Flow (OF), followed by further validation with *in situ* measurements from an acoustic Doppler current profiler (ADCP). The validated current fields reveal the flow structures of the tidal currents through Galveston Bay inlet, offering a cost-efficient remote sensing tool to interpret surface coastal transport processes.

METHODS

We conducted a preliminary field campaign near the north jetty of Freeport Harbor Channel (120 m outside the jetty) using two UAS platforms to intercompare the velocity from the UAS wave-based current mapping method with the image-based current retrieval methods. The main UAS platform used for image acquisition over the ocean water surface was a DJI Mavic 2 Pro (M2P), a small quadcopter that provides high-resolution images with 10-bit color depth. We used a DJI Matrice 600 Pro (M600P) with a custom release mechanism to carry and release bio-degradable floating particles to the imaging region. We recorded 5-minutes of video footage, including a section of the seeding particles, while hovering the M2P at 120 m above ground. The images in the first 40 seconds of the UAS video footage were used as the image input for the current retrieval methods. Image pre-processing involved extraction of the blue channel from the image sequence and an additional noise removal step for image-based current retrieval methods by global subtraction of the minimum intensity level. We employed open-source toolboxes for the UAS wave-based current mapping (CopterCurrents), PIV (PIVLab), and Optical Flow (OpenOpticalFlow) to generate velocity maps for surface currents. After computing current vectors, we identified erroneous vectors using a median filter and replaced them using interpolation among neighboring valid vectors.

Upon comparison of the current retrieval methods, we conducted the main field campaign near the inlets of Galveston Bay, TX, to observe the exchange dynamics during tidal cycles. The UAS wave-based method was the main current retrieval method, and thus, the M600P platform for particle seeding was excluded. We determined the imaging sites for this field campaign based on the formation of the lateral boundary layers and ebb-tidal starting jets observed from the historical Sentinel-2 satellite imagery. We collected a total of 22 UAS video recordings at nadir with an average duration of 2.7 minutes each along four tracks near the Galveston Bay entrance during a flood and ebb tide, as shown in Figure 1. For validation of the wave-based velocity measurement, we simultaneously acquired *in situ* measurements of the current profiles at the imaging sites using an ADCP mounted on a pontoon boat, as well as surface drifters. The ADCP measurements were spatially averaged within the top 1 m bins and time-averaged over 10 m segments of the boat drift.

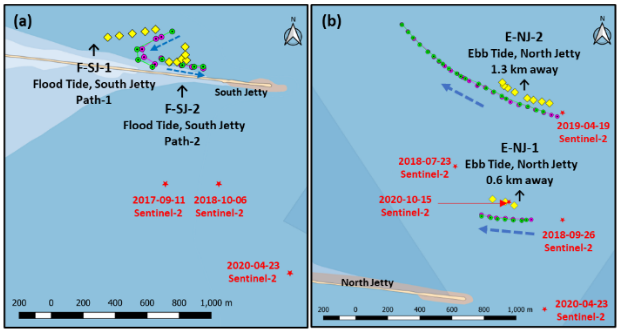

Figure 1 – Locations of the field experiments at Galveston Bay inlet: (a) near the south jetty during flood tide and (b) north of the north jetty during ebb tide. Yellow diamonds represent UAS video segments, and green and purple circles show the drifter tracks. Red stars indicate typical vortex centers of the ebb-tidal starting jets from the historical Sentinel-2 imagery.

RESULTS AND DISCUSSION

Figure 2 shows the resulting current maps obtained from all three current retrieval methods at the Freeport jetties. The UAS wave-based current mapping method yielded current measurements in the full field-of-view (FOV) of the image, with an average magnitude of 0.22 m/s. The direction of the wave-based current vectors suggested surface currents flowing along the north jetty. In contrast, the velocity vector fields from the image-based methods showed uncorrelated, random motions in the unseeded region due to the lack of high image contrast and texture. Thus, PIV and Optical Flow data are only summarized for the seeded region in Figure 2. Within this region, both PIV and Optical Flow methods yielded coherent current fields consistent with the observed wave motion and the dominant wind direction (coming from the East at 85°). Instantaneous vector fields were dominated by the orbital displacements of the surface; time-average vectors are depicted in Figure 2. Overall, the UAS wave-based method was deemed a more suitable technique for its extensive coverage and inherent ability to obtain the underlying currents through the Doppler-shifted dispersion relation. Further validation of the UAS currents was conducted in the Galveston Bay field campaign.

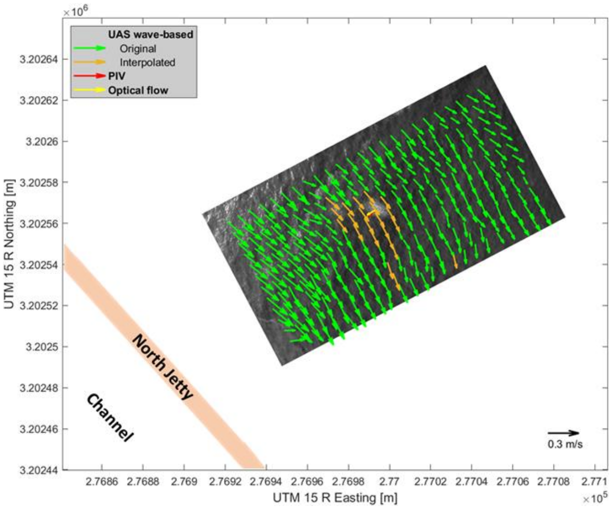

Figure 2 – Current vector map using the wave-based method (green: original vectors, orange: interpolated vectors) and the image-based methods (red: PIV, yellow: Optical Flow).

We validated the estimated currents from the wave-based method with the ADCP current measurements in Galveston Bay. Figure 3 shows the comparison result of the wave-based measurements with the top 1 m bin of the ADCP measurements, which had a blanking distance of 0.44 m at the ocean surface. The magnitude and direction of the wave-based current data corresponded well with the *in situ* current measurements, showing the root-mean-square-error (RMSE) of 0.06 m/s and 16°, with correlation coefficients of 0.95 and 0.98, respectively. The magnitudes of the wave-based currents showed approximately positive biases of 9.5% over the ADCP currents. This may be due to the fact that the ADCP measurement domain begins at 0.44 m depth, whereas the wave-based method integrates the velocity beginning at the ocean surface.

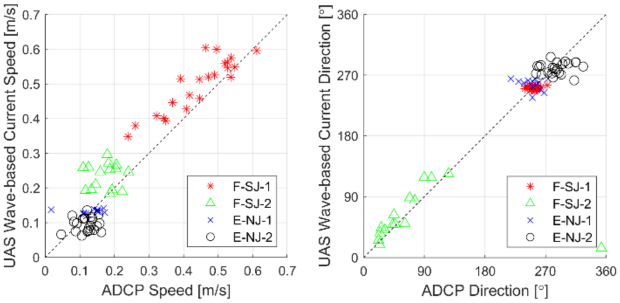

Figure 3 – Comparison of the current measurements in both speed (left) and direction (right) between the UAS wave-based current mapping method and the *in situ* ADCP, along with the 45°, perfect-correspondence line.

We reconstructed the flow structures of the currents through the Galveston Bay inlet during the tidal cycle using the current maps generated from the wave-based method. Figure 4 illustrates the mosaic of the current maps along the UAS recording routes at the south jetty during flood tide. A circulating boundary layer forming from the current separation at the edge of the jetty is evident in Figure 4. The unidirectional current vectors at the measurement track F-SJ-1 denote the incoming flood tide. More evidently, the recirculating flow pattern at F-SJ-2 indicates the observation of the convergence of the outflow along the jetty with the incoming flood tide.

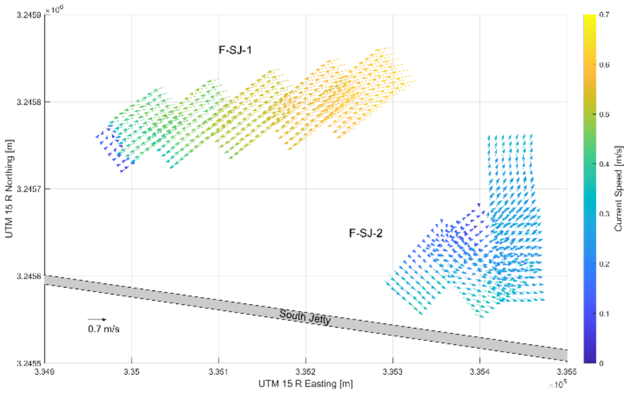

Figure 4 – Mosaics of wave-based current maps generated near the south jetty in Galveston Bay during flood tide (see Figure 1(a) for detailed locations).

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