SUSTAINABLE FISHERIES MANAGEMENT PROJECT (SFMP)

SMALL UNMANNED AIRCRAFT (SUA)

PILOT PROJECT

DECEMBER, 2015

This publication is available electronically on the Coastal Resources Center's website at http://www.crc.uri.edu/projects_page/ghanasfmp/

For more information on the Ghana Sustainable Fisheries Management Project, contact:

USAID/Ghana Sustainable Fisheries Management Project
Coastal Resources Center
Graduate School of Oceanography
University of Rhode Island
220 South Ferry Rd.
Narragansett, RI 02882 USA
Tel: 401-874-6224 Fax: 401-874-6920 Email: info@crc.uri.edu

Cover photo: DJI Phantom 2. (Credit: SZ DJI Technology Co., Ltd.)

Detailed Partner Contact Information:
USAID/Ghana Sustainable Fisheries Management Project (SFMP)
10 Obodai St., Mempeasem, East Legon, Accra, Ghana

Brian Crawford	Chief of Party	brian@crc.uri.edu
Najih Lazar	Senior Fisheries Advisor	nlazar@crc.uri.edu
Patricia Mensah	Communications Officer	patricia.sfmp@crcuri.org
Bakari Nyari	Monitoring and Evaluation Specialist	hardinyari.sfmp@crcuri.org
Don Robadue, Jr.	Program Manager, CRC	don@crc.uri.edu
Justice Odoi	USAID Administrative Officer Representative	jodoi@usaid.gov

Kofi.Agbogah
kagbogah@henmpoano.org
StephenKankam
skankam@henmpoano.org
Hen Mpoano
38 J. Cross Cole St. Windy Ridge
Takoradi, Ghana
233 312 020 701

Andre de Jager
adejager@snvworld.org
SNV Netherlands Development Organization
#161, 10 Maseru Road,
E. Legon, Accra, Ghana
233 30 701 2440

Donkris Mevuta
Kyei Yamoah
info@fonghana.org
Friends of the Nation
Parks and Gardens
Adiembra-Sekondi, Ghana
233 312 046 180

Peter Owusu Donkor
Spatial Solutions
powusu-donkor@spatialdimension.net
#3 Third Nautical Close,
Nungua, Accra, Ghana
233 020 463 4488

Thomas Buck
tom@ssg-advisors.com
SSG Advisors
182 Main Street
Burlington, VT 05401
(802) 735-1162

Victoria C. Koomson
cewefia@gmail.com
CEWEFIA
B342 Bronyibima Estate
Elmina, Ghana
233 024 427 8377

Lydia Sasu
daawomen@daawomen.org
DAA
Darkuman Junction, Kaneshie Odokor
Highway
Accra, Ghana
233 302 315894

Gifty Asmah
giftyasmah@Daasgift.org
Daasgift Quality Foundation
Headmaster residence, Sekondi College
Sekondi, Western Region, Ghana
233 243 326 178

For additional information on partner activities:

CRC/URI:	http://www.crc.uri.edu
CEWEFIA:	http://cewefia.weebly.com/
DAA:	http://womenthrive.org/development-action-association-daa
Daasgift:	https://www.facebook.com/pages/Daasgift-Quality-Foundation-FNGO/135372649846101
Friends of the Nation:	http://www.fonghana.org
Hen Mpoano:	http://www.henmpoano.org
SNV:	http://www.snvworld.org/en/countries/ghana
SSG Advisors:	http://ssg-advisors.com/
Spatial Solutions:	http://www.spatialsolutions.co/id1.html

Acronyms

CAA   Civil Aviation Authority
CCM   University of Cape Coast Center for Coastal Management
DFAS   UCC Department of Fisheries and Aquatic Science
DSAS   Digital Shoreline Analysis System
DSM   Digital Surface Model
FLIR   Forward Looking Infrared
FON   Friends of the Nation
GIS   Geographic Information System
GPS   Global Positioning System
HM   Hen Mpoano
LiDAR   Light Detection and Ranging
MPA   Marine Protected Area
MP&C   Mission Planning and Control
NGO   Non-Governmental Organization
QA/QC   Quality Assurance/ Quality Control
RGB   Red Green Blue
SFMP   Sustainable Fisheries Management Project
SLR   Sea Level Rise
SNV   SNV Netherlands Development Organization
TCPD   Town and Country Planning Department
UAV   Unmanned Aerial Vehicle
UCC   University of Cape Coast
UCC Geo   University of Cape Coast Department of Geography
UNDP GEF   United Nations Development Program/ Global Environmental Facility
URI   University of Rhode Island
USA   United States of America
USGS   U.S. Geological Survey
USAID   United States Agency for International Development

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

PART A – PROJECT DESCRIPTION

Introduction

Advances in technology over the last decade have made Unmanned Aerial Vehicles (UAVs), and the imagery they capture, a valuable tool for environmental research and scientific analysis. With a wide array of sensors currently available, systems can be tailored to specific needs including localized base mapping, elevation modeling, vegetation analysis or health, wetland delineation and coastal monitoring. UAV systems fill an important niche for researchers, filling the void between course satellite imagery and traditional, expensive aerial surveys. With rapid deployment and low flight ceilings, these systems are not hampered by clouds or weather, and provide a cost-effective means of acquiring accurate, on-demand digital data.

The popularity of these systems stems from the level of flexibility these units provide. Being highly mobile and easy to deploy, UAV systems allow researchers to survey specific areas at

Figure 1: Pilot UAV study areas along the western coastline of Ghana.

regular intervals to establish baseline conditions and monitor/quantify change. Core functionality is derived from the georeferenced, high-resolution color images these systems capture (< 5cm ground sample distance) and the speed with which output products can be generated. Typical data products include digital ortho-photo mosaics and elevation/surface models which are easily brought into a Geographic Information System (GIS) for visualization, data extraction and further analysis.

Demonstration Projects

To highlight the utility of UAV imagery for evaluating the health and preparedness of coastal ecosystems and infrastructure, a series of pilot studies (Figure 1) were conducted for priority areas identified through the USAID-funded Sustainable Fisheries Management Project (SFMP):

- Mapping the fisheries value chain and economic development along the waterfront (Axim)
- Shoreline change and vulnerability of coastal infrastructure (Sanwoma)
- Wetland delineation and encroachment monitoring (Iture)

The purpose of these pilots was to demonstrate to project partners how a UAV platform operates, the quality of the imagery than can be captured and the value these products hold for deriving additional data that can feed the policy and decision-making processes.

Site Descriptions

Sanwoma

Sanwoma is a small fishing village located within the Ellembelle district of Ghana's Western Region. Located at the mouth of the estuary where the Ankobra river meets the sea, residents struggle to maintain their homes and livelihoods as they cope with the effects of riverine flooding and coastal erosion. The community faces daily inundation as river waters rise with the tide, and along the beach, coastal erosion rates are some of the highest in Ghana. The effects from climate change are likely exacerbating these issues and placing the community in an extremely vulnerable and precarious position.

Iture Wetland Complex

The Iture wetlands are part of the Kakum River estuary and are located in the Ghana's Central Region within the Cape Coast Metropolitan Assembly district. This wetland ecosystem is biologically diverse and contains all five species of mangroves present in Ghana. Primary stressors to the system are mangrove cutting and garbage dumping which continue to degrade the environment. The Iture mangroves have been identified as a good candidate for restoration and are in need of an accurate survey to record baseline conditions for future change monitoring.

Lower-Axim Landing site

Axim lies within the Nzema East district and is the largest grouping of fish landing sites in Ghana's Western Region. The area is highly developed and faces pressures from an eroding coast, failing shoreline infrastructure and poor sanitary conditions throughout the landing area. With little room for expansion, the Axim waterfront is in desperate need of redesign through sound community planning. Aerial imagery will provide district planners with the big-picture view needed to assess on-the-ground conditions and develop alternatives to improve health and safety conditions throughout the landing area.

UAV Permitting Process

This effort sought full compliance with Ghanaian Law regarding UAV operations as outlined by their Civil Aviation Authority (CAA). The CAA is the official permitting agency and all applications for flight must receive their approval before a permit will be granted. The permit application process is composed of the following steps:

1. Submission of a UAV flight request that includes:
   a. Purpose of the flights
   b. Location and dates of operation
   c. List of government offices or institutions involved and how the proposed operations will benefit these groups
   d. Type and specification of equipment to be used

> e. Map of proposed operating areas
> f. Non-refundable $1,000 USD permit fee
2. Submission of a Flight Operations Manual following CAA protocol that describes all components of safe equipment operation.
3. Provide proof of liability insurance during the operations period
4. Demonstrated flight capability of the lead UAV pilot

In return, the CAA issues a provisional approval letter and forwards the request to the Ghana National Security Office for final approval. Copies of the permit application, flight operations manual and CAA provisional approval letter are contained in Appendices 1-3.

PART B – EQUIPMENT AND IMAGERY CAPTURE

UAV System Description

Unmanned aerial vehicles designed for mapping or data capture differ from their recreational counterparts in that the actual drone is but one of four distinct components of an aerial survey platform.

The Aircraft

UAV bodies consist of a sensor platform and some means of lifting and propelling that sensor package over the ground. The are many styles of aircraft bodies, but the two most common classes are "fixed wing" or "rotary wing" (Figure 2). Fixed wing aircraft most closely resemble traditional model aircraft; generally having two wings and a single propeller. The primary strengths of these systems include typical flight times of 1-2 hours and higher operating speeds, which directly translate into more area covered per individual flight. Limitations of fixed wing platforms include the inability to hover in place and larger launch/land areas required for operation. However, the need for more space is mitigated by the increased flight times, allowing the operator to select an appropriate ground control area and fly some distance to the actual survey location.
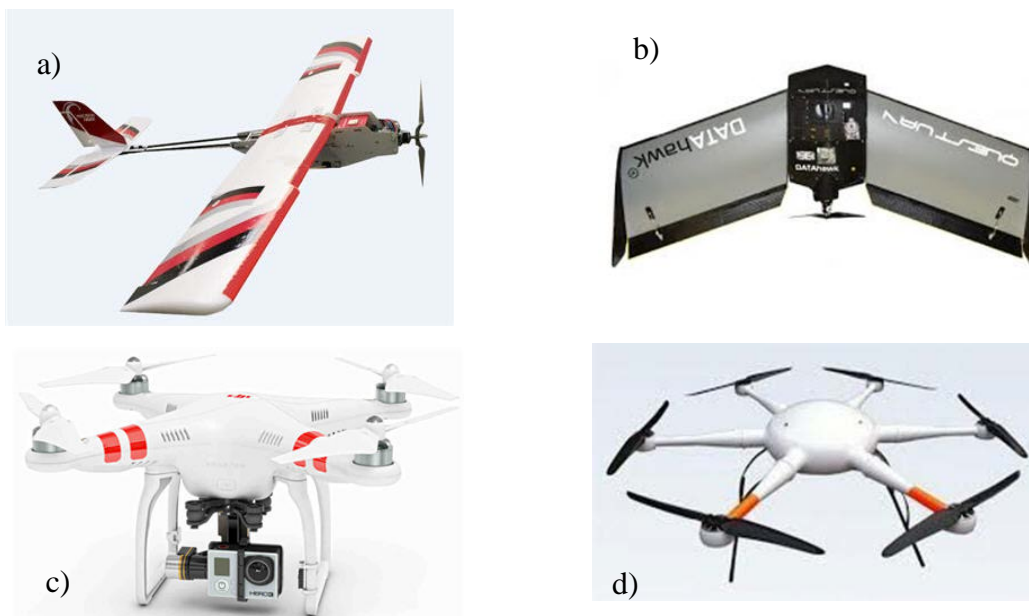
Figure 2 Common UAV body designs for both fixed wing and rotary wing aircraft. a) Precision Hawk Lancaster; b) Quest Data Hawk; c) DJI Phantom 2 Vision+; and d) HiWing HW-X210

Rotary wing systems can have 1 (helicopter) to 4 (quadcopter) or more propellers. These systems launch or land vertically and require much less space for ground control operations. In addition, these aircraft have the ability to hover in place making them an ideal platform for inspecting equipment and infrastructure, such as power transmission lines and oil platforms. The largest drawback to rotary wing platforms are the brief 20-60 minute flight times which impact operations in two ways. First, the operator must launch the aircraft in very close proximity to the aerial survey location since there is a limited battery capacity to transit to/from the area of interest. In difficult terrain or congested environments this can directly limit options for locating ground operations. Second, more flights are required to capture the same amount of imagery a fixed wing aircraft could collect in a single flight, necessitating additional batteries and in-field charging capabilities. With a full suite of sensors available for either body style, in the end, there is no right or wrong aircraft design. Each have their strengths and weaknesses and mission needs will ultimately dictate which system is preferable.

Sensor Systems

UAVs rely on remote sensing technologies to capture and record information about the areas in which they operate. While this ability to record data without physically making contact with an object or environment has traditionally been accomplished with satellites or large aircraft, the rapid miniaturization of these same tools now make them viable technologies for UAV surveying. Though a complete description of the various sensor types is beyond the scope of this document, Table 1 lists the common classes of sensor packages available and the primary uses for each. As with the airframe, design sensor choice will be driven by project goals. In general, true color and multispectral sensors will be the most affordable and will provide the greatest flexibility for the majority of environmental planning and monitoring applications.

Table 1 Common UAV sensor packages and typical applications for each.

Sensor Type	Primary Use
Multispectral	Agriculture; Vegetation Health
Light Detection and Ranging (LiDAR)	Elevation Mapping

Mission Planning and Control

The mission planning and control (MP&C) software is a critical component of an aerial mapping system and is generally included by the manufacturer as part of any UAV package intended for aerial surveying. The primary goal of conducting aerial surveying operations is the creation of a seamless, georeferenced, high-resolution orthomosaic created from the tens (10's) to thousands (1000's) of individual images captured by the UAV sensors. Once reconstructed, the imagery can be used as a base

map for simple visualization or ingested into a Geographic Information System (GIS) for further data extraction and analysis.

In order to develop an accurate reconstruction, it is paramount that individual images are captured at regular intervals along the flight path and there is adequate overlap to facilitate accurate mosaicking during post-processing. In general, overlap of approximately 80% along track and 60% between tracks are required to correctly match adjacent images during mosaicking. Proper mission planning allows the operator to evaluate multiple sampling strategies by modifying all of the flight and image collection parameters, including the size and shape of the flight path, flight altitude and speed and the desired amount of image overlap (Figure 3). All of these variables have a direct impact on flight times and final image quality so it is important to develop a sound survey plan prior to actually beginning the image collection process.

During flight the MP&C connects to the Global Positioning System (GPS) satellite network for accurate position information allowing the software to control the UAV during the survey. The software follows the pre-determined mission plan and automatically triggers the sensor at regular intervals for data collection. Throughout the autonomous control process important information regarding UAV status is relayed to the operator on the ground including the aircraft's location, count of GPS satellites used to fix the aircraft's position, number of images collected and the remaining battery life. If problems are detected at any point during autonomous flight the operator can regain manual control of the UAV to correct the issue or land the vehicle. Prior to flight the software is used to design a survey plan which includes the area of collection, flight altitude, and required amount of overlap between images.

Figure 3 User interface for the Pix4D Capture App, a UAV Mission Planning and Control (MP&C) utility.

Image Post-Processing and Mosaicking

The American Society for Photogrametry and Remote Sensing (ASPRS) defines photogrammetry as *". . . the art, science, and technology of obtaining reliable information about physical objects and the environment, through processes of recording, measuring, and interpreting images and patterns of electromagnetic radiant energy and other phenomena."* The sub-discipline stereophotogrammetry is employed to estimate the three-dimensional position of an object based on measurements collected from two or more photographic images with different vantage points. Taken together, these areas of study provide the foundation for all post-processing of UAV imagery and are what allow hundreds of individual images to be "stitched" together into a seamless, spatially correct mosaic.

Modern image processing software has largely automated the mosaicking and orthorectification process for data captured via UAV and there are several third-party software manufacturers that provide the necessary tools. Figure 4 diagrams the complete post-processing workflow, however there are six major steps involved when converting individual UAV images into a seamless mosaic :
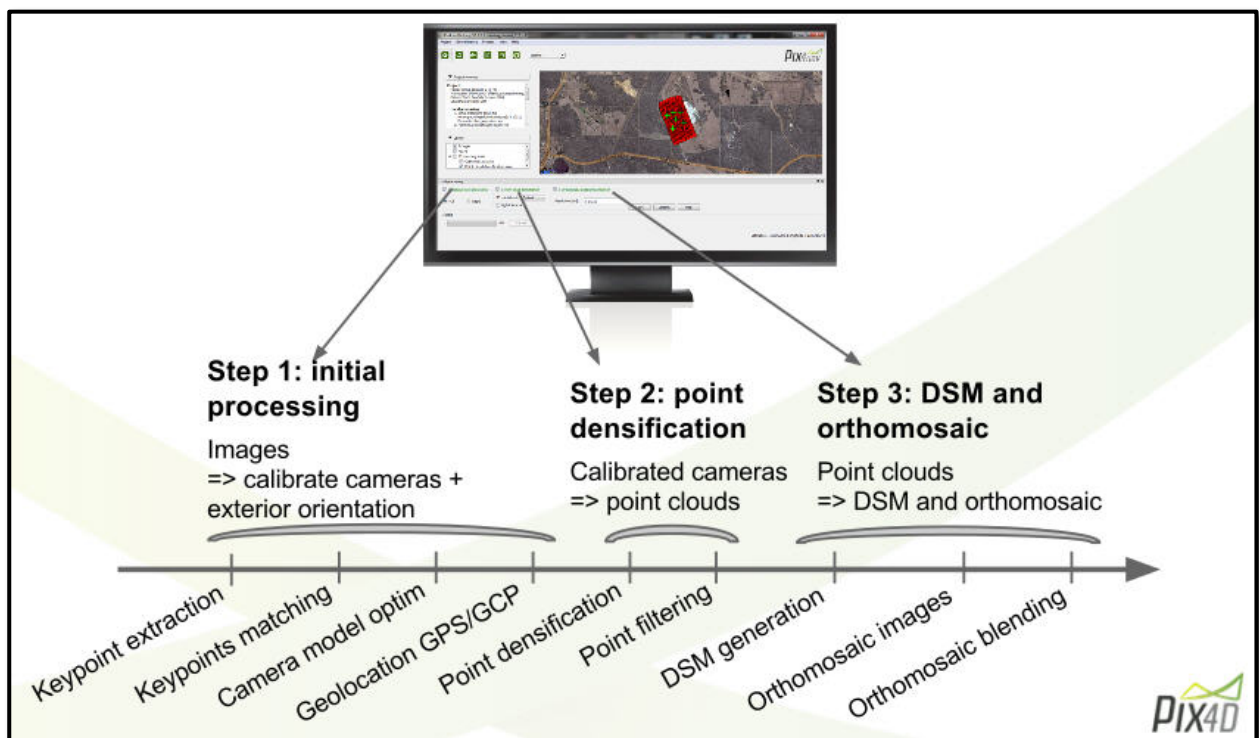
Figure 4 General and detailed workflows for post-processing UAV imagery. Source: Pix4D®.

1. <u>Identify keypoints within each image</u> –
   Keypoints are simply areas in the image with unique spectral characteristics that are easy to identify and target for matching. Building edges, shadow lines and areas of high contrast all could be used as keypoints. It is not uncommon for the software to identify up to 60,000 unique keypoints per single image.
2. <u>Find matching points between images</u> –
   The software will cycle through all of the available keypoints for an image and attempt to match with keypoints from adjacent images. With good imagery, the original 60,000 keypoints are reduced to an average of 3,000 matched pairs

per image. This matching process is dependent upon images having the correct amount of overlap; too little overlap and it's not possible to accurately join an image with its neighbors.

3. <u>Remove distortion caused by the camera lens</u> –
    Wide-angle lenses common on UAV cameras introduce a type of optical distortion known as "fisheye" that must be corrected prior to mosaicking. With fisheye, objects in the center of the frame appear normal but objects along the margins are distorted so that straight lines appear curved (Figure 5).

4. <u>Orient each camera and generate a 3-D point cloud using triangulation</u> –
    The software reads the imager header files to obtain the camera orientation (yaw, pitch, roll) for each image and uses this information to generate a georeferenced point for all of the matched keypoints. Figure 6 displays the triangulation process where a feature common to each image is identified and a line is drawn from the camera location to the point of interest. The point of intersection for these lines represents the position of the feature in geographic space ("Photogrametry", n.d.). Once finished with the keypoints, this process is repeated for any other objects that can be identified across multiple images and is known as point densification.

Figure 5 An example of a raw UAV image (left) showing the effects of fisheye distortion caused by the wide angle lens, and the same image after the distortion has been removed (right) during post processing.
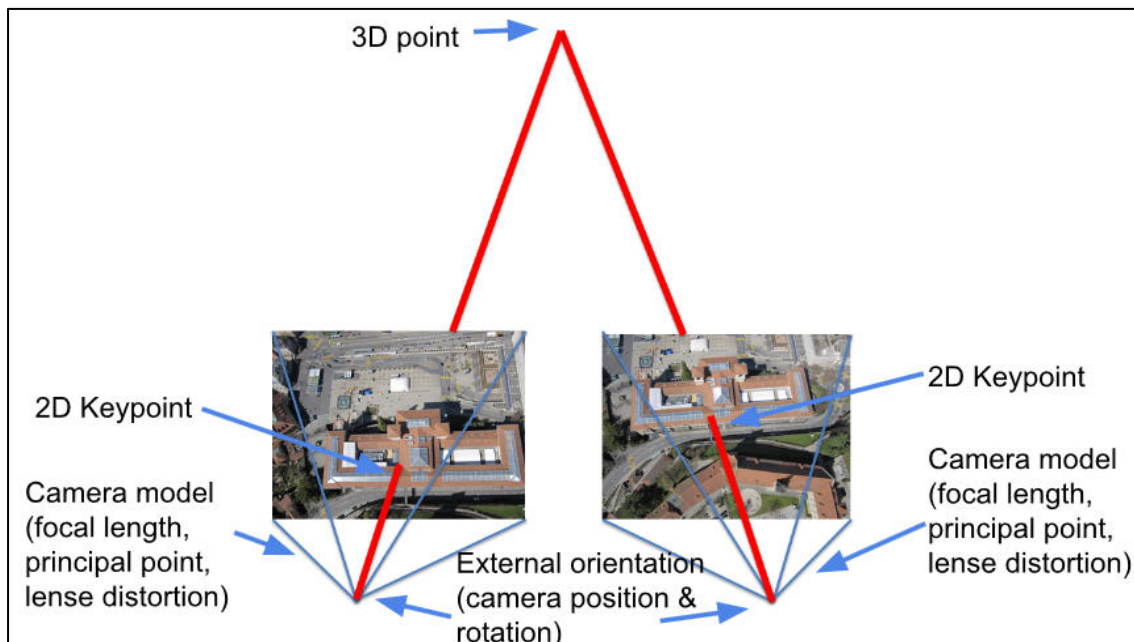
Figure 6 Stereophotogrammetry can be used to find the geographic position of an object common to both photos through triangulation. Source: Pix4D®.

5. <u>Create a Digital Surface Model (DSM)</u> –
   Using interpolation, the 3-D points are converted into a continuous, Digital Surface Model or DSM. Unlike a Digital Elevation Model (DEM) that displays only "bare earth" terrain elevations, a DSM contains terrain elevations in addition to buildings, trees and any other objects recorded by the UAV during flight.

6. <u>Generate orthorectified image mosaic</u> –
   An orthophoto is an aerial photograph that has been geometrically corrected to account for topographic relief, lens distortion, and camera tilt. Unlike an uncorrected aerial photograph, an orthophotograph has a uniform scale and can provide accurate measurements of true distance ("Othhophoto", n.d.). This correction process is applied to each image before a final blending of adjacent images into a seamless orthomosaic.

PART C – IMAGE COLLECTION AND PROCESSING

The UAV platform used for this work was a DJI Phantom2 Vision+; a rotary wing aircraft with a 14 megapixel true color camera and a maximum flight time of approximately 20 minutes. A full listing of the Phantom's technical specifications are listed in Appendix 4. The Pix4D Capture App was used for MP&C and was specifically designed to work with the Phantom aircraft and camera. All image post-processing and ortho mosaicking was completed using the Pix4Dmapper Pro® software.
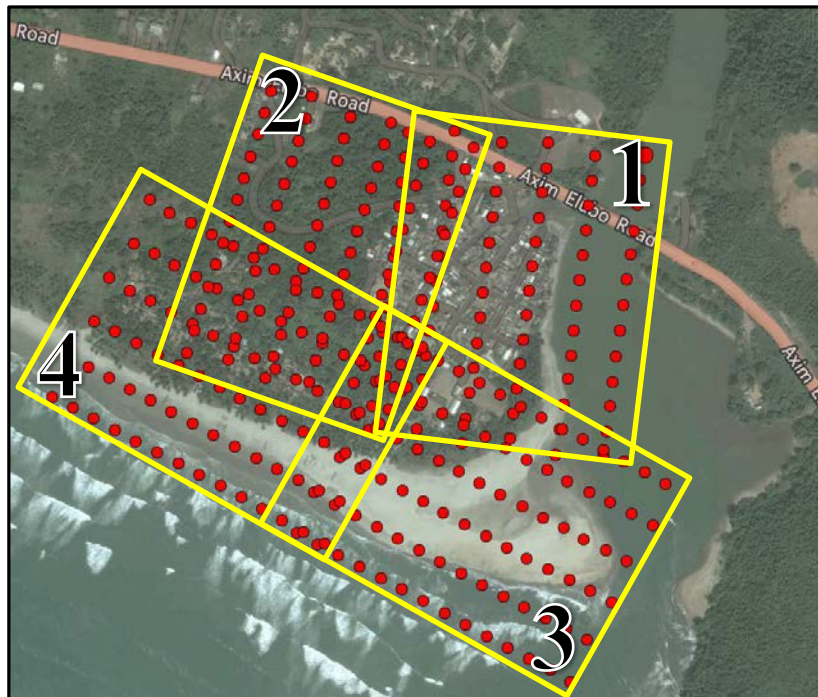
Figure 7 Mission planning for the Sanwoma study area showing individual flight layouts and amount of overlap between missions

Mission Planning

For each study location, the desired area of coverage was larger than what could be gathered from a single flight. The Pix4D Capture App was used to manually construct a series of overlapping mission grids appropriate for each situation. At each site, the size and shape of each flight pattern was determined by balancing site accessibility and the availability of launch/land points with maximum aircraft flight time. In all cases images were collected at 100m above ground level with approximately 80% overlap between images along the flight path. This resulted in a final image resolution of approximately 5cm. Figure 7 provides an example showing the Sanwoma study site and the approximate layout of each flight grid. Just as having the appropriate level of overlap is important between images of a single flight, multiple missions must also have adequate overlap so that all images from a study site can be tied together during post-processing.

Raw UAV images

Images after color balancing
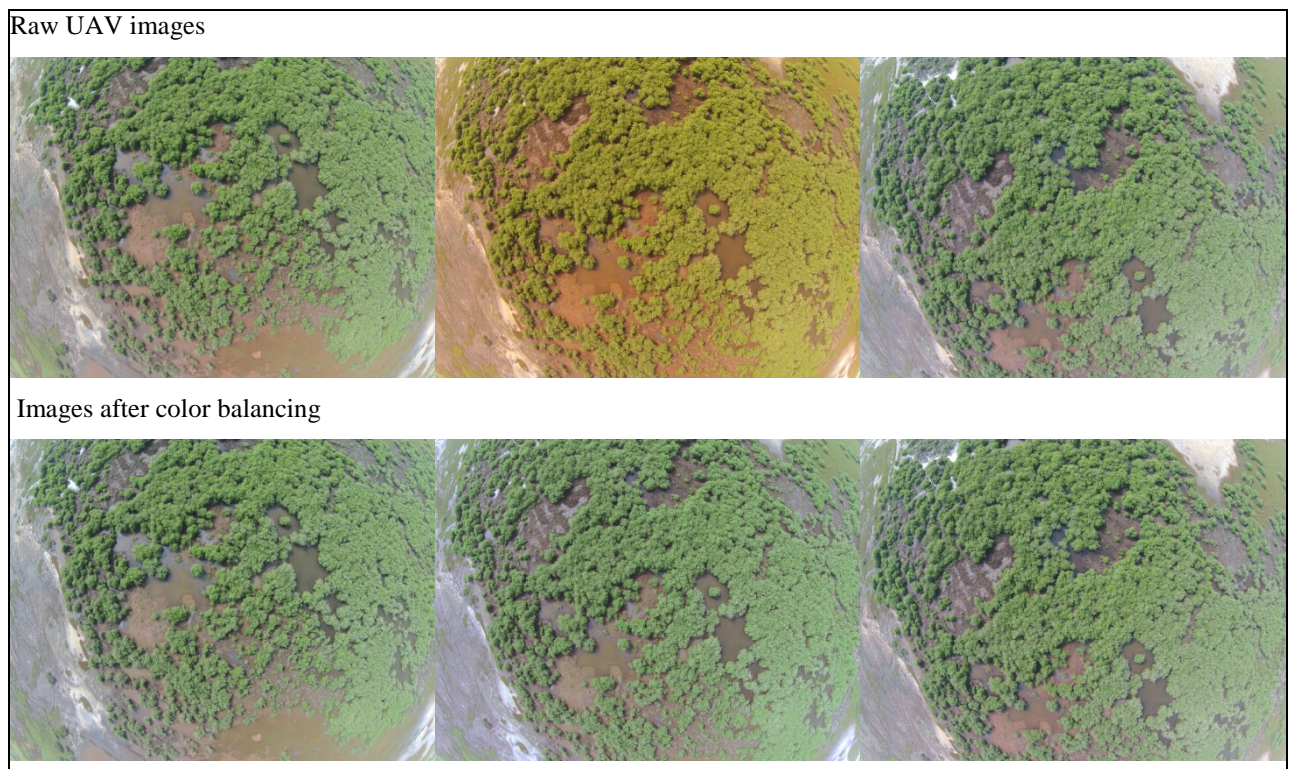
Figure 8 Three consecutive mangrove images along flight path before (Row 1) and after (Row 2) color balancing

Color Balancing Raw Imagery

After each flight, images were transferred from the aircraft to a laptop computer for quality checks and to safeguard the images should the UAV accidently be lost during a subsequent mission. During the quality control (QA/QC) process it was noted that the color balance between individual photos along the flight track could differ greatly depending on the amount of blue light recorded by the camera sensor. Too little light in the blue spectrum and the images retained a distinctly yellow tone that was very different from the surrounding photos. These off-color images surfaced randomly and appear to be directly related to the camera used by the Phantom 2 Vision+ platform. Since it was impossible to predict in the field what factor(s) were contributing to the off colors, it was determined that re-flying effected missions had a low probability of correcting the issue. Rather, the team chose to apply selective color correction during post-processing using the *Match Color* adjustment tool within the Adobe Photoshop CS® software package. As can be seen in Figure 8, this option provided an effective means of removing color deficiencies prior to final mosaicking.

Generating Mosaics

For each study area, images for individual flights were collected and processed as a single unit using the Pix4Dmapper Pro® (v2.0.104) software (Table 2). During processing, a Quality Report (Figure 9) was generated after each processing step that would highlight any potential problems detected either with the data or processing outputs. Examples of information contained in the report include the average number of keypoints identified per image, the number of points matched between images and whether the software was able to effectively correct for image distortion. Prior to final mosaicking the quality reports were reviewed and used to modify mosaicking parameters, if necessary, to ensure the best quality results. Copies of the quality reports for each study area are contained in Appendix 5. As a final step, each of the image mosaics were exported from Pix4D as georeferenced TIFF images that were directly ingested into the ArcGIS® 10.3.x software package for further analysis.

Table 2 Input and output summary for the image mosaicking process

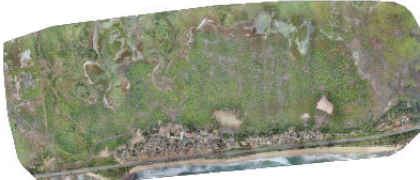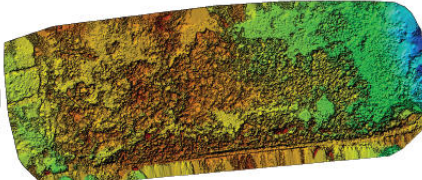| Location	Flight Height	Number Flights	Number Images	Mosaic Resolution
Sanwoma	100m	4	324	5cm
Axim	100m	6	609	5cm
Iture	100m	7	823	5cm

Figure 9 Partial image quality report produced by Pix4D. These reports flag any potential issues with the data or processing allowing changes to be made prior to final mosaicking

PART D – METHODS AND FINDINGS

Sanwoma

The project emphasis for Sanwoma was to evaluate the role UAV imagery could play in identifying and quantifying threats to coastal communities. In Sanwoma, the imagery was used to aid vulnerability mapping efforts and evaluate the community's susceptibility to shoreline erosion and riverine flooding.

Erosion/Accretion rates for the immediate coastline were computed using the Digital Shoreline Analysis System (DSAS®) developed by the U.S. Geological Survey (USGS) (Thieler et al. 2009). Run as an extension from within ArcGIS®, this software constructs a series of transect lines perpendicular to the beach face and computes a rate-of-change between multiple shoreline positions. Shoreline location was determined by manually digitizing the most recent high tide line or "wet line" on both the existing 2005 orthophotos and the 2015 UAV mosaic. Because it was impossible to know the exact stage of the tide cycle at which the images were captured, the wet line provided the most consistent feature that could be identified in each set of imagery. An arbitrary baseline was created which served as the reference "0" point for measurements, and DSAS was used to generate a series of perpendicular transects at 50m intervals and compute rates of change over the 10-year period (Figures 10 and 11).

Along the open coast, erosion rates between 2005 and 2015 vary from approximately -1.6 m/yr at the western boundary of the community to over -4 m/yr as one moves east towards the river mouth. These rates align well with erosion estimates for the Ghanaian coast put forth by Ghana's Hydrological Services Department and in published literature (Appeaning-Addo, K. 2009; Boateng, 2012). Immediately inside the river's mouth accretion is the dominant process due to the strong longshore current driven by the prevailing southwesterly winds.   Shoreline gains in this location range from 3 m/yr to 130 m/yr, though this area remains unstable and undevelopable. Coastal storms, longshore currents and riverine flow volume all have a direct impact on the durability of the deposited sands, and it is unlikely that these new low-lying deposits will transform into anything more than a temporary environment.

In addition to vulnerabilities from coastal erosion, the community experiences daily flooding due to the confluence of tides and riverine flow. Barring significant weather events, flood waters due not enter the community from the ocean through overtopping of the dunes, but rather through the low-lying canoe landing site along the river. Although there is no small-scale topographic data available for much of Ghana, the high-resolution Digital Surface Model (DSM) created as part of the image mosaicking process (Figure 12) provided the foundation for visualizing flood impacts. Elevation values for the water level were obtained by inspecting the imagery mosaic and identifying areas that were wet and had obviously been submerged during the last high tide. Coupled with field observations made during the UAV flights, the DSM was interrogated in several locations and the values averaged to arrive at a base flood height. Using a standard "bath tub" approach, an inundation surface was generated by filling the DSM to the estimated daily flood level (Figure 13). Due to Sanwoma's existing vulnerability to flooding and low topographic relief, the potential effects from Sea Level Rise (SLR) are also a concern for the long-term sustainability of this community. Mean sea level is rising approximately 3 mm/yr in Ghana and modeled predictions indicate that water levels could rise approximately 36 cm by 2100 (Sagoe-Addy and Addo, 2013). To visualize how SLR might affect the daily flooding of the community, inundation modeling was repeated with an additional 40 cm added on top of the base water level.

Sanwoma Discussion

The UAV mosaic provided the means to visualize two prominent threats to the community in a manner not possible with existing imagery or data. Having up-to-date aerial photography meant that not only could current erosion rates could be estimated, but the dynamic nature of the location could be visualized. Coastal erosion is clearly an issue for the community and this will likely worsen in the future as sea level rise aggravates the problem by exposing more shore to the physical processes that cause erosion. While the receding coast may not have a direct impact on the community now, as can be clearly seen in the imagery, Sanwoma is rapidly losing the undeveloped buffer area along the coast that has historically provided a level of protection for the community and the infrastructure within. Erosion impacts will be most apparent in the west where over 40m of coastline have been lost over the last ten years and where more frequent overtopping of the dunes by waves will threaten the non-permanent villagers living there.

The surface model developed as part of the mosaic workflow also provided a new means to visualize and quantify flooding impacts Sanwoma. It's no secret that high waters cause daily issues for the community, but the DSM affords much greater detail in visualizing the scope of the problem and identifying who is most affected. Combined with the imagery, the DSM open new doors for planning efforts and can be used for siting important infrastructure, limiting development in hazardous areas, assessing flood mitigation options and making future flood exposure predictions.

Iture Wetlands

The wetland complex at Iture was specifically selected as a study site to evaluate the efficacy of UAV imagery to quantify mangrove stand size, identify areas of cutting and aid replanting efforts. Different from larger mangrove stands within the Ankobra and Pra estuaries, the mangroves at Iture are a compact package that could be completely surveyed using a small UAV with limited flight times. The challenge, however, was that the DJI Phantom camera was not designed for vegetation survey work and only records traditional 3-band (Red, Blue, Green or RGB) color images not intended for these types of analyses. While it is possible to manually digitize mangrove stands directly from color imagery, this is laborious and time consuming work. It was hoped that alternate methods could be employed that would automate the delineation process and reduce overall processing time.

Unlike ordinary color photographs, multispectral images capture information in both the visible and non-visible portions of the electromagnetic spectrum (Figure 14). For vegetation or agricultural studies, it is common to utilize imagery having one or more additional bands of information within the infrared portion of the spectrum to aid in identifying vegetation class (wetland or upland) and/or assessing vegetation health. Lacking this information in the Iture mosaic, a hybrid method of mangrove identification was explored that coupled spectral grouping with manual classification techniques.
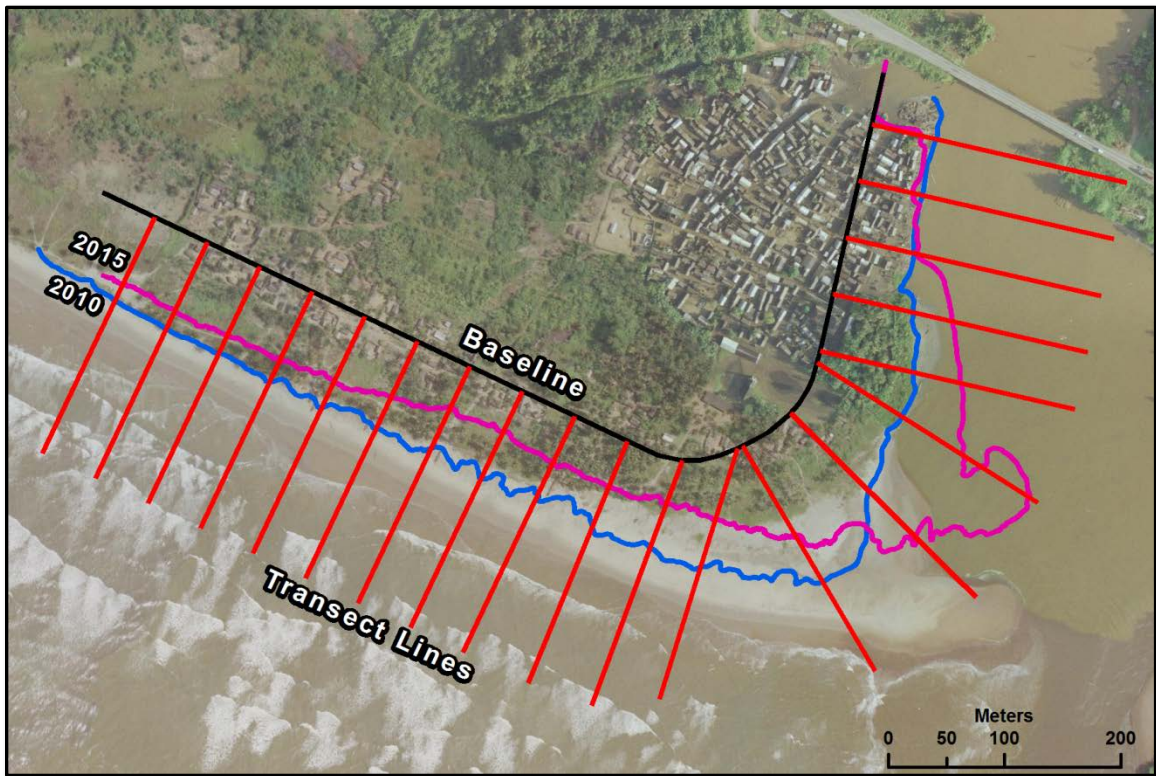
Figure 10 DSAS outputs for the shoreline change analysis at Sanwoma, Ghana. Shown are the average yearly change rates in meters, with the 10-year cumulative shoreline change envelope in parentheses. Negative rates signify erosion; positive values indicate accretion
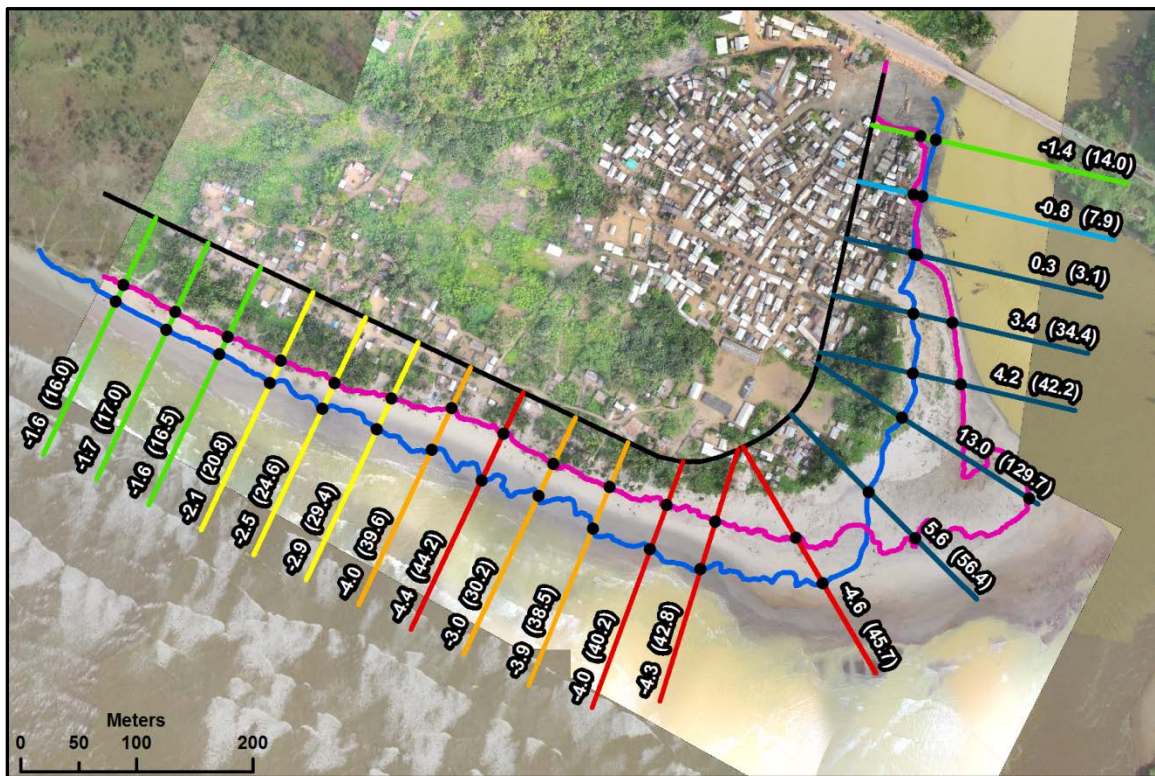
Figure 11 Inputs for the shoreline change analysis at Sanwoma, Ghana. Displayed are the manually digitized shoreline positions from 2010 (blue) and 2015 (pink), along with the reference baseline and shore transects used by DSAS to compute the change metrics
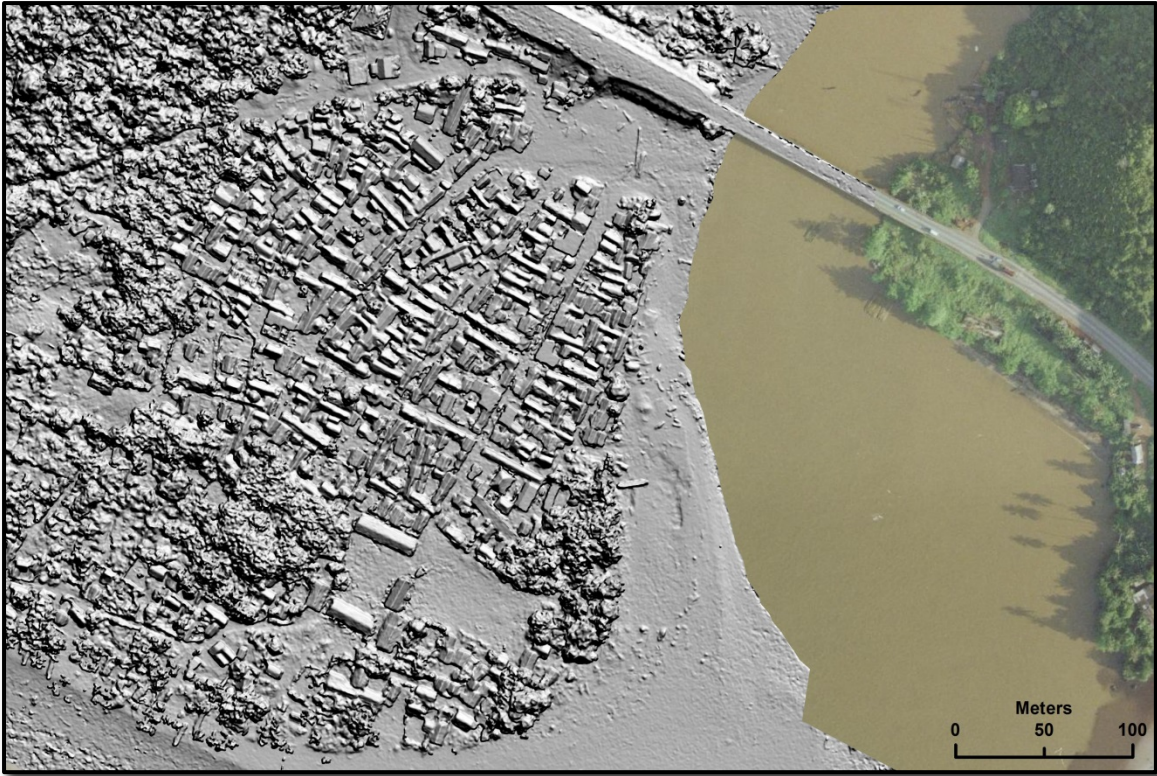
Figure 12 Digital Surface Model (DSM) for Sanwoma that was generated as part of the image mosaicking process. Under normal weather conditions flood waters enter the community daily through the canoe landing area just south of the highway bridge
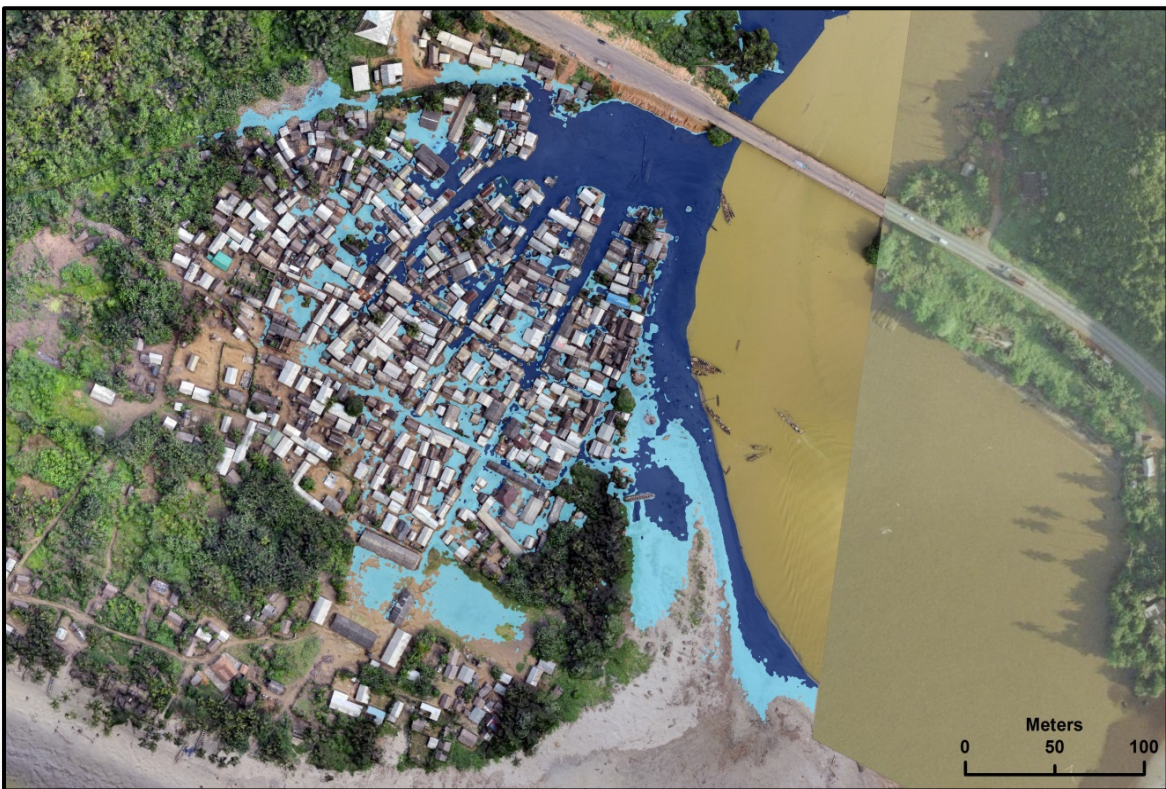
Figure 13 Estimated flood inundation levels for Sanwoma. Dark blue areas represent current daily flood conditions under normal circumstances; light blue areas highlight the probable extent of daily flooding with the addition of 0.4m of sea level rise

Ordinary color photographs only record information in the visible portion of the spectrum (RGB) while multispectral images for vegetation studies include additional bands of information in infrared portion of the spectrum. Source: MicaSense®.
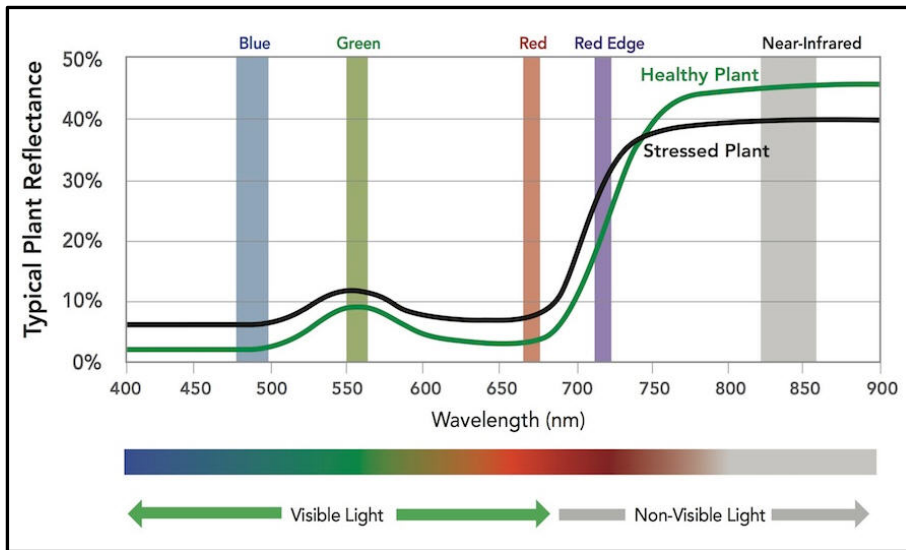
Figure 14 The electromagnetic spectrum as it relates to vegetation studies showing both the visible and non-visible portions.
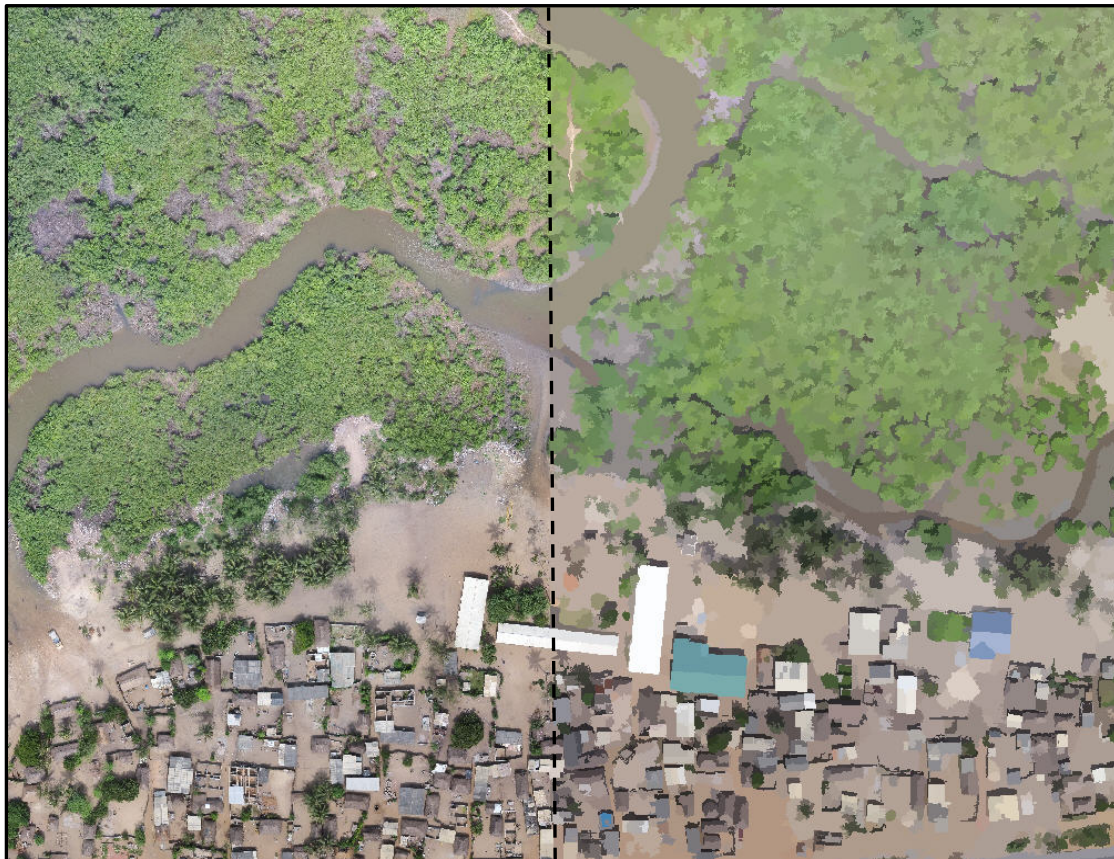
Figure 15 A subset of the Iture image mosaic displaying the original image (left) alongside the results from the image segmentation process (right).

16

With the release of ArcGIS 10.3, Esri® introduced a new suite of image processing tools for image segmentation and classification. The *Segment Mean Shift* tool, similar to an object-based classification, departs from conventional pixel-by-pixel image analysis and allows spectrally similar adjacent pixels to be grouped into much larger objects and manually placed into categories. This process, while not fully automated, provided a direct means of identifying mangrove areas despite the lack of multispectral data. Figure 15 provides a side-by-side comparison of the image before and after the segmentation tool was run.

After completing the segmentation, a generic classification scheme was created to define broad classes of information (i.e. healthy mangrove, dying or cut mangrove, open water, bare sand, other, etc.) and representative clusters of pixels were placed into each bin. The exact number and designation of each class was unimportant; they were simply groups of information that were readily identifiable in the imagery. These training samples were then used as the basis for the *Interactive Supervised Classification* which applied the spectral characteristics of each group to the entire mosaic, placing all of the pixel clusters into one of the available classes.

Figure 16 Iture wetland complex showing both healthy mangrove areas and locations where cutting has occurred.

Without the benefit of data from at least one infrared band, results from the segmented classification were quite poor as there was simply too much spectral similarity between objects of different groups – mangroves resemble grass flats, wet muddy areas appear similar to locations where mangrove are dead/dying or have been cut and turbid waters look much like wet sandy areas. Despite cross-class contamination, the segmentation did a very good

job of placing all of the vegetation into a single group due to the strong reflectance of light in the green wavelength. Thus, while the mangrove class may have included extraneous information pertaining to grass flats, palm trees and private gardens, most all of the actual healthy mangrove clusters were included as well. Using this knowledge, the mangrove class was exported as a separate polygon layer and manually edited to delete all of the erroneous bundles of pixels that had been included. This workflow was repeated to isolate locations where mangrove cutting has occurred (Figure 16), and summary statistics were generated to tabulate the area covered by each. Through this process it was determined that the Iture wetland complex holds approximately 38.1 hectares of living mangroves, with 3.5 hectares showing obvious signs that the stand is dead, dying or has been cut.

Iture Discussion

The lack of multispectral imagery definitely added challenges to the mangrove delineation process, but regardless, the UAV mosaic proved extremely useful for quantifying mangrove stand size. What the imagery lacked in spectral capabilities, it made up for with its resolution that allowed mangrove patches to be clearly delineated both by the software algorithms and by eye.

As described by Kuenzer et al. (2011), aerial photography can play an important role in mangrove management and is particularly well suited for local studies aimed at mapping local ecosystems and monitoring change. Mangrove ecosystems are typically difficult to access making traditional field surveys very time-consuming and expensive. The main advantages of UAV imagery are the low acquisition costs, ready availability and high spatial resolution. As confirmed through this work, a principal disadvantage is that detection automation is usually not possible without at least 1-band of information in the infrared portion of the spectrum and strong visual interpretation skills are required.

It is clear from the imagery that cutting of the Iture mangroves has occurred in the past and continues to this day. While this work identified a small percentage ($< 10\%$) of the Iture stand displaying definite signs of degradation, these numbers could increase significantly with additional ground surveys as there were large bare sections on the imagery where it was not possible to determine whether the main drivers were natural or anthropogenic. With regard to mangrove harvesting, two questions arise: 1) Is cutting is having a negative impact on the ecosystem?; and 2) Is cutting is being performed in a sustainable manner?

The Iture wetland complex is unique in that it possess very rich diversity containing all five of the mangrove species present in Ghana (deGraft-Johnson, 2010). From 2008 to 2010, the UNDP GEF Small Grants Program funded an effort in the Iture complex entitled "*Integrated Management of Iture Mangroves to Rehabilitate the Degraded Abakam-Elmina Coastal Wetlands and Ramsar Sites in the Central Region*". Pertinent to the funding decision was an assessment concluding the Iture mangrove ecosystem was moderately polluted, over stressed but an overall good candidate for restoration. In 2011 Sackey et al. awarded the Iture system a poor site rating suggesting the system was still experiencing severe stress due to cutting activities and garbage dumping. Current, high-resolution UAV imagery has the ability to fill an important void in ecological surveys and habitat vulnerability assessments by providing the necessary baseline data essential to ongoing monitoring efforts, performing change detection and identifying prime locations for replanting. Though not explored for this work, the underlying surface model from the mosaic also holds promise for assessing canopy height and estimating biomass; both important parameters in determining the carbon sequestration potential of the ecosystem.

Lower Axim Landing Site(s)

Lower Axim differed from the other two locations studied in that quantitative analyses were not part of the workplan, rather the goal was to provide a current, high-resolution canvas for community planning efforts led by the Ghana Town and Country Planning Department (TCPD). Part of the Ministry of Environment, Science and Technology, TCPD is charged with providing planning services to promote the responsible development of human settlements.
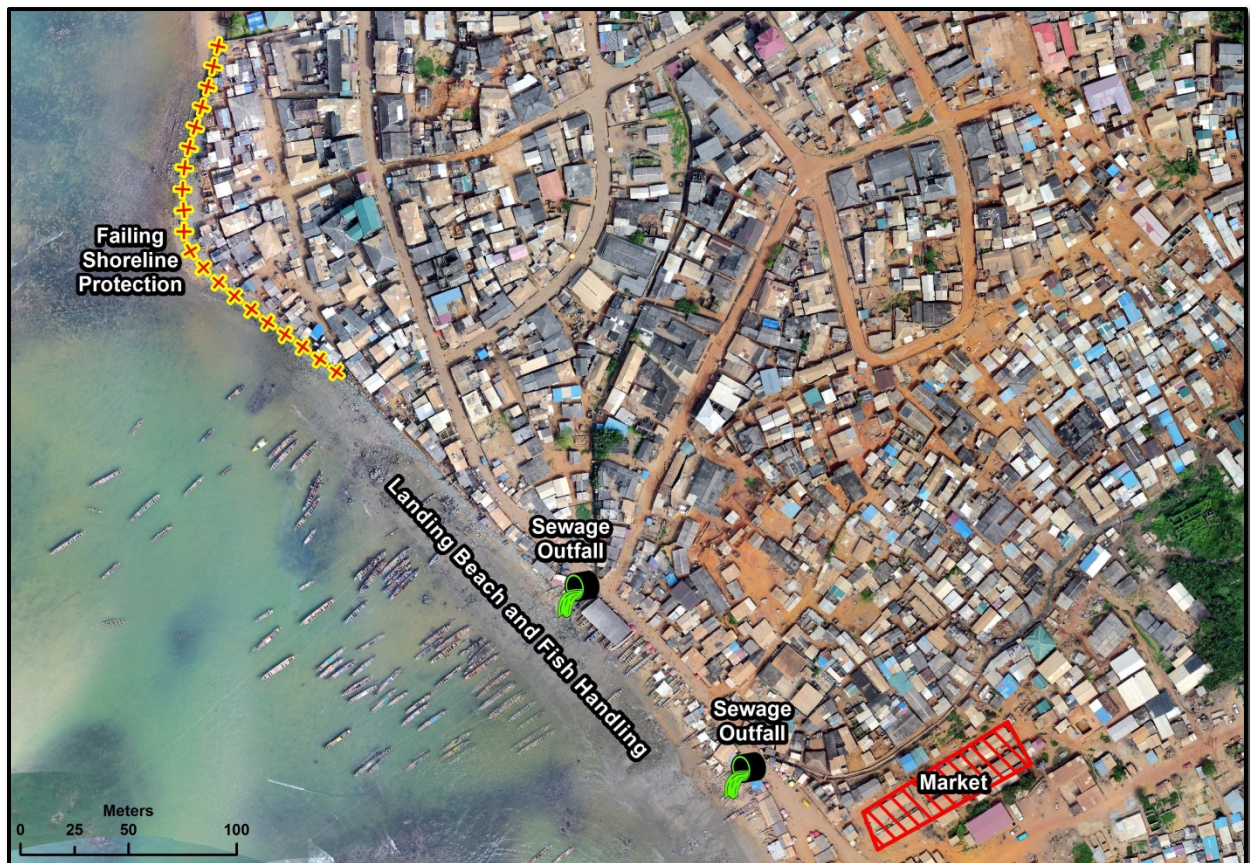
Figure 17 One of the canoe landing areas in Lower Axim showing the location of fish handling in relation to other health and safety issues which include poor sanitation and degraded shoreline protection.

As part of their work in the Western Region, TCPD and their technical contractors Spatial Solutions are in the process of mapping the fisheries value chain along the Lower Axim waterfront to evaluate strategies for the redevelopment and management of the canoe landing and fish handling areas. According to the 2013 Marine Canoe Frame survey, the multiple landing beaches of Upper and Lower Axim comprise the largest landing area in the Western Region with greater than 400 canoes and 4,000 fishermen.

From a planning perspective, Lower Axim is a challenging environment with dense development and limited expansion potential along the waterfront. Critical issues facing the community are ongoing shoreline erosion, failing shoreline protection infrastructure and poor sanitary conditions surrounding the landing area (Figure 17). Of immediate need to Spatial Solutions and TCPD was a high-resolution orthomosaic of the area that could be used to visualize existing conditions and test redevelopment designs.

PART E – SUMMARY

This project sought to evaluate emerging UAV technology and demonstrate its utility for providing high-resolution base imagery that supports a host of data collection, environmental/community planning and analytical research activities. With a suite of sensors available to meet different project needs, UAVs can play a critical role in mitigating a problem common in developing nations – the lack of current data to support effective decision-making.

Due in large part to the successes of this work, Year2 Q3 of the SFMP will see additional small UAV flights to capture imagery for priority locations and will directly support activities by SFMP implementing partners Friends of the Nation (FoN), Hen Mpoano (HM), SNV and Spatial Solutions/TCPD. Proposed survey locations include the landing sites at Old Shama and Elmina (fisheries infrastructure), the Anlo Beach communities (erosion, vulnerability and improved smoker siting), portions of the Pra wetland complex (mangrove monitoring and replanting) and the communities of Supomu Dunkwa and Beposo (TCPD community development).

As was done during the pilot study, upcoming work will extend beyond simple data collection and will include true capacity building activities for partner organizations. At the NGO level (FoN, HM, SNV) this will translate into direct assistance with extracting derivative data from the imagery, GIS database development and aid with geospatial analyses to support SFMP activities. For cooperating USAID partners (UCC Department of Geography; UCC Center for coastal Management; TCPD/Spatial Solutions) the focus will be on enhancing technical capabilities by including personnel from each organization in the data acquisition process and providing imagery to feed ongoing projects. Finally, at the institutional level (UCC) the aim will be to lay a foundation of internal experience and knowledge that the university can capitalize on to become a national leader in the application of UAV technology for environmental management and coastal planning.

For all of the successes, this pilot study also highlighted practical limitations with regard to the application of recreational UAVs for aerial surveying – the camera, mission planning and control and GPS positioning systems simply were not designed for this type of application which demands a higher level of precision than the average user requires. One means of overcoming these limitations that should be explored would be an organizational partnership to acquire a larger fixed-wing UAV platform designed specifically for aerial surveying. A system of this type would allow larger areas to be surveyed and would possess multispectral imaging capabilities to provide the greatest flexibility in meeting partner needs.

An example of this might be a collaborative effort between the USAID-funded Sustainable Fisheries Management Project (SFMP), and the University of Cape Coast's Center for Coastal Management (CCM) and Department of Geography (UCC Geo). The focus of this partnership would be on building institutional capacity to utilize new technology in the push for sustainable development and resource management. This arrangement is a win-win-win: as a nationally recognized spatial analysis laboratory, UCC Geo would receive training in cutting-edge technologies to support their work in resource management and environmental analysis; the CCM would receive similar training, and would work to improve the geospatial information base for Ghana's coastal region to aid spatial planning activities at the regional and district levels; and the SFMP, through their network of engaged project partners, would have the opportunity to showcase innovative methods that will improve the quality of project deliverables and serve as a catalyst for strengthening multidisciplinary, multi-organizational partnerships.

Without a doubt, advances in technology have made it much easier for researchers and project managers in developing nations to acquire the data they need to effect real change and to develop policies based on sound science. UAVs have a strong role to play in this, and as results from this pilot indicate, there is simply no other means of data collection that provides the same level of quality, flexibility and cost-effectiveness for small to medium scale efforts as UAV-acquired information.

PART F – REFERENCES

Akyeampong, S., K. Amador, and B. Nkrumah. 2013. Report on the 2013 Ghana Marine Canoe Frame Survey. Republic of Ghana, Ministry of Fisheries and Aquaculture Development, Fisheries Scientific Survey Division. Information Report #35. 76pp.

Appeaning-Addo, K. 2009. Detection of Coastal Erosion Hotspots in Accra, Ghana. *Journal of Sustainable Development in Africa*. 4(11):253-258.

Boateng, I. 2012. An Application of GIS and Coastal Geomorphology for Large Scale Assessment of Coastal Erosion and Management: A Case Study of Ghana. *J Coast Conserv*. 16:383-397.

deGraft-Johnson, K.A.A., J. Blay, F.K.E. Nunoo, and C.C. Amankwah. 2010. Biodiversity Threats Assessment of the Western Region of Ghana. The *Integrated Coastal and Fisheries Governance (ICFG) Initiative Ghana*.

Kuenzer, C., A. Bluemel, S. Gebhardt, T. Vo Quoc, and S. Dech. 2011. Remote Sensing of Mangrove Ecosystems: A Review. *Remote Sens.* 3:878-928.

Sackey I , W. M. Kpikpi, and A-W. M. Imoro. 2011. Ecological Studies in the Iture Estuary Mangrove Forest in Ghana. *Journal of The Ghana Science Association*. 13(2):37- 44.

Sagoe-Addy, K. and K.A. Addo. 2013. Effect of Predicted Sea Level Rise on Tourism Facilities Along Ghjana's Accra Coast. *J. Coast Conserv.* 17:155-166.

Thieler, E.R., E.A. Himmelstoss, J.L. Zichichi, and A. Ergul. 2009. Digital Shoreline Analysis System (DSAS) version 4.0— An ArcGIS extension for calculating shoreline change: U.S. Geological Survey Open-File Report 2008-1278.

Wikipedia contributors. Orthophoto. Wikipedia, The Free Encyclopedia. September 14, 2015, 10:31 UTC. Available at: https://en.wikipedia.org/w/index.php?title=Orthophoto&oldid=680967581. Accessed April 18, 2016.

Wikipedia contributors. Photogrammetry. Wikipedia, The Free Encyclopedia. April 8, 2016, 11:57 UTC. Available at: https://en.wikipedia.org/w/index.php?title=Photogrammetry&oldid=714220947. Accessed April 9, 2016.

PART G - APPENDICES

A1: UAV Permit Application
See Attached document

A2: Operations Manual
See Attached document

A3: CAA UAV Provisional Flight Approval
See Attached document

A4: DJI Phantom 2 Vision+ Specifications

Aircraft

Weight (Battery & Propellers Included)	1242g (2.8307lbs)
Diagonal Length (Motor-Motor Distance)	350mm (13.780in)
Max Flight Time	25mins
Max Ascent / Descent Speed	Ascent: 6m/s; Descent: 2m/s
Max Flight Speed	15m/s (Not Recommended)
Hover Accuracy (Ready To Fly)	• Vertical: 0.8m (2.6247ft) • Horizontal: 2.5m (8.2021ft)
Max Yaw Angular Velocity	200°/s
Max Tiltable Angle	35°
Supported Battery	DJI 5200mAh LiPo Battery

Gimbal

Control Accuracy	±0.03°
Controllable Range	Pitch : -90°－0°
Maximum Angular Speed	Pitch : 90°/s
Working Current	Static : 750mA; Dynamic : 900mA

Camera

Sensor Size	1/2.3″
Effective Pixels	14 Megapixels
Image Resolution	4384×3288
File Formats	• JPEG • RAW
Video Recording	• 1080p/1080i • 720p
Frame Rate	• 30 fps (1080) • 60 fps (1080/720)
Video Transmitting	• 640×640 (30fps) • 320×240 (15fps)
Recording FOV	110° / 85°
Operating Environment Temperature	0℃-40℃

Remote Control

Type	New version, left-dial
Features	Preinstalled smartphone holder
Operating Frequency	5.728 GHz－5.85 GHz
Communication Distance (Open Area)	• CE Compliance: 400m (1312.3ft) • FCC Compliance: 800m (2624.7ft)
Receiver Sensitivity (1%PER)	-93dBm
Transmitter Power	• CE Compliance: 25mW • FCC Compliance: 100mW
Working Voltage	120 mA@3.7V
Built-In LiPo Battery Working Current/Capacity	3.7V, 2000mAh
Left Dial	√ Control gimbal pitch movement
Throttle Lock	√ Lock the throttle stick
Trainer Port	√ Run simulation application to practice your flying skills

DJI 'Smart Battery'

Type	3S LiPo
Capacity	5200mAh, 11.1V
Charging Environment Range	0℃ to 40℃
Discharging Environment Range	-20℃ to 50℃

Range Extender

Operating Frequency	2412-2462MHz
Communication Distance (Open Area)	500-700m (1640.4-2296.6ft)
Transmitter Power	20dBm
Power Consumption	2W

A5: Image Mosaic Quality Reports
See Attached document

Date: 16 October, 2015

The Director General
Ghana Civil Aviation Authority
Accra, Ghana

Dear Sir or Madam,

This letter is a formal request for permission to conduct a series of small, unmanned aerial vehicle (UAV) fights in the Central and Western Regions December 7-18, 2015. The purpose of these activities will be to implement three pilot studies demonstrating how the technology operates; the quality of the imagery that can be captured, and the value these products hold for developing derivative geospatial data. The high-resolution imagery being gathered will support the following research topics:

1. Mapping the fisheries value chain and economic development along the waterfront;
2. Shoreline change and vulnerability of coastal infrastructure, and;
3. Wetland delineation and replanting/encroachment monitoring

We will be joined in these efforts by project partners and collaborators including Spatial Solutions, technical contractors for the Town and Country Planning Department (TCPD); the University of Cape Coast (UCC) Department of Geography and UCC Center for Coastal Management. The goal is to begin building capacity within each of these organizations to capitalize on emerging technologies. All partners will receive both raw and processed versions of the data at the end of the exercise.

The three communities we have identified for our work are Sanwoma, Ellembelle, WR; Axim, Nzema East, WR; and Elmina, Komenda/Edina/Eguafo/Abriem, CR. A map highlighting the study areas is attached.

Proposed equipment and flight specifications include:
Type of the equipment: DJI Phantom 2 Vision+
Exercise start/end date: December 7-18 to account for weather and technical issues
Proposed Number of Flights: 9 at 20 minutes/flight
Minimum/Maximum UAV altitude: 100/200m
Maximum Range: 800m
Frequency for transmission: 5.728 GHz－5.85 GHz for control and 2412-2462MHz for video feed.

We thank you for your consideration.
Respectfully,

Table of Contents

Part A

<u>Introduction</u>

1. *Contents*
   This document lists the general policies and guidelines the SFMP project will follow when operating a UAV for aerial image collection. For specific information on UAV operation, refer to the UAV user manual contained in Appendix 2.

2. *Introductory Statement*
   Advances in technology have made Unmanned Aerial Vehicles (UAVs), and the imagery they capture, a valuable tool for environmental research and scientific analysis. With a wide array of sensors currently available, systems can be tailored to specific needs including localized base mapping, elevation modeling, vegetation analysis or health, wetland delineation and coastal monitoring.

   All SFMP UAV operations will abide by the guidelines contained in this manual, and operators will ensure that all proper permissions (Federal, local, and landowner) have been obtained prior to flight.

3. *Definitions*
   AGL – Above Ground Level
   AP – Auxiliary Pilot
   CoP – Chief of Party
   GCAA – Ghana Civil Aviation Authority
   OM – Operations Manual
   OPAREA – Operating Area
   PIC – Pilot in Command
   SFMP – USAID/Ghana Sustainable Fisheries Management Project
   SUA or UAV – Small Unmanned Aircraft or Unmanned Aerial Vehicle
   VLOS – Visual Line of Sight
   VO – Visual Observer

4. *Document Control*
   Current OM Version- 1.0; December, 2015

<u>Organization</u>

5. *Organization Structure*
   On October 21, 2014, USAID/Ghana awarded the Coastal Resources Center (CRC) at the University of Rhode Island (URI) a cooperative agreement (AID-641-A-15-00001) to implement the USAID/Ghana Sustainable Fisheries Management Project (SFMP).

URI leads a team of core implementing partners including Friends of the Nation, Hen Mpoano, SNV Ghana (Netherlands Development Organization), the Central & Western Fish Mongers Improvement Association in Ghana/CEWEFIA, Daasgift Quality Foundation and Development Action Association (DAA). Technical supporting partners include, SSG Advisors and Spatial Solutions. Key government project beneficiaries and partners are The Ministry of Fisheries and Aquaculture Development (MOFAD) and the Fisheries Commission (FC), the University of Cape Coast and the Department of Town and Country Planning (TCPD) in the Central and Western Regions.

Project Contact Information: USAID/GhanaSustainable Fisheries Management Project (SFMP), 10 Obodai St., Mempeasem, East Legon, Accra, Ghana

6. *Nominated Personnel*
   Operations Manager – Brian Crawford, SFMP CoP
   Technical Manager – Donald Robadue, URI Coastal Resources Center
   Chief Pilot – Christopher Damon, URI Environmental Data Center
   Auxiliary Pilots – Various project partners
   Visual Observers – Various project partners

7. *PIC Responsibilities and Duties*
   The PIC is the lead on-site authority for UAV operations and is responsible for the safety and well-being of the equipment, support personnel and nearby property/persons. It is the PIC responsibility to ensure that all documentation is in order and all required permissions have been obtained prior to launching the vehicle. The PIC will operate the aircraft in a safe manner, adhering to the guidelines in this OM and the UAV user manual. The PIC will make the final decision to fly based upon an on-site assessment of local weather conditions, locations of potential obstructions and the identification of a safe take-off/landing zone.

8. *Support Personnel Responsibilities and Duties*
   Support personnel will assist the PIC with mission planning, equipment checks and a pre-flight survey of the OPAREA. For safety, they will keep the surrounding area clear of pedestrians during take-off/landing. During flight operations, it will be the responsibility of the VO to keep the UAV in sight at all times and warn the PIC if an issue arises that may jeopardize the mission.

   Auxiliary pilots may selected from SFMP project partners to build capacity within local organizations for UAV operations. Prior to flight, APs must read and understand both the OM and DJI User Manual; watch all the official DJI Phantom 2 Vision+ training videos on the DJI website (http://www.dji.com) and complete a hands-on, flight competency check. At no time will an AP fly a mission without the PIC present, and the PIC may resume full control of the flight at any time during the mission.

9. *SUA Technical Description*

The DJI Phantom 2 Vision+ is a small, battery operated quadcopter weighing 1 Kg. It is designed for capturing high-resolution color images and video and has a flight time of approximately 25 minutes. For a complete list of the system specifications, refer to *OM Part D, Appendix 2 – DJI Phantom 2 Vision+ Specifications*.

10. *Area of Operation*

The SFMP UAV OPAREA will include the coastal zone within Ghana's Western and Central Regions. Specific flight locations will be based on project objectives and might include the mapping of fisheries infrastructure, monitoring shoreline erosion and coastal flooding, identification of coastal wetlands and evaluating coastal forests and mangrove stands for replanting potential.

11. *Operating Limits and Conditions*

Operating altitude is directly related to the resolution of imagery captured. Minimum and maximum flying height during image acquisition will be 45m and 125m AGL. Operations will cease if the VO is unable to maintain visual contact with the UAV due to reduced visibility or if wind speeds exceed 28kph.

Operational Control

12. *Supervision of SUA Operations*

Prior to heading to the field for acquiring imagery, the PIC will inform both the Operations Manager and Technical Manager of the desired OPAREA and purpose for the flight(s). If additional permissions are required, the Operations Manager or Technical Manager will submit the necessary documentation to the regulating authority for official approval.

13. *Accident Prevention and Flight Safety*

Accidents can be prevented by following general SAU operating guidelines:
- Do not operate the aircraft in severe weather conditions. These include wind speed exceeding category 4, snow, rain and smog;
- Fly in open areas as high buildings and steel structures may affect the accuracy of the onboard compass;
- Keep the UAV away from obstacles, crowds, high-voltage power lines and large trees while in flight;
- Reduce chances of electromagnetic interference by not flying in areas with high levels of electromagnetism, including base stations and radio transmission towers and;
- Do not fly within no-fly zones or controlled airspace without informing the proper authorities and receiving written permission to do so.

If an accident does occur the names of the affected parties along with their contact information will be recorded and submitted to local authorities along with a description of the incident. Injured parties will also receive contact information for the SFMP project. Upon returning from the field, an accident report will be created detailing all of the pertinent information. It will be

signed by both the PIC and the VO and submitted to the SFMP Operations Manager, Technical Manager and the CAA.

14. **Flight Team Composition**
To maximize effectiveness and safety, the flight team requires a minimum of 2 persons, the PIC and the VO. Any additional persons will assist the PIC and VO as needed in performing the site assessment and ensuring the take-off/landing area is kept clear of non-essential personnel.

15. **Operation of Multiple SUA Types**
During a mission, the PIC may only operate 1 UAV at a time.

16. **Qualification Requirements**
Prior to flight, PICs and APs must read and understand both the OM and DJI User Manual; watch all the official DJI Phantom 2 Vision+ training videos on the DJI website (http://www.dji.com) and complete a hands-on, flight competency check over an unpopulated area. The PIC must be familiar with all phases of the flying process including mission planning, flight operations, emergency recovery procedures and data post-processing. The PIC will instruct the VO on required responsibilities and ensure they understand mission procedures prior to taking off.

17. **Crew Health**
No person may be part of the flight crew if they are unable to perform the required tasks for their position. The PIC will make the final determination on personnel and may remove an individual from the crew if needed.

18. **Logs and Records**
As part of the SFMP reporting process to USAID, all flights will be documented detailing the OPAREA, purpose of the flight and description of the data captured.

Part B

Operating Procedures

1. **Flight Planning/Preparation**

   1.1. **Determination of Tasks**
   UAV tasking will be decided in consultation with project partners and will support SFMP priority areas. Prioritization of image collection efforts will be determined by the SFMP Technical Manager.

   1.2. **OPAREA Site Assessment**
   Prior to flight the PIC and VO will conduct a full assessment of the OPAREA being mindful of the following hazards or concerns:

Issue	Example	Action
Type of Airspace	Controlled airspace	Inform authorities and obtain any needed permissions.
Other Aircraft Operations	Nearby airfields	Inform authorities and obtain any needed permissions.
Hazards	High-intensity radio transmission	Avoid or relocate OPAREA.
Local Laws	--	Inform authorities and local chief prior to flight.
Obstructions	Wires, trees, buildings, topography, etc.	Avoid or relocate OPAREA.
Extraordinary Restrictions	Closed airspace near sensitive facilities	Inform authorities and obtain any needed permissions.
Habitation	Homes, public gathering places	Minimize flights over populated areas
Public Access	Accessibility by non-essential personnel	VO and flight crew will keep non-essential personnel at a safe distance during take-off and landing.
Landowner Permission		Avoid operating from private property or receiver landowner permission prior to flight. Relocate launching/landing area if needed.
OPAREA and Alternatives	Planned OPAREA and alternative sites	Identify alternative launch/land locations during mission planning.
Weather Conditions	--	Obtain latest weather forecast prior to heading out to field. Final determination of conditions will be made on-site by PIC.

1.3. Risk Management
See *OM Part B, Section 1.2 – OPAREA Site Assessment*

1.4. Communications

Organization	Contact Person	Contact Number
CAA, Accra		
CAA, Takoradi		

1.5. Pre-Notification
See *OM Part B, Section 1.2 – OPAREA Site Assessment*

1.6. Site Permission
See *OM Part B, Section 1.2 – OPAREA Site Assessment*

1.7. **Weather**

See *OM Part B, Section 1.2 – OPAREA Site Assessment*

1.8. **Equipment Preparation**

Refer to *OM Part D, Appendix 3 – DJI Phantom 2 Vision+ User Manual* for all required pre-flight checks and procedures.

2. ***On-Site Procedures and Pre-flight Checks***

2.1. **Site Survey**

Visual check of OPAREA and identification of possible hazards. Refer to *OM Part B, Section 1.2*

2.2. **Selection of OPAREA and Alternate**

Visual inspection of surrounding landscape. Landing zone for an automatic 'home' return will be identified and kept clear during flight operations.

2.3. **Crew Briefing**

Perform final crew briefing ensuring each person understands the goal of the mission and their required duties.

2.4. **Cordon Procedure**

The VO and any additional flight crew will ensure that non-essential personnel are kept a safe distance away from the launch/land site during operations. This includes keeping the automatic 'home' area clear.

2.5. **Communications**

Will be completed prior to launching. Refer to *OM Part B, Sections 1.2 – OPAREA Site Assessment and 1.4 – Communications.*

2.6. **Weather Checks**

Perform a final on-site determination of local weather conditions. Postpone operations if weather conditions are expected to deteriorate during the flight window.

2.7. **Refueling**

Proper charging of batteries will occur before heading out to field. Refer to *OM Part D, Appendix 3 – DJI Phantom 2 Vision+ User Manual* for proper battery evaluation and recharging methods.

2.8. **Loading of Equipment**

All equipment will continuously monitored by the PIC and VO while in the field. Any unused/unneeded equipment will remain secured in a vehicle while on-site.

2.9. SUA Preparation and Assembly

To be performed in accordance with manufacturer's instructions. Refer to *OM Part D, Appendix 3 – DJI Phantom 2 Vision+ User Manual*.

2.10.   Pre-Flight Equipment Checks

To be performed in accordance with manufacturer's instructions. Refer to *OM Part D, Appendix 3 – DJI Phantom 2 Vision+ User Manual*.

3. Flight Procedures

All pre-, during and post flying details are outlined in *OM Part D, Appendix 3 – DJI Phantom 2 Vision+ User Manual*. Topics covered include:

- Equipment checks and start-up
- Take-off procedures
- In-flight operations
- Landing procedures and;
- Equipment shutdown

4. Emergency Procedures

4.1. Processes

The Phantom will enter Failsafe mode when its connection to the Remote Controller is lost. The Flight Control System will automatically control the aircraft to return to home and land to prevent injury or damage. Failsafe mode will activate if:

1. The control unit is powered off.
2. The UAV has flown out of effective remote controller range.
3. The signal between the control unit and the AUV has been blocked.
4. There is interference causing a signal problem with the control unit.

For Failsafe procedures and the setting of a "home Location" refer to Refer to *OM Part D, Appendix 3 – DJI Phantom 2 Vision+ User Manual*.

4.2. Fire

Lithium polymer (LiPo) batteries used to power the UAV have the potential to catch fire if not handled properly. All battery inspection and recharging procedures will follow the manufacturer's recommended guidelines outlined in *OM Part D, Appendix 3 – DJI Phantom 2 Vision+ User Manual*.

4.3. Accidents

Refer to *OM Part A, Section 13 – Accident Prevention and Flight Safety*

Part C

<u>Training</u>

1. *Training Details*

   PICs and APs must read and understand both the OM and DJI User Manual; watch all the official DJI Phantom 2 Vision+ training videos on the DJI website (http://www.dji.com) and complete a hands-on, flight competency check over an unpopulated area. The PIC and AP must be familiar with all phases of the flying process including mission planning, flight operations, emergency recovery procedures and data post-processing. The AP will not be allowed to fly a non-training mission until the PIC is satisfied with AP competency. For auxiliary flight crew, the PIC will instruct the VO on required responsibilities and ensure they understand mission procedures prior to taking off.

Part D

<u>Appendices</u>

1. *CAA Permission*

   See Attached document

*2. **DJI Phantom 2 Vision+ Specifications***

Aircraft

Weight (Battery & Propellers Included)	1242g (2.8307lbs)
Diagonal Length (Motor-Motor Distance)	350mm (13.780in)
Max Flight Time	25mins
Max Ascent / Descent Speed	Ascent: 6m/s; Descent: 2m/s
Max Flight Speed	15m/s (Not Recommended)
Hover Accuracy (Ready To Fly)	• Vertical: 0.8m (2.6247ft) • Horizontal: 2.5m (8.2021ft)
Max Yaw Angular Velocity	200°/s
Max Tiltable Angle	35°
Supported Battery	DJI 5200mAh LiPo Battery

Gimbal

Control Accuracy	±0.03°
Controllable Range	Pitch : -90°－0°
Maximum Angular Speed	Pitch : 90°/s
Working Current	Static : 750mA; Dynamic : 900mA

Camera

Sensor Size	1/2.3"
Effective Pixels	14 Megapixels
Image Resolution	4384×3288
File Formats	• JPEG • RAW
Video Recording	• 1080p/1080i • 720p
Frame Rate	• 30 fps (1080) • 60 fps (1080/720)
Video Transmitting	• 640×640 (30fps) • 320×240 (15fps)
Recording FOV	110° / 85°
Operating Environment Temperature	0℃-40℃

Remote Control

Type	New version, left-dial
Features	Preinstalled smartphone holder
Operating Frequency	5.728 GHz－5.85 GHz
Communication Distance (Open Area)	• CE Compliance: 400m (1312.3ft)

	• FCC Compliance: 800m (2624.7ft)
Receiver Sensitivity (1%PER)	-93dBm
Transmitter Power	• CE Compliance: 25mW • FCC Compliance: 100mW
Working Voltage	120 mA@3.7V
Built-In LiPo Battery Working Current/Capacity	3.7V, 2000mAh
Left Dial	√ Control gimbal pitch movement
Throttle Lock	√ Lock the throttle stick
Trainer Port	√ Run simulation application to practice your flying skills
DJI 'Smart Battery'	
Type	3S LiPo
Capacity	5200mAh, 11.1V
Charging Environment Range	0℃ to 40℃
Discharging Environment Range	-20℃ to 50℃
Range Extender	
Operating Frequency	2412-2462MHz
Communication Distance (Open Area)	500-700m (1640.4-2296.6ft)
Transmitter Power	20dBm
Power Consumption	2W

3. *DJI Phantom 2 Vision+ Operators Manual*

The most recent version of the user manual is version 1.8. Click Here to view the pdf file.

Ghana Civil Aviation Authority

Our ref: AIR 4152/ 46/ 07

14th March, 2016

Your ref:

The Chief of Party
USAID/Sustainable Fisheries Management Project
10 Obodai Street, Mempresem,
East-Legon
Accra – Ghana.

ATTN: PETER DONKOR

Dear Sir,

SMALL UNMANNED AERIAL VEHICLE (UAV) OPERATIONS AUTHORISATION:
DJI PHONTOM 2 VISION + AIRCRAFT WITH SERIAL NUMBER PH645267213

Please find attached original copy of the UAV Operations Authorisation for the above mentioned unmanned aircraft.

The Authorisation is valid from 14th March, 2016 to 12th December, 2016, unless varied, suspended or revoked.

Kindly note that this Authorisation and a copy of a current insurance certificate shall be carried at all times during operations by the Person In Charge of the unmanned aircraft, as they may be randomly inspected by GCAA Aviation Safety Inspectors.

USAID/Sustainable Fisheries Management Project must always notify the Authority of the following before commencing any operation:

1. Purpose of operating the unmanned aircraft.
2. Specific location(s) for intended flight.

Kindly note that the Air Traffic Control Tower must be contacted with information of intended flight to help prevent inadvertent flight conflicting with other air traffic.

Also, please be advised that subsequent requests for renewals shall be accompanied with evidence of Refresher Training, as well as copies of Logbook entries for jobs performed.

We wish you success in your operation.

Yours faithfully,

DANIEL ACQUAH
DIRECTOR, SAFETY REGULATION
FOR: DIRECTOR-GENERAL

CC: DIRECTOR-GENERAL
     DEPUTY DIRECTOR-GENERAL (TECHNICAL)

Private Mail Bag	**Tel:** (233)-(30) 2776171	**Sita:** ACCXTYF
Kotoka International Airport	**Fax:** (233)-(30) 2773293	**AFTN:** DGAAYFYX
Accra, Ghana	**E-mail:** info@gcaa.com.gh	**Website:** www.gcaa.com.gh

Safety & Security, Our Priority

A4: DJI Phantom 2 Vision+ Specifications

Aircraft

Weight (Battery & Propellers Included)	1242g (2.8307lbs)
Diagonal Length (Motor-Motor Distance)	350mm (13.780in)
Max Flight Time	25mins
Max Ascent / Descent Speed	Ascent: 6m/s; Descent: 2m/s
Max Flight Speed	15m/s (Not Recommended)
Hover Accuracy (Ready To Fly)	• Vertical: 0.8m (2.6247ft) • Horizontal: 2.5m (8.2021ft)
Max Yaw Angular Velocity	200°/s
Max Tiltable Angle	35°
Supported Battery	DJI 5200mAh LiPo Battery

Gimbal

Control Accuracy	±0.03°
Controllable Range	Pitch : -90°－0°
Maximum Angular Speed	Pitch : 90°/s
Working Current	Static : 750mA; Dynamic : 900mA

Camera

Sensor Size	1/2.3″
Effective Pixels	14 Megapixels
Image Resolution	4384×3288
File Formats	• JPEG • RAW
Video Recording	• 1080p/1080i • 720p
Frame Rate	• 30 fps (1080) • 60 fps (1080/720)
Video Transmitting	• 640×640 (30fps) • 320×240 (15fps)
Recording FOV	110° / 85°
Operating Environment Temperature	0℃-40℃

Remote Control

Type	New version, left-dial
Features	Preinstalled smartphone holder
Operating Frequency	5.728 GHz－5.85 GHz
Communication Distance (Open Area)	• CE Compliance: 400m (1312.3ft) • FCC Compliance: 800m (2624.7ft)
Receiver Sensitivity (1%PER)	-93dBm
Transmitter Power	• CE Compliance: 25mW

- FCC Compliance: 100mW

Working Voltage	120 mA@3.7V
Built-In LiPo Battery Working Current/Capacity	3.7V, 2000mAh
Left Dial	√ Control gimbal pitch movement
Throttle Lock	√ Lock the throttle stick
Trainer Port	√ Run simulation application to practice your flying skills

DJI 'Smart Battery'

Type	3S LiPo
Capacity	5200mAh, 11.1V
Charging Environment Range	0℃ to 40℃
Discharging Environment Range	-20℃ to 50℃

Range Extender

Operating Frequency	2412-2462MHz
Communication Distance (Open Area)	500-700m (1640.4-2296.6ft)
Transmitter Power	20dBm
Power Consumption	2W

A5: Image Mosaic Quality Reports

> ⚠ **Important**: Click on the different icons for:
>
> ❓ Help to analyze the results in the Quality Report
>
> ℹ Additional information about the sections

> 💡   Click here for additional tips to analyze the Quality Report

Summary

Project	Sanwoma_Combined
Processed	2016-02-02 20:00:38
Average Ground Sampling Distance (GSD)	4.51 cm / 1.77 in
Area Covered	0.4635 km^2 / 46.3533 ha / 0.1791 sq. mi. / 114.601 acres

Quality Check

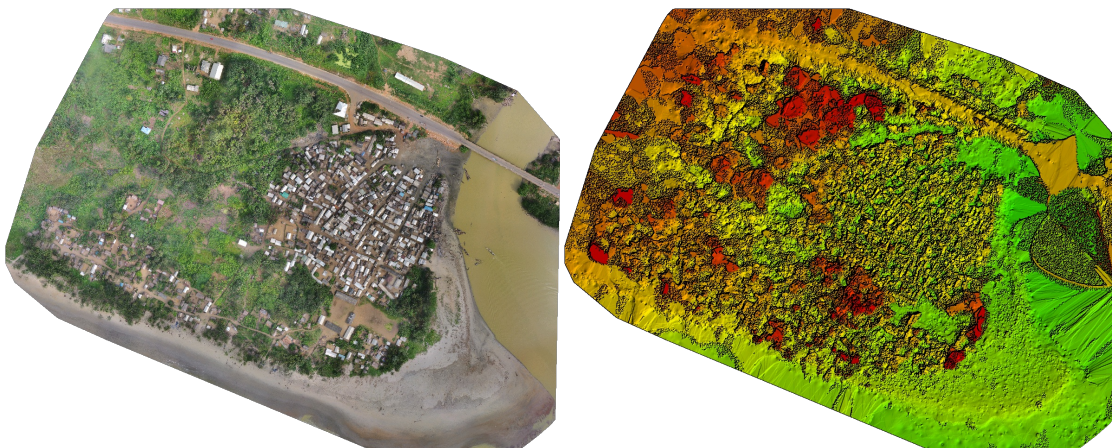|			
❓ **Images**	median of 39514 keypoints per image		✓
❓ **Dataset**	294 out of 324 images calibrated (90%), all images enabled		⚠
❓ **Camera Optimization**	3.24% relative difference between initial and optimized internal camera parameters		✓
❓ **Matching**	median of 4036.74 matches per calibrated image		✓
❓ **Georeferencing**	yes, no 3D GCP		⚠

❓ **Preview**

Figure 1: Orthomosaic and the corresponding sparse Digital Surface Model (DSM) before densification.

Calibration Details

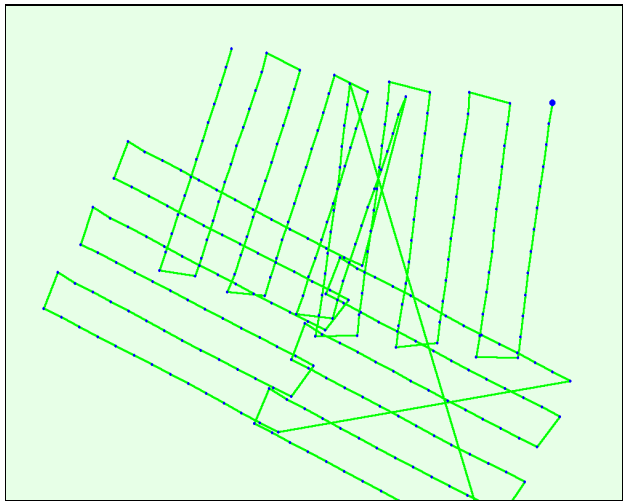|	
Number of Calibrated Images	294 out of 324
Number of Geolocated Images	324 out of 324

❓ **Initial Image Positions**

Figure 2: Top view of the initial image position. The green line follows the position of the images in time starting from the large blue dot.

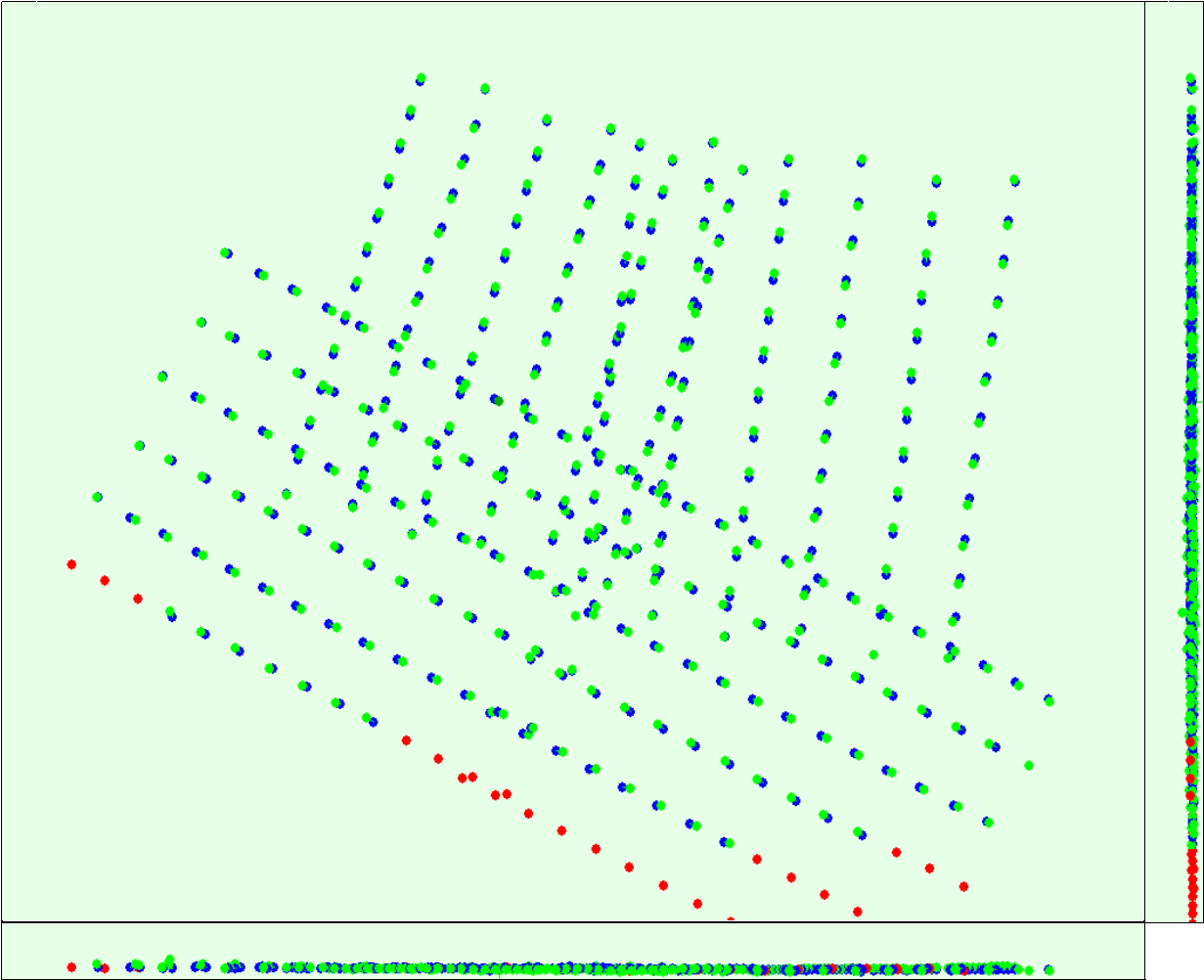## Computed Image/GCPs/Manual Tie Points Positions

Figure 3: Offset between initial (blue dots) and computed (green dots) image positions as well as the offset between the GCPs initial positions (blue crosses) and their computed positions (green crosses) in the top-view (XY plane), front-view (XZ plane), and side-view (YZ plane).
Red dots indicate disabled or uncalibrated images.

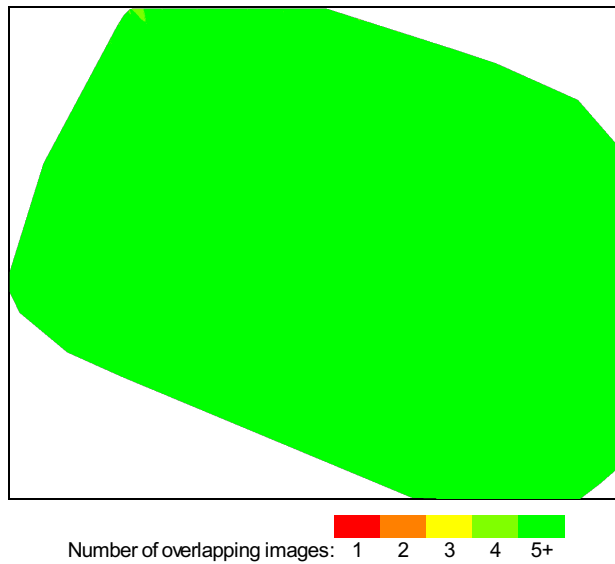## Overlap

Number of overlapping images: 1 2 3 4 5+

Figure 4: Number of overlapping images computed for each pixel of the orthomosaic.
Red and yellow areas indicate low overlap for which poor results may be generated. Green areas indicate an overlap of over 5 images for every pixel. Good quality results will be generated as long as the number of keypoint matches is also sufficient for these areas (see Figure 5 for keypoint matches).

Bundle Block Adjustment Details

Number of 2D Keypoint Observations for Bundle Block Adjustment	1248551
Number of 3D Points for Bundle Block Adjustment	551430
Mean Reprojection Error [pixels]	0.235652

	Poly[0]	Poly[1]	Poly[2]	Poly[3]	Poly[4]	c	d	e	f	Principal Point x	Principal Point y
Initial Values	0.000103	1.000000	-0.000586	-0.144035	0.000000	4081.42	0.00	0.00	4081.42	2303.98	1728.00
Optimized Values	-0.000082	1.000000	-0.015297	-0.047163	-0.063392	3949.18	0.00	0.00	3949.18	2269.86	1692.95
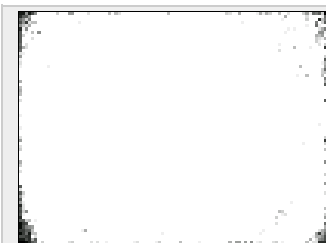
The number of Automatic Tie Points (ATPs) per pixel averaged over all images of the camera model is color coded between black and white. White indicates that, in average, more than 16 ATPs are extracted at this pixel location. Black indicates that, in average, 0 ATP has been extracted at this pixel location. Click on the image to the see the average direction and magnitude of the reprojection error for each pixel. Note that the vectors are scaled for better visualization.

	Number of 2D Keypoints per Image	Number of Matched 2D Keypoints per Image
Median	39514	4037
Min	18952	195
Max	59447	16316
Mean	38036	4247

In 2 Images	465585
In 3 Images	56523
In 4 Images	15870
In 5 Images	6385
In 6 Images	3126
In 7 Images	1647
In 8 Images	904
In 9 Images	556
In 10 Images	290
In 11 Images	195
In 12 Images	124
In 13 Images	71
In 14 Images	54
In 15 Images	42
In 16 Images	18
In 17 Images	17
In 18 Images	8
In 19 Images	3
In 20 Images	5
In 21 Images	1
In 22 Images	1
In 23 Images	1
In 24 Images	2
In 25 Images	1
In 27 Images	1

2D Keypoint Matches

Number of matches

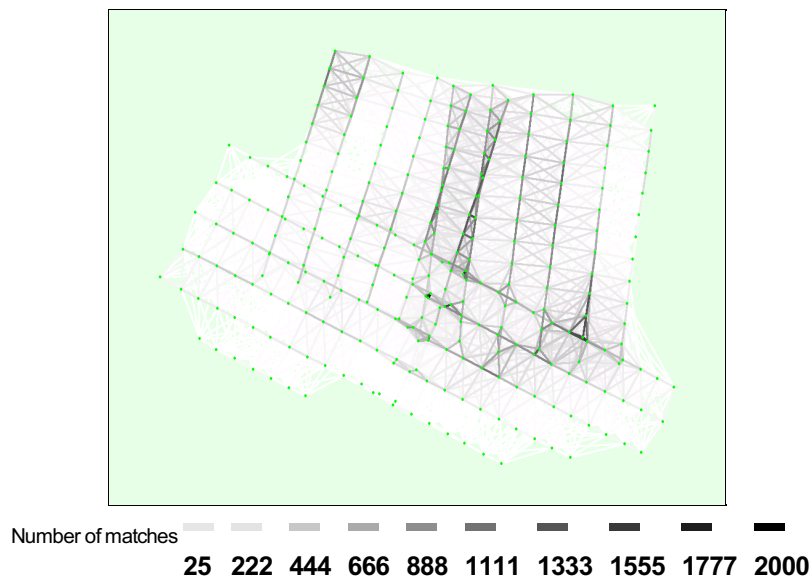**25 222 444 666 888 1111 1333 1555 1777 2000**

Figure 5: Top view of the image computed positions with a link between matching images. The darkness of the links indicates the number of matched 2D keypoints between the images. Bright links indicate weak links and require manual tie points or more images.

Geolocation Details

Absolute Geolocation Variance

1 out of 294 geolocated and calibrated images have been labeled as inaccurate.

Min Error [m]	Max Error [m]	Geolocation Error X [%]	Geolocation Error Y [%]	Geolocation Error Z [%]
-	-15.00	0.00	0.00	0.00
-15.00	-12.00	0.00	0.00	0.00
-12.00	-9.00	0.00	0.00	0.00
-9.00	-6.00	1.02	3.75	0.34

-6.00	-3.00	20.82	23.21	2.05
-3.00	0.00	27.65	22.18	41.64
0.00	3.00	33.11	24.23	55.63
3.00	6.00	17.06	23.89	0.34
6.00	9.00	0.34	2.73	0.00
9.00	12.00	0.00	0.00	0.00
12.00	15.00	0.00	0.00	0.00
15.00	-	0.00	0.00	0.00
Mean [m]		0.000044	-0.000105	-0.000903
Sigma [m]		3.174114	3.969018	1.318105
RMS Error [m]		3.174114	3.969018	1.318105

Min Error and Max Error represent geolocation error intervals between -1.5 and 1.5 times the maximum accuracy of all the images. Columns X, Y, Z show the percentage of images with geolocation errors within the predefined error intervals. The geolocation error is the difference between the intial and computed image positions. Note that the image geolocation errors do not correspond to the accuracy of the observed 3D points.

⊘ **Relative Geolocation Variance**

Relative Geolocation Error	Images X [%]	Images Y [%]	Images Z [%]
[-1.00, 1.00]	88.05	69.97	100.00
[-2.00, 2.00]	100.00	100.00	100.00
[-3.00, 3.00]	100.00	100.00	100.00
Mean of Geolocation Accuracy [m]	5.000000	5.000000	10.000000
Sigma of Geolocation Accuracy [m]	0.000000	0.000000	0.000000

Images X, Y, Z represent the percentage of images with a relative geolocation error in X, Y, Z.

Geolocation Orientational Variance	RMS [degree]
Omega	7.170244
Phi	5.579975
Kappa	3.707018

Geolocation RMS error of the orientation angles given by the difference between the initial and computed image orientation angles.

Processing Options

Hardware	CPU: Intel(R) Xeon(R) CPU X5650 @ 2.67GHz RAM: 24GB GPU: NVIDIA Quadro FX 4800 (Driver: 9.18.13.697), RDPDD Chained DD (Driver: unknown), RDP Encoder Mirror Driver (Driver: unknown), RDP Reflector Display Driver (Driver: unknown)
Operating System	Windows 7 Ultimate, 64-bit
Camera Model Name	PHANTOMVISIONFC200_5.0_4608x3456 (RGB)
Image Coordinate System	WGS84
Output Coordinate System	WGS84 / UTM zone 30N
Keypoints Image Scale	Full, Image Scale: 1
Advanced: Matching Image Pairs	Aerial Grid or Corridor
Advanced: Matching Strategy	Use Geometrically Verified Matching: no
Advanced: Keypoint Extraction	Targeted Number of Keypoints: Automatic
Advanced: Calibration	Calibration Method: Standard, Internal Parameters Optimization: All, External Parameters Optimization: All, Rematch: yes

Point Cloud Densification details

Processing Options

Image Scale	multiscale, 1/2 (Half image size, Default)
Point Density	Optimal
Minimum Number of Matches	3
3D Textured Mesh Generation	yes, Maximum Number of Triangles: 1000000, Texture Size: 8192x8192
Advanced: Matching Window Size	7x7 pixels
Advanced: Image Groups	RGB
Advanced: Use Densification Area	yes
Advanced: Use Annotations	yes
Advanced: Limit Camera Depth Automatically	no
Time for Point Cloud Densification	02h:38m:56s
Time for 3D Textured Mesh Generation	30m:22s

Results

Number of Generated Tiles	12
Number of 3D Densified Points	28556546
Average Density (per m^3)	40.22

DSM, Orthomosaic and Index Details

Processing Options

DSM and Orthomosaic Resolution	1 x GSD (4.52 [cm/pixel])
DSM Filters	Noise Filtering: yes, Surface Smoothing: yes, Sharp
DSM Generation	yes, Method: Inverse Distance Weighting, Merge Tiles: yes
Time for DSM Generation	36m:46s
Time for Orthomosaic Generation	02h:22m:34s

Quality Report

⚠ **Important**: Click on the different icons for:

? Help to analyze the results in the Quality Report

ⓘ Additional information about the sections

💡 Click here for additional tips to analyze the Quality Report

Summary

Project	Iture_Combined
Processed	2016-02-01 12:42:23
Average Ground Sampling Distance (GSD)	4.94 cm / 1.94 in
Area Covered	1.4692 km^2 / 146.921 ha / 0.5676 sq. mi. / 363.236 acres
Time for Initial Processing (without report)	03h:25m:54s

Quality Check

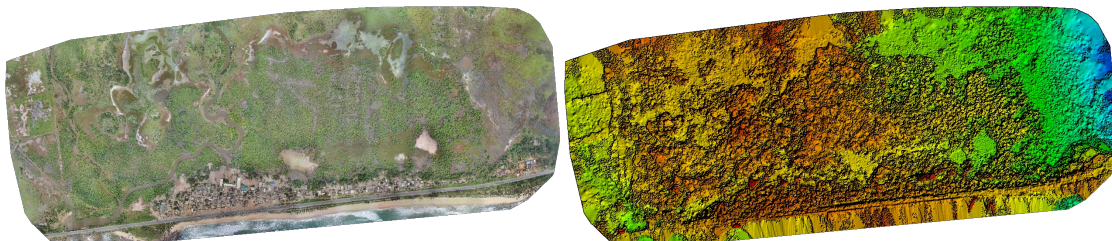|			
? **Images**	median of 39319 keypoints per image		✓
? **Dataset**	822 out of 823 images calibrated (99%), all images enabled		✓
? **Camera Optimization**	0.74% relative difference between initial and optimized internal camera parameters		✓
? **Matching**	median of 2307.94 matches per calibrated image		✓
? **Georeferencing**	yes, no 3D GCP		⚠

? **Preview**

Figure 1: Orthomosaic and the corresponding sparse Digital Surface Model (DSM) before densification.

Calibration Details

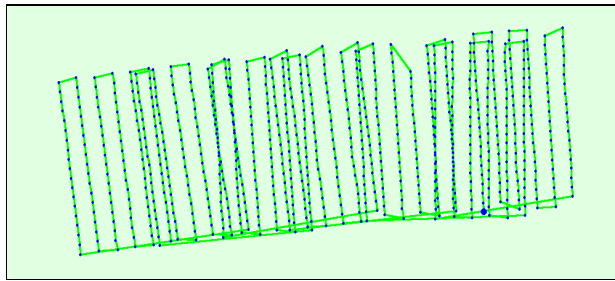|	
Number of Calibrated Images	822 out of 823
Number of Geolocated Images	823 out of 823

? **Initial Image Positions**

Figure 2: Top view of the initial image position. The green line follows the position of the images in time starting from the large blue dot.

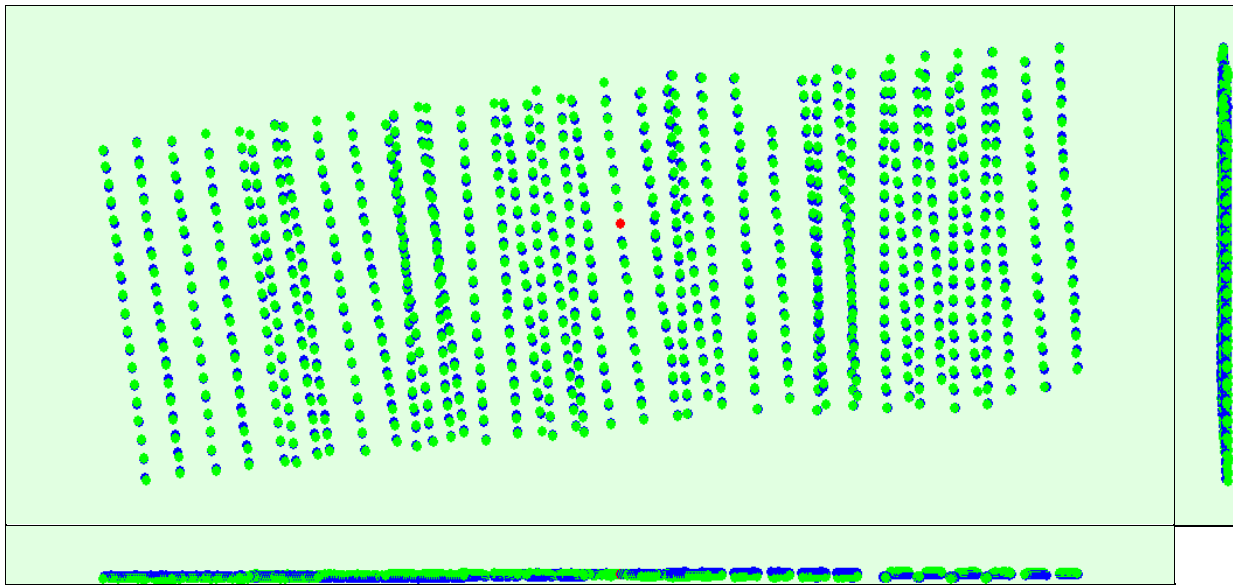## ⑦ Computed Image/GCPs/Manual Tie Points Positions

Figure 3: Offset between initial (blue dots) and computed (green dots) image positions as well as the offset between the GCPs initial positions (blue crosses) and their computed positions (green crosses) in the top-view (XY plane), front-view (XZ plane), and side-view (YZ plane).
Red dots indicate disabled or uncalibrated images.

⑦ Overlap

Number of overlapping images: 1 2 3 4 5+

Figure 4: Number of overlapping images computed for each pixel of the orthomosaic.
Red and yellow areas indicate low overlap for which poor results may be generated. Green areas indicate an overlap of over 5 images for every pixel. Good quality results will be generated as long as the number of keypoint matches is also sufficient for these areas (see Figure 5 for keypoint matches).

Bundle Block Adjustment Details

Number of 2D Keypoint Observations for Bundle Block Adjustment	2211031
Number of 3D Points for Bundle Block Adjustment	911122
Mean Reprojection Error [pixels]	0.130299

Internal Camera Parameters

PHANTOMVISIONFC200_5.0_4608x3456 (RGB). Sensor Dimensions: 6.485 [mm] x 4.864 [mm]

EXIF ID: PHANTOMVISIONFC200_5.0_4608x3456

	Poly[0]	Poly[1]	Poly[2]	Poly[3]	Poly[4]	c	d	e	f	Principal Point x	Principal Point y
Initial Values	0.000103	1.000000	-0.000586	-0.144035	0.000000	4081.42	0.00	0.00	4081.42	2303.98	1728.00
Optimized Values	-0.000072	1.000000	-0.012933	-0.140984	-0.003718	4111.68	0.00	0.00	4111.68	2270.38	1694.12

The number of Automatic Tie Points (ATPs) per pixel averaged over all images of the camera model is color coded between black and white. White indicates that, in average, more than 16 ATPs are extracted at this pixel location. Black indicates that, in average, 0 ATP has been extracted at this pixel location. Click on the image to the see the average direction and magnitude of the reprojection error for each pixel. Note that the vectors are scaled for better visualization.

2D Keypoints Table

	Number of 2D Keypoints per Image	Number of Matched 2D Keypoints per Image
Median	39319	2308
Min	20144	213
Max	55514	7348
Mean	38894	2690

3D Points from 2D Keypoint Matches

	Number of 3D Points Observed
In 2 Images	705917
In 3 Images	121225
In 4 Images	45075
In 5 Images	17546
In 6 Images	8829
In 7 Images	4479
In 8 Images	2674
In 9 Images	1653
In 10 Images	1088
In 11 Images	735
In 12 Images	514
In 13 Images	357
In 14 Images	284
In 15 Images	195
In 16 Images	166
In 17 Images	98
In 18 Images	77
In 19 Images	57
In 20 Images	43
In 21 Images	27
In 22 Images	27
In 23 Images	21
In 24 Images	10
In 25 Images	8
In 26 Images	5
In 27 Images	3
In 28 Images	3
In 29 Images	1
In 30 Images	1
In 31 Images	1

In 32 Images	1
In 34 Images	1
In 35 Images	1

? 2D Keypoint Matches

Number of matches

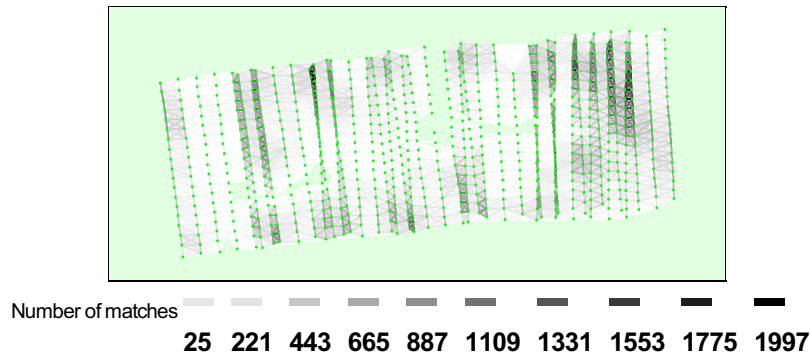**25 221 443 665 887 1109 1331 1553 1775 1997**

Figure 5: Top view of the image computed positions with a link between matching images. The darkness of the links indicates the number of matched 2D keypoints between the images. Bright links indicate weak links and require manual tie points or more images.

Geolocation Details

? Absolute Geolocation Variance

0 out of 822 geolocated and calibrated images have been labeled as inaccurate.

Min Error [m]	Max Error [m]	Geolocation Error X [%]	Geolocation Error Y [%]	Geolocation Error Z [%]
-	-15.00	0.00	0.00	0.00
-15.00	-12.00	0.00	0.00	0.00
-12.00	-9.00	0.00	0.00	0.00
-9.00	-6.00	0.00	14.96	0.00
-6.00	-3.00	1.82	30.05	30.54
-3.00	0.00	39.54	4.50	21.17
0.00	3.00	58.64	4.26	23.72
3.00	6.00	0.00	34.31	16.79
6.00	9.00	0.00	11.92	7.66
9.00	12.00	0.00	0.00	0.12
12.00	15.00	0.00	0.00	0.00
15.00	-	0.00	0.00	0.00
Mean [m]		0.000028	0.000009	-0.001883
Sigma [m]		1.102476	5.306456	3.777784
RMS Error [m]		1.102476	5.306456	3.777785

Min Error and Max Error represent geolocation error intervals between -1.5 and 1.5 times the maximum accuracy of all the images. Columns X, Y, Z show the percentage of images with geolocation errors within the predefined error intervals. The geolocation error is the difference between the intial and computed image positions. Note that the image geolocation errors do not correspond to the accuracy of the observed 3D points.

? Relative Geolocation Variance

Relative Geolocation Error	Images X [%]	Images Y [%]	Images Z [%]
[-1.00, 1.00]	100.00	39.90	100.00
[-2.00, 2.00]	100.00	100.00	100.00
[-3.00, 3.00]	100.00	100.00	100.00
Mean of Geolocation Accuracy [m]	5.000000	5.000000	10.000000
Sigma of Geolocation Accuracy [m]	0.000000	0.000000	0.000000

Images X, Y, Z represent the percentage of images with a relative geolocation error in X, Y, Z.

Geolocation Orientational Variance	RMS [degree]
Omega	9.765776
Phi	2.492514
Kappa	3.583507

Geolocation RMS error of the orientation angles given by the difference between the initial and computed image orientation angles.

Processing Options

Hardware	CPU: Intel(R) Xeon(R) CPU X5650 @ 2.67GHz RAM: 24GB GPU: NVIDIA Quadro FX 4800 (Driver: 9.18.13.697), RDPDD Chained DD (Driver: unknown), RDP Encoder Mirror Driver (Driver: unknown), RDP Reflector Display Driver (Driver: unknown)
Operating System	Windows 7 Ultimate, 64-bit
Camera Model Name	PHANTOMMSIONFC200_5.0_4608x3456 (RGB)
Image Coordinate System	WGS84
Output Coordinate System	WGS84 / UTM zone 30N
Keypoints Image Scale	Full, Image Scale: 1
Advanced: Matching Image Pairs	Aerial Grid or Corridor
Advanced: Matching Strategy	Use Geometrically Verified Matching: no
Advanced: Keypoint Extraction	Targeted Number of Keypoints: Automatic
Advanced: Calibration	Calibration Method: Standard, Internal Parameters Optimization: All, External Parameters Optimization: All, Rematch: no

Point Cloud Densification details

Processing Options

Image Scale	multiscale, 1/2 (Half image size, Default)
Point Density	Optimal
Minimum Number of Matches	3
3D Textured Mesh Generation	yes, Maximum Number of Triangles: 1000000, Texture Size: 8192x8192
Advanced: Matching Window Size	7x7 pixels
Advanced: Image Groups	RGB
Advanced: Use Densification Area	yes
Advanced: Use Annotations	yes
Advanced: Limit Camera Depth Automatically	no
Time for Point Cloud Densification	14h:44m:52s
Time for 3D Textured Mesh Generation	02h:35m:07s

Results

Number of Processed Clusters	2
Number of Generated Tiles	22
Number of 3D Densified Points	106143259
Average Density (per m^3)	42.59

DSM, Orthomosaic and Index Details

Processing Options

DSM and Orthomosaic Resolution	1 x GSD (4.94 [cm/pixel])
DSM Filters	Noise Filtering: yes, Surface Smoothing: yes, Sharp
DSM Generation	yes, Method: Inverse Distance Weighting, Merge Tiles: yes

Time for DSM Generation	01h:56m:33s
Time for Orthomosaic Generation	05h:37m:58s

Quality Report

> ⚠ **Important**: Click on the different icons for:
>
> ❓ Help to analyze the results in the Quality Report
>
> ℹ Additional information about the sections

> 💡 Click here for additional tips to analyze the Quality Report

Summary

Project	axim_combined_nogeo
Processed	2016-02-03 12:11:07
Average Ground Sampling Distance (GSD)	4.62 cm / 1.81 in
Area Covered	1.2211 km^2 / 122.113 ha / 0.4717 sq. mi. / 301.905 acres
Time for Initial Processing (without report)	02h:24m:29s

Quality Check

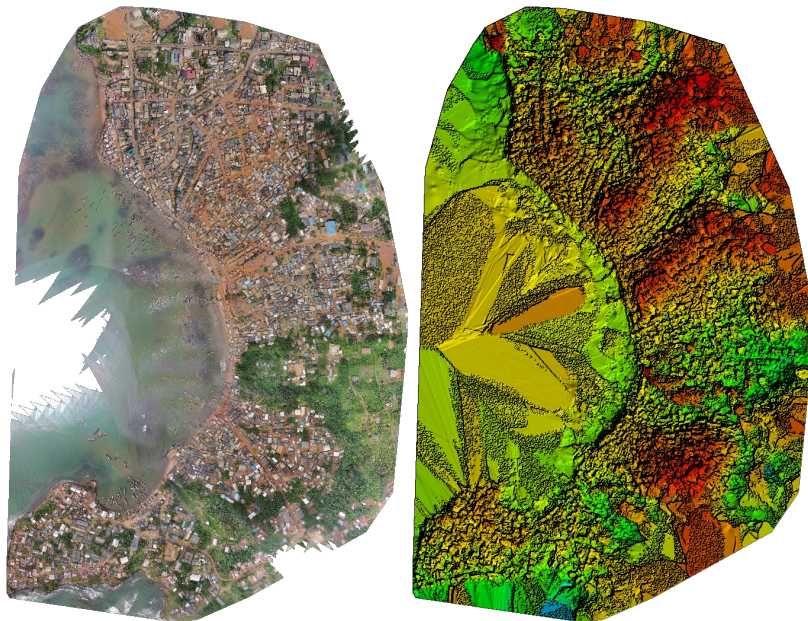|			
❓ **Images**	median of 38880 keypoints per image		✔
❓ **Dataset**	602 out of 609 images calibrated (98%), all images enabled		✔
❓ **Camera Optimization**	0.46% relative difference between initial and optimized internal camera parameters		✔
❓ **Matching**	median of 3095.07 matches per calibrated image		✔
❓ **Georeferencing**	yes, no 3D GCP		⚠

❓ **Preview**

Figure 1: Orthomosaic and the corresponding sparse Digital Surface Model (DSM) before densification.

Calibration Details

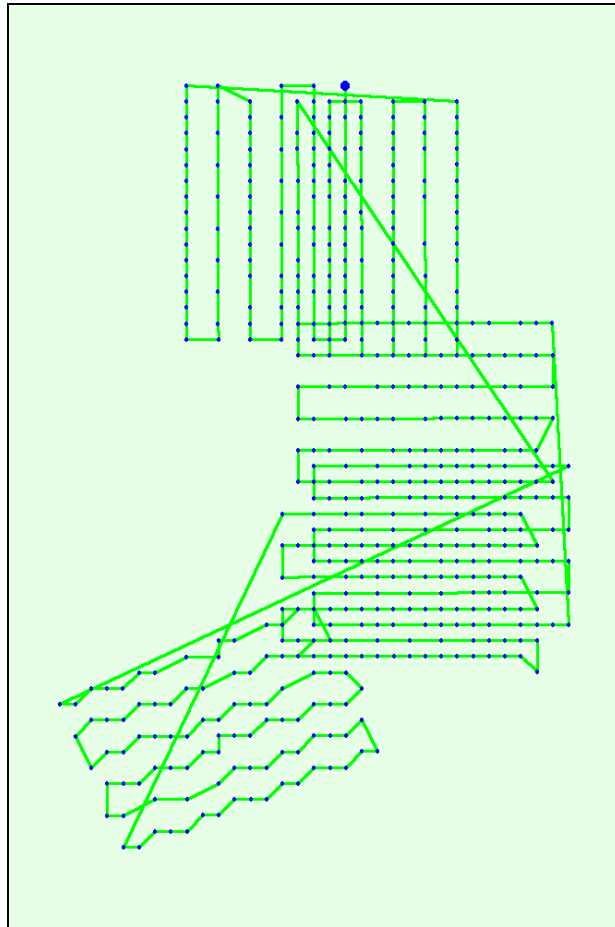|	
Number of Calibrated Images	602 out of 609

Initial Image Positions

Figure 2: Top view of the initial image position. The green line follows the position of the images in time starting from the large blue dot.

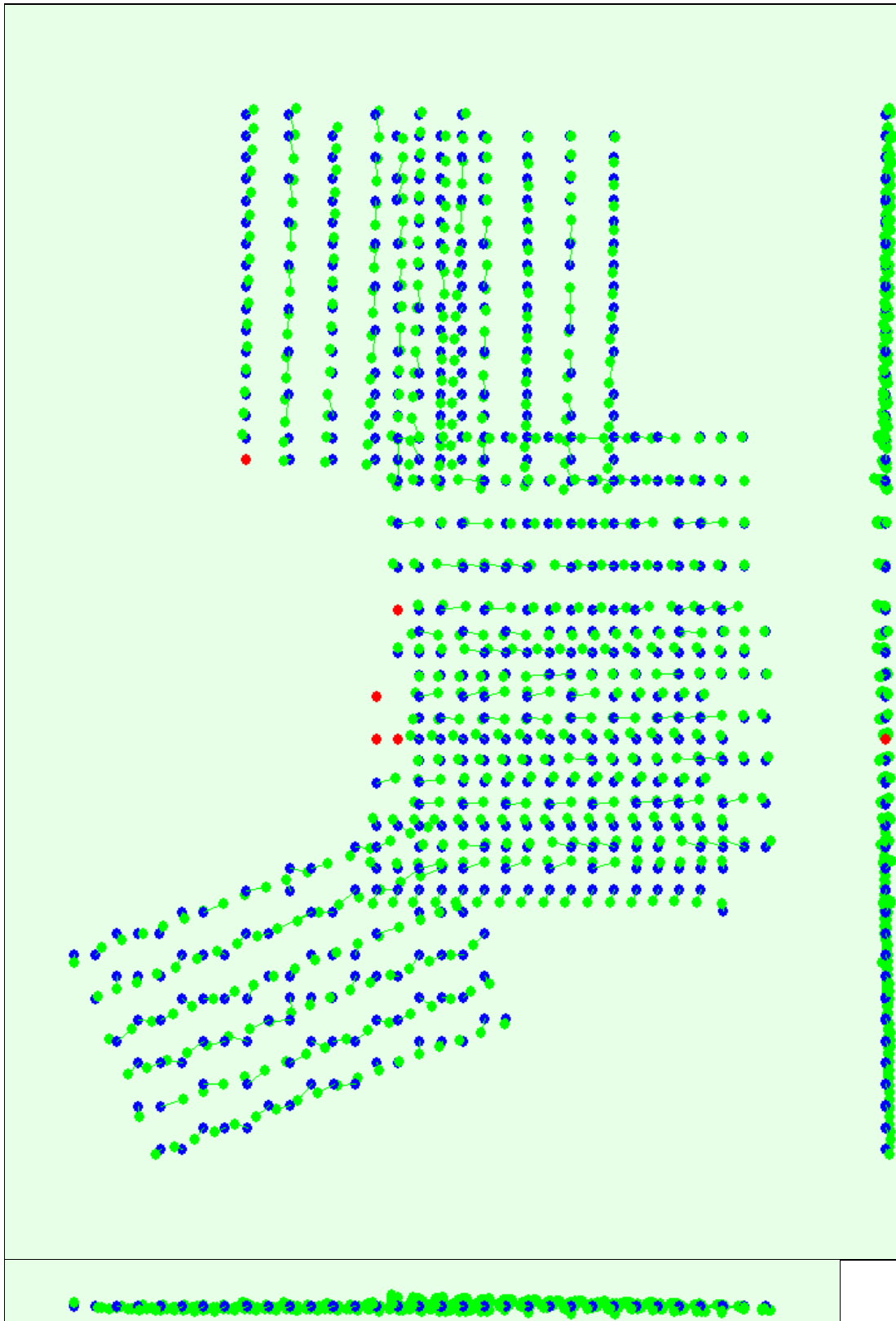## Computed Image/GCPs/Manual Tie Points Positions

Figure 3: Offset between initial (blue dots) and computed (green dots) image positions as well as the offset between the GCPs initial positions (blue crosses) and their computed positions (green crosses) in the top-view (XY plane), front-view (XZ plane), and side-view (YZ plane). Red dots indicate disabled or uncalibrated images.

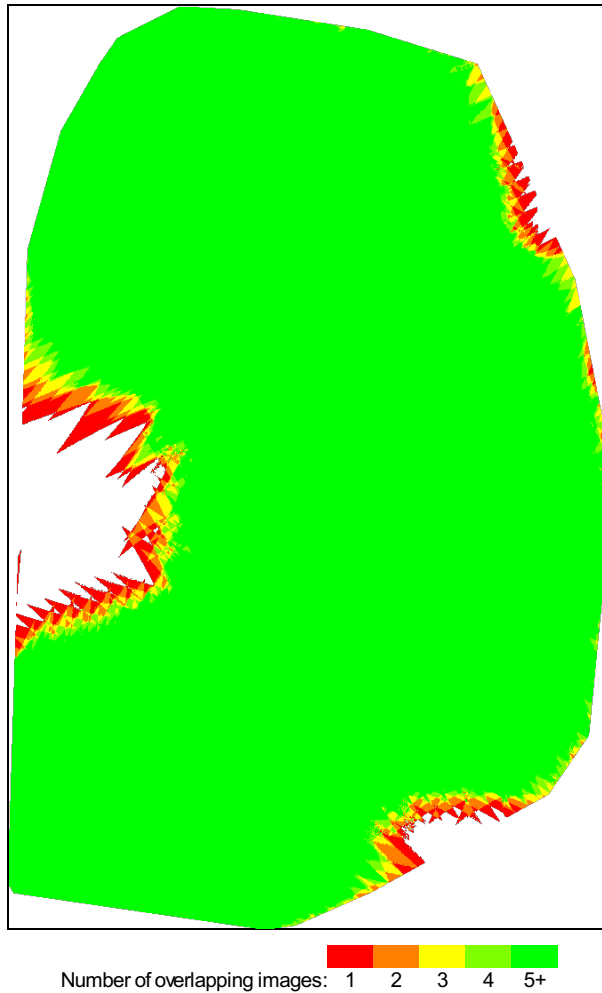## Overlap

Number of overlapping images: 1 2 3 4 5+

Figure 4: Number of overlapping images computed for each pixel of the orthomosaic.
Red and yellow areas indicate low overlap for which poor results may be generated. Green areas indicate an overlap of over 5 images for every pixel. Good quality results will be generated as long as the number of keypoint matches is also sufficient for these areas (see Figure 5 for keypoint matches).

Bundle Block Adjustment Details

Number of 2D Keypoint Observations for Bundle Block Adjustment	1887573
Number of 3D Points for Bundle Block Adjustment	771254
Mean Reprojection Error [pixels]	0.157638

Internal Camera Parameters

PHANTOMVISIONFC200_5.0_4608x3456 (RGB). Sensor Dimensions: 6.485 [mm] x 4.864 [mm]

EXIF ID: PHANTOMVISIONFC200_5.0_4608x3456

	Poly[0]	Poly[1]	Poly[2]	Poly[3]	Poly[4]	c	d	e	f	Principal Point x	Principal Point y
Initial Values	0.000103	1.000000	-0.000586	-0.144035	0.000000	4081.42	0.00	0.00	4081.42	2303.98	1728.00
Optimized Values	-0.000067	1.000000	-0.010527	-0.138168	-0.002701	4100.23	0.00	0.00	4100.23	2270.09	1693.78

The number of Automatic Tie Points (ATPs) per pixel averaged over all images of the camera model is color coded between black and white. White indicates that, in average, more than 16 ATPs are extracted at this pixel location. Black indicates that, in average, 0 ATP has been extracted at this pixel location. Click on the image to the see the average direction and magnitude of the reprojection error for each pixel. Note that the vectors are scaled for better visualization.

❓ 2D Keypoints Table

	Number of 2D Keypoints per Image	Number of Matched 2D Keypoints per Image
Median	38880	3095
Min	20123	44
Max	60765	7066
Mean	37725	3136

❓ 3D Points from 2D Keypoint Matches

	Number of 3D Points Observed
In 2 Images	582366
In 3 Images	114989
In 4 Images	38801
In 5 Images	16438
In 6 Images	7874
In 7 Images	4337
In 8 Images	2478
In 9 Images	1463
In 10 Images	873
In 11 Images	591
In 12 Images	335
In 13 Images	234
In 14 Images	147
In 15 Images	117
In 16 Images	76
In 17 Images	45
In 18 Images	32
In 19 Images	17
In 20 Images	13
In 21 Images	12
In 22 Images	5
In 23 Images	2
In 24 Images	5
In 25 Images	2
In 29 Images	1
In 33 Images	1

❓ 2D Keypoint Matches

Number of matches

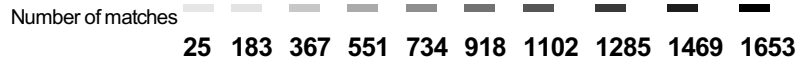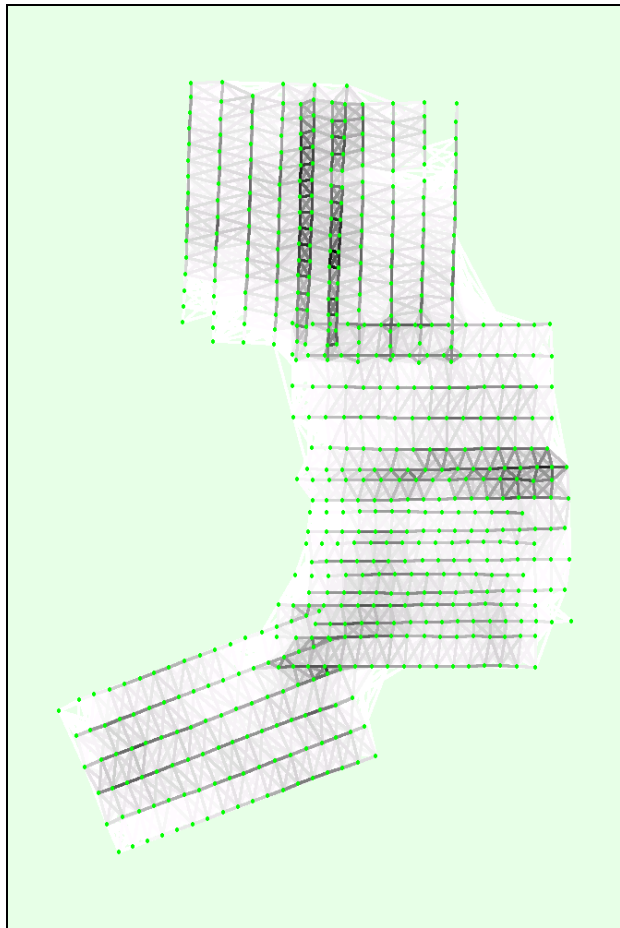**25 183 367 551 734 918 1102 1285 1469 1653**

Figure 5: Top view of the image computed positions with a link between matching images. The darkness of the links indicates the number of matched 2D keypoints between the images. Bright links indicate weak links and require manual tie points or more images.

Geolocation Details

0 out of 602 geolocated and calibrated images have been labeled as inaccurate.

Min Error [m]	Max Error [m]	Geolocation Error X [%]	Geolocation Error Y [%]	Geolocation Error Z [%]
-	-75.00	0.00	0.00	0.00
-75.00	-60.00	0.00	0.17	0.00
-60.00	-45.00	0.17	0.00	0.00
-45.00	-30.00	2.99	1.83	0.00
-30.00	-15.00	9.14	3.16	0.00
-15.00	0.00	33.89	52.66	43.52
0.00	15.00	44.19	33.55	56.48
15.00	30.00	7.97	5.81	0.00
30.00	45.00	1.50	2.82	0.00
45.00	60.00	0.17	0.00	0.00
60.00	75.00	0.00	0.00	0.00
75.00	-	0.00	0.00	0.00
Mean [m]		-0.020214	-0.002523	0.235995
Sigma [m]		13.635401	11.916250	4.639373
RMS Error [m]		13.635416	11.916250	4.645371

Min Error and Max Error represent geolocation error intervals between -1.5 and 1.5 times the maximum accuracy of all the images. Columns X, Y, Z show the percentage of images with geolocation errors within the predefined error intervals. The geolocation error is the difference between the intial and computed image positions. Note that the image geolocation errors do not correspond to the accuracy of the observed 3D points.

Relative Geolocation Error	Images X[%]	Images Y[%]	Images Z[%]
[-1.00, 1.00]	100.00	99.83	100.00
[-2.00, 2.00]	100.00	100.00	100.00
[-3.00, 3.00]	100.00	100.00	100.00
Mean of Geolocation Accuracy [m]	50.000000	50.000000	50.000000
Sigma of Geolocation Accuracy [m]	0.000000	0.000000	0.000000

Images X, Y, Z represent the percentage of images with a relative geolocation error in X, Y, Z.

Processing Options

Hardware	CPU: Intel(R) Xeon(R) CPU X5650 @ 2.67GHz RAM: 24GB GPU: RDPDD Chained DD (Driver: unknown), RDPDD Chained DD (Driver: unknown), RDP Encoder Mirror Driver (Driver: unknown), RDP Reflector Display Driver (Driver: unknown)
Operating System	Windows 7 Ultimate, 64-bit
Camera Model Name	PHANTOMVISIONFC200_5.0_4608x3456 (RGB)
Image Coordinate System	WGS84 (egm96)
Output Coordinate System	WGS84 / UTM zone 30N
Keypoints Image Scale	Full, Image Scale: 1
Advanced: Matching Image Pairs	Aerial Grid or Corridor
Advanced: Matching Strategy	Use Geometrically Verified Matching: no
Advanced: Keypoint Extraction	Targeted Number of Keypoints: Automatic
Advanced: Calibration	Calibration Method: Standard, Internal Parameters Optimization: All, External Parameters Optimization: All, Rematch: no

Point Cloud Densification details

Processing Options

Image Scale	multiscale, 1/2 (Half image size, Default)
Point Density	Optimal
Minimum Number of Matches	3
3D Textured Mesh Generation	yes, Maximum Number of Triangles: 1000000, Texture Size: 8192x8192
Advanced: Matching Window Size	7x7 pixels
Advanced: Image Groups	group1
Advanced: Use Densification Area	yes
Advanced: Use Annotations	yes
Advanced: Limit Camera Depth Automatically	no
Time for Point Cloud Densification	05h:29m:39s
Time for 3D Textured Mesh Generation	28m:42s

Results

Number of Generated Tiles	14
Number of 3D Densified Points	61451191
Average Density (per m^3)	30.57

DSM, Orthomosaic and Index Details

Processing Options

DSM and Orthomosaic Resolution	1 x GSD (4.62 [cm/pixel])
DSM Filters	Noise Filtering: yes, Surface Smoothing: yes, Sharp
DSM Generation	yes, Method: Inverse Distance Weighting, Merge Tiles: yes
Time for DSM Generation	59m:21s
Time for Orthomosaic Generation	03h:44m:57s