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Lessons Learned from Coastal Mapping Efforts during the 2018 Hurricane Season Using Unmanned Aerial Systems (UAS) at Sandbridge, Virginia

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PURPOSE: This Engineer Research and Development Center (ERDC) Coastal and Hydraulics Laboratory (CHL) Engineering Technical Note (CHETN) details coastal mapping efforts at federal beach project scales utilizing small unmanned aircraft systems (UAS) to measure changes in the sub-aerial beach and dunes in response to extreme storm events. The document summarizes the lessons learned from pilot mapping exercises at Sandbridge Federal Coastal Storm Damage Reduction Project (CSDR), a project at the Sandbridge community within Virginia Beach, VA (Norfolk District [NAO]), carried out during the 2018 hurricane season. The pilot surveys highlight the Concepts of Operations (CONOPs) required for high-resolution/accuracy geospatial data collection at a typical federal beach project scale (5 miles [mi] alongshore) utilizing UAS.

BACKGROUND: The U.S. Army Corps of Engineers (USACE) requires efficient and cost-effective tools to map coastal environments, where frequent surveys are necessary to accurately characterize coastal change and to inform flood risk management activities. Due to its cost-effectiveness and ease of use, UAS deployment has become an increasingly popular candidate for capturing high-resolution aerial imagery for small-scale environments (<5 mi). Many UAS applications make use of Structure from Motion (SfM) and Multi-View Stereo photogrammetric algorithms to generate survey-grade, three-dimensional topographic point clouds and digital surface models (DSMs) from acquired imagery. UAS have been shown to be effective for a number of coastal applications, from land cover analysis to mapping beach elevation and surf zone bathymetry (e.g., Fischer et al. 2019; Sturdivant et al. 2017; Holman et al. 2017; Seymour et al. 2017; Turner et al. 2016; Mancini et al. 2013; Brodie et al. 2019a,b). In June 2017, USACE coordinated a large field experiment comparing a variety of cost-effective commercial-off-the-shelf UAS platforms and sensors to identify useful UAS tools to improve district surveying capabilities in coastal systems (Bruder et al. 2018).

Following initial assessment of these systems' capabilities, ERDC worked with the USACE Flood Risk Management Community of Practice to develop a UAS Implementation Plan. The Implementation Plan identified the need for pilot projects with USACE districts to encourage rapid transition of this technology. ERDC conducted several collaborative UAS pilot projects with USACE districts during the late summer and early fall of 2018 to establish general CONOPS for surveying federal beach projects in pre/post-storm scenarios. The UAS pilot projects evaluated UAS beach surveying CONOPs for USACE district applications while also providing supplemental datasets for district use. Previous UAS surveys of the coastal environment by the CHL team and others have frequently been collected for limited stretches of coastline, often less than 0.5 mi in length (e.g., Bruder et al. 2018; Conlin et al. 2018; Fischer et al. 2019; Mancini et al. 2013; Sturdivant et al. 2017; Seymour et al. 2017; Brodie et al. 2019a,b). Federal beach projects, however, can span multiple miles in the alongshore. Surveying these extended (5 mi) lengths of beach via

UAS introduced a number of challenges associated with data collection that affected the quality of SfM-generated data products, which are discussed below, and improved upon in a second data collection effort.

This CHETN documents the data collection and processing for two UAS surveys for the pilot project with NAO at the Sandbridge Federal CSDR Project, hereon referred to as Sandbridge. NAO needed surveys to estimate the topographic volume change that occurred during the 2018 Hurricane season as well as to inform a planned 2019 renourishment of the federal beach project. Resultant data from the first flight produced topographic point clouds with sub-standard accuracy, which will be described and used to refine procedures in the second flight. For the second flight, a number of steps were taken in data acquisition CONOPS and SfM processing to address issues that arose during the initial data collect. This document describes the federal beach project, pre-storm field CONOPS and data processing, and pre-storm data quality. The CHETN then summarizes the modifications made to CONOPs, the improved data, and overall lessons learned regarding the use of UAS for federal beach project evaluation.

SITE DESCRIPTION: The community of Sandbridge is located within Virginia Beach, along the most southeastern coast of Virginia between the U.S. Navy Dam Neck facility to the north and the Back Bay National Wildlife Refuge to the south (Figure 1 A-B). The CSDR project is located within the USACE NAO jurisdiction and is jointly managed with the city of Virginia Beach. Most wave energy affecting the northeast-oriented coastline originates from the northeast; the mean significant wave height and mean peak wave period were estimated to be 3.6 feet (ft) and 9 seconds, respectively, at Wave Information Study Atlantic Station 63201 located approximately 10 mi offshore for the 1980 to 2014 time period (WIS 2019). While not as densely populated or visited as the rest of Virginia Beach (which draws over 10 million visitors annually), the Sandbridge community is a popular tourist attraction (Virginia Beach 2019).

Figure 1. (A) Local and (B) regional map of Sandbridge field site. Local coordinate system shown in white (XY). (C) Utilized UAS platform: BirdsEyeView FireFLY6 PRO.

The initial nourishment of the CSDR project occurred in 1998, with periodic nourishment authorized through 2048. Additional nourishments have occurred in 2003, 2007, and 2013 (WS&E and CP&E

2017). Each nourishment consisted of a beach berm with an average width of 50 ft and elevation of 6 ft. The 2013 renourishment volume was 2.2 million; the dunes increased in overall volume (363,000 cubic yards [cy]) since the 2013 nourishment (Joyner and Chen 2018). While the site had experienced several significant storms prior to the fall of 2018, such as Tropical Storm Hermine and Hurricane Matthew in 2016, none made direct landfall in Sandbridge (though impacts still occur with bypassing storms). An October 2017 lidar survey of Sandbridge suggests that both the dunes and sub-aerial beach experienced erosion between the survey and the fall of 2016 (loss of 33,000 and 156,000 cy, respectively). While there have been no federal-, state-, or town-sponsored dune building actions following these events, individual homeowners have occasionally transported sand that had moved landward towards their homes back onto the dunes or beach in front of their properties according to communications with the City of Virginia Beach Department of Public Works¹. The UAS team also observed grooming of the beach in certain areas during their surveys, possibly influencing sediment mobility as well. The next beach nourishment contract has been awarded, and as of this document's writing, has been scheduled to take place in 2019.

DATA COLLECTION/PROCESSING OVERVIEW: Two CHL Coastal Observation and Analysis Branch staff conducted UAS flights at Sandbridge on September 7 and October 23, 2018, capturing the required aerial imagery to generate a georectified orthomosaic image of the region, a topographic point cloud, and DSM before and after the 2018 hurricane season. Sandbridge was chosen as a demonstration location for mapping coastal projects due to the NAO region's frequent impact by Atlantic hurricanes, proximity to the CHL Field Research Facility (FRF), and a planned 2019 renourishment. Between the September and October surveys, Hurricanes Florence and Michael impacted the region on September 13 and October 12, 2018, respectively. Though neither storm severely affected the site, both generated wave heights over 6 ft in the area (as measured at the FRF; ~40 mi southeast from Sandbridge and National Data Bouy Center Station 44099, ~20 mi north-northeast).

UAS surveys are generally conducted as close to low tide as possible to maximize data collection of the sub-aerial beach. Low tides during the survey windows occurred at 11:57 and 13:30 on September 7 and October 23, respectively. The October post-storm collection could be conducted over a broader range of the day centered around low tide, as beach crowds were reduced during this non-peak tourist period. For both surveys, all necessary equipment was transported within the pickup truck used for data collection. As described below, the UAS survey effort consisted of ground control point (GCP) deployment, UAS platform preparation and flights at different take-off zones, and equipment breakdown and GCP collection. Once at the field collection site, each data collection required over 8 hours (hr). However, as the pre- and post-storm collections were pilot efforts and included additional flights/operations, one would better estimate total required labor as 5 and 8 hr, respectively.

The Sandbridge project is under Class G airspace (uncontrolled airspace from the surface up to overlying Class E air space, which is controlled but unclassified), and all UAS operations were conducted under the Federal Aviation Administration (FAA) Part 107 regulations with a maximum flight altitude of 400 ft above ground level (AGL). All nearby airfields were at least 5 mi away from the site. The U.S. Navy Dam Neck Training Support Center resides at the northern terminus of the project, and caution was exercised to not breach the restricted airspace. The standard USACE small

¹ J. White. 2019. Personal communication. City of Virginia Beach Department of Public Works.

UAS Mission Planning and Reporting protocol was followed along with a Deliberate Risk Assessment (DD2977) determined to be “LOW” risk. Winds were approximately 5-15 knots for both field data collections, with clear skies on September 7 and mostly clear skies on October 23.

UAS Platform and Instrumentation. The Sandbridge aerial imagery for the pre-Storm and post-Storm surveys was collected using the FireFLY6 PRO Vertical Takeoff and Landing (VTOL) fixed-wing platform designed by BirdsEyeView Aeronautics (Figure 1C). The platform was equipped with a 24-megapixel Sony a6000 camera payload and can fly continuously up to approximately 45 minutes (min) on a single set of batteries. The FireFLY6 PRO was operated via the FireFLY6 Planner v2.3 software, installed on a Panasonic Toughbook CF-30 and a connected controller. The platform contains a Real Time Kinematic Global Positioning System (RTK-GPS) receiver capable of receiving error correction signals from a base receiver located at the take-off area. This RTK-GPS system affords inch-scale platform positioning accuracy and permits geo-tagging of the camera’s images, increasing the georectification accuracy and decreasing post-processing time. Overall, the FireFLY6 PRO platform and associated equipment used for this data collection cost approximately \$13,500. The standard USACE air-worthiness release requirements were obtained prior to flight, ensuring that the FireFLY6 PRO could be safely maintained and operated.

PRE-STORM CONOPS

Ground Control. The UAS survey team deployed GCPs that are used in post-processing to constrain the final image positions and poses of the imagery for survey-grade accuracy of the final products. Due to the importance of GCP distribution for generating accurate DSMs using SfM (e.g., Sabz-Ablanedo et al. 2018; Tonkin and Midgley 2016; James and Robson 2012), the team attempted to evenly distribute GCPs within and along edges of the area of interest (AOI). This distribution aimed to obtain ground-truthed data along the three cardinal axes of the AOI to constrain geometric transformations by the SfM algorithms. The geometry of the Sandbridge survey area presented challenges when utilizing GCPs, due to the long and narrow project region, which limits ideal GCP distribution.

Given the project’s length (~5 mi), 14 GCPs were distributed as quickly as possible approximately every 0.4 mi along the shoreline, alternating between the upper beach (close to the dune toe), and lower beach (Figure 2A). Relative to the 4.8 mi spread of GCPs in the alongshore direction, the survey area had limited GCP spread in the cross-shore and vertical directions (365 and 3.9 ft, respectively), leading to potential SfM issues (see Data Quality Section). On September 7, the UAS survey team began setting out GCPs shortly before 08:00 to be ready for UAS operations before the beach became crowded, while still collecting data as close to low tide (11:57) as possible. The GCPs consisted of 4 × 4 ft white type-1 rigid polyvinyl chloride sheets with opposite corners painted black to create a checkered pattern that allows for identification of the target center when processing imagery. These GCPs were held down with cinderblocks or other available heavy objects to reduce the chance of movement during the course of the survey. To deploy the GCPs along the entire project within a reasonable amount of time (~70 min), a four-wheel-drive truck was driven onto the beach, and targets were deployed from the truck bed. The approximate GCP locations were designated beforehand in Google Earth, which allowed for quick identification of the deployment location along the beach for GCP deployment.

Nine of the GCPs were surveyed by placing Propeller AeroPoints centered on top of the traditional GCPs (see Figure 3). The AeroPoints are $25.26 \times 25.26 \times 1.38$ -inch checkerboard-shaped targets that also include a solar powered, self-contained, and self-recording L1/L2 carrier phase receiver. The AeroPoints record geographic position once per second and are post-processed once the raw Global Navigation Satellite System (GNSS) observations are complete to achieve sub-inch accuracy in the horizontal and vertical position. The AeroPoint targets can be difficult to view alone in imagery collected from higher altitude flights, so combining them with larger targets allowed for efficient surveying and easier identification in post-processing. The remaining five GCPs were surveyed via a bipod-mounted Trimble R10 RTK-GPS receiver survey utilizing corrections from the National Geodetic Survey's Continuously Operating Reference Station network. These survey techniques have been previously compared for consistency. Following the flight, breakdown of equipment and GCP collection took approximately 1 hr.

Figure 2. (A) Pre-Storm GCP distribution and (B) flight lines in local coordinates XY. VTOL denotes the vertical take-off/landing positions. Flights were flown at 393.7 ft AGL.

Figure 3. Example of GCP surveyed via AeroPoint, maintaining GCP visibility in aerial imagery (4×4 ft) while increasing GCP survey efficiency. The AeroPoints survey their own positions via a post-processing workflow of raw GNSS data.

UAS Flight Operations. The FireFLY6 PRO was flown in accordance with FAA and USACE UAS flight operation guidelines as defined in FAA Part 107 Authority and Army Regulations 95-1. The two-person team alternated acting as pilot in command (PIC) and visual observer (VO). Current CHL flight planning and surveying operations require all PICs and VOs to maintain a visual line-of-sight (VLOS) of the airframe from the ground station. This distance varies depending on flight team and atmospheric conditions. For the Sandbridge project, the airframe was visible up to an average of slightly more than 5,000 ft from the PIC and VO. This distance limited individual flight coverage per flight to approximately 10,000 ft, or 5,000 ft in both alongshore directions from the PIC/VO (Figure 2B).

The three flights shown in Figure 2B were conducted from three different take-off locations (dots in Figure 2B) to allow for sufficient overlap of the aerial imagery. While VLOS limitations with other UAS platforms have been addressed by chasing the UAS in a vehicle (e.g., Brodie et al. 2019b), the FireFLY6 PRO RTK-GPS system operates over the same datalink as the controls; therefore, platform controls are tethered to the same location as the RTK-GPS base station receiver, and mobile flight control is not feasible. The RTK-GPS base had to be moved and re-established for each take-off location to allow for VLOS operations. As the RTK-GPS base station receiver position accuracy improves the longer it remains in a fixed position, more accurate position corrections required keeping it stationary for at least 15 min for each flight.

Flight plans were designed in FireFLY6 Planner software with flights lines oriented parallel to the coastline at 393.7 ft AGL with 65% overlap along-shore and 65% sidelap cross-shore. As shown in Figure 2B, the along-shore directed flight lines were generally positioned over the lower beach and the dune crest when possible. Once flown, the images were geo-tagged and downloaded from the FireFLY6 PRO.

PRE-STORM RESULTS

Data Processing. The imagery from the pre- and post-storm surveys were processed using Agisoft PhotoScan Professional v1.4.4 software to generate rectified orthophotos and red-green-blue (RGB)-colored topographic point clouds. The following workflow for image processing using Agisoft according to the methods of Sloan¹ was utilized to generate the final data products: (1) initial key point generation, (2) tie point matching and photo alignment, (3) human-guided GCP placement, (4) gradual filtering, (5) bundle optimization, and (6) final dense point cloud reconstruction. For each survey, the processing workflow took approximately 8 hr to complete. The processing was completed on a custom-built Microway Systems computer with 2x Intel Xeon E5-2697 processors at 2.7 gigahertz with 24 cores; 256 gigabytes (GB) RAM; 2x AMD Radeon R9 290X graphic processing units (GPUs) at 8 GB, and an NVIDIA Quadro K600 discrete graphics card with an additional GPU. The dense point cloud was output in Virginia State Plane, South, U.S. survey feet horizontal coordinates, as requested by NAO. Orthophotos were generated at 0.5 ft and 1 ft cell resolution and were output as GEOTIFFs. The dense cloud was imported into Quick Terrain Modeler data visualization software, where outliers and spurious oscillations were manually removed, and a nearest-neighbor gridding algorithm was used to transform the point cloud into a DSM at 1 ft and 3 ft cell resolution grid (Figure 4).

¹ J. Sloan. 2017. Personal communication. Agisoft PhotoScan (ver. 1.2.6) Workflow - based on close-range photogrammetry error reduction techniques, TN Photogrammetry LLC.

Figure 4. September 7 pre-storm (A) and October 23 post-storm (B) point clouds. Elevations in North American Vertical Datum of 1988. White lines refer to profiles in Figure 5.

Data Quality. For easier data handling, the pre-storm, dense point cloud was decimated by a factor of ten and contained approximately 110 million points with approximately 6 points per square foot. All points contained a corresponding RGB value from the imagery to colorize the dense cloud for a photo-realistic scene when visualizing the data. Quantitative data quality control and quality assurance was performed by subtracting the SfM-derived point cloud from a DSM generated from airborne lidar data collected by the Joint Airborne Lidar Bathymetry Technical Center of Expertise (JALBTCX) following the passage of Hurricane Matthew (2016). Since 24 months had passed between the JALBTCX airborne lidar and the pre-storm UAV survey, differences in elevation on the beach and dune were expected between the two datasets. Therefore, the first line of oceanfront houses and paved surfaces (rigid, non-moving structures) were used as an indicator of rectification accuracy as these features are stationary.

While certain regions of the DSM were adequate, overall the pre-storm SfM-generated data products were substandard. Figure 5 shows cross-shore elevation profiles that were extracted at three locations along the project site from the SfM-derived point clouds and from the 2016 JALBTCX data to illustrate relative data quality. In profile A, the UAS data from the pre-storm collection (red profile) is horizontally rectified appropriately, as noted by the presence co-occurrence of the roof and house structures (50-150 ft cross-shore distance) visible across all datasets. However, there are vertical mismatches between the pre-storm UAS and the JALBTCX datasets. At Profile A, the data at the structure's roof line is approximately 5 ft below the JALBTCX data. A similar positive offset is observed in profile C, noted by the roof cross section approximately 5.5 ft above the JALBTCX data. While the AOI of the survey focuses on the sub-aerial beach and does not encompass the structures landward of the dune, these orientation errors likely affect the SfM-derived beach elevations and therefore limit the use of these data. These errors varied spatially within the AOI, with some regions producing higher quality data than others.

Figure 5. Profile comparisons between the 2016 JALBTCX airborne Lidar point cloud and the UAS-derived point clouds collected pre- and post- storm. A, B, C refer to profiles in Figure 4. The blue data series represent JALBTCX data collected after Hurricane Matthew (2016); red series illustrate the September 7, 2018, Pre-Storm UAS survey; and green series represent the October 23, 2018, post-storm UAS data collection conducted with modified CONOPS.

Jaud et al. (2019) and James and Robson (2014) show that geometric distortions or doming effects can lead to significant errors within SfM-derived point clouds and DSMs for surveys of linear AOIs where GCP distributions are limited. As described previously, the geometry of the Sandbridge beach AOI was linear, and the GCP placement was constrained to a narrow, linear array, particularly for the pre-storm survey. Though studies have differed on identifying the most efficient number of GCPs and their distribution, research has often indicated that greater numbers of GCPs increase the horizontal and vertical accuracy of SfM-generated Digital Elevation Models, by minimizing drift in images only connected through tie points (e.g., Aguera-Vega et al. 2017; Goncalves and Henriques 2015; Sanz-Ablanedo et al. 2018; Tonkin and Midgley 2016). When GCP number and distribution may not be improved for areas with constrained geometries, increasing the diversity of camera views can limit negative effects (e.g., different altitudes, directions, and oblique angles) (Jaud et al. 2019; James and Robson 2014). As described above, these studies informed several adjustments made and applied to the October post-storm Sandbridge survey flight and ground control CONOPS.

POST-STORM CONOPS

Ground Control. As detailed in the previous section, the surface generated by SfM processing of the pre-storm survey data was inadequate, likely due to the limited cross-shore and vertical distribution of GCPs and imagery along the extended linear AOI. To expand the cross-shore baseline of GCPs beyond the pre-storm deployment of 14 GCPs along the beach, 15 additional GCPs were placed within the dune field as well as along the beach road (Sandfiddler Rd) in visible areas (e.g., the end of public access ramps or other clear areas along public easements) (Figure 6A). The GCP distribution maintained the same along-shore length as the pre-storm survey but more than doubled the maximum separation in the cross-shore direction and quadrupled their vertical spread (over 818 ft and 16.1 ft, respectively). Given placement considerations, the distribution of additional GCPs along the street and dune required ~2 hr to deploy (1 hr more than the pre-storm process). This deployment also increased post-survey equipment breakdown and GCP pick-up time to over 100 min (up from ~60 min). Sandbridge was significantly less crowded during this survey time period due to the close of the tourism season; therefore, GCP deployment and flights began later and were planned around the midday low tide of 13:30.

Figure 6. (A) Post-storm GCP distribution and (B) flight lines in local coordinates XY. Note, for the last line within each flight, the platform dropped to 262 ft AGL to increase camera view diversity while the majority of lines were flown at 328 ft AGL. VTOL denotes the vertical take-off/landing positions.

UAS Flight Operations. Basic flight operations were primarily the same as pre-storm operations with the FireFLY6 PRO but were adjusted to efficiently increase the number of flight lines and associated camera views (Figure 6B). One flight line was added to capture the GCPs deployed landward of the dune crest near Sandfiddler Rd while another was flown across the central beach. The majority of the flights were flown at 328 ft AGL, while the last line for each area was flown at 262 ft AGL. These additional flight lines increased the total platform airtime to over 69 min, or nearly twice the pre-storm air time. Active collection time (including travel between sites) was therefore increased to greater than 3 hr.

POST-STORM RESULTS

Data Quality. The CONOPS adjustments made to the post-storm data collection, processed in the same manner as the pre-storm collection, significantly improved the rectification of the point cloud generated from UAS imagery. This improvement is shown in profiles A, B, and C as the post-storm data (green) closely follow the rigid structural roof lines and pavement of the JALBTCX data (blue) (Figure 5). The horizontal position was found to be within 1 inch, and the vertical position was found to be accurate up to 6 inches relative to the JALBTCX data throughout the site. The orientation anomalies present in the pre-storm data were not evident in the post-storm data.

Beach Evolution. The UAS surveys of Sandbridge were intended to quantify changes in beach volume caused by the passage of Hurricanes Florence and Michael. Unfortunately, the pre-storm data collection errors prevented true volume change calculations between the two UAS surveys. However, the JALBTCX and post-storm UAS survey data can be compared to quantify beach change between October 2016 (after Hurricane Matthew) and October 2018. In addition to erosion in the lower beach, potential dune growth was identified in several areas (Figure 5B and 4C), with the foredune gaining 3 to 4 ft in elevation since 2016. A personal memo to the City of Virginia Beach from Joyner and Chen (2018) notes gains in dune volume since the 2013 placement as well. Communications with the City of Virginia Beach Department of Public Works confirms that no major official beach sediment management actions took place since 2013. As noted in the Site Description section, private property owners do take action to place sand that has blown into their property back onto the dune field. Therefore, the observed dune growth may be a result of a combination of natural processes and human influences.

LESSONS LEARNED AND NEXT STEPS: This CHETN details ERDC efforts to use UAS to quantify sub-aerial beach topography at Sandbridge and the improvements made to CONOPS to address challenges faced in coastal mapping with UAS at federal beach project scales. CONOPS changes included adding more GCPs and distributing them across a greater cross-shore distance. Additional flight lines provided more camera view diversity and data overlap within the AOI that likely contributed to better convergent imaging geometry within the SfM processing algorithms. The CONOPS and flight path changes combined to reduce the surface distortions that were present in the pre-storm data. While these additional steps did improve the quality of the data output, these steps approximately doubled the time for the survey team for ground control deployment and collection (increasing from ~2 to ~4 hr) and tripled the required flight air time (increasing from nearly 36 min to nearly 110 min). These changes increase estimated UAS beach survey times from 5 to 8 hr under similar conditions.

Moving forward, the CHL team intends to assess these CONOPS adjustments more rigorously (including more ground control) and identify their individual contributions to data quality improvements for surveying federal beach projects. Several refinements to UAS survey CONOPS that must be further evaluated through additional field testing include identifying the minimum number of flight lines to accurately reconstruct the beach morphology along long, linear coastlines; utilizing oblique imagery for increased image geometry convergence within the AOI; and varying altitudes with each flight. Future efforts should also better quantify the costs of VLOS flight regulations to survey efficiency, including increased flight times and decreased UAS mobilization and demobilization.

UAS coastal operations should also detail how to most efficiently distribute and deploy GCPs along extended lengths of beaches, how to effectively position GCPs while also considering distribution concerns among residential/commercial areas and streets that exist behind most beaches. Projects that demand more frequent surveying might also consider the establishment of fixed GCPs in the duneline or nearby streets, though manual GCPs likely would remain necessary on the sub-aerial beach. The GCP deployment concern may be alleviated by reducing GCP dependence through future enhanced RTK-GPS integration. Independently measuring the position of the FireFLY6 PRO RTK-GPS base station receiver may support improved broadcast of absolutely accurate corrections to the airframe. Finally, the development of kinematic CONOPs that allow for the flight team to follow the airframe (rather than demanding a stationary RTK-GPS base) would allow for greater survey coverage per flight and/or different flight paths because VLOS could be maintained over greater distances and the take-off and landing areas could differ.

All these suggested upgrades are intended to balance increased data quality with data acquisition efficiency for extended coastal UAS surveys. GCP deployment and collection efforts remain significant time-sinks for utilizing UAS for multiple miles of coastal corridor surveying. The next steps forward will focus on making improvements to the efficiency of the data collection task or further minimizing dependency on GCPs while preserving or improving data quality.

ADDITIONAL INFORMATION: This CHETN was prepared as part of the USACE Flood and Coastal Systems R&D Program by Alexander Renaud, Nicholas Spore, Brittany Bruder, and Katherine Brodie, ERDC, CHL, Coastal Analysis and Observations Branch, Duck, NC. Questions pertaining to this CHETN may be directed to Dr. Katherine Brodie Katherine.L.Brodie@usace.army.mil or to the USACE Flood and Coastal R&D Technical Director, Dr. Julie D. Rosati, Julie.D.Rosati@usace.army.mil.

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