A Complete Delair UX11 Workflow for Producing Accurate Maps in Your Preferred Coordinate System Using TBC

Version 1

13 March 2019

Topics covered include:

Best practices for GCPs and base station setup

PPK processing in Delair After Flight

Using Trimble Business Center to set preferred coordinate system

Getting started in Trimble UASMaster or Pix4Dmapper

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1 Introduction

The purpose of this document is to explain how to process a Delair UX11 mission for use within maps in any coordinate system. Examples and screenshots will be displayed for a sample project in the United States using the North American Datum of 1983 (NAD83) and the North American Vertical Datum of 1988 (NAVD88). However, it should be noted that the workflow is applicable for other projected coordinate systems around world, including those containing local coordinates and site calibrations.

This document will demonstrate to users a workflow that utilizes tools that are familiar with Geospatial Professionals. This workflow will highlight a process using Trimble Business Center (TBC) v5.0 and UASMaster. Pix4Dmapper will also be introduced using a workflow that utilizes Trimble Business Center for transformation parameters to successfully complete a project by eliminating the lack of geoid problem in Pix4D.

There are two ways to process the UX11 data:

- Without PPK, using only GCPs
- With PPK, with or without using GCPs

The first part of this document is explaining how to prepare a mission, especially how to correctly set up GCPs and the base station for a UX11 flight.

The second part of this document will explain how to correctly set up your Trimble Business Center project prior to visiting the field to collect GCP, the processing of RTK data for GCP validation upon return from the field and the importing of a JXL file, exported by Delair After Flight

2 GCPs

When using GCPs the following aspects need to be taken into consideration:

- Number and distribution of GCPs
- GCP shape and colour
- GCP acquisition

Quantity and distribution of GCPs

The GCPs should be placed evenly throughout the area of interest. The area can be represented as a large table and the GCPs are the legs that will support it. If all the "legs" are placed at the same location of the "table," then it will tilt. If the "legs" are homogeneously spread, then the "table" will be stable. Additionally, it is also recommended to place one GCP in the center of the area in order to further increase the quality of the reconstruction.

⚠	**Important:** A minimum of 5 GCPs is recommended. 5 to 10 GCPs are usually enough, even for large projects. More GCPs do not contribute significantly to increase accuracy except for very large area projects or for projects that will be split into smaller sub-projects for photogrammetry processing Do not place the GCPs exactly at the edges of the area, as they will only be visible in few images.

> Please refer to Digital Map Accuracy Standards that apply for the region where your project will occur. Additional GCPs may be required to meet certain accuracy requirements.

GCP shape and colour

An important thing to remember is that the GCP must be easily visible in the aerial imagery. This is achieved by using high-contrast colours and by making sure the ground control point is large enough to be seen from the flight altitude.

This GCP was spray-painted onto the concrete using a stencil. The marker needs to be large enough to be visible from far away. A center mark helps eliminate any confusion as to where the center point is located.

GCP acquisition

The ground control points can be:

- GCPs measured in the field
- GCPs defined from other sources

GCPs measured in the field

Measuring GCPs in the field requires spending some time in the area and locating the position where they should be measured. This process requires the terrain to be accessible. The following parameters will need to be identified and equipment available in order to measure GCP coordinates:

- GCP coordinate system
- GCP accuracy
- Topographic or Surveying equipment

GCP coordinate system

A coordinate system is a set of numbers and parameters that are used in order to define the position of an object in the 2D or 3D space. The chosen GCP coordinate system depends on the needs of the end-user. Coordinate system types include:

- **Global coordinate systems:** They are defined using 3D ellipsoid coordinates (latitude, longitude, height).
- **National coordinate systems:** They are usually defined using a projection defined for a specific country (X, Y, elevation).

- **Local coordinate systems:** They are defined using a projection. The user sets the origin and orientation where it is most convenient (X, Y, elevation).

Note: The elevation can be either geometric (using as reference the height of the ellipsoid), orthometric (using Mean Sea Level as reference) or another geoid.

⚠	**Important:** The GCP coordinate system should be identical to that of the base station if those GCPs are going to be used as a checkpoints. Please refer to section 4 for additional information about setting proper coordinate systems within TBC.

GCP accuracy

In order to define the accuracy with which the GCPs will be measured, the following factors must be taken into account:

- **Accuracy needed for the final results:** The accuracy of the GCPs should correspond to the final absolute accuracy the user's needs. For example, for projects where an accuracy of several meters is acceptable (e.g. rapid assessment tasks), then the accuracy of the GCPs is NOT required to be within a few centimetres. For projects where high accuracy is very important (e.g. construction sites) then the GCPs should be measured with an accuracy of a few centimetres in order to comply with the project requirements. In general, the accuracy of the GCPs should be better than the expected accuracy of the final results.
- **Ground Sampling Distance of the images:** The GCPs should be visible in the images. The GCP photogrammetric target should have about five to ten times the dimensions of the GSD. If the GCP is natural (a characteristic point in the area that is not signed by a photogrammetric target), then the GCP can be even more difficult to identify and mark.

Note: For the best results, the GCP accuracy needs to be more accurate than 1/2 of the GSD. For example, if the GSD is 10 cm, the GCP accuracy should not be below 5 cm.

⚠	**Important:** The accuracy of the GCPs must be known in order to correctly set the GCP accuracy (horizontal and vertical) for processing.

GCPs defined from other sources

If no GCPs have been measured in the field, coordinates can often be extracted from other data sources for physical objects that are visible in the images collected during the drone flight that can then be used as GCPs (e.g. painted stripes in parking lots or centers of manhole covers). The advantage of such GCPs is that they can be extracted at any time from the office. The disadvantage is that they give no true measure of the accuracy and that the coordinate system may not match the coordinate system of the project, which will require a transformation before they can be used.

GCPs can be extracted from two types of sources

- **GCPs extracted from high-accuracy sources:** GCPs can be extracted from sources such as existing maps and laser scanning outputs of the same area. If these sources are updated, then the GCPs can be very accurate. The coordinate system and the accuracy of these points depend on the source.

- **GCPs extracted from Web Map Services:** Web Map Services provide online georeferenced maps using a standard protocol called a Web Map Service (WMS). Some servers have their GIS databases publicly available and free-of-charge.

3 Base/Reference station for PPK

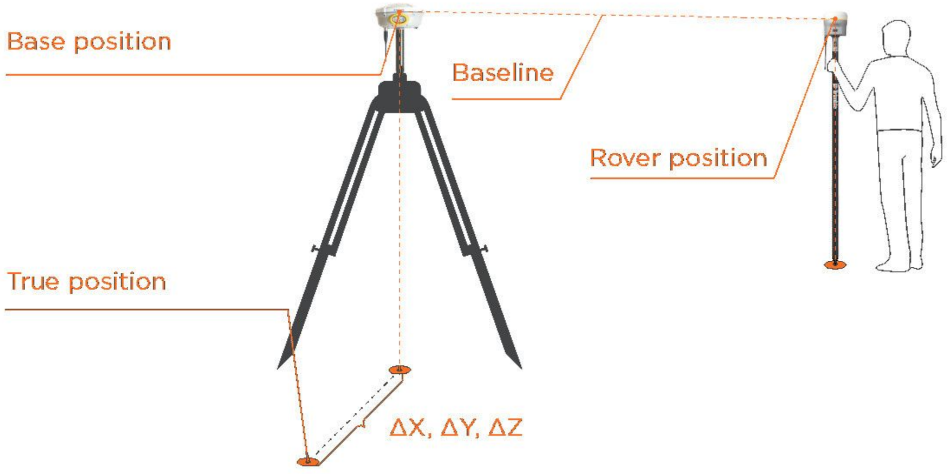
The PPK process requires two GNSS receivers. One of them is stationary and is called **“base station”** or **“reference station”**. The other one moves around measuring different positions is called the **“rover”**. A rover may be a GNSS receiver on the ground in the case of measuring GCPs, but can also be a drone, like the UX11 as it takes photos and GNSS positions from the air. The base station is mounted over a point with known coordinates (often called a benchmark, monument, or control point) and constantly receives information and is logging GNSS data. Knowing that it is stationary over a known position, the error in the GNSS data can be measured for a given moment in time relative to the base station position. This known error can then be used to calculate the GNSS position error of a rover in proximity to the base, and correct the rover positions to be more accurate.

A user may provide their own base station but there are also several base station networks that can be used. There are even free ones whose data can be downloaded via the internet. The distance between the reference station and local rover should not exceed 10-15 km as a best practice. If the network reference station is located too far or simply does not exist in the area where the rover will operate, then a local base station will be mandatory to do PPK processing.

It is important to pay attention to this document if the operator is willing to set up his own base. A good understanding of different ways to set up the base will help to reach the desired accuracy.

Absolute and relative accuracy of a position

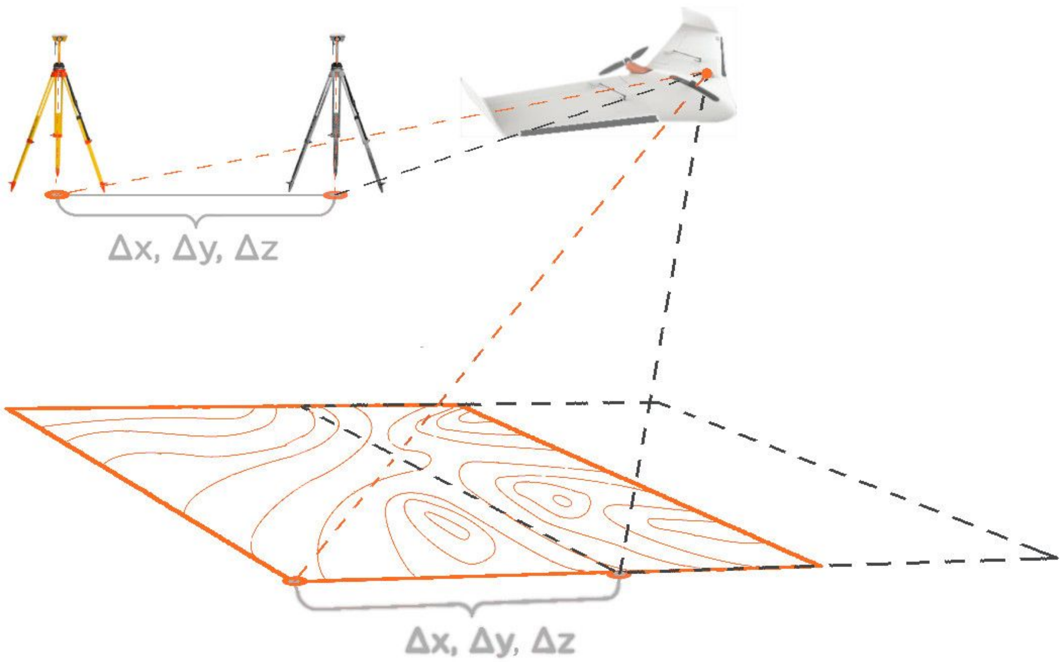
On the illustration below (figure below), a PPK algorithm precisely calculates the distance, direction and elevation difference between a base and a rover. This is called a baseline. The rover position is precisely determined relative to the base position. At the same time, the rover coordinates offset from the real position depends on the position accuracy of the base at a similar moment in time. If the position that has been set in the base station is different from the true position on earth, an offset equal (or very near) to this difference will be observed in the rover position as well.



It is often enough to know the precise position of an object relative to the base station but for some applications like surveying and mapping, it is critical to get an accurate absolute position. In this case, the offset ΔX, ΔY, ΔZ between the true position and the base station position should be eliminated.

Important: The absolute position of the rover is only as accurate as the position of the base station.

Proper positioning of the base station is key to successful data collection. The shift of base coordinates will keep the collected data precise but will make it inaccurate (which may be acceptable for volumetric measurements but unacceptable if the collected data has to be tied to global or local coordinates). If the base reference coordinates have shifted relative to the true earth position, the map produced with data collected by a PPK-enabled UX11 will be shifted as well (figure below).



Ways to determine the base station reference coordinates

There are many ways to position the base station and determine its true position or location. You can manually enter the base coordinates, use an averaging feature of a GNSS receiver, or PPK techniques to determine the coordinates.

No matter which method you use to establish a base station reference coordinate for your drone survey, the relative position of the rover (drone) to your base will always be cm-precise following the PPK process. However, , the actual absolute accuracy of your photo positions from your drone survey will be set by depend heavily on the absolute accuracy of the base position.

The table below shows different methods to establish a base station's location.

Base setup method	Accuracy*	Requirement	Observation time*
Manual, over a known point	Same as the known point	Known point	0 min
Autonomous GNSS position	30cm-10m	GNSS receiver, averaging recommended	< 5 min
Real-time Kinematic (RTK) position with base station	5mm-50mm	Survey-grade base and rover GNSS system	< 5 min
RTK position with VRS or RTN	5mm-50mm	Internet connection and NTRIP stream from base (ideally <15km)	< 5 min
Post-Processed Kinematic (PPK) position	2mm-50mm	Log files from a base station	15 min-24 hr

**Numbers in the table are approximate and only for reference purposes. Accuracy of positions can vary widely depending on the GNSS receiver or instrument used and many other factors. Your experience may vary in different conditions. Always follow appropriate survey practices!*

Manual

This method consists of placing the base station receiver exactly over a known point. The most popular scenarios include finding a control point from a publicly available directory of survey control points or by hiring a professional surveyor who will set a benchmark point of control quality. In this case, absolute accuracy depends on how accurately the point's coordinates were determined.

It's very important to place the base over a known position and measure the height of the antenna reference point from the mark. This will help avoid shifts in your overall dataset from the absolute position of the control point and keep measurements accurate.

Autonomous GNSS

This approach is used when you don't require absolute accuracy. A single autonomous position from a GNSS receiver may be used or multiple positions may be averaged in order to provide some correction for error that is inherent in GNSS data. This is done without using any correction source and the absolute accuracy will depend on the manufacturer and quality of the GNSS receiver used. An autonomous GNSS position may include up to several meters of error.

Real-time Kinematics (RTK)

Using an RTK fixed GNSS solution is much more accurate than an autonomous position. This is made possible when the GNSS receiver used to measure the position is either (a) connected directly to another base station via a radio communication link, or (b) by being connected to the internet and configured to receive correction messages like RTCM from a virtual reference station (VRS), GNSS real-time network (RTN) or a single base station through an NTRIP connection (Networked Transport of RTCM via Internet Protocol).

Post-processed Kinematics (PPK)

PPK method can also be used to determine the position of your base station with high accuracy. It is as accurate as the RTK fix solution. The only difference is that you won't have the position of your base in real time. Some websites can calculate your base station position using PPK methods.

With either RTK or PPK processing, if the baseline is too long, a *fixed* GNSS solution may be difficult to obtain. In this case, a *float* solution may be achieved which generally provides a position whose absolute accuracy is somewhere between a few centimeters and one meter.

Websites that offer free GNSS post-processing services:

- CenterPoint RTX: Trimble Navigation

  http://www.trimblertx.com/UploadForm.aspx

- NGS OPUS: Online Positioning User Service, National Geodetic Survey

  https://www.ngs.noaa.gov/OPUS/

- CSRS-PPP: Canadian Spatial Reference System, Natural Resources Canada

  http://webapp.geod.nrcan.gc.ca/geod/tools-outils/ppp.php

- AUSPOS: Geoscience Australia

  http://webapp.geod.nrcan.gc.ca/geod/tools-outils/ppp.php

- GAPS: University of New Brunswick

  http://gaps.gge.unb.ca/indexv520a.php

- APPS: Jet Propulsion Laboratory

  http://apps.gdgps.net/apps_file_upload.php

- SCOUT: Scripps Orbit and Permanent Array Center (SOPAC), University of California San Diego

  http://apps.gdgps.net/apps_file_upload.php

- magicGNSS: GMV

  http://magicgnss.gmv.com/ppp/

General steps for using an online postprocessing service

Here are the general steps for using an online postprocessing service to establish your base reference coordinate for a drone survey:

- Set up your base receiver over the marked control point you wish to create
  - Enable logging of static GNSS data with an interval of one second
  - Record log for a duration of 30 minutes prior to flight and 30 minutes after flight
  - A minimum of 2 hours is recommended for successful PPK processing
- Convert your base receiver file into RINEX
- Upload your RINEX file to a relevant website such as those listed above to get an accurate position of your base station
- When possible request an XML file as a deliverable from the selected processing service

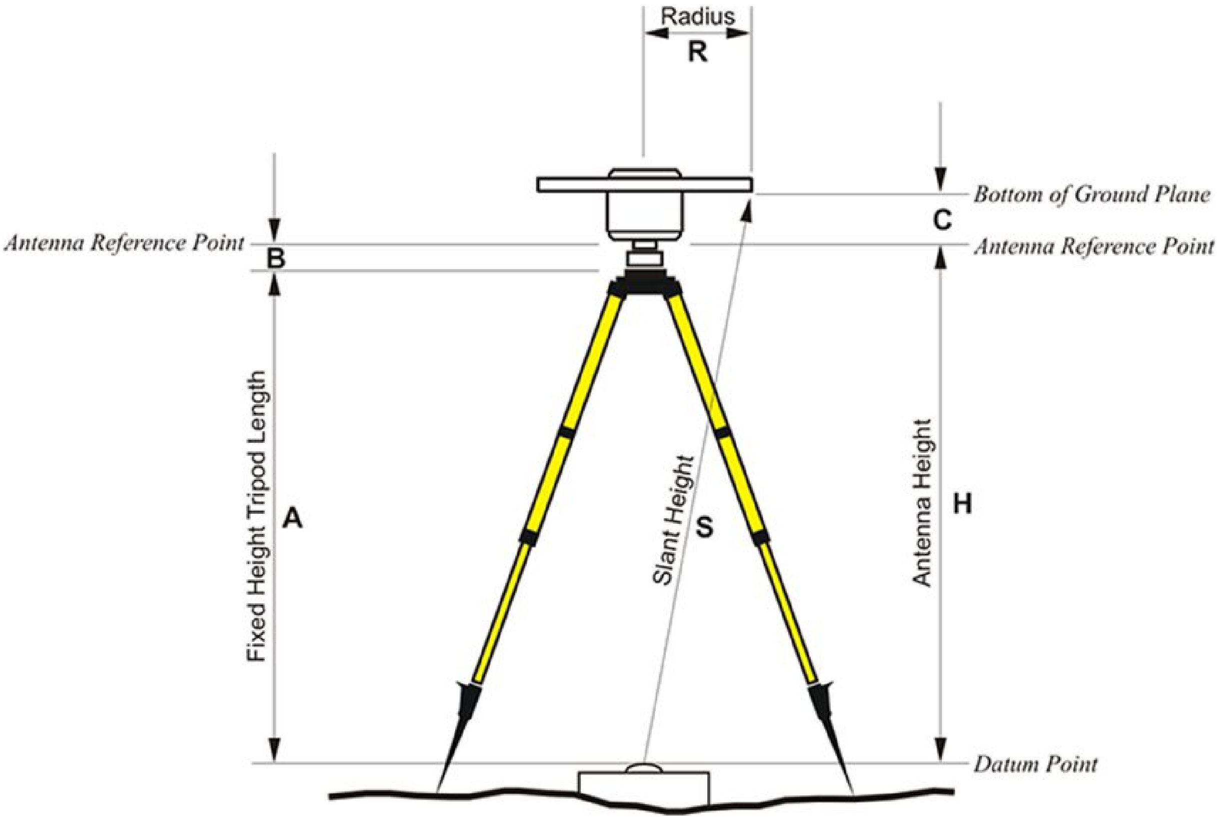
Note: The base data required for establishing a base station reference coordinate can be the same base data used for PPK-processing of UX11 data if best practices for both needs are observed.

⚠	**Important:** If using Trimble equipment and processing with RTX, there is no need to convert the outputted file into Rinex, please use T02 file.

Placing the base station in the field

Make sure that the base station receiver is placed on a tripod and levelled precisely above the marked control point whose position is known.

When using a known point or a physical marker on the ground as the benchmark, such as a control point you intend to use more than once for a survey with drones or other tools, it is critical that you correctly measure the antenna height. Once the GNSS base station antenna is mounted properly and level over the mark, use a tape measure to precisely measure the vertical distance between the mark and the antenna reference point (ARP). The ARP depends on the GNSS antenna model, but is generally the base of the antenna (where the outside housing of the antenna meets the mount of your tripod) or another physical mark on the antenna. Check with the manufacturer of the GNSS antenna for details.



⚠	**Pay Attention:** A mismeasured height of the antenna above the mark is one of the most pervasive and frequent mistakes made in GPS control surveying. A best practice is to double measure instrument heights with two different units. (i.e. When operating in the United States, measure heights in both feet and meters.)

Storing the base position

If you want to reuse the determined base location for a future survey:

- Carefully mark physical position on the ground *before* initial installation of base station
- Carefully measure the antenna height and record each time you set up the base station
- Save the position coordinates on your base station and/or manually for future reference
- When using this position next time, accurately place the base station over the same mark and use the same coordinates for your PPK processing of the drone data

You will simply need to record the static base data during the same time period of your subsequent drone flight(s).

4 Trimble Business Center - Project Setup

Trimble Business Center (TBC) is a proven geospatial office software in use by Trimble equipment operators worldwide. Many land surveying projects begin and end within the TBC environment. There are many coordinate systems available to users of this software. While this document will focus on using NAD83 (2011) and the NAVD88 Datum as an example of a workflow relevant in the United States, **this workflow may be applied worldwide where specific regional coordinate systems, both horizontal and vertical, are required**. In fact, this work flow can even support the use of local (or custom) coordinate systems such as those commonly used on construction sites or mines.

Project setup

Understanding the location of your project and the coordinate system required for your final product. For this example we selected the following from the Project Settings Dialog box.

- Coordinate System Group: United States/ITRF to NAD83
- Zone: California Zone 5 0405
- Datum Transformation: ITRF to NAD 1983 (2011) (Seven Parameter)
- Geoid Model: GEOID12B (Conus)

> **Important:** Trimble Business Center does not contain unit specific coordinate systems. The units used in the projection must be set by either selecting the proper template upon project startup or by going to the distance tab, which is located under Units from the Project Settings dialog box.

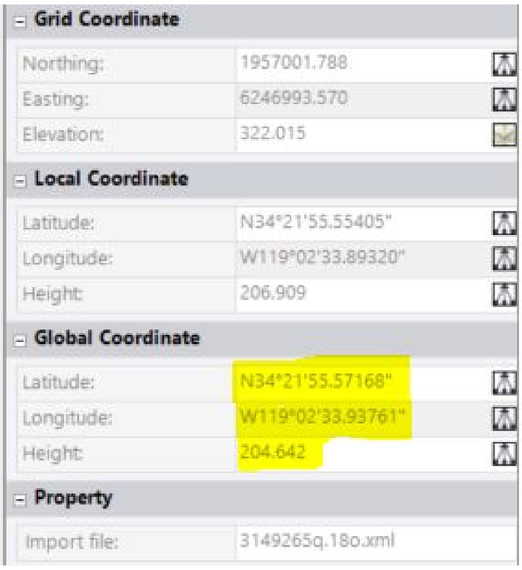
Importing base station data

Navigate to the location where the Static Base Station data was stored after performing steps in section 3. In this example we will be using the OPUS provided solution which was delivered as a txt file and XML. Import the XML file by dragging and dropping into the workspace:

Name	Date modified	Type	Size
3149265q.18o.txt	12/12/2018 10:28 ...	Text Document	3 KB
3149265q.18o.xml	12/6/2018 12:04 AM	XML Document	5 KB

Understanding your location

The point created during the import step will become the base station used for PPK processing in Delair After Flight (See Section 5 for this workflow) The position imported by the OPUS solution is a NAD83 coordinate expressed as latitude and longitude. A grid coordinate was also created, and is dependant upon the user-selected coordinate system. Due to the selected coordinate system, United States/ITRF to NAD83, a global ITRF08 coordinate was also created.



⚠	**Important:** Trimble Business Center does not contain unit specific coordinate systems. The units used in the projection must be set by either selecting the proper template upon project startup or by going to the distance tab, which is located under Units from the Project Settings dialog box.

Using your location for PPK in Delair After Flight

The Global Coordinate value listed under your base station location should be used in the next step of the process, which will be the PPK processing within Delair After Flight.

⚠	**Important:** In order to ensure a minimized transformation shift, please use only the values listed under the Global Coordinate field as noted above. Should you pull WGS84 location information directly from a datasheet, RTX report, OPUS report or other static processor report, a shift may be realized.

Save project and minimize TBC. You will return to TBC upon completion of post processing within Delair After Flight.

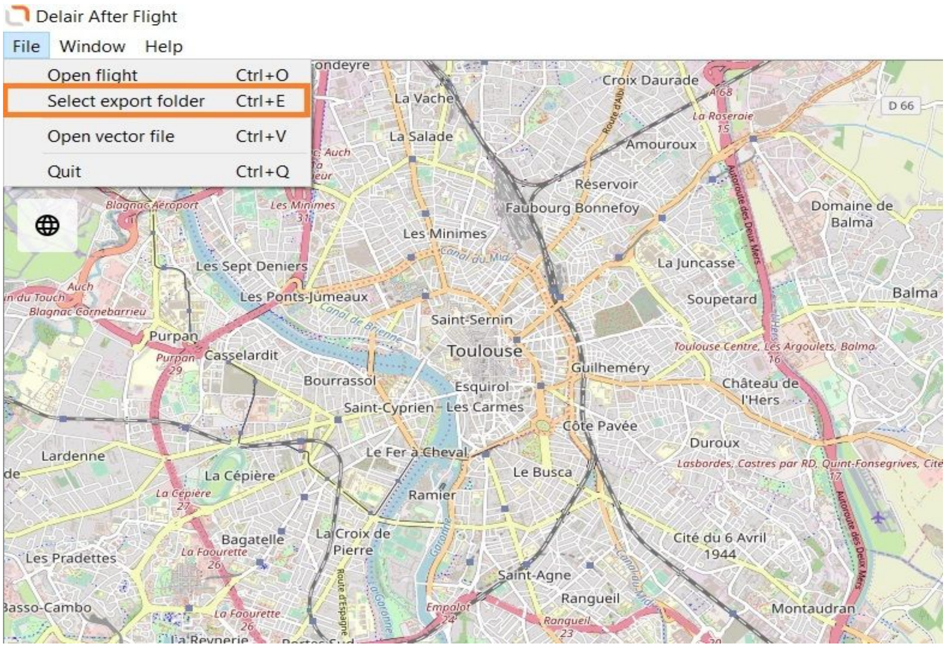
5 Delair After Flight

As a reminder, **Delair After Flight** is a software that will enable the operator to preview, select and export UX11 pictures. This software is also used for executing the PPK process to have geotagged pictures with high-precision locations.

After performing the flight with the UX11, open Delair After Flight.

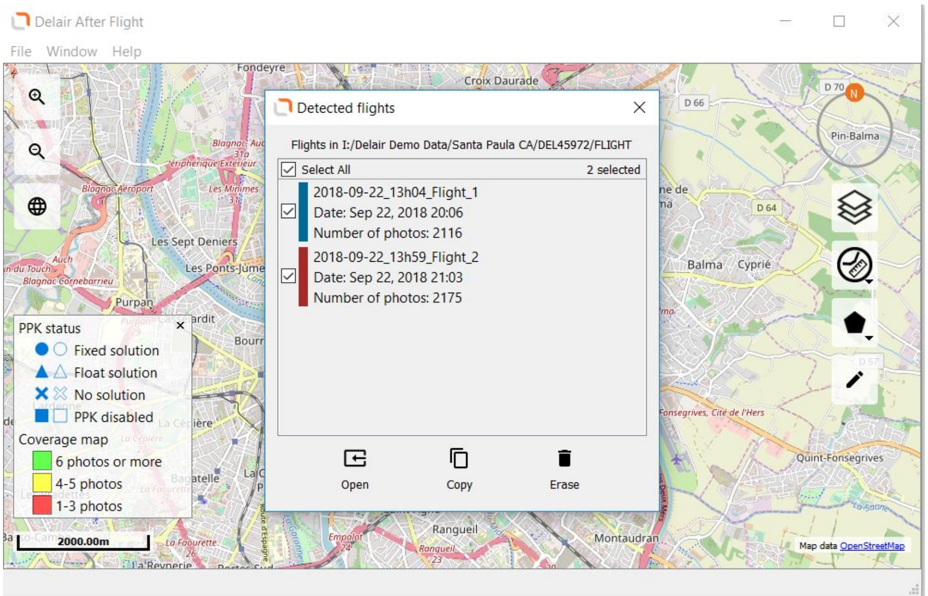
Setting your export folder location

This should be changed to your project specific folder and must be changed each time you process a different project, as it defaults to the previously used directory.



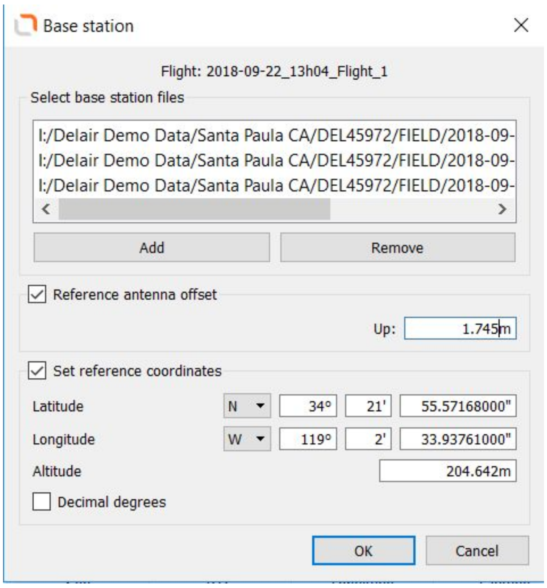
Importing flight data

Navigate to the folder location that was chosen when downloading flight mission data from the UX11. Select the folder that includes the flights and drag into After Flight.



Settings for reference station

Upon successful import of the flight data, a popup will appear which will require the user to import the selected reference station RINEX data, set the antenna height, and enter the reference station location and ellipsoidal height. Reference station coordinates must be a global location only and should be tied to the ITRF2008 realization of WGS84. **Please refer to the global field in TBC for your reference station location.**

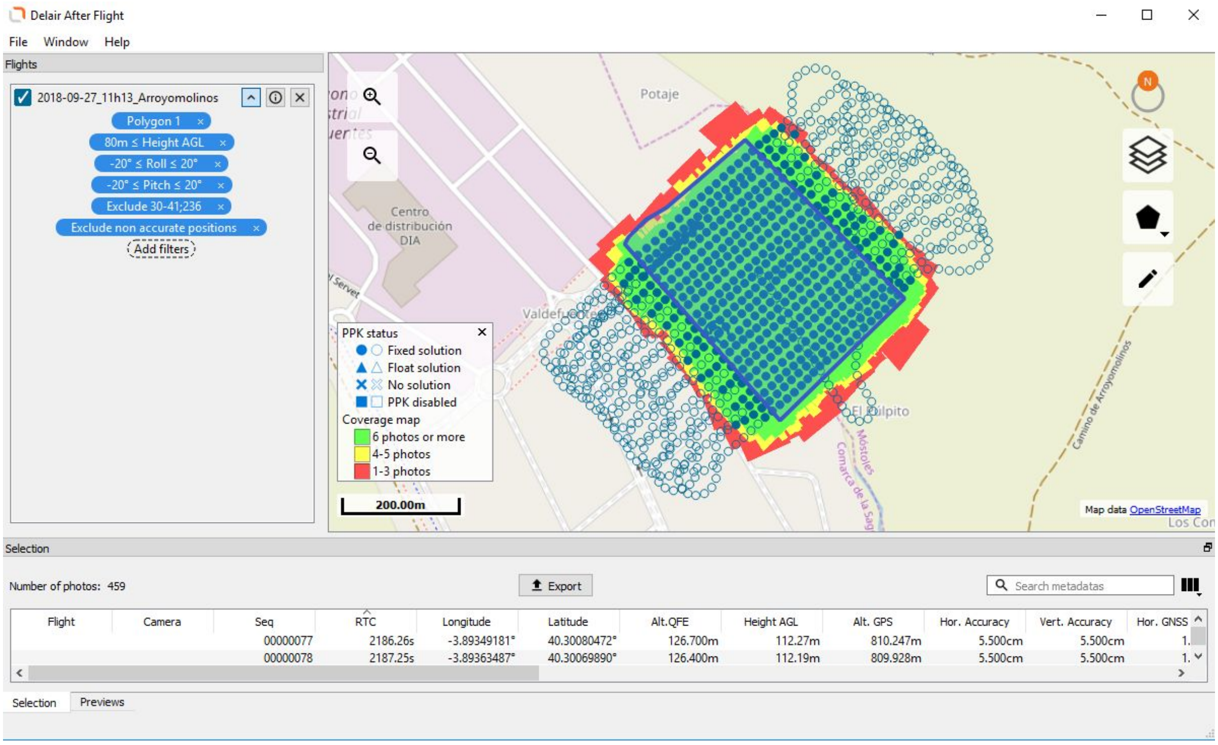


Mission will begin post processing datasets immediately upon hitting OK.

⚠	**Important:** As explained above, if the wrong base reference coordinate is entered the entire dataset can be shifted. In some instances of incorrect locations being used, After Flight may be unable to provide a solution for PPK processing.

Applying mission parameter filters

Various filters can be applied to the mission to allow the user to export only those images required for the mission at hand. These filters include altitude, polygon area, +/- roll, +/- pitch, inclusion/exclusion of images based on file name and various other methods. It is recommended to experiment with each filter for every flight in order to achieve the desired subset of images to export for photogrammetry processing. This enables you to optimize photogrammetry processing time by only taking with you the images that correspond to your true area of interest.

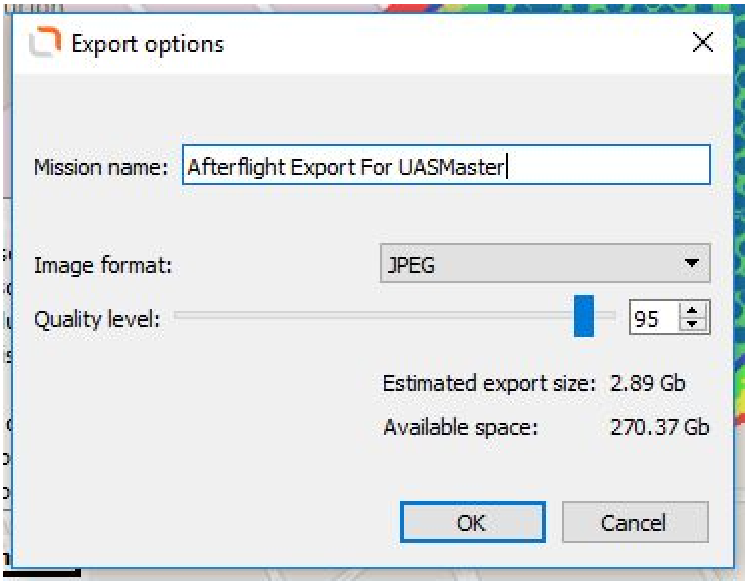


Exporting mission for photogrammetry processing

After Flight will export a variety of files once the user selects the export function. Expected outputs include:

- Geotagged JPG (or TIFF) images with EXIF data reference to WGS84 and elevation (EGM96)
- Two (2) UASMaster project files (.PRJ)
  - One with image coordinates in latitude/longitude in WGS84, ellipsoid height
  - One with image coordinates in UTM, WGS84, EGM96 elevation
- Two (2) Trimble Job XML files (.JXL)
  - A high-precision JXL file for use in TBC v5.0 or later (for PPK-processed UX11 datasets only)
  - A standard JXL file for earlier versions of TBC (does not support high-precision processing in TBC)
- Two (2) comma separated files (CSV) with metadata
  - One with image coordinates in latitude/longitude in WGS84, ellipsoid height
  - One with image coordinates in UTM, WGS84, EGM96 elevation
- Processing quality report

It is recommended to export most jobs with a 95% quality level, with the exception of photos that were taken from a very high flight height above the ground (e.g. > 300m AGL). This changes the level of JPG compression. When this setting is adjusted, the resolution of images will be the same (21 MP), but the color values of adjacent pixels will be more generalized as you decrease the quality level. If decreased significantly, the images may appear blurry or grainy. However, the difference between 95% and 100% is not noticeable to the human eye in most cases and will have little to no impact on the photogrammetry process, with the benefit of the file size being approximately half which can help expedite export and processing time.



Reviewing quality report

The quality report will include all user entered and selected information as described above. The user should pay special attention to the:

- Base station reference coordinates
- Reference antenna offset
- Fixed PPK solution percentage
- Camera position accuracy
- GNSS position accuracy

Should any item listed above not be correct, the user must restart the PPK process within After Flight.

6 Trimble Business Center - Project Review

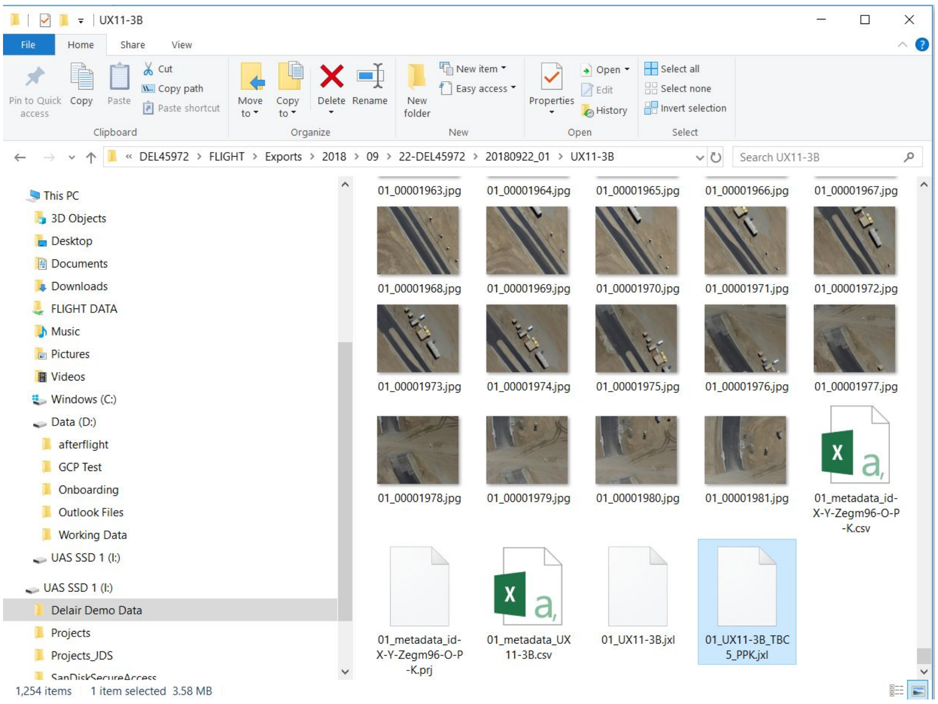
Open or maximize the previously created TBC project as outlined in section 4. The purpose of this step is to validate the coordinate system and the data exported during the After Flight process.

⚠	**Important:** It is recommended to import any GCPs into the TBC project at this point. If collected with Trimble equipment, review the vectors to ensure that the base station position used for RTK is identical to the reference station position used for PPK. If a different base station was used for either GCPs or PPK processing, such as a VRS network, it is a best practice to establish coordinates for your base station from the VRS network prior to placing the received over the location.

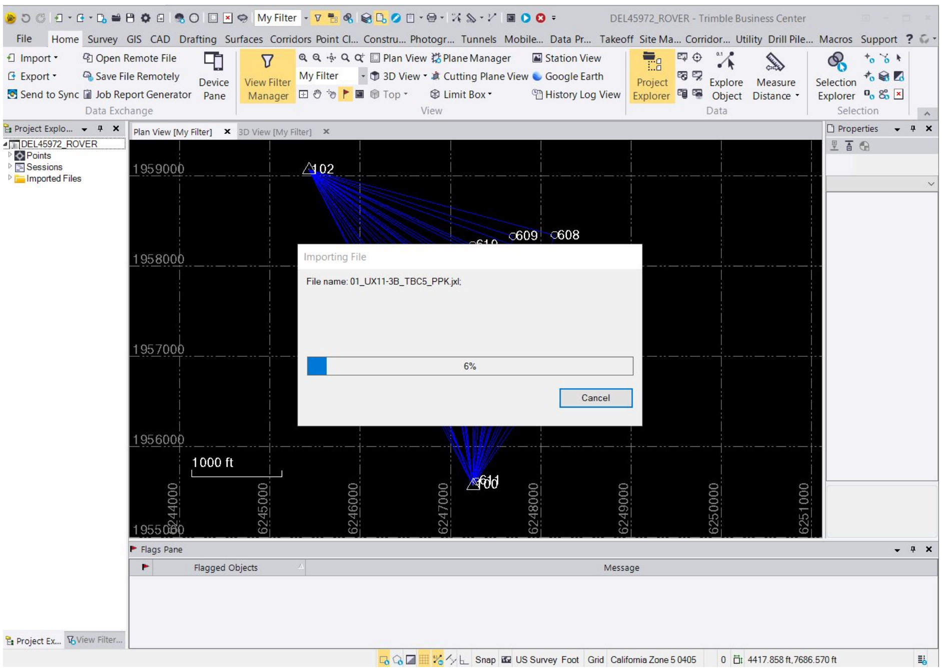
⚠	**Note:** The following steps assume you are using Trimble Business Center v5.0 or later and that you have a license for the Aerial Photogrammetry Module (APM). If you have an older version or do not have the APM module, the following steps may be different, have limited functionality, or impossible and you may be required to modify your workflow accordingly.

Importing JXL

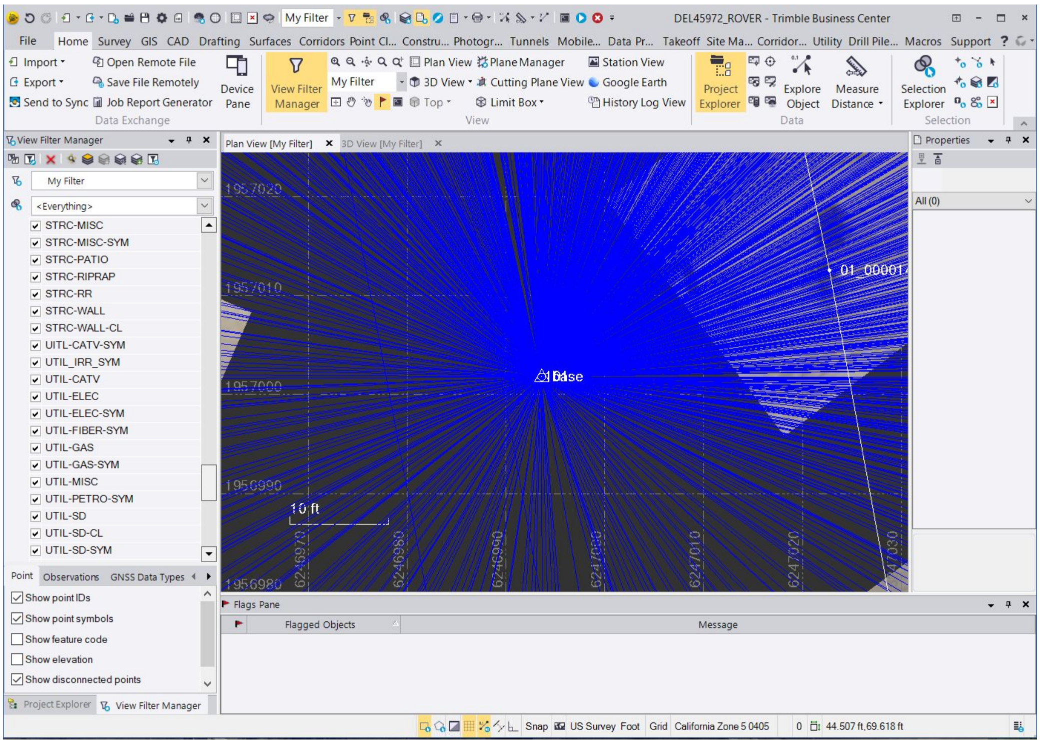
Navigate to the project export folder selected in After Flight. Select the PPK JXL and drag into TBC.



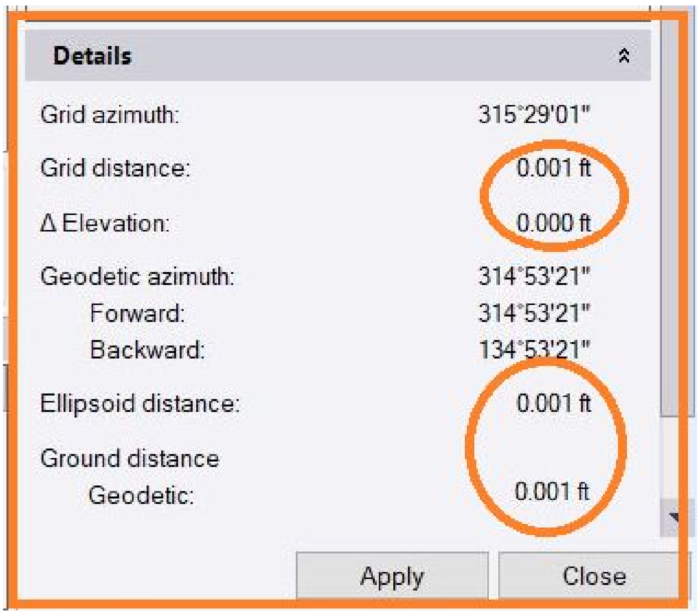
The processing of the vectors will begin immediately. Depending on size of the flight, this may take a few moments. Please be patient.



Navigate to the location on screen of the base station point imported with the xml file from section 4 and the base station point created by the JXL file.



Verify the two base positions are similar by using the **inverse** or **measure distance** command to check the distance and elevation between the two base station points. For this example, points “101” and “base” were used.



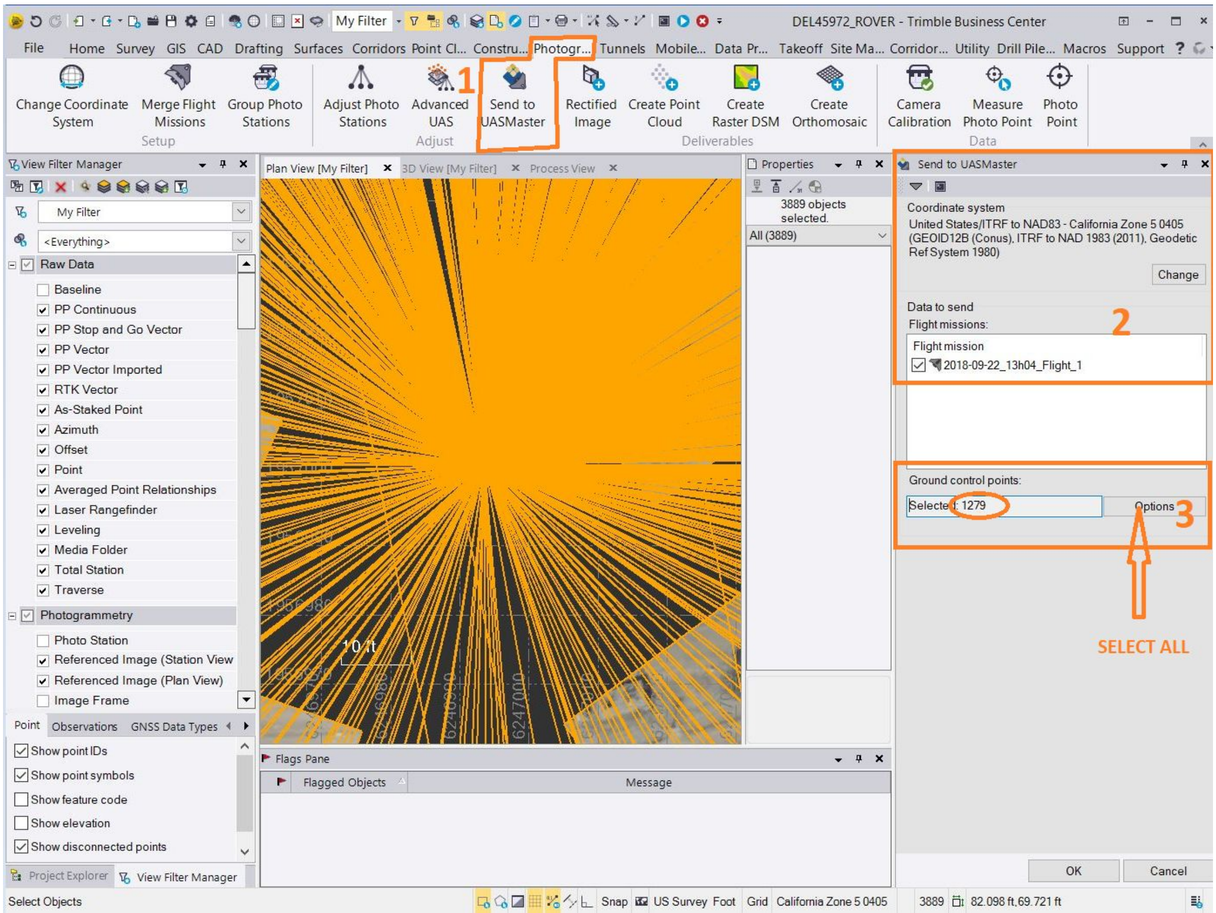
At this stage, you are ready to **proceed to photogrammetry processing**. For example, this may be done in Trimble Business Center directly, in Trimble UASMaster, or in Pix4Dmapper. See instructions below for how to get started in UASMaster or Pix4D.

7 Getting Started in UASMaster

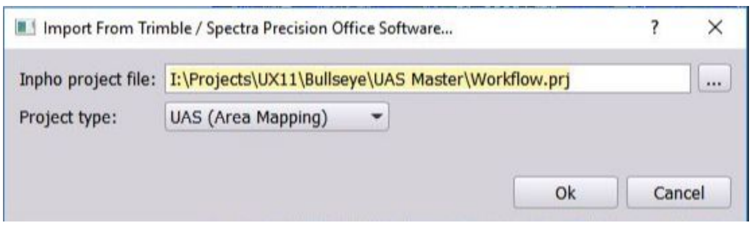
This section describes an overview of the the workflow for processing the UX11 PPK with the photogrammetric software, UASMaster

Exporting from TBC to UASMaster

- Select the *Photogrammetry* tab from the top of the Ribbon in TBC
- Click *Send to UASMaster*
    - Select *Flight Mission*
    - Select All Objects for GCPs
    - Hit the **OK** to send to and open UASMaster

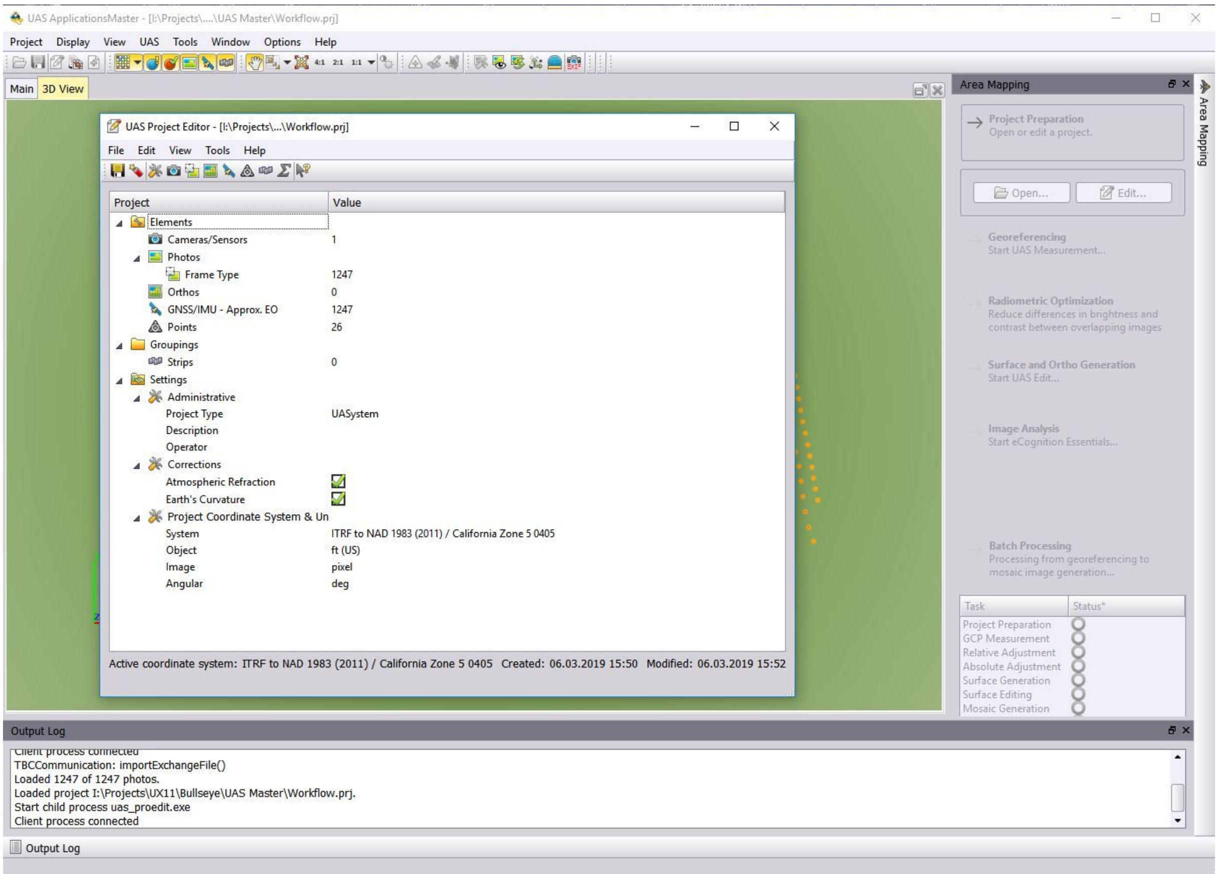


- UASMaster will automatically open and all primary settings within the software should automatically be configured. You must now save your project.



Reviewing project settings UASMaster

As mentioned earlier, creating your project directly from TBC ensures that all settings, cameras, photos, points and PPK locations are automatically set within the UAS Project Editor. As a standard operating procedure, these should be verified prior to continuing the photogrammetric process.



Cameras/sensors settings

- Unique camera ID and sensor size of 5048 pix (width) x 4228 pix (height)
  - Focal length = 12.0042 mm
  - Pixel size = 1.6700 µm (width) x 1.6700 µm (height)
- Platform camera mount rotation is 90.0000 degrees

⚠	**Note:** The camera sensor within the UX11 was focused and tested in the factory, but was not individually calibrated during the assembly process. Each sensor has its own unique distortion values that may vary slightly from one to another. Photogrammetry software like UASMaster and Pix4Dmapper are quite effective at identifying the difference in distortion values from the initial values. You may consider performing a camera calibration at your discretion.

Photo settings, metadata and frame type

Displays all photos exported during the ***Send to UASMaster*** process in TBC. The position shown will be based on the project coordinate system assigned in TBC. The positions listed are to the projection centers of the sensor and have had the GNSS offset applied.

Frame Photos

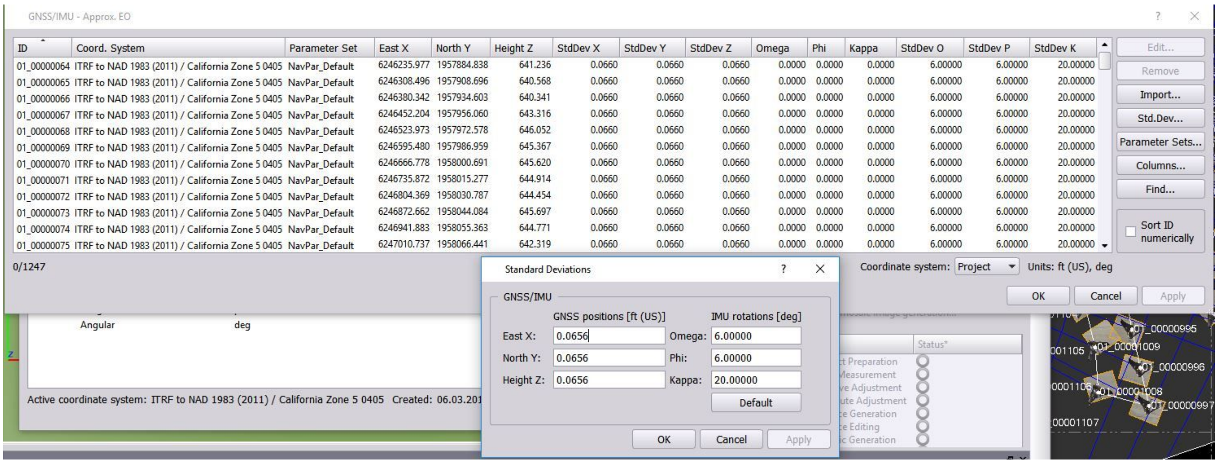
ID	Camera	Coord. System	East X	North Y	Height Z	Omega	Phi	Kappa	Terrain
01_00000064	4271	ITRF to NAD 1983 (2011) / California Zone 5 0405	6246236.012	1957884.307	641.426	-8.9829	-8.1716	-71.5665	336.171
01_00000065	4271	ITRF to NAD 1983 (2011) / California Zone 5 0405	6246308.569	1957908.159	640.727	-5.7638	-4.4526	-68.3018	335.471
01_00000066	4271	ITRF to NAD 1983 (2011) / California Zone 5 0405	6246380.378	1957934.039	640.332	10.9642	-0.2505	-72.8946	335.077
01_00000067	4271	ITRF to NAD 1983 (2011) / California Zone 5 0405	6246452.197	1957955.497	643.262	15.5055	1.2237	-77.6640	338.007
01_00000068	4271	ITRF to NAD 1983 (2011) / California Zone 5 0405	6246523.937	1957972.016	646.095	5.7049	-0.1423	-80.3469	340.840
01_00000069	4271	ITRF to NAD 1983 (2011) / California Zone 5 0405	6246595.412	1957986.402	645.431	3.4084	-1.6192	-83.4075	340.176
01_00000070	4271	ITRF to NAD 1983 (2011) / California Zone 5 0405	6246666.679	1958000.141	645.702	1.4592	-1.0201	-86.8005	340.447
01_00000071	4271	ITRF to NAD 1983 (2011) / California Zone 5 0405	6246735.804	1958014.728	645.026	-1.6413	-1.4954	-83.5012	339.771
01_00000072	4271	ITRF to NAD 1983 (2011) / California Zone 5 0405	6246804.254	1958030.234	644.447	9.9901	-4.8219	-87.8246	339.192
01_00000073	4271	ITRF to NAD 1983 (2011) / California Zone 5 0405	6246872.592	1958043.524	645.729	6.9620	0.7299	-84.0443	340.474
01_00000074	4271	ITRF to NAD 1983 (2011) / California Zone 5 0405	6246941.741	1958054.819	644.829	2.8492	-5.8251	-90.5022	339.573
01_00000075	4271	ITRF to NAD 1983 (2011) / California Zone 5 0405	6247010.584	1958065.908	642.425	-1.7126	-3.0393	-92.1022	337.170
01_00000076	4271	ITRF to NAD 1983 (2011) / California Zone 5 0405	6247080.343	1958082.241	640.505	8.3355	-2.8261	-87.4234	335.249
01_00000077	4271	ITRF to NAD 1983 (2011) / California Zone 5 0405	6247151.122	1958099.875	640.957	2.4506	-4.7259	-90.6017	335.701

0/1247 Units: ft (US), deg

GNSS/IMU - Approximate exterior orientations

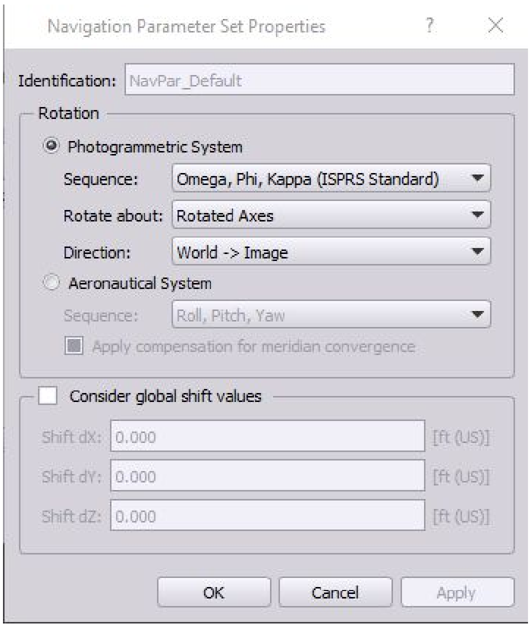
Displays all image trigger events corrected during the PPK process in After Flight. The position shown will be based on the project coordinate system assigned in TBC.

- The GNSS standard deviations should match the values shown the After Flight export report. Please review these values.
- The IMU rotational standard deviations are at its default setting, as the UX11 does not include a high-accuracy IMU. The following settings are recommended:
  - Omega = 6.00 degrees
  - Phi = 6.00 degrees
  - Kappa = 20.00 degrees



ID	Coord. System	Parameter Set	East X	North Y	Height Z	StdDev X	StdDev Y	StdDev Z	Omega	Phi	Kappa	StdDev O	StdDev P	StdDev K
01_00000064	ITRF to NAD 1983 (2011) / California Zone 5 0405	NavPar_Default	6246235.977	1957884.838	641.236	0.0660	0.0660	0.0660	0.0000	0.0000	0.0000	6.00000	6.00000	20.00000
01_00000065	ITRF to NAD 1983 (2011) / California Zone 5 0405	NavPar_Default	6246308.496	1957908.696	640.568	0.0660	0.0660	0.0660	0.0000	0.0000	0.0000	6.00000	6.00000	20.00000
01_00000066	ITRF to NAD 1983 (2011) / California Zone 5 0405	NavPar_Default	6246380.342	1957934.603	640.341	0.0660	0.0660	0.0660	0.0000	0.0000	0.0000	6.00000	6.00000	20.00000
01_00000067	ITRF to NAD 1983 (2011) / California Zone 5 0405	NavPar_Default	6246452.204	1957956.060	643.316	0.0660	0.0660	0.0660	0.0000	0.0000	0.0000	6.00000	6.00000	20.00000
01_00000068	ITRF to NAD 1983 (2011) / California Zone 5 0405	NavPar_Default	6246523.973	1957972.578	646.052	0.0660	0.0660	0.0660	0.0000	0.0000	0.0000	6.00000	6.00000	20.00000
01_00000069	ITRF to NAD 1983 (2011) / California Zone 5 0405	NavPar_Default	6246595.480	1957986.959	645.367	0.0660	0.0660	0.0660	0.0000	0.0000	0.0000	6.00000	6.00000	20.00000
01_00000070	ITRF to NAD 1983 (2011) / California Zone 5 0405	NavPar_Default	6246666.778	1958000.691	645.620	0.0660	0.0660	0.0660	0.0000	0.0000	0.0000	6.00000	6.00000	20.00000
01_00000071	ITRF to NAD 1983 (2011) / California Zone 5 0405	NavPar_Default	6246735.872	1958015.277	644.914	0.0660	0.0660	0.0660	0.0000	0.0000	0.0000	6.00000	6.00000	20.00000
01_00000072	ITRF to NAD 1983 (2011) / California Zone 5 0405	NavPar_Default	6246804.369	1958030.787	644.454	0.0660	0.0660	0.0660	0.0000	0.0000	0.0000	6.00000	6.00000	20.00000
01_00000073	ITRF to NAD 1983 (2011) / California Zone 5 0405	NavPar_Default	6246872.662	1958044.084	645.697	0.0660	0.0660	0.0660	0.0000	0.0000	0.0000	6.00000	6.00000	20.00000
01_00000074	ITRF to NAD 1983 (2011) / California Zone 5 0405	NavPar_Default	6246941.883	1958055.363	644.771	0.0660	0.0660	0.0660	0.0000	0.0000	0.0000	6.00000	6.00000	20.00000
01_00000075	ITRF to NAD 1983 (2011) / California Zone 5 0405	NavPar_Default	6247010.737	1958066.441	642.319	0.0660	0.0660	0.0660	0.0000	0.0000	0.0000	6.00000	6.00000	20.00000

- The Parameter Set defines the rotational sequence, the rotational axes and transformation direction. The following settings are recommended:
    - Photogrammetric System
        - Sequence: Omega, Phi, Kappa (ISPRS Standard)
        - Rotated about: Rotated Axes
        - Direction: World ⇒ Image



GCPs and checkpoints

During the during the ***Send to UASMaster*** process in TBC, you have the opportunity to select as many or as little GCPs/CPs that you have available in your TBC project. The default type of these points are full horizontal and vertical control points (or HV). The following settings are recommended:

Due to the accurate geolocation of the UX11 PPK, you may elect to use all your points as check points only. This will give you a better estimate of the overall accuracy of the To do this you must select the points.

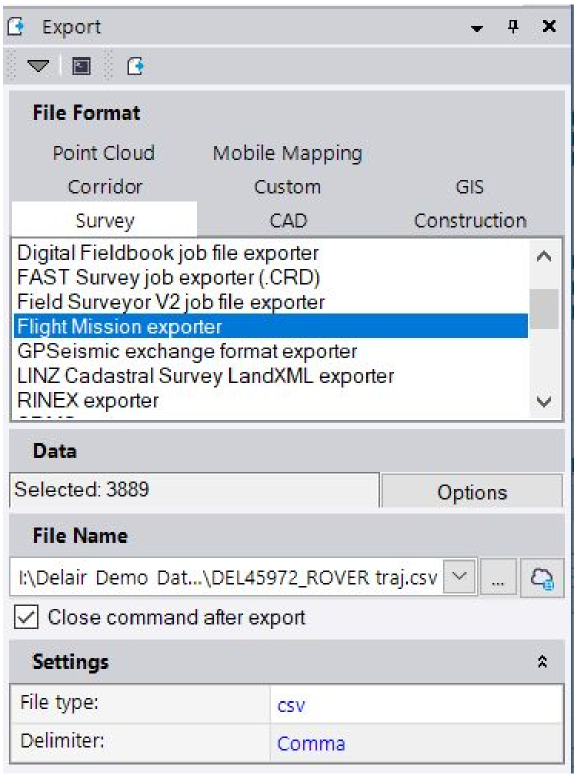
8 Getting Started in Pix4Dmapper

This section describes an overview of the the workflow for processing the UX11 PPK with the photogrammetric software, Pix4Dmapper.

Export flight mission data from TBC for use in Pix4D

The following steps can be taken to export a CSV file with image locations in your preferred coordinate system, including orthometric heights (such as NAD83 and NAVD88 in this example). This step works around the lack of support in Pix4Dmapper for geoid models such as the CONUS 12B geoid for North America.

- Click on the *Data* toolbar in the ribbon of TBC
- Click on *Export*
- Under the Survey tab select *Flight mission exporter*
- Ensure that all the features are selected
- Select a destination directory to save the file
- Click OK to export



Important: When exporting the Flight Mission from TBC, a CSV file is created, but it includes columns not recognized by Pix4D. You must remove the following columns from the exported CSV before proceeding to import into Pix4D.

Delete Column B *"uniqueid"*, **Column C** *"fixed quality"* and **Column** J *"gpstime"*

These columns are shown in red below:

	A	B	C	D	E	F	G	H	I	J
1	#image	uniqueid	fixedquality	x	y	z	roll	pitch	yaw	gpstime
2	01_00000064.jpg	1052301_00000064	1	1903856.544	596764.3304	195.5070555	-11.13970	4.80810	70.45440	0
3	01_00000065.jpg	1052301_00000065	1	1903878.66	596771.6003	195.293899	-7.00420	1.98510	67.95610	0
4	01_00000066.jpg	1052301_00000066	1	1903900.547	596779.4887	195.1735952	10.41900	3.44240	73.23260	0
5	01_00000067.jpg	1052301_00000067	1	1903922.437	596786.0292	196.0666933	15.41080	2.12100	77.78440	0
6	01_00000068.jpg	1052301_00000068	1	1903944.304	596791.0641	196.9301468	5.60100	1.09470	80.40750	0
7	01_00000069.jpg	1052301_00000069	1	1903966.089	596795.4488	196.7277693	3.20190	1.99690	83.51150	0
8	01_00000070.jpg	1052301_00000070	1	1903987.812	596799.6366	196.8104931	1.40030	1.09970	86.82700	0
9	01_00000071.jpg	1052301_00000071	1	1904008.881	596804.0826	196.6043934	-1.80050	1.29940	83.45930	0
10	01_00000072.jpg	1052301_00000072	1	1904029.745	596808.8089	196.4279115	9.83970	5.12390	88.68770	0
11	01_00000073.jpg	1052301_00000073	1	1904050.574	596812.8597	196.8186467	7.00000	0.00000	83.99990	0
12	01_00000074.jpg	1052301_00000074	1	1904071.651	596816.3025	196.5441419	2.91490	5.79250	90.79470	0
13	01_00000075.jpg	1052301_00000075	1	1904092.634	596819.6824	195.8115272	-1.60230	3.09880	92.01340	0
14	01_00000076.jpg	1052301_00000076	1	1904113.897	596824.6607	195.2261822	8.21260	3.16730	87.85690	0
15	01_00000077.jpg	1052301_00000077	1	1904135.47	596830.0356	195.3639379	2.50840	4.69550	90.80570	0
16	01_00000078.jpg	1052301_00000078	1	1904156.582	596835.6483	195.6812036	3.70770	3.69230	91.13940	0

Corrected format should be in the following order:

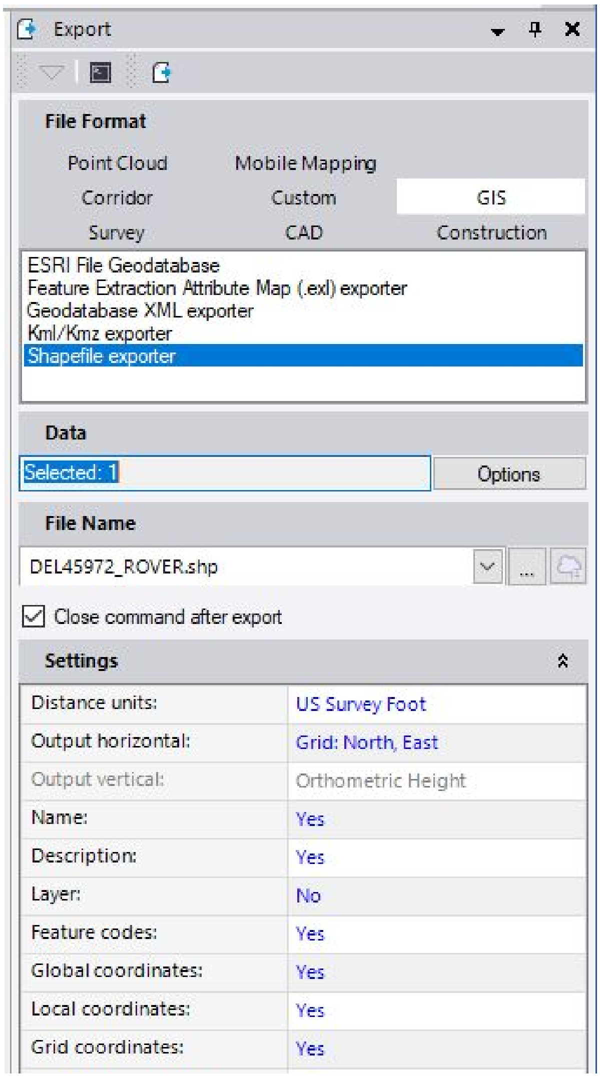
- **#image, Easting (X), Northing (Y), Elevation (Z), Roll, Pitch, Yaw**

This format is shown below:

	A	B	C	D	E	F	G
1	#image	x	y	z	roll	pitch	yaw
2	01_00000064.jpg	1903856.544	596764.3304	195.5070555	-11.13970	4.80810	70.45440
3	01_00000065.jpg	1903878.66	596771.6003	195.293899	-7.00420	1.98510	67.95610
4	01_00000066.jpg	1903900.547	596779.4887	195.1735952	10.41900	3.44240	73.23260
5	01_00000067.jpg	1903922.437	596786.0292	196.0666933	15.41080	2.12100	77.78440
6	01_00000068.jpg	1903944.304	596791.0641	196.9301468	5.60100	1.09470	80.40750
7	01_00000069.jpg	1903966.089	596795.4488	196.7277693	3.20190	1.99690	83.51150
8	01_00000070.jpg	1903987.812	596799.6366	196.8104931	1.40030	1.09970	86.82700
9	01_00000071.jpg	1904008.881	596804.0826	196.6043934	-1.80050	1.29940	83.45930
10	01_00000072.jpg	1904029.745	596808.8089	196.4279115	9.83970	5.12390	88.68770
11	01_00000073.jpg	1904050.574	596812.8597	196.8186467	7.00000	0.00000	83.99990
12	01_00000074.jpg	1904071.651	596816.3025	196.5441419	2.91490	5.79250	90.79470
13	01_00000075.jpg	1904092.634	596819.6824	195.8115272	-1.60230	3.09880	92.01340
14	01_00000076.jpg	1904113.897	596824.6607	195.2261822	8.21260	3.16730	87.85690
15	01_00000077.jpg	1904135.47	596830.0356	195.3639379	2.50840	4.69550	90.80570
16	01_00000078.jpg	1904156.582	596835.6483	195.6812036	3.70770	3.69230	91.13940

Export projection file from TBC for use in Pix4D

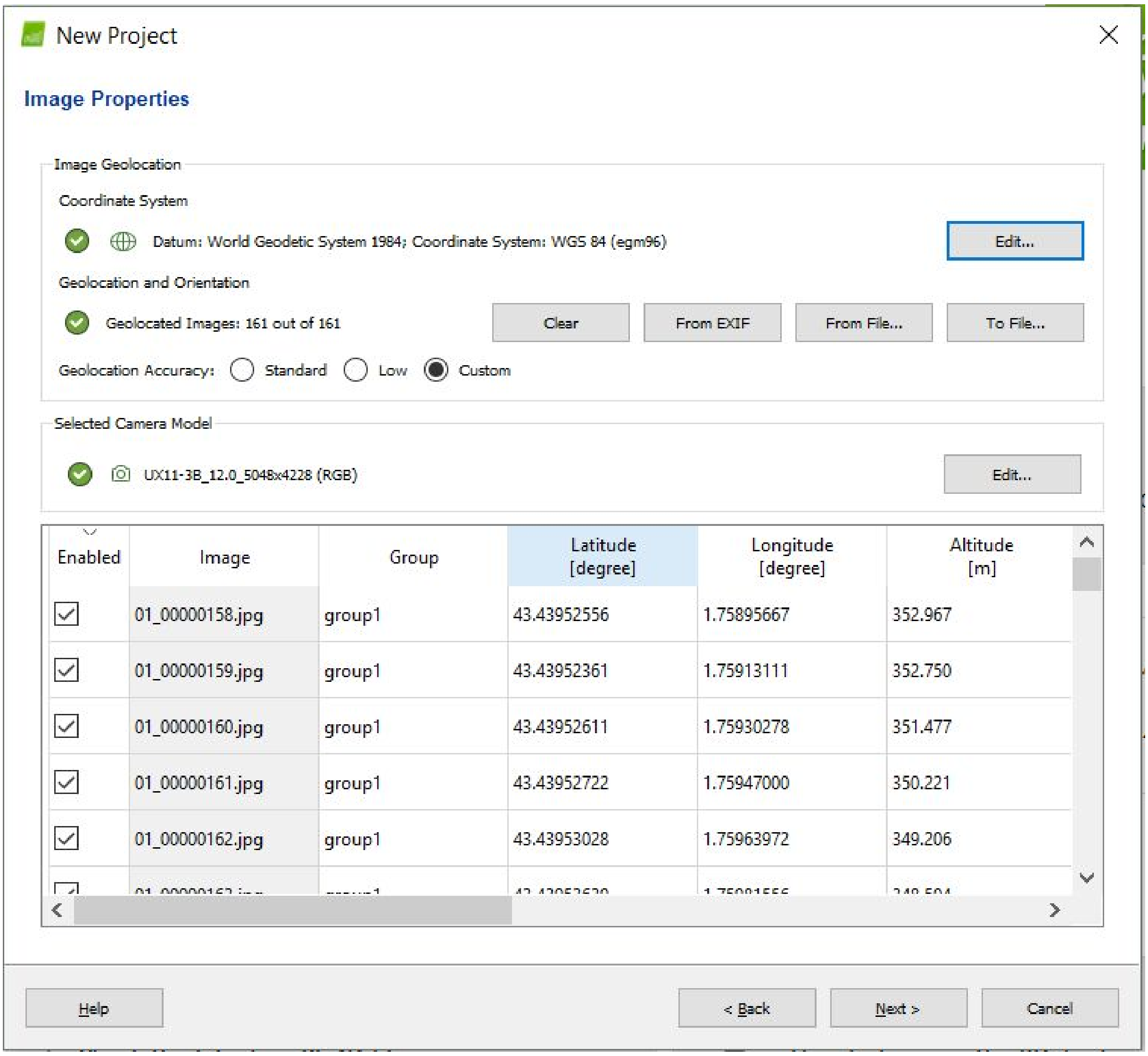
- Click on the *Data* toolbar in the ribbon of TBC
- Click on *Export*
- Under the GIS tab select *Esri shapefile exporter*
- It is not necessary to select all the features here as we are only after the projection (.prj) file, so you only need to select a single point from the dataset (e.g. the base point)
- Select a destination directory to save the file
- Set the output horizontal to the appropriate format.
  - For projected systems please select *Grid: North,East*
- Click *OK* to export



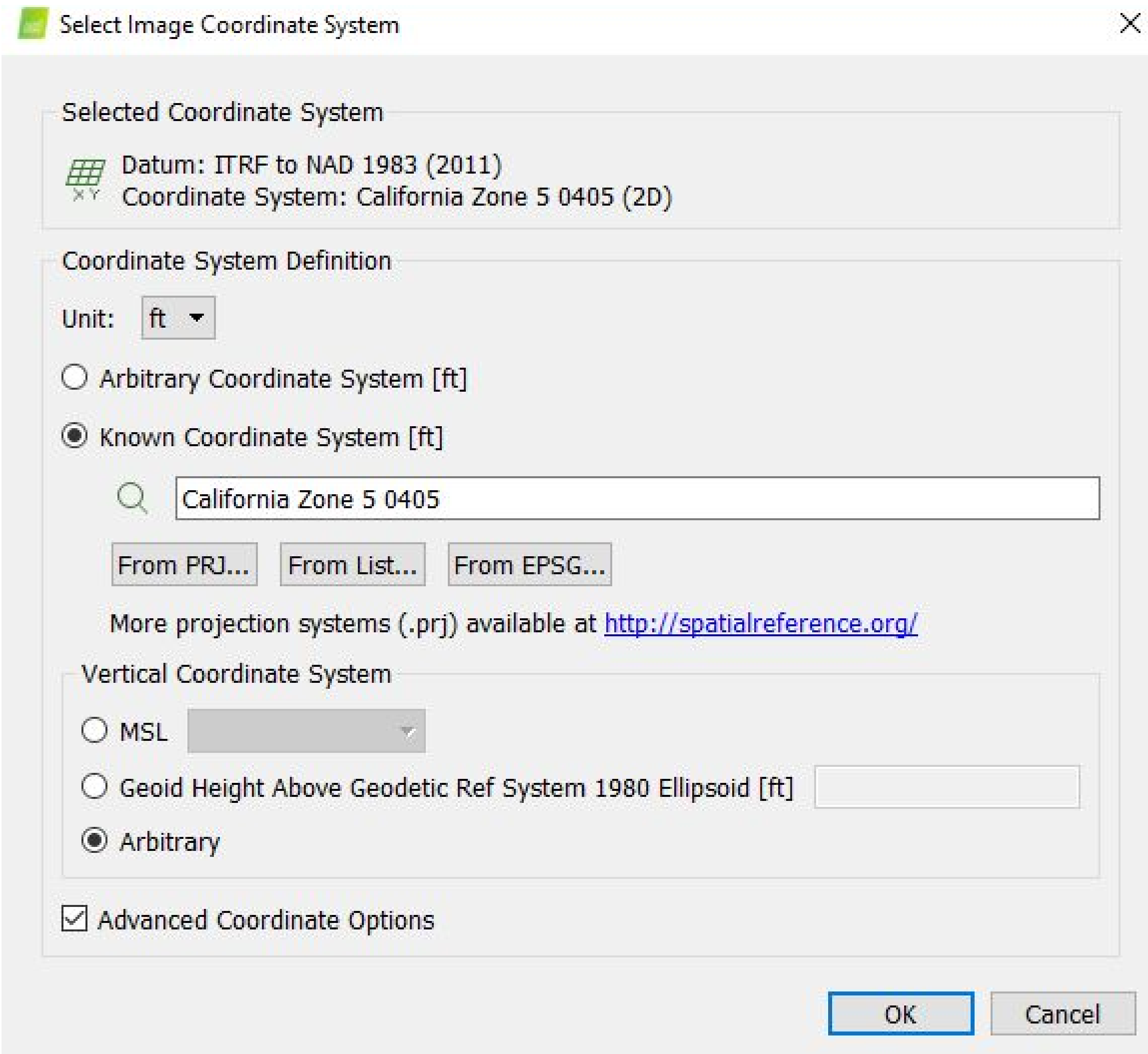
Project setup in Pix4Dmapper

Set up a new project in Pix4D using the flight mission and projection files exported from TBC. This helps to avoid incorrect transformations or coordinates from being used.

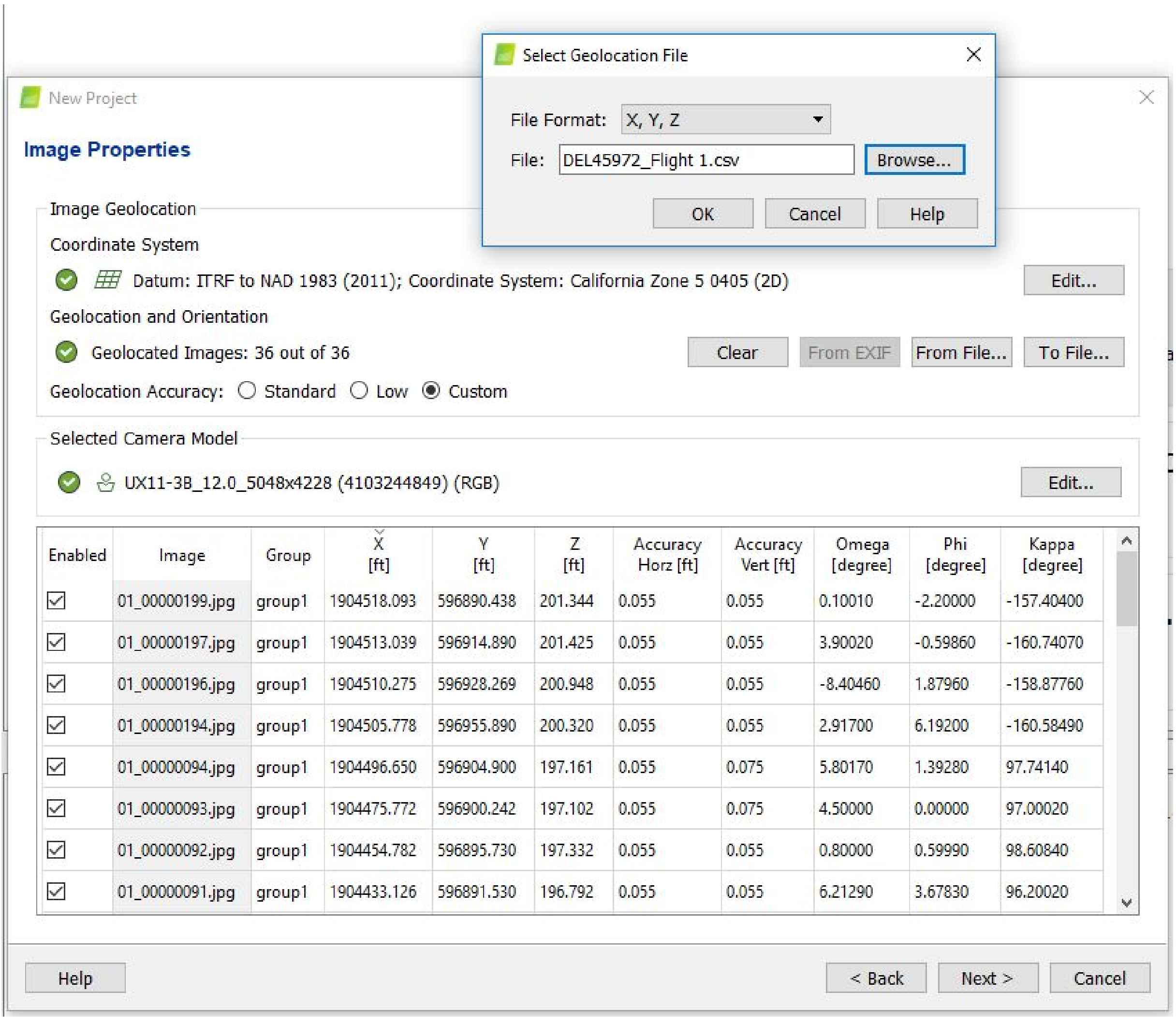
- Create a new project
- In the *Image Properties* window you must:
  - *Edit* the coordinate system
  - Import the geolocation of the images "*From File...*"



- In the *Select Image Coordinate System* window you must:
    - Select *Advanced Coordinate Options*
    - Select *Known Coordinate System*
        - Click on *From PRJ…*
        - Select the .prj file exported from TBC
    - Select *Arbitrary* for the vertical coordinate system



- In the *Image Properties* window you must:
    - Select *From File* under the geolocation and orientation sub-menu
    - Select *File Format* of X,Y,Z
        - Select the modified .csv file exported from TBC



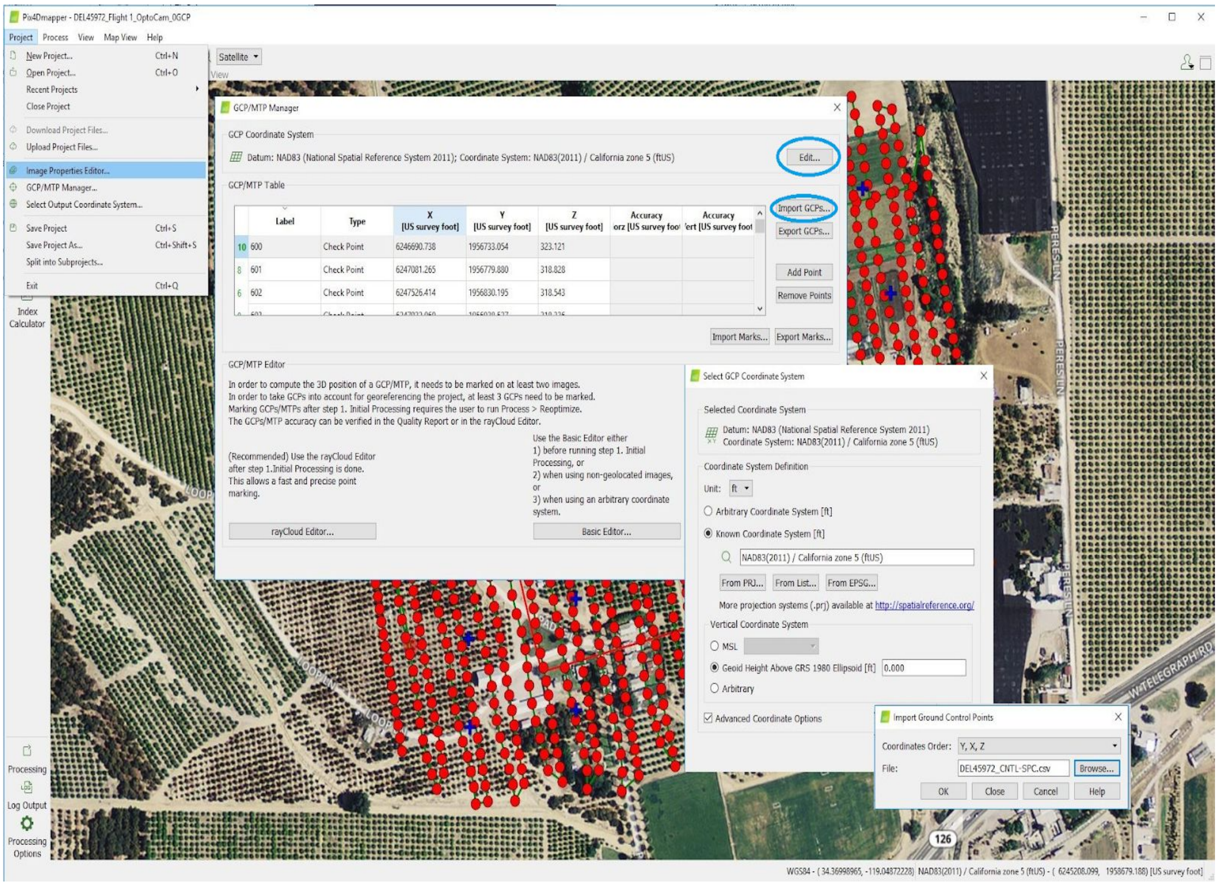
Note: You should verify the estimated image geolocation accuracies with those from the After Flight report generated in Section 5 of this document. If values are different please adjust accordingly.

Adding GCPs and checkpoints

Ground control points (GCPs) are used to georeference the model produced during the photogrammetry process. A minimum of three GCP's are required to scale, rotate and locate the model. GCPs improve the relative and absolute accuracy of the model.

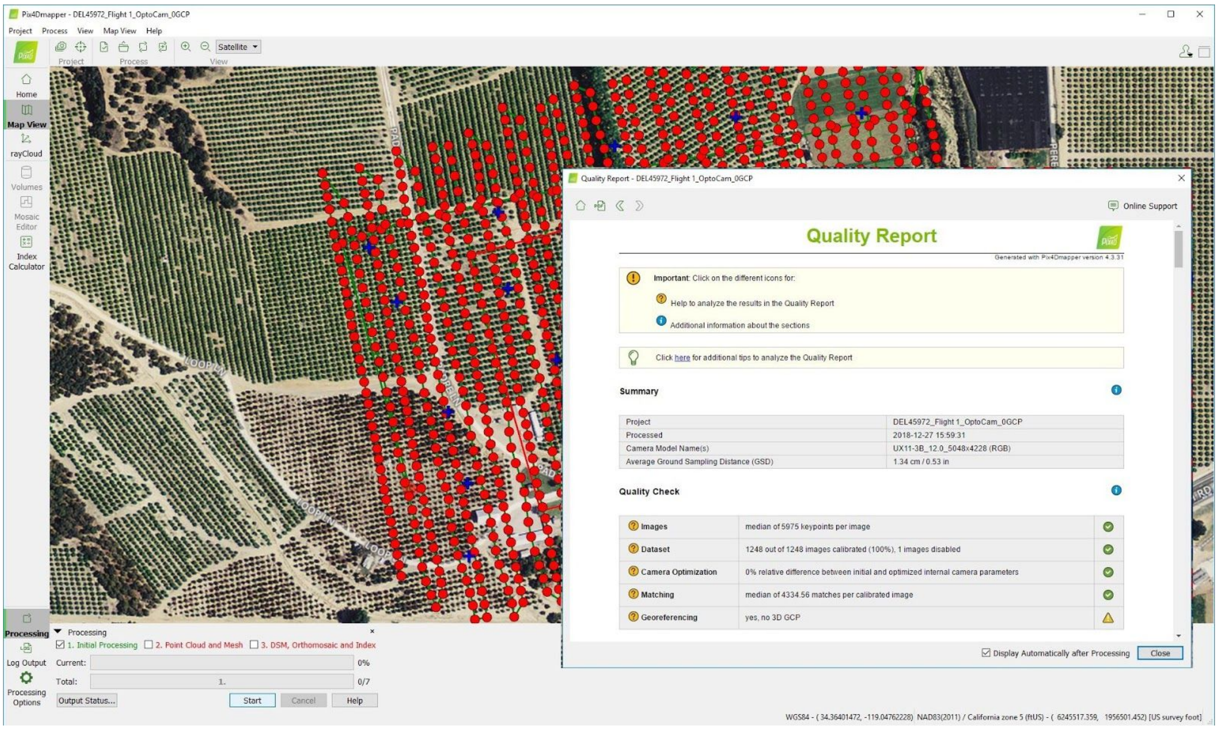
Checkpoints (CPs) are used to assess the absolute accuracy of the model. The marks of the checkpoints are used to estimate the initial 3D position within the model. The differences reported between the initial and computed positions help give an estimation of the absolute accuracy of the model in the general area of the Checkpoint.

- On the *Project* menu, select *GCP/Manual Tie Point Manager:*
    - If necessary, edit the coordinate system of the control points via the *Edit…* button
        - Default setting is based on the output coordinate system assigned during project setup
    - Select *Known Coordinate System*
        - Click *Advanced Coordinate Options*
        - Click on *From PRJ…*
        - Select the .prj file exported from TBC
    - Select *Arbitrary* for the vertical coordinate system
    - Add the control points
        - This can be done manually by selecting *Add Points* or from a CSV by using the *Import GCP…* button



Running Pix4D Initial Processing

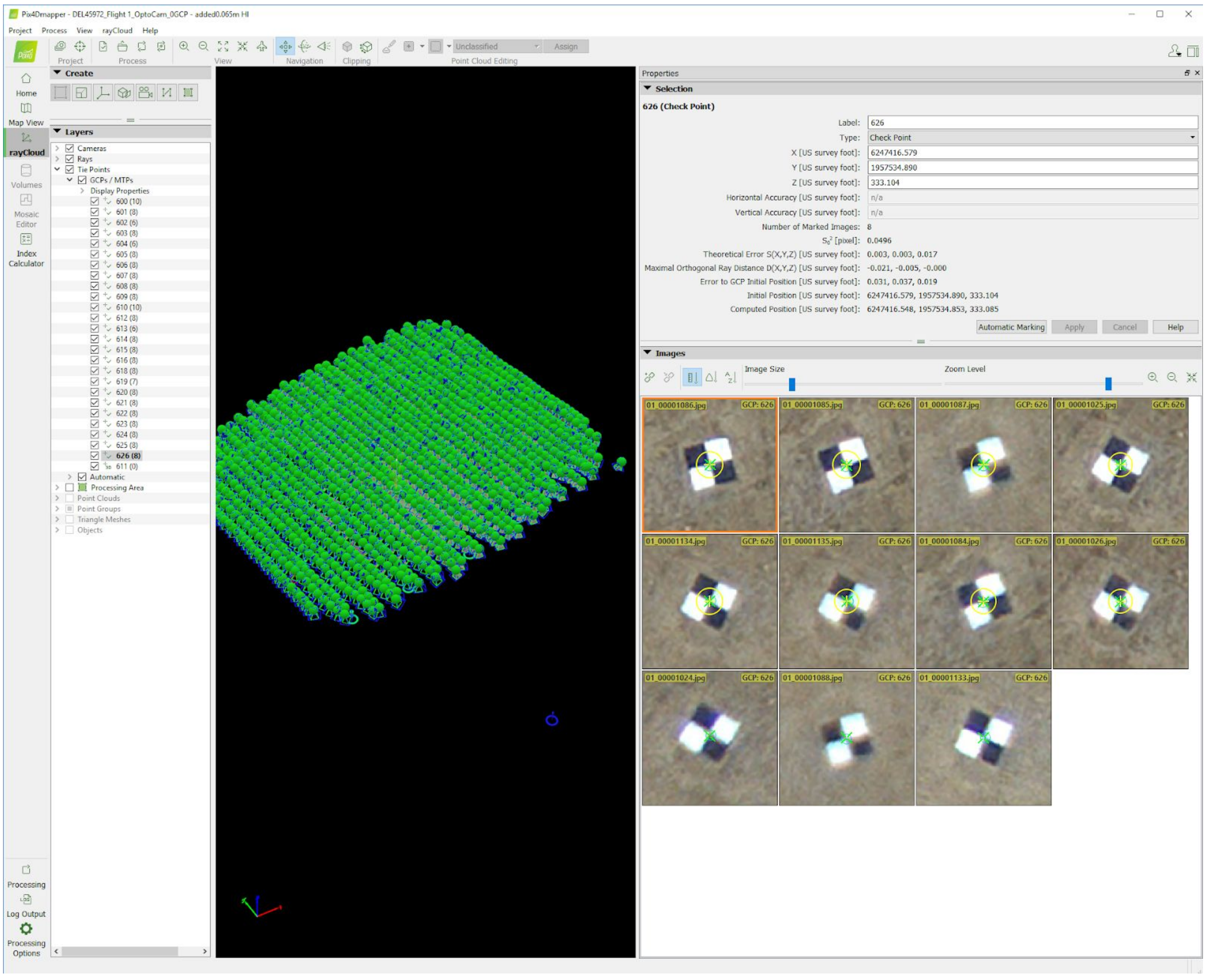
- The first step is to run the *Initial Processing*. Make sure that processing steps 2 and 3 are deselected as shown below.
- When this step is finished, a Quality Report will appear



Adding marks for GCP/CP using the rayCloud Editor

Marks associate the coordinates of a GCP or a CP with a visual mark on one or more photographs. Remember that GCPs improve the relative and absolute accuracy of the model while CP's help assess the absolute accuracy of the model.

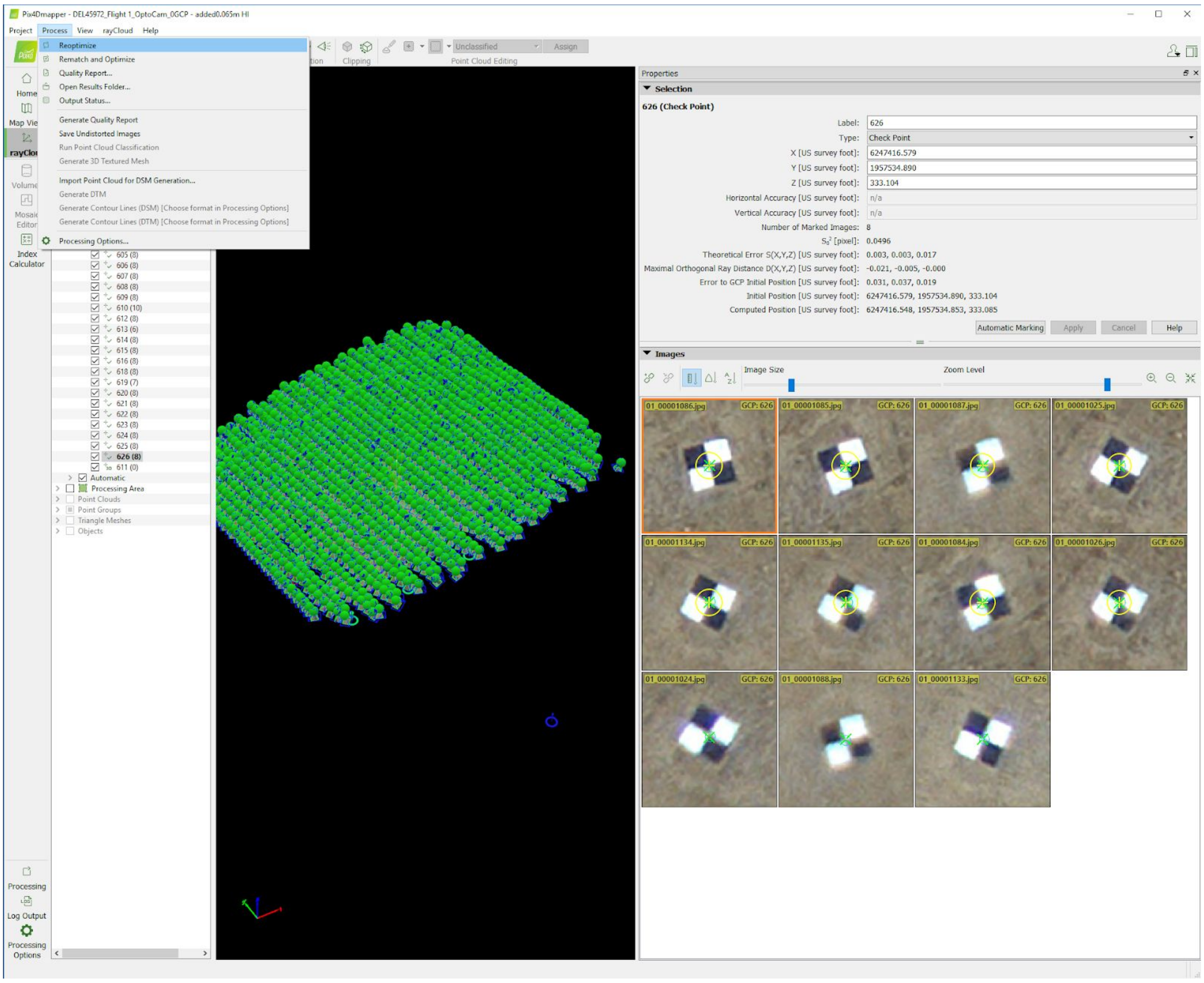
- On the *View* menu, select *rayCloud*, go to *Layers* and expand *Tie Points* until you see all GCPs/MTPs that have been imported.
  - Go through each of the GCPs in turn and mark the precise location of the ground marker.
  - The initial processing step will already have made preliminary marks of the GCP in the photograph and so the visual ground marker should be close by.
  - It is recommended to place a mark in a minimum of 5 images. Additional image marks may improve estimated accuracy.



Reoptimizing in Pix4D

Having marked each GCP/CP location in the photographs, the Pix4D project should now be reoptomized for better results.

- In the *Process* menu, select *Reoptimize*



You are now ready to complete the Pix4D processing of your UX11 PPK dataset. Should any questions arise during this the Pix4D process please refer to the software manual created during the installation of your software. Pix4D has an [extensive online forum community and help section](#) available directly through the the *Help* menu.