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GEOMATICS CANADA
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2016 unmanned aerial vehicle study at Mer Bleue, Ontario

S.G. Leblanc and H.P. White

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INTRODUCTION

The Canada Centre for Remote Sensing (CCRS), a division of the Canada Centre for Mapping and Earth Observation (CCMEO) at Natural Resources Canada, recently started using unmanned Aerial Vehicles (UAVs) to test their potential in different aspects of their research. Small, affordable UAVs are fairly new, especially for vegetation mapping (e.g. Chianucci et al., 2016) and several aspects of the data acquisition and processing still need to be tested based on our previous investigations (e.g. Leblanc et al., 2016) to obtain the best products possible. The CCRS UAV work presented here was a combined effort between the Mer Bleue Arctic Surrogate Simulation Site (MBASSS, Soffer et al., 2017) and the CCMEO Floodplain Mapping Program activities. The overall goal of the UAV work at Mer Bleue was to test the use of off-the-shelf UAVs for mapping. Specific goals included: (1) To test mission plans that balance area covered and ground resolution; (2); to produce point clouds, visible orthomosaics and digital surface models (DSM) of selected dates that coincide with Sentinel-2 data acquisition and the NRC Twin Otter Research Aircraft flights; (3) to investigate the potential of the UAV data as a new temporal and spatial data source and to permit scaling between ground in-situ and airborne and satellite remote sensing data; and finally, (4) to produce an initial accuracy and precision assessment of the measurements.

For this activity, the main UAV used was the DJI Phantom 3 Professional (P3P) (see Figure 1a and Appendix 1). The P3P is an off-the-shelf consumer quadcopter that is relatively inexpensive, easy to carry (under 2kg), and it is full of technological advances that make it easy and safe to use. The camera on the P3P is not changeable: it is made by Sony and it produces 12 MP still photographs and video capability up to 4K (4096 × 2160 pixels) at 24 frames per second, with a fixed aperture of f/2.8 and a field of view of 94°.

The P3P was to be the only UAV used at Mer Bleue in 2016, but the renewal of our permit (SFOC) to fly the Phantom issued by Transport Canada expired on May 1 and was only renewed on May 23, 2016. However, CCRS still had a permit to fly a larger PX8 Spyder octocoper UAV until May 15, so we flew the PX8 (see Figure 1b) for one mission on May 12 corresponding to the Sentinel-2 overpass of May 11. The PX8 is a powerful UAV with eight propellers (4 pairs) that can carry larger cameras. It has a maximum flight time of about 18 min with a camera and gimbal. A 24-megapixel Sony a6000 mirrorless camera with Sony f/2.8 20 mm pancake lens was mounted to the PX8. Mission Planner v1.3 software was used to create autonomous 13 min missions in a grid pattern with up to 90% forward overlap and 83% side photo overlap at 50 m altitude above ground. For Mer Bleue, it gave us a ground resolution of 1 cm. Photographs in JPEG format were captured in shutter priority mode at a 1/1000 s interval, 250–400 ISO, and with focus fixed at infinity. GPS tags were added to the JPEG EXIF information using the log file from the onboard 3DR UBlox GPS that provided a 5 Hz update rate.

The main steps for using UAVs by CCRS are presented in Figure 2. Preparation is key in order to define the area to be studied and define the flight plans. This can also be an iterative process for cases where revisits are possible such as this project. In that case, initial results can be used to refine flight plans in order to improve the flights and the final results.

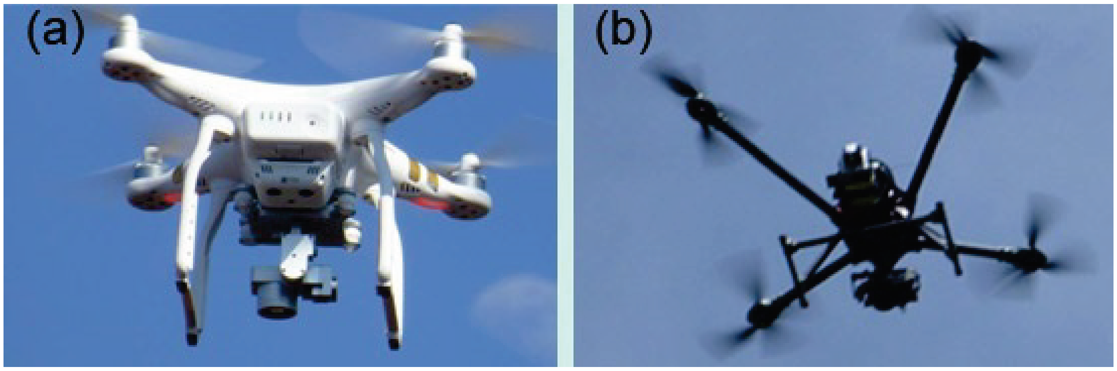

Figure 1: a) DJI Phantom 3 Professional (P3P) and b) PX8 Spyder Octocopter used in this study.

Mer Bleue is an ombrotrophic bog (Lafleur et al. 2007) located on the east side of Ottawa, On, Canada (45.401° -75.490°) at about 70 m above sea level). Our group had two sites at Mer Bleue (see Figure 3): one was at the Research Boardwalk (MRB) and the other at the Public Boardwalk (MBP). The MRB site had up to five planned flights, with three regular flights as showed in Figure 4 that were to be flown on several dates, ideally sunny clear-days that coincided with Sentinel-2 data acquisition. The other two flights were: one above the forested areas between the parking area and the MRB and one low altitude flights near the Research station sheds and flux tower (see Figure 5). The flight mission for MBP can be seen in Figure 6. Overall, the number and extent of the flights were based on areas we wanted to cover and the battery and line of sight with the UAV required by Transport Canada. To be on the safe side, all our flights were under 18 minutes and the pilot and/or observers were within 300m of the UAV at all times.

Creating both point clouds and orthomosaics requires obtaining high overlap between images. The overlap is more important for the creation of point clouds than the mosaics. The technique used to obtain a point cloud is a combination of Structure from Motion (SfM) and photogrammetry (Westoby et al, 2012). These two techniques combined allow the retrieval of camera and target positions in a three-dimensional system for all photographs. Georeferencing information can be added to the 3D scenes with ground control point and/or photographs tagged using the onboard GPS. Several commercial programs are available for SfM processing.

For orthomosaics that only maps areas without 3D information, even simpler software like Photoshop can be used. But for photogrammetry/SFM, specialised programs are required. We tested a few programs and decided on Pix4D (www.pix4d.com) for its ease to use, good demo version that allows several tests to be done, and very good 3D reconstruction. The overlap between photographs allows multiple views of the same target points and depends on a few factors:

1) Field of view of the camera
2) Distance to the target, for UAV
3) Image acquisition frequency and flight line separation

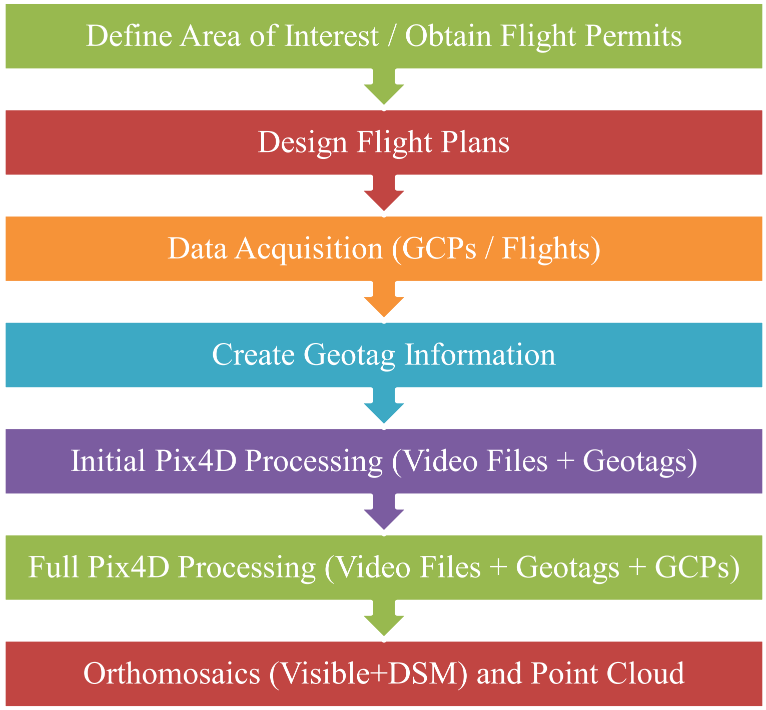

Figure 2: CCRS UAV Acquisition and Processing Steps

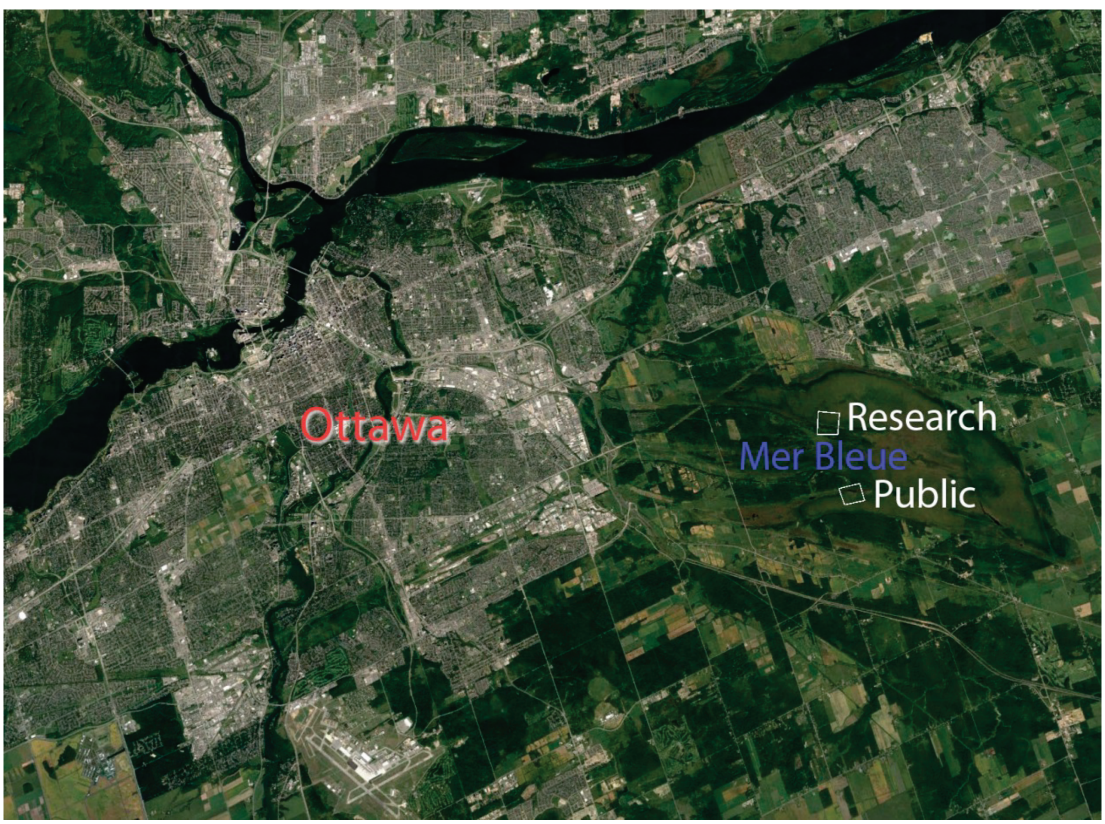

Figure 3: Location of the two Mer Bleue sites: Research (MBR) and Public (MBP) Boardwalks.

One major challenge in using the P3P is that the camera can only take one photograph every two seconds in the interval time shooting mode (note that it was only capable of one every three second when it was first released, Leblanc et al., 2016, Leblanc 2017). This can be low for SfM analysis as it requires the UAV to fly slowly to obtain the desired overlap between photos. As an alternative, we made some tests with the 4K video capability of the P3P. A frame extracted from a 4K video is almost 9 MP, which is very close to the still frame of 12 MP. At 9 MP, the video frames have 4096 pixels as compared to 4000 for the still photographs, in *x* (perpendicular to flight in normal forward mode), with only 28% less pixel in *y* (flight direction) with 2160 pixels for the video frames and 3000 for the still photographs. It is understood that image quality might suffer by using the video instead of the still photographs, but the quality difference was not large enough to slow down the UAV speed and cover smaller areas.

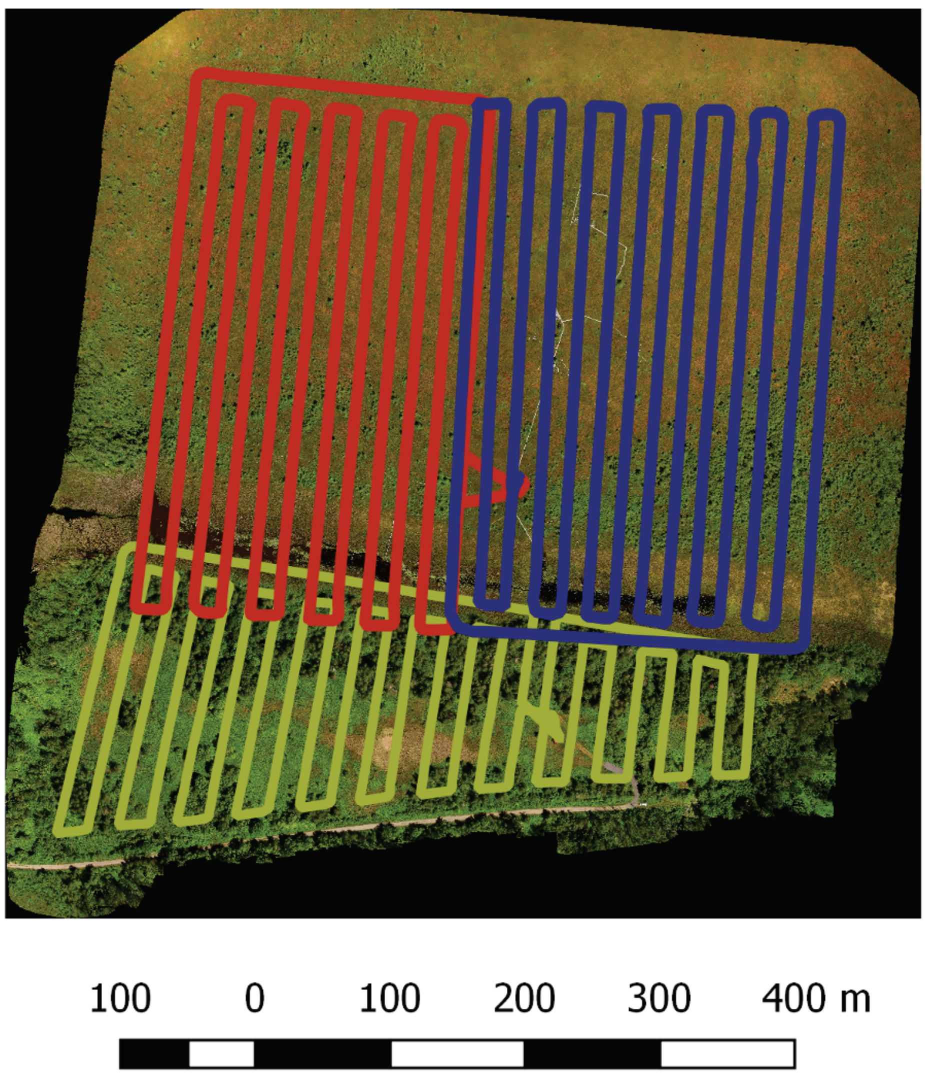

Figure 4: The three main flights at the MRB from actual flight logs. Underlying layer is an orthomosaic based of these three UAV flights from June 30, 2016. Green is Parking Mission, red and blue are West and East Research Boardwalk respectively.

In terms of resolution and image size, the difference in y can be more than compensated for by having 24 frames per second available from the videos. 4K videos are saved in compressed 10-bit per channel as compared to 8-bit per channel for still jpeg files and it was found that using the videos directly in Pix4D gives better results than using in 8-bit jpeg of the same videos (Leblanc et al., 2016), indicating that Pix4D utilises the extra radiometric range found in the 4K video. At the speed we usually fly the P3P (under 25km/h) at 70m above ground, we get more than 90% overlap in the along flight direction between frame extracted every one second.

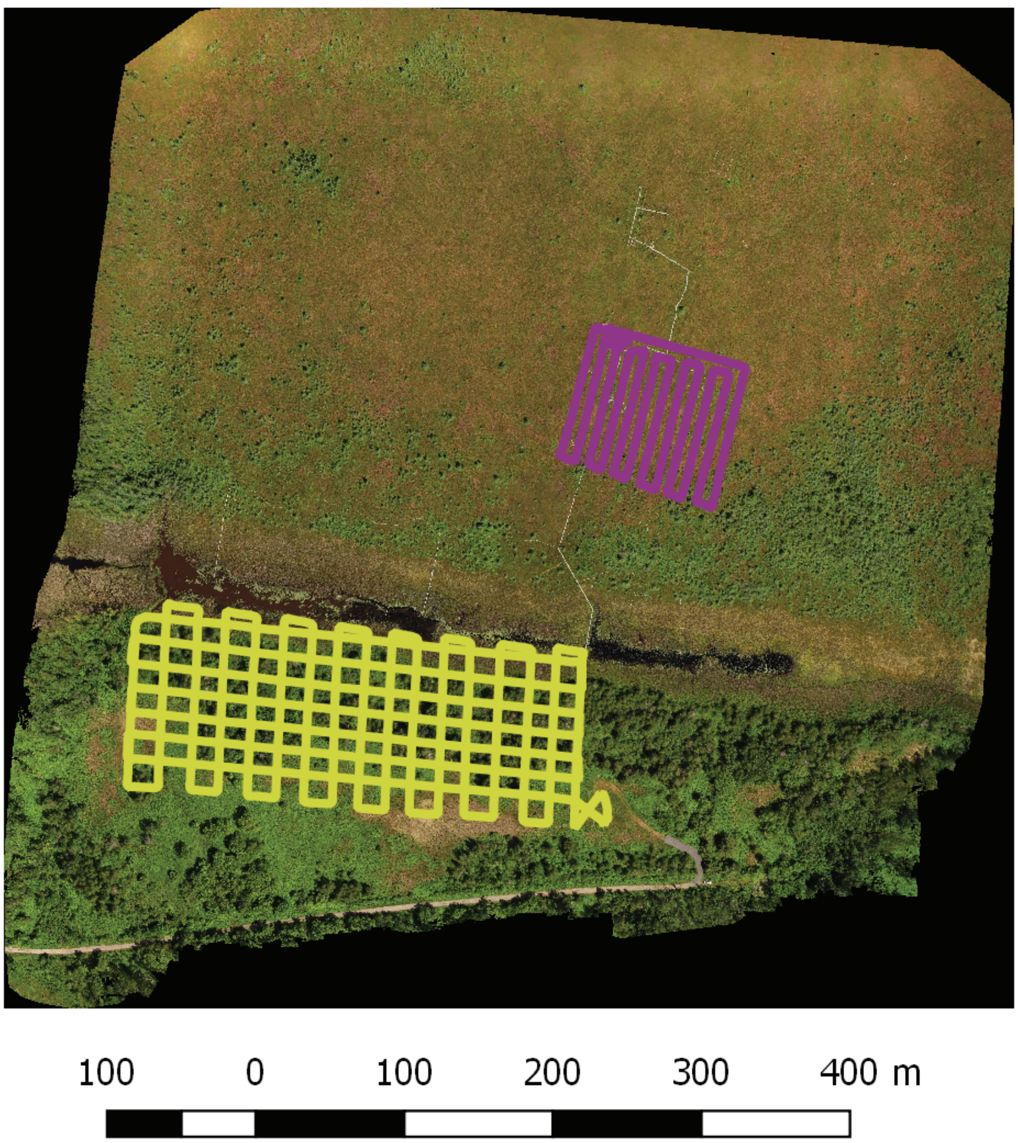

Figure 5: The two supplemental flights at the (MBR) from actual flight logs. Underlying layer is an orthomosaic based of these three UAV flights from June 30, 2016. Pink is low altitude (30m) Mission over the wetland near the MRB, and yellow is the Forest mission at 45m with a cross-pattern.

The across track overlap depends on the distance between flight lines and altitude. At 70m altitude, a separation of 20-25m between flight line gave us 80-85% cross track overlap.

The P3P did not come with its own automation system. Since the P3P requires a device such as a smartphone or a tablet to run, we looked for automation apps that could run on those devices. We tested a few free mission planning tools and selected Litchi (flylitchi.com) that allows repeatable missions to be created on their web interface from any computer. Litchi does not calculate overlap between images, so this was calculated manually using the geometry of the camera and flight speed and altitude and flight line separation.

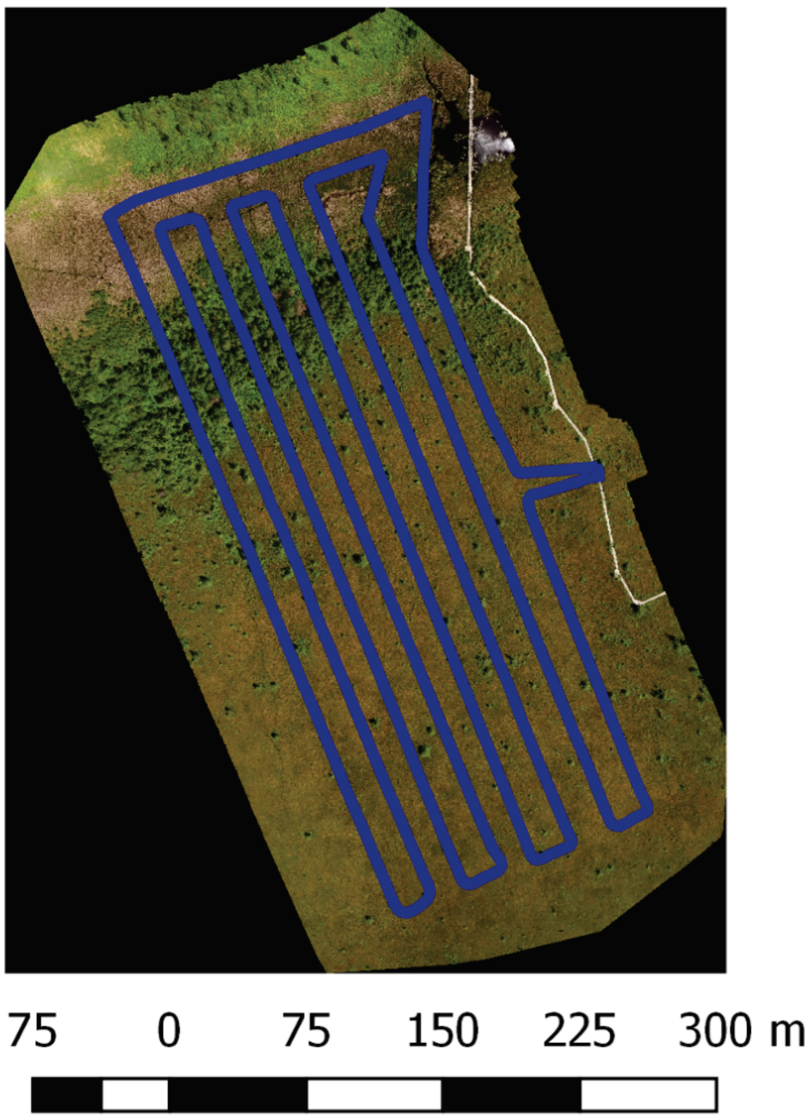

Figure 6: The flight at the MBP site from an actual flight log. Underlying layer is an orthomosaic based of UAV flight from June 23, 2016.

Frames extracted from videos, unlike still photographs, are not automatically geocoded. Pix4D can read a text file with the images geocoding information; it is very simple to extract that information from the flight logs. We designed a small application that can read the coordinates from the healthydrone.com flight path. Images geoinformation is not a requirement when using ground control points (GCPs). We had enough GCPs towards the end of the seasons (Prévost and White, 2016) for the MBR site (see Figure 7), but not early in the spring and not enough for the MBP as the site extents to an area where we could not walk and create GCPs. So geocoding the frames was important and it also improve the processing speed in Pix4D as the software has an initial position for the image and it does not need to look in all images to find overlapping areas (pix4d.com).
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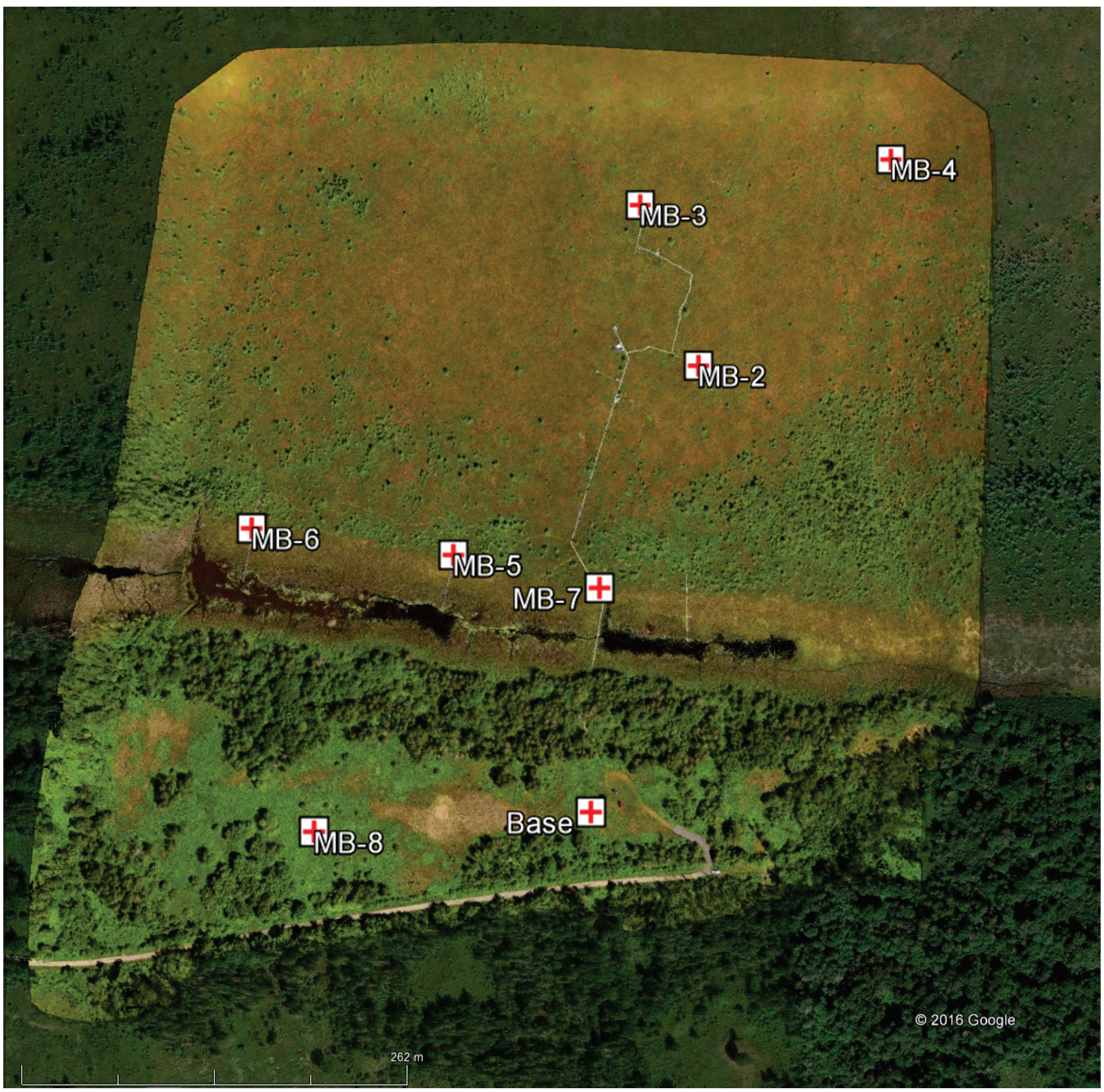

Figure 7: Ground Control Point for MBR with underlying layer from UAV data from June 30, 2016.

DATA ACQUISITION

CCRS flew a P3P UAV on 17 dates at Mer Bleue between April and December 2016, and the PX8 on May 12, 2016. Table 1 shows the UAV raw data acquisition dates at Mer Bleue. Dates corresponding (or closest) to the Sentinel-2 and NRC aircraft data acquisition are underlined. All CCRS data from the P3P were acquired in 4K video mode while 24 MP photographs were acquired with the PX8. Most P3P flights had two video files since each file cannot be larger than 4 GB. One 16-18-minute flight generally gives between 6.0 and 7.0 GB of video. For each P3P flight, one flight log was extracted using Healthy Drones (healthydrones.com) and was used for tagging frames extracted from the video. For the first six dates, P3P missions were flown with automatic camera exposures, but starting on June 30, 2016, a fixed exposure was used, generally 1/400 or 1/800 of a second. Most flights were within two hours of solar noon, except for July 20, 2016 that was flown in the evening between 6:00pm and 8:00pm EDT. After the first few flights that were at 80m AGL, the altitude for all flights was finalized at 70m AGL for all MBR Parking and Bog area flights. Each flight at the MBR Parking and Bog were about 15 ha each, but once combined they cover only 38 ha due to overlap between them. The two flights at the MBP were flown at 60m above ground since the area to be covered was only 12 ha. All flights were taken under sunny or partly cloudy conditions, except for December 2, 2016 when data were acquired under cloudy conditions. Only the MBP, MBR Parking and Bog areas have been completely processed using Pix4D. All flight altitudes, imagery ground resolutions, number of frames extracted from video, or number of photographs, and ground area (in hectare) covered are presented in Table 1. For all flights with video, one frame per second was used in Pix4D. UAV data were not acquired on the exact Sentinel-2 overpass by CCRS. April 20 and May 24, UAV data were acquired on the same day as the overpasses and the NRC flights, but May 11 UAV data were acquired on May 12 (with the PX8) and the June 23 UAV data were acquired partly on June 23 (until it became too cloudy to fly), with the Main MBR data acquired the next week on June 30.

Table 1: UAV data acquisition at Mer Bleue for 2016. For each site: Altitude AGL (in meter), ground pixel resolution (in cm), number of images used in Pix4D, and area extend in hectare.

Date	Public Boardwalk	Parking	Research Boardwalk	Forest	Research Boardwalk Low Altitude
13-Apr-16			70m / 2.8cm 720i / 18ha		
15-Apr-16		80m / 3.4cm 778i / 14ha	80m / 3.3cm 1522i / 28ha	45m / 1.9cm 870i / 12ha	
20-Apr-16		80m / 3.4cm 808i / 14ha	80m / 3.3cm 1665i / 28ha	45m / 2.0cm 887i / 12ha	
12-May-16			50m / 1.0cm 682i /9ha		
24-May-16	60m / 2.7cm 719i / 12ha	80m / 3.5cm 735i / 14ha	80 / 3.1cm 1630i / 30ha	45 / 2.2cm 830i / 10ha	
01-Jun-16		70m / 3.0cm 864i / 14ha	70m / 3.0cm 1600i / 32ha		30m / 1.3cm 464i / 2ha

23-Jun-16	60m / 2.6cm 767i / 13ha	70m / 3.1cm 867i / 15ha			
30-Jun-16		70m / 3.1cm 844i / 15ha	70m / 3.1cm 1699i / 30ha	45m / 2.1cm 864i / 10ha	
20-Jul-16		70m / 3.1cm 861i / 15ha	70m / 3.1cm 1667i / 31ha		
15-Sep-16		70m / 3.0cm 860i / 14ha	70m / 3.0cm 1675i / 30ha		
27-Sep-16		70m / 3.1cm 838i / 14ha	70m / 3.0cm 1675i / 30ha	45m / 2.0cm 850 / 10ha	30m / 1.3cm 463i / 2ha
04-Oct-16		70m / 3.0cm 860i /14ha	70m / 3.0cm 1733i/ 30ha		
12-Oct-16		70m / 3.0cm 830i / 14ha	70m / 3.0cm 1645i / 30ha		
19-Oct-16		70m / 3.0cm 829i / 14ha	70m / 3.0cm 1692i / 30ha		
02-Nov-16		70m / 3.0cm 824i / 14ha	70m / 3.0cm 1639i / 30ha		
08-Nov-16		70m /3.0cm 838i / 14ha	70m / 3.0cm 1662i / 30ha		
02-Dec-16		70m / 3.0cm 840i / 14ha	70m / 3.0cm 1730i /31ha		
09-Dec-16		70m / 3.1cm 956i / 15ha	70m / 2.6cm 2349i / 28ha		

PRELIMINARY RESULTS

This section covers the processing and quality control of the CCRS UAV products. The main products that can be produced from overlapping UAV images are orthomosaics, DSMs and point clouds. After several tests, CCRS processing parameters in Pix4D were finalised as follows: 1) For the initial automatic tie points, which are areas of images commonly found automatically by the software, we used the maximum (full) setting with aerial grid option. 2) For the full processing of the point cloud, which densified the tie points found in the first processing part, we used half image, optimal point density and a minimum of three matches (from three images) to get a point. 3) The visible and DSM orthomosaics are created at the default ground resolution of our images in saved in GeoTIFF format.

All processing for the CCSR UAV data was performed on an HP Z840 Workstation with 32 Xeon E5-2650 2.3GHz CPUs, 96 GB of RAM Memory, a 500 GB solid-State drive, and a NDVIA Quadro M6000 video card. Using these parameters with the HP Z840 workstation allowed us to get results in about a half day for a single 15-18-minute flight, while using maximum output can take up to seven days of processing on the same computer. Other settings that are important in Pix4D relate to the accuracy of the input data geolocation, but they have little influence on the processing time. For example, assigning low geolocation accuracy to images allows Pix4D to play with the acquisition geometry (camera/UAV position and orientation) through SfM techniques and can induce errors as Pix4D tried to optimize camera and target geo-information. Horizontal (X-Y) accuracy can be set to the default of 5m from the P3P GPS, but the Z accuracy should be set below 1m since the P3P uses barometric pressure for its altitude, which is more accurate that GPS altitude (which is the default at 10m). We found that using 0.50m in Z accuracy gave better results (closer to actual elevation) that the default of 10m.

CCRS UAV output products generated using Pix4D are presented below. Figure 8 shows all 16 non-normalized orthomosaics over the MBR Bog from the UAV data taken with the DJI P3P. The different flight plans used at the earliest dates show different mosaics, but the area covered is consistent starting from June 30, 2016. A few dates (July 20, November 8 and December 2 in Figure 8) show a clear difference in brightness between the west and east side of the mosaics due to time acquisition difference between the two flights needed to cover this mosaic, and in some cases, the presence of cloud shadows during part of the acquisitions. The first five mosaics from April 13 to June in Figure 8 shows many north-south brightness strips that follow the flight lines. This was in part due to the camera being set in automatic mode and the low overlap (under 70% across flight) on April 13 might also have contributed to the effect.

Figure 9 shows all orthomosaics for the MBR Parking area just south of the MBR Bog area. Although there is a large overlap between the MBR Bog and Parking areas (mainly a marsh area), they have been generally processed separately as processing three P3P flights require a lot of computing power.

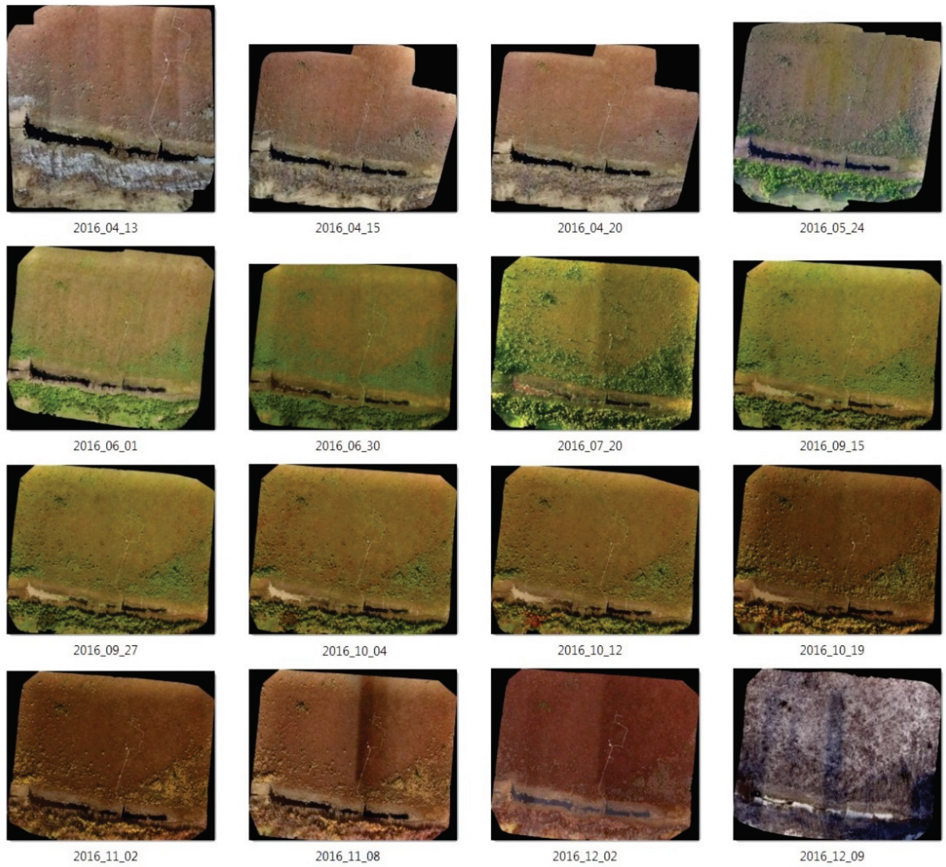

Figure 8: Non-normalized orthomosaics of all CCRS P3P flights at the MBR Bog area between April and December 2016. Mosaics sizes are variable before June 30, but starting June 30 they are all about 31 ha. Each mosaic starting with April 15 is based on data from two UAV flights.

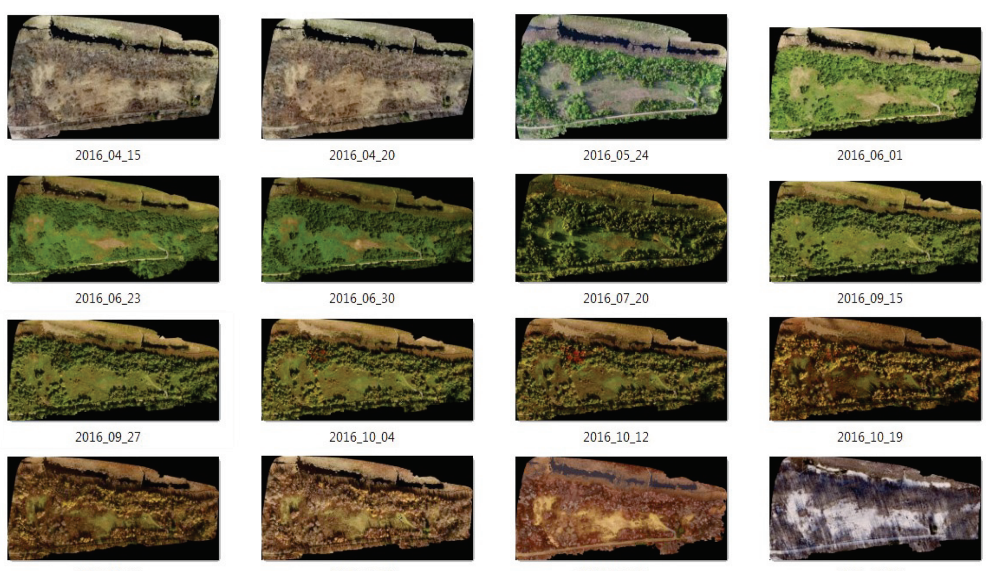

Figure 9: Non-normalized orthomosaics of all CCRS P3P flights at the MBR Parking between April and December 2016. Each mosaic covers between 14 and 15 ha of ground area.

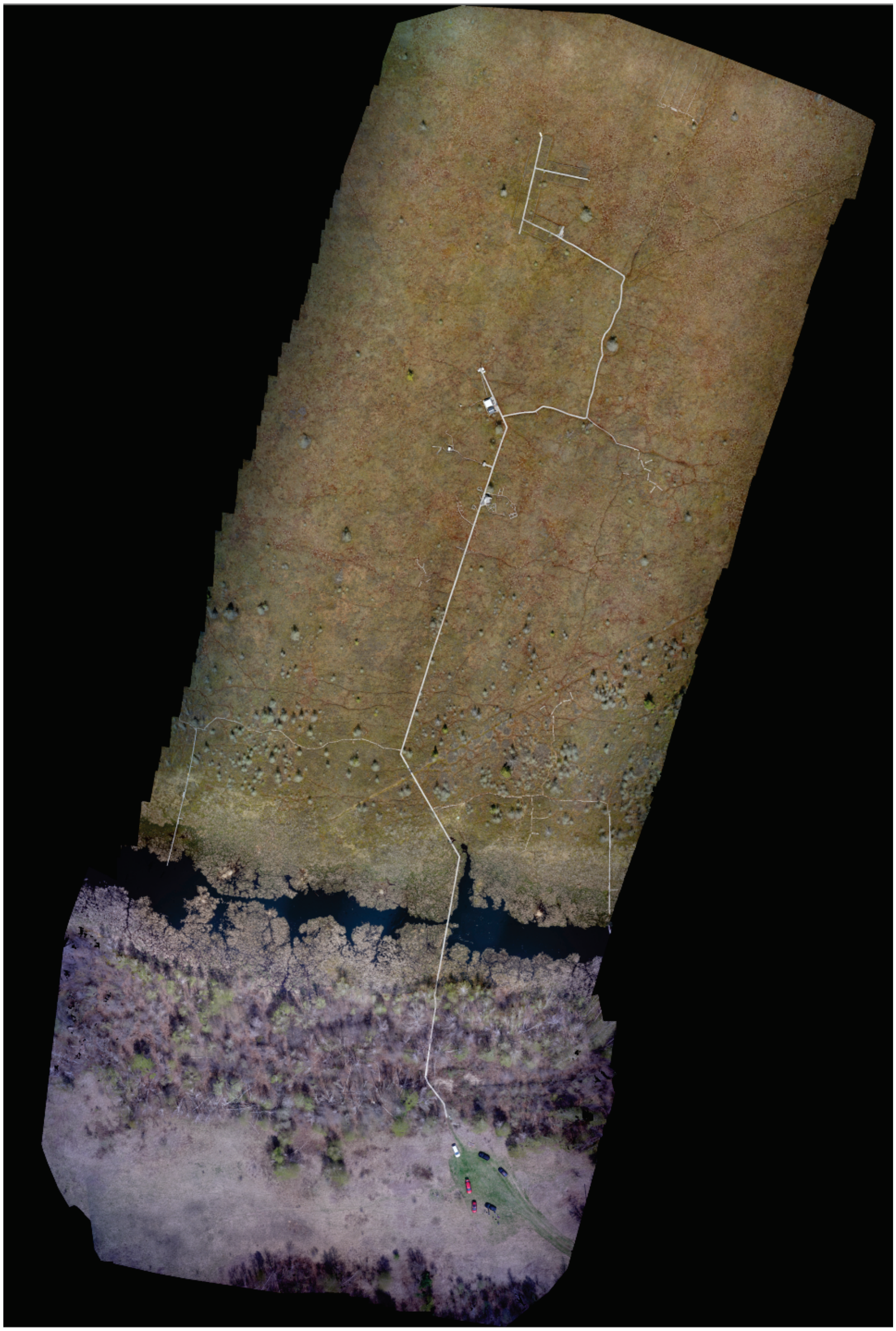

Figure 10: Orthomosaic at 1cm resolution covering part of the MBR Bog and Parking of the Parking areas based on photographs acquired with the PX8 UAV on May 12, 2016

The effect of the automatic camera setting is not as visible on these mosaics as compared to the MBR Bog, which is probably due to less variability in the images and larger overlap (higher than 85% for all flights). Starting with the June 30 data, all flight plans were finalised and stayed the same until December. The PX8 was flown only on one date and the orthomosaic created from its two flights are shown in Figure 10. This mosaic combined two PX8 flights and covers parts of the P3P MBR Bog and Parking areas.

Figure 11 shows the two orthomosaics from the MBP from May 24 and June 23, 2016. Pix4D originally produced a mosaic with very variable brightness because the P3P camera was in automatic exposure mode in the May 24 acquisition. To compensate for this variability in brightness, the video extracted images from that date were pre-processed using Adobe Photoshop to obtain more consistent brightness. This technique was only applied to this flight as the original orthomosaic exhibited larger brightness variability than all the other mosaics we produced in 2016. There was a slight change in flight plans between May 24 and June 23 to get more of the boardwalk in the north of the mosaic where one of the spectrometer point measurements was taken.

For each of the orthomosaics, a point cloud was also created. Figure 12 shows an example of a point cloud for the combined three flights of the MBR Bog and Parking areas for June 30, 2016. This is our only point cloud processed using a combined three flights so far as it required a lot of computer time to produce. A point cloud being a three-dimensional product, it can be viewed from any angle and Figure 13 shows a side view of that same point cloud. Each point in the cloud has an RGB value (0-255 for each channel) and 3D coordinates.

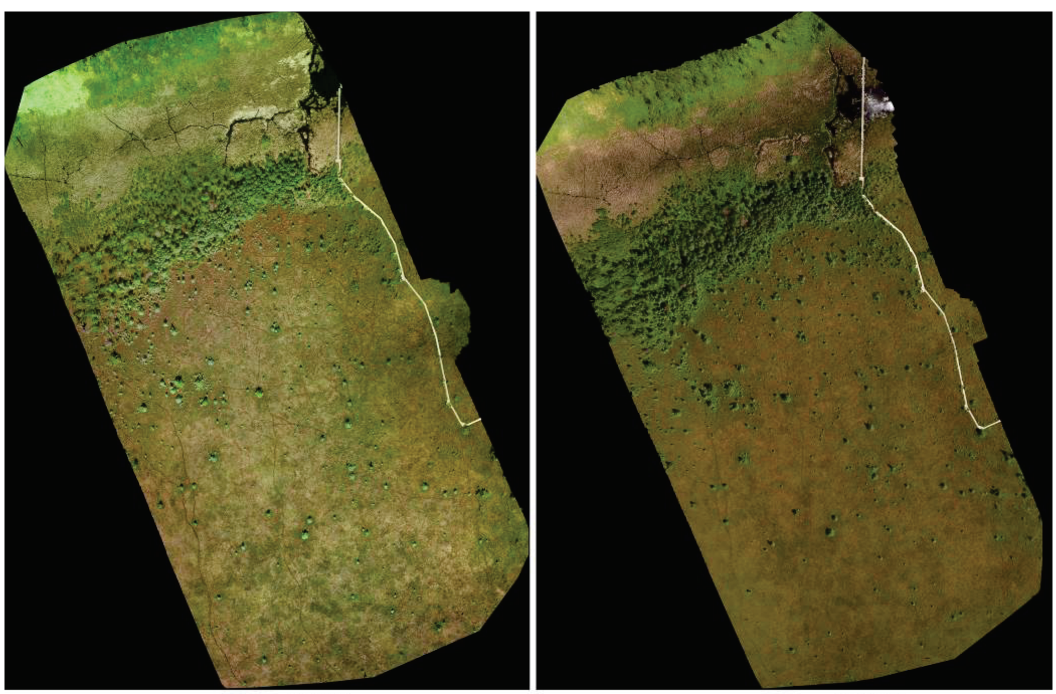

Figure 11: Non-normalized orthomosaics of the two CCRS P3P flights at the MBP on 24 May 2016 and 23 June 2016. Each mosaic covers about 12 ha.

The edges of the mosaics in Figure 12 were cropped as they have less photograph overlap and are generally not as accurate as the mosaic centres. This cropped point cloud contains above 90 million points (see Table 1 for the point cloud numbers for each site processed), which is 10 million more than just the MBR Bog area that has 80 million points from two uncropped UAV flights. The point cloud does not show any evidence of visual artefacts. Although other mosaics and point clouds have brightness artefacts due automated camera setting, clouds and no real BRDF correction, the retrieval of the elevation model was minimally affected. In lieu of BRDF correction, it appears that Pix4D uses the centre of the images as much as possible to avoid VZA brightness variations.

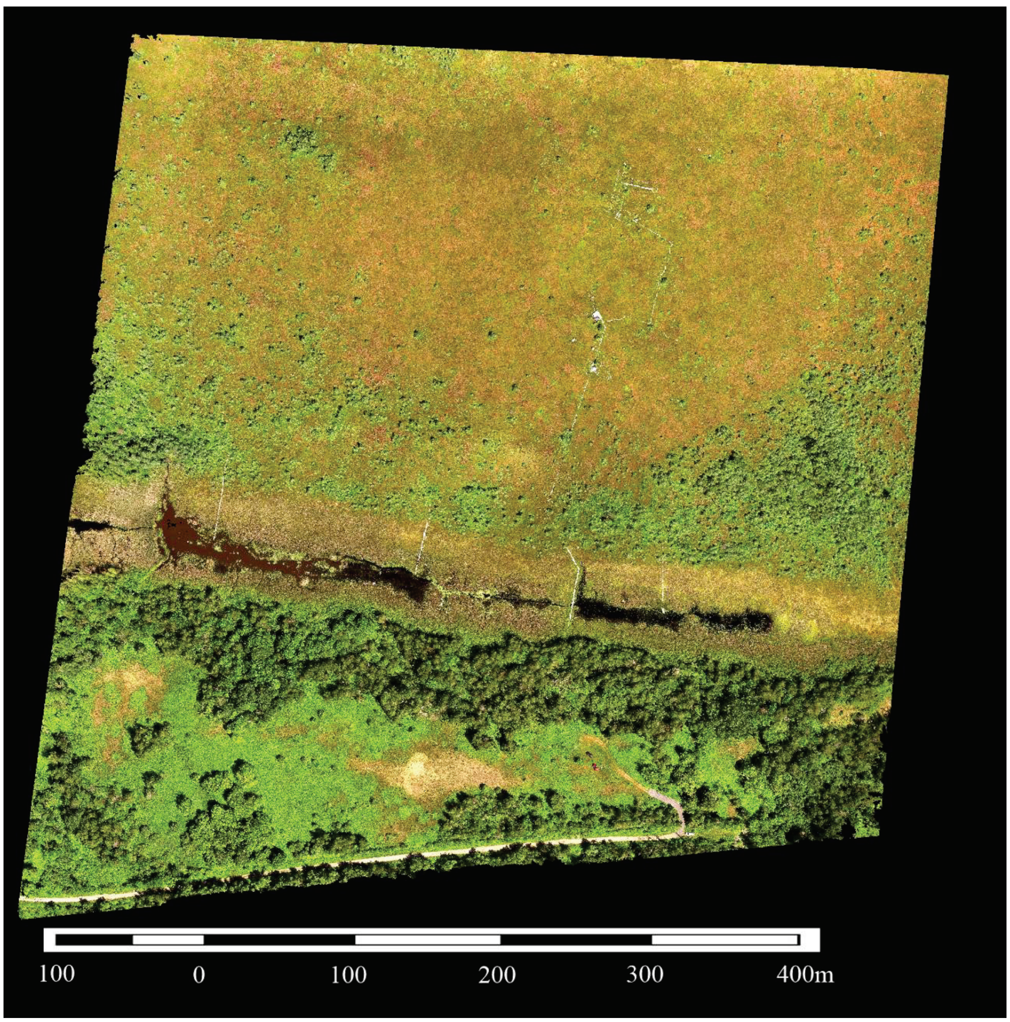

Figure 12: Nadir visualization of the point cloud from three CCRS P3P flights at the MBR Bog and Parking areas acquired on June 30, 2016. Edges of the original point cloud were removed where image overlap was not enough to get proper image brightness colours.

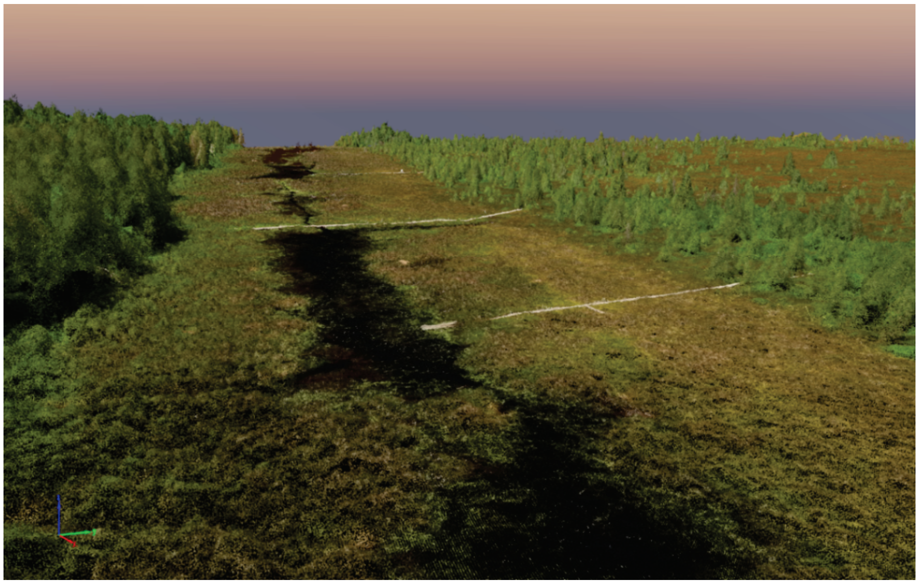

Figure 13: Three-dimensional side-view (looking west) of the point cloud from Figure 12

Figure 14 shows the elevation information from the same point cloud as Figure 12 and Figure 14 for the combined MBR Bog and Parking areas. The lowest points are on the marsh part and open water at about 69m above sea level. It must be noted that for acquisition days where the water was free of sediments, 3D information was not retrieved as well as this example from June 30. SfM and photogrammetry do not work on featureless or mirror like water surfaces, as clouds can be seen that represented objects not at the water surface. There is more than one meter elevation difference between the marsh area and the land as can be seen in Figure 14. The highest retrieved height was at 81m above sea level, which is nearly 20m higher than the ground level on firm land outside the wetland, which corresponds to the highest tree height in that forested area.

To assess the need to have accurate GCPs, some of the UAV data processing was performed with and without GCPs. Our initial results using only four dates (June 1, September 27, December 2 and 9) show that when using only the GPS on board the P3P without using the GCPs, the accuracy of six to eight GCPs found in the point cloud is near 1m in x and y and about 3m in Z. As mentioned before, the GPS coordinate accuracy of the imagery used in Pix4D must be changed in Z from default values to obtain such results. Since the P3P uses barometric pressure for its altitude, we do not expect it to change altitude during a given flight and its accuracy should be near or less than 1m. We found that using 50cm gives better results, both for overall altitude of the scene, which in this study is around 70 above sea level, but also it helps in producing consistent DSM from the centre to the edges of each flight/domain when no GCPs are used. Our GCPs have accuracy of about 2 cm in X-Y and 3cm in Z, which is better than our UAV ground resolution, which is about 3cm when the P3P flies at 70m AGL. We estimated that using the GCPs in the processing allows more consistent products that have accuracy of the order of 3 to 4 times the ground separation (pixel resolution), namely 15 cm in X and 25 cm in Z. Our GCP target centres were 5x5 cm^2 with a bolt that is not always clearly defined on our images and on some days, the targets were covered by our GPS antenna, which may make it difficult to get accuracy at the level of our ground separation of 3 cm. Large UAVs with better GPS and cameras would give better results, but for a much higher cost than the DJI P3P. We have not tested the PX8 accuracy yet, but the added image resolution should give better accuracy than that of the P3P.

All point clouds produced from UAV images yields a large number of points (see Table 2). Generally speaking, the number of points increased with the appearance of vegetation, but also with the UAV image resolution and area covered. But there is still a lot to verify to understand the changes in point clouds during the June-December period where the flights were nearly identical. Windy days such as September 27 seems to have given a point cloud with an unusual large number of points (49 M) at the MBR Parking area as opposed September 15 (40 M) and October 4 (40 M). This could be explained by the photogrammetric process that found the same target, such as top of trees, in different spatial positions in enough images due to the wind to count those more than once.

For all dates and sites, DSM orthomosaics were also produced using Pix4D. We have not yet assessed the quality of those products, but we looked into the elevation of the point cloud that is used to produce the DSM. Although the DSM is an important product, the digital elevation model (DEM) is more important and Pix4D has just recently (December 15, 2016) added this products to its output options. Previously, only a classification of the point cloud was possible into ground and objects (i.e. any elevated object such as trees or building) which gave mixed results.

Table 2: Number of points in clouds from UAV flights at Mer Bleue

Date	MBP	MBR Parking	MBR Bog
13-Apr-16			34,594,991
15-Apr-16		31,231,155	57,132,265
20-Apr-16		30,160,002	63,117,589
12-May-16			117,833,196
24-May-16	35,146,105	31,044,303	70,107,958
1-Jun-16		37,567,466	80,081,859
23-Jun-16	40,883,738	36,699,411	
30-Jun-16		37,114,350	81,121,166
20-Jul-16		40,793,901	66,102,890
15-Sep-16		40,295,556	74,593,330
27-Sep-16		48,775,388	67,722,605
4-Oct-16		39,652,795	57,390,150
12-Oct-16		33,838,630	56,715,461
19-Oct-16		32,991,772	55,187,127
2-Nov-16		31,600,837	52,949,286
8-Nov-16		33,595,927	55,643,496
2-Dec-16		30,314,392	66,932,766
9-Dec-16		32,448,962	70,951,982

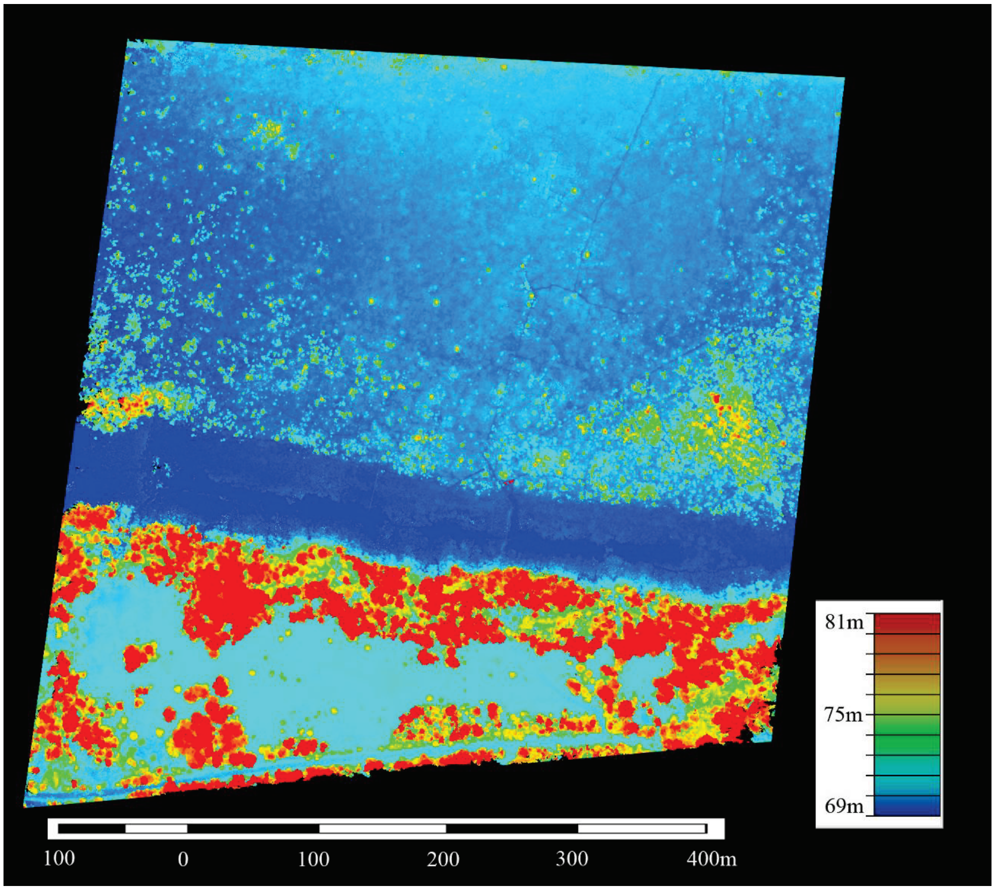

Figure 14: Nadir visualization of the point cloud coded with elevation above sea level from the same dataset as Figure 12 and Figure 14 at MBR. Edges of the original point cloud were removed where image overlap was not enough to get proper 3D information.

Height variability of the retrieved point clouds was assessed and height information was investigated for classification purposes (see Figure 15). We extracted the data in a 600 m transect (see Figure 15b) and in a 30x30 m^2 area (Figure 15d) from our combined point cloud of June 30, 2016. The transect shows that our elevation model is very stable, due in large part to the GCPs. Without using the GCPS, flat ground surfaces were not always retrieved as flat. Figure 15c and Figure 15d show the potential that additional information from 3D point clouds can provide: the visible point cloud did not give much information about the bog composition, but the elevation reveals hollows and hummock parts of the bog. A resolution of 3 cm seems adequate in this particular bog, but our PX8, along with a few lower altitude flights with the P3P can be used to assess if resolution can reveal more useful details. Mapping elevation in a wetland to a cm resolution could be a useful tool in field data acquisition preparation to pinpoint possible area of interest. Preliminary comparisons using the MBR Parking data were conducted to test for seasonal changes in UAV-photogrammetry-based point clouds. Data from April 20, 2016 and May 24, 2016 that represent leaf-off and leaf-on condition of the forested area (Figure 16) were used for change detection. Both dates have the exact same flight plan.

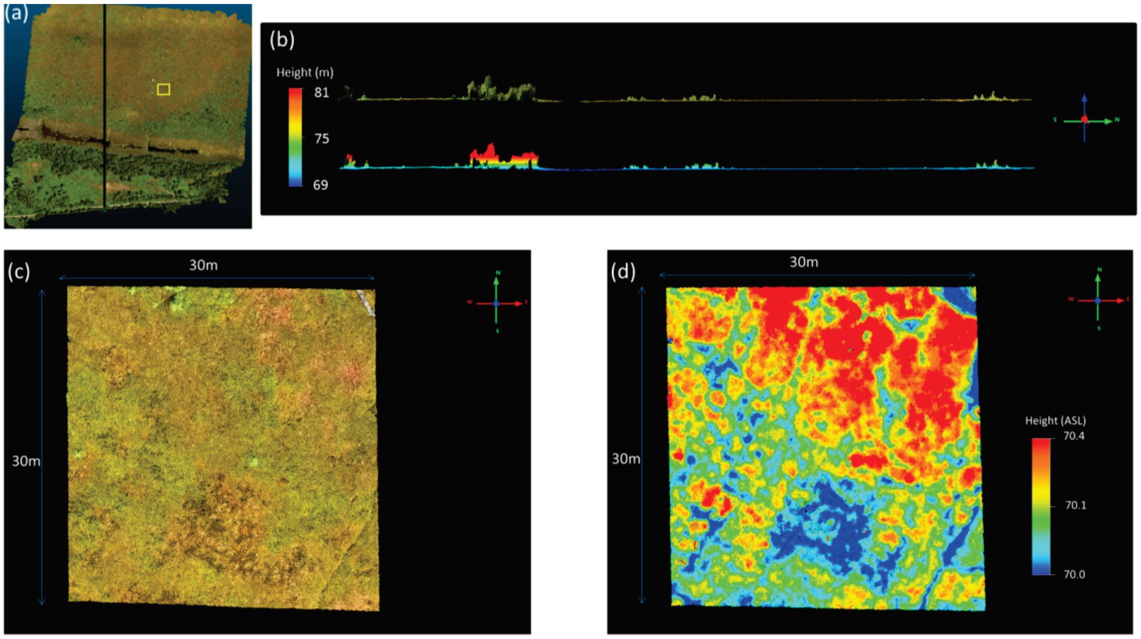

Figure 15: Position in MBR of a 600m north-south transect in black (for b) and a 30x30m² area in yellow (for c and d) extracted from the point cloud in Figure 12 and Figure 14. b) the visible (RGB) and height (above sea level) north-south transect profiles; (c) the visible (RGB) nadir view point cloud within the 30x30m² area and d) the nadir view point cloud height within the 30x30m² area showing potential hollows in blue and green.

Before doing any comparisons between the clouds, we used the freeware CloudCompare (http://www.danielgm.net/cc/) to fine-tune the alignment of the two point clouds since we did not have enough GCPs for the MBR Parking area prior to September. Once the two clouds were aligned, CloudCompare was used to calculate the Euclidian distance between the closest points between the two date point clouds. Edges of the point clouds were removed for the analysis because of low confidence in the retrieved point clouds and also because of the presence of water in the northern part of the mosaic. Standing water can be problematic for photogrammetry because of the mirror effects of the water or the uniform colour. Grass had not grown much between these two dates, but the leaves in the trees did and can be clearly seen as the maximum distance in Figure 16c.

Being able to co-register two point clouds is important even when using GCPs, since as mentioned before, we have an accuracy of 15 cm in X-Y and 25 cm in Z. It must be noted that distances between points is more consistent than the accuracy as locally, the deviation is often in the same direction. We checked the precision of the size of some objects (e.g. sheds) in the MBR Bog clouds and found for example that the roofs above the electric circuitry of the research station was 2.43m long with a standard deviation (S.D) of 0.06m (2%) using 4 dates. Similarly, the base in front of the two sheds was measured at 6.04m in length with S.D. of 0.04m (1%). The new shed did not yield as good results with 2.96m on average between the 2 opposite corners with S.D. of 0.21m (6%). For the latter, the north-west corner was not as well defined and was causing most of the deviation measured from date to date. Actual lengths will be measured on our next visit to MBR.

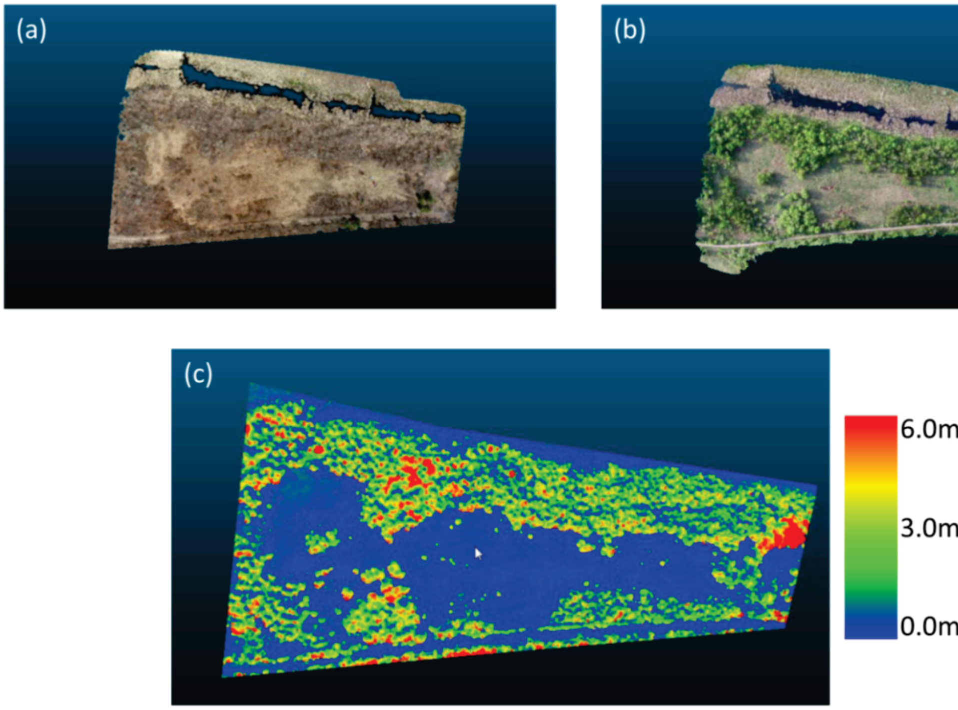

Figure 16: a) nadir view of MBR Parking point cloud from April 20, 2016 and b) nadir view of MBR Parking point cloud from May 24, 2016. c) Eucledian distance between two closest points from the point clouds in (a) and (b).

Point clouds can also be used to characterise the vegetation vertical profile using techniques developed for LiDAR data (e.g. Leblanc 2014). Vertical vegetation profile was estimated with a small area in the forested part of the MBR Parking point cloud (see Figure 17). First, the number of points was tabulated for each 1m layer above the ground. Second, from the number of points in a given layer and the number of points below it, a gap fraction can be calculated for each layer. Using Beer's law that relates gap fraction to Leaf Area Index (LAI) can be estimated vertically (e.g. Leblanc 2014). The LAI here includes both woody and foliage and is not corrected for foliage clumping (generally referred as effective LAI):

$$L = -\frac{\ln[P(\theta)]\cos\theta}{G(\theta)} \, , \tag{1}$$

where L is the effective LAI, P is the gap fraction; θ is the view zenith angle (θ=0 at nadir); and G is the projection coefficient that is assumed to be 0.5 (random foliage orientation assumption) here. The vertical effective LAI profile can be seen in Figure 17d. The effective LAI for the area is the sum of all layers and gives a value of 2.8, which is in the right order of values for an area. UAV-based LAI mapping has the potential to improve in-situ LAI from a few points to a larger area, which would add more points to validation of such products. Moreover, not only the total LAI could be mapped over 10-20 ha in one UAV flight, but vertical LAI too.

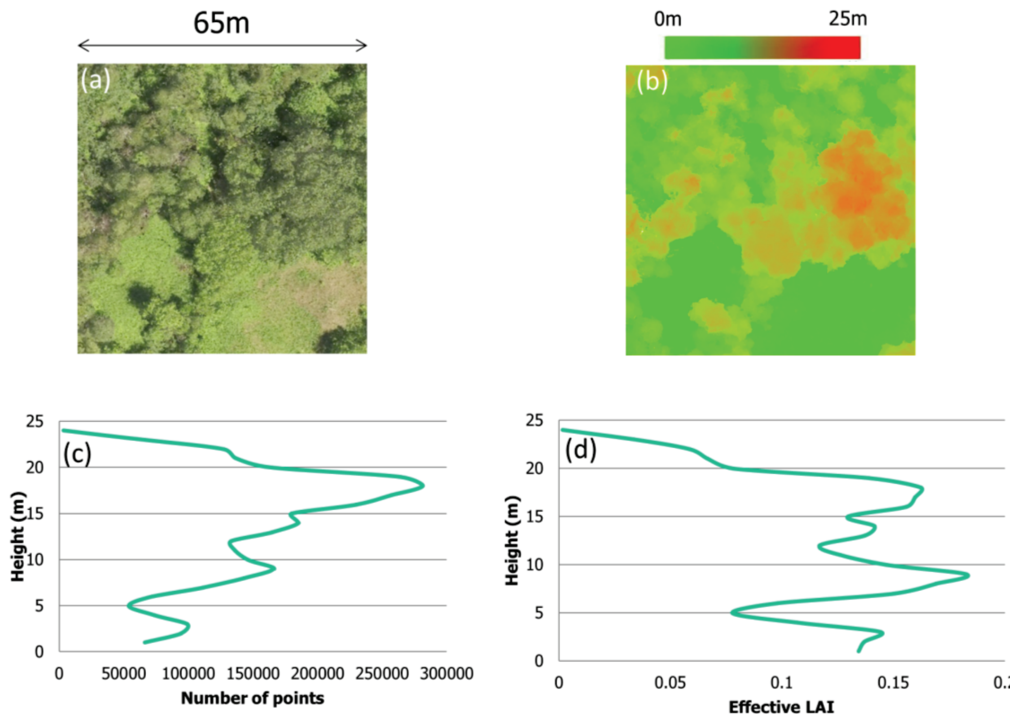

Figure 17: Estimation of vegetation vertical profile. (a) Visible nadir view of one 65x65m² area from the MBR Parking from June 30, 2016. b) Nadir view of height information for same area as (a) (note that the number of points on the ground level is not shown). c) Vertical of the number of points from (b) Using Beer's law, estimate of effective LAI vertical profile.

CONCLUSIONS

The CCRS UAV images acquired at MBR and MBP are a rich dataset that has not been investigate to its full potential yet. Our early efforts focused on data acquisition and processing standards. We are still working on a more comprehensive accuracy assessment. Using simulations of vegetated areas such as in Leblanc and Fournier (2014) and Leblanc (2014) to assess accuracy and precision of point clouds and derived products should be strongly considered. We also intend to conduct more comparisons, for example, with multispectral content from airborne or satellite sensors, in the next steps for the use of the UAV data. There is also a need to develop a methodology to normalize the imagery by using known invariant targets for a relative calibration, and targets with known reflective properties (such as reflectance standards) for accurate reflectance values. Only cameras with visible bands were used in this study, but multi-spectral cameras can be mounted on larger UAVs such as the PX8. Such cameras would be more closely related to what satellite multi-spectral sensors measure and be useful in validating satellite reflectance products.

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APPENDIX

Phantom 3 Professional Specs.

Weight	1280 g
Diagonal size	590 mm
Max Ascent Speed	5 m/s (18 km/h)
Max Descent Speed	3 m/s (10.8 km/h)
Hover Accuracy	• Vertical: +/- 0.1 m (when Vision Positioning is active) or +/- 0.5 m • Horizontal: +/- 1.5 m
Max Speed	16 m/s (57.6 km/h) (ATTI mode, no wind)
Max Service Ceiling Above Sea Level	6000 m (Default altitude limit: 120 m above takeoff point)
Operating Temperature	0°C to 40°C
GPS Mode	GPS/GLONASS

GIMBAL

Controllable Range	Pitch -90° to +30°
Stabilization	3-axis (pitch, roll, yaw)

REMOTE CONTROLLER

Operating Frequency	2.400 GHz-2.483 GHz
Max Distance	Up to 5 km or 3.1 miles (unobstructed, free of interference)
Video Output Port	USB
Operating Temperature	0°C- 40°C
Battery	6000 mAh LiPo 2S

Mobile Device Holder	For tablet or phone (we used a Samsung Tab A tablet)
Receiver Sensitivity (1%PER)	-101 dBm ±2 dBm
Transmitter Power (EIRP)	• FCC: 20 dBm • CE: 16 dBm
Working Voltage	1.2 A @7.4 V

INTELLIGENT FLIGHT BATTERY

Capacity	4480 mAh
Voltage	15.2 V
Battery Type	LiPo 4S
Energy	68 Wh
Net Weight	365 g
Max Flight Time	Approximately 23 minutes
Operating Temperature	-10°C to 40°C
Max Charging Power	100

Camera

Sensor	1/2.3”CMOS Effective pixels: 12.4 M (total pixels: 12.76 M)
Lens	FOV 94° 20 mm (35 mm format equivalent) f/2.8, focus at ∞
ISO Range	• 100-3200 (video) • 100-1600 (photo)
Shutter Speed	8s -1/8000s
Image Max Size	4000×3000
Still Photography Modes	• Single Shot • Burst Shooting: 3/5/7 shots

	• Auto Exposure Bracketing (AEB): 3/5 • Bracketed Frames at 0.7EV Bias • Time-lapse
Video Recording Modes	• UHD: 4096x2160p 24/25, 3840x2160p 24/25/30 • FHD: 1920x1080p 24/25/30/48/50/60 • HD: 1280x720p 24/25/30/48/50/60
Supported SD Card Types	Micro SD Max capacity: 64 GB. Class 10 or UHS-1 rating required
Max Video Bitrate	60 Mbps
Supported File Formats	FAT32 (≤ 32 GB); exFAT (> 32 GB)
Operating Temperature	32° to 104° F (0° to 40° C)
Photo	JPEG, DNG
Video	MP4, MOV (MPEG-4 AVC/H.264)