Measuring Accuracy of the DJI Mavic 3 Enterprise RTK using DroneDeploy Photogrammetry

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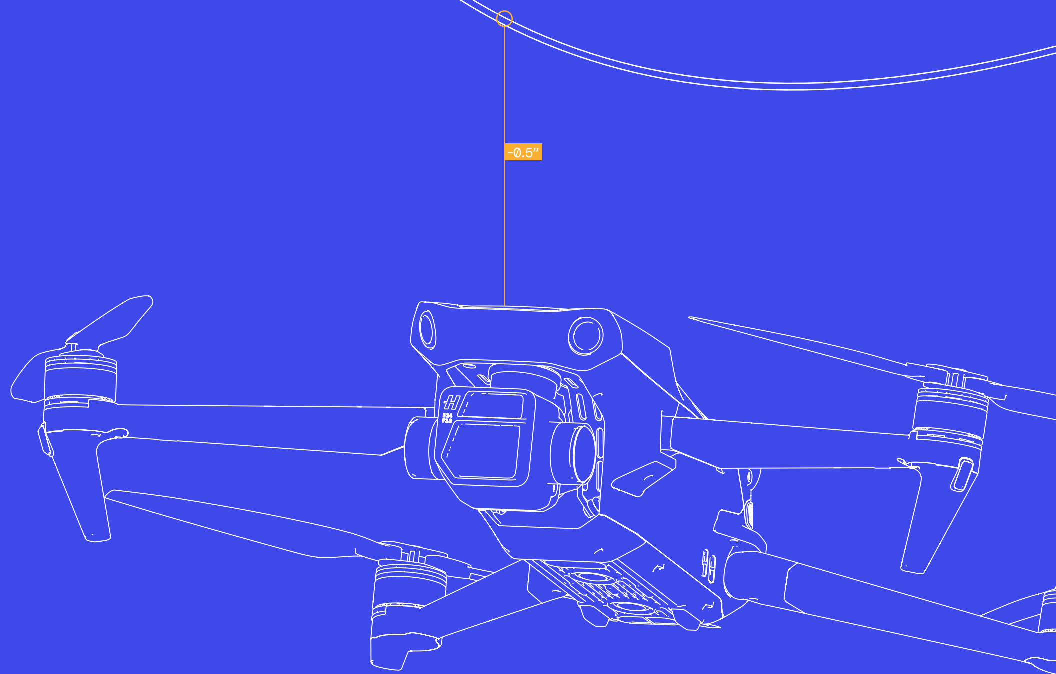
DroneDeploy



01 Abstract

Abstract

Ten years ago, drones were not widely used on job sites at scale. To early adopters, the value of drone data was clear, but it was difficult to capitalize on without a geomatics, surveying or aviation background. However, the hardware, software and regulatory environment has evolved substantially over the last decade. In the last five years alone, drone technology has reached mass adoption as companies have tested, evaluated and realized the value it can provide. For many companies, reality capture is now a fundamental pillar within their technology stack.

Drone photogrammetry is often used in reality capture to provide a holistic view of the built world. Photogrammetry involves making accurate, high-resolution 3D models of job sites using overlapping georeferenced photos, typically captured autonomously. These models often look lifelike and provide an entry point for non-technical individuals. There is also a high depth of analytics for those who want to understand progress over time, inspect, conduct QA/QC analysis, create designs and measure earthwork changes.

Due to the wide range of use cases and the speed and ease of autonomous capturing, drones can provide greater value than traditional capture methods such as ground based, surveying, laser scanning or mobile photos.

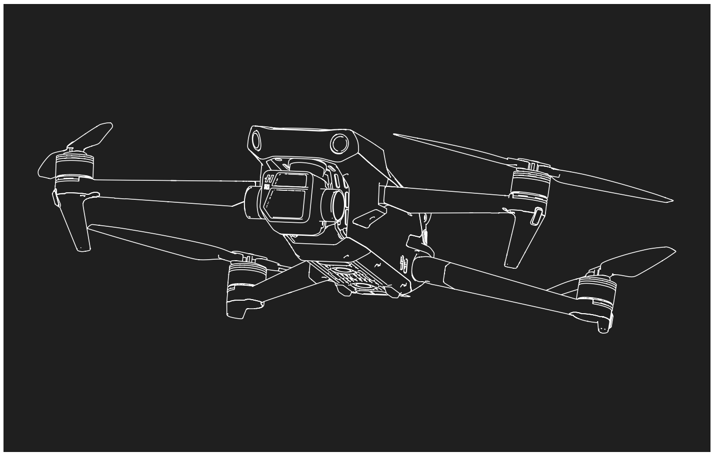
The proliferation of easy-to-use photogrammetry software and mature drone hardware has made it easier for companies to generate high quality data, even if they do not have a surveying background. However, there are still unanswered questions for companies seeking to adopt drone-based reality capture in their workflow, such as:

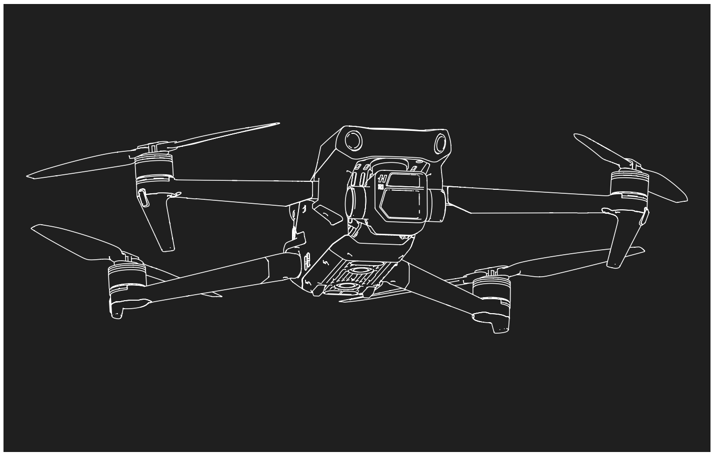
'What type of drone do I need to get?'

'What is RTK, and do I need it?'

'How accurate is this data?'

'What are GCPs, and how should I use them?'

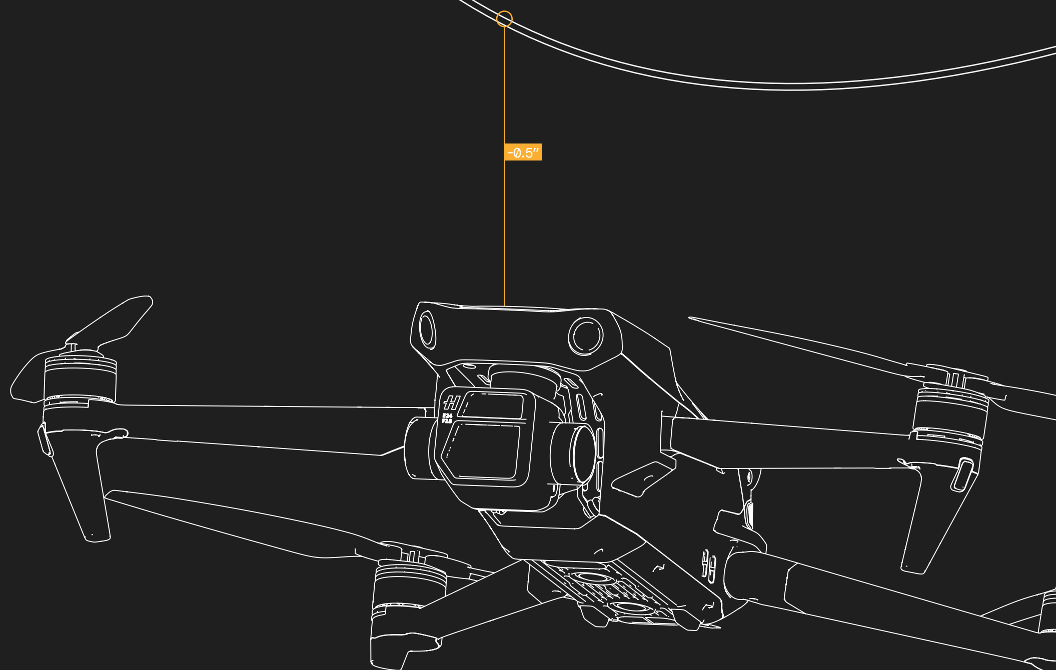




This whitepaper will provide answers to these questions, debunk common myths and validate findings around utilizing high accuracy drone data and photogrammetry.

We will evaluate the DJI Mavic 3 Enterprise RTK and Air 2S drones and observe the impact RTK, flight altitude, drone model and GCPs can have on map accuracy. We will also analyze the flight time, efficiency and measurement accuracy of the two drone models used with the DroneDeploy platform. Among our many findings, there is one clear standout result - we found consistent inch-level map accuracy with the Mavic 3 Enterprise RTK and DroneDeploy.

DroneDeploy



02

Introduction

Goals of this study

The goal of this study is to measure the positional and linear measurement accuracy of the DJI Mavic 3 Enterprise RTK (M3E). In addition to comparing the M3E against a control, we will investigate how flight altitude, GCPs and RTK can impact map accuracy. The results will help firms understand what workflows and methods are necessary to achieve desired levels of accuracy.

RC Pro Enterprise smart controller with Mavic 3 Enterprise RTK drone

Absolute vs relative accuracy

Map accuracy can be divided into two main categories: relative and absolute accuracy. The workflows required to generate good absolute or relative accuracy are different, as are the use cases. In this whitepaper you will see references to both, and the kind of accuracy you care about will depend on your use case.

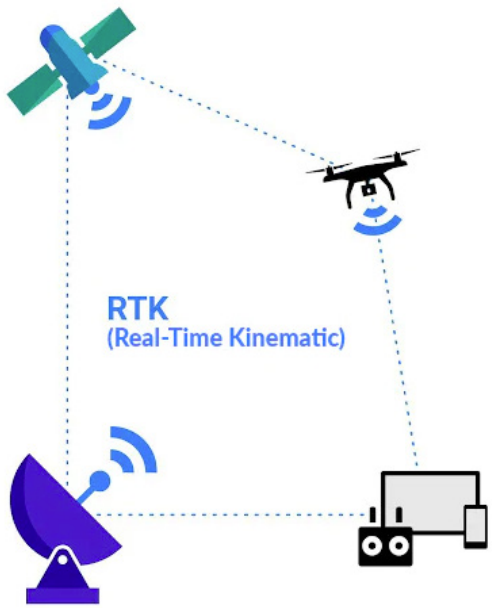
Relative accuracy describes how accurate points within the map are to each other. For example, the distance between two embeds on a job site is a matter of relative accuracy. Another example would be the volume of a stockpile. With relative accuracy, you can ignore where the map should be placed in the world, and you can focus on the scale, shape and size of the map. If you are only measuring values within a particular map, or you're comparing that map to an aligned PDF overlay, only relative accuracy is important. In this study, surface distance measurements are used to validate relative accuracy.

Absolute accuracy, sometimes referred to as global or positional accuracy, describes how accurately positioned the map is in the world compared to its actual real coordinates. For example, if a particular point on a map has been brought up to a final grade elevation you'll want to view the results in terms of absolute accuracy. If you're trying to accurately track change over time (especially for earthworks), compare it to other georeferenced data, or conduct surveys and engineering workflows, absolute accuracy will be very important. In this study, map checkpoint errors are used to validate absolute accuracy.

Ground Control Points (GCPs)

The most reliable and standard method of ensuring high absolute map accuracy uses ground control points (GCPs). GCPs are known positions on a job site that are measured with survey-level accuracy. The map is 'tied down' to these positions, similar to how push pins force a poster to stay on a wall.

A canvas marker or sticker, stenciled spray paint, or existing civil features can all be used as GCPs. The marker should be a flat surface big enough to see from the drone images, with a well-defined center point. The number and placement of GCPs will have a significant impact on map accuracy. You can find guidance on this topic in our DroneDeploy Academy High Accuracy Mapping Course.



RTK diagram

Example of a Ground Control Point (GCP) marker

Real-time Kinematic Positioning (RTK)

A drone with standard GPS, such as the DJI Air 2S or Phantom 4 Pro V2.0 will typically have at least a few feet of GPS error. It is possible to achieve inch-level map accuracy with one of these standard GPS drones by using GCPs. However, the reliance on GCPs for high absolute accuracy can be reduced or even removed if the drone itself is equipped with more precise positional capability.

Real-Time Kinematic (RTK) is the most commonly used workflow to generate high-precision positional data directly from the drone itself.

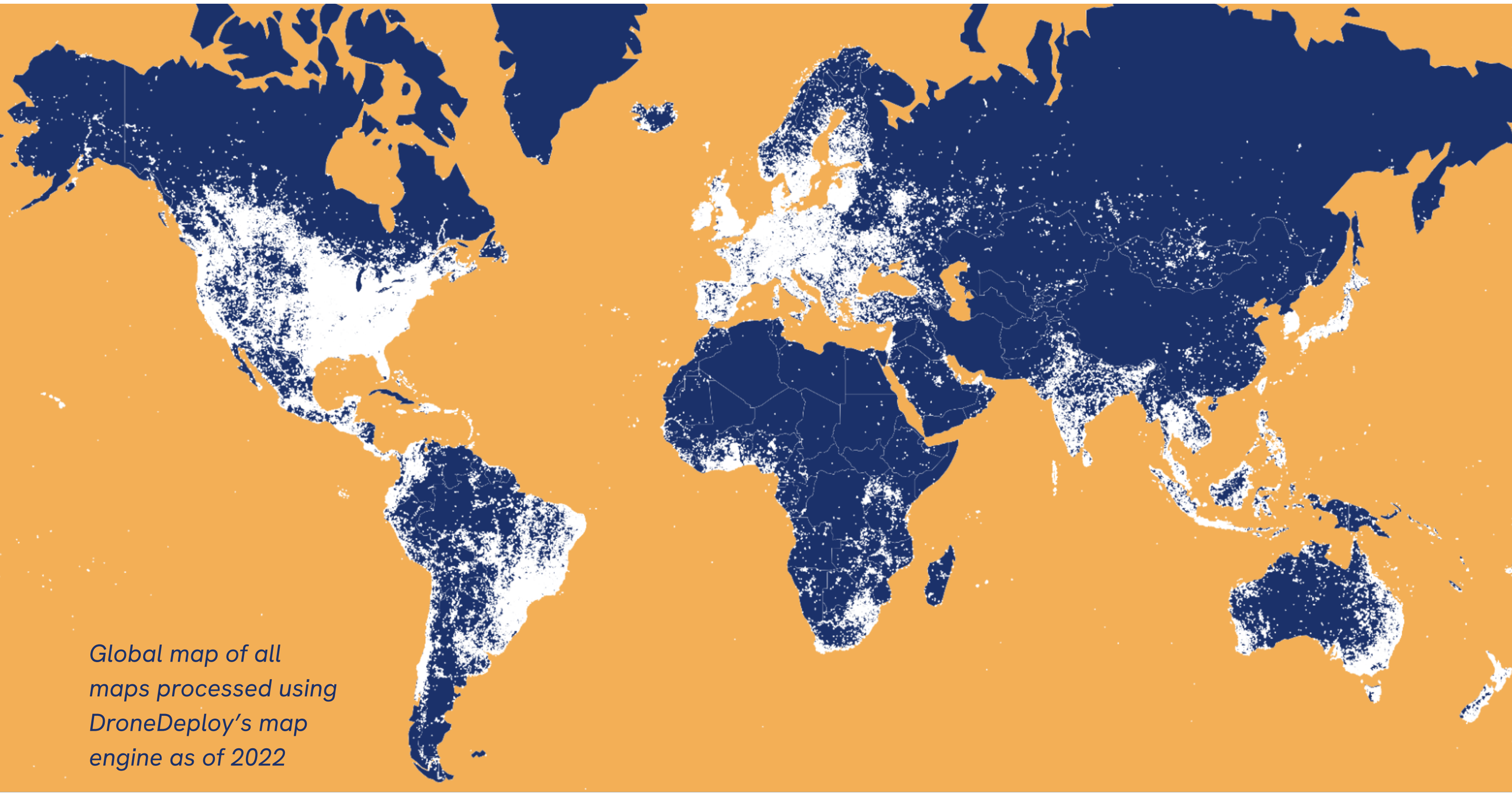
RTK works by having a source of corrections to 'double check' the position the drone thinks it is at. The corrections source can either be a physical base station set up on the job site, or a corrections network, which operates similarly to a cellular network.

By connecting to a corrections source, RTK drones can establish positions within inch-level accuracy, which makes creating high-accuracy maps easier than with a standard drone. There is nuance to what level of accuracy you can achieve with drone RTK maps without GCPs, and what that means for you in terms of GCPs and analysis use cases. That is a topic we hope to clarify in this whitepaper.

DroneDeploy Map Engine

Released in 2018, Map Engine is our in-house, cloud-based photogrammetry pipeline that processes all drone map data uploaded to DroneDeploy. Map Engine is capable of drag-and-drop processing for almost any set of georeferenced overlapping JPG images, allowing up to 10,000 images per map. Map Engine ingests standard RGB visible light photos, thermal radiometric, near-infrared and multispectral images. Map Engine can also accept RTK, PPK and GCP data for survey-grade data accuracy and validation. It's even capable of stitching real-time orthomosaics in-flight via DroneDeploy's Live Map workflow. With DroneDeploy's scalable cloud-based infrastructure, there's no need for users to rely on their own computing power. Users can process as much simultaneous data across their organization as needed.

Since 2018, Map Engine has processed 1.2 million maps covering a total of 310 million acres, which is approximately the size of the areas of Spain, Italy, Greece, the UK, Austria and Belgium put together. It is the most widely used cloud-based drone photogrammetry engine in the world.



Global map of all maps processed using DroneDeploy's map engine as of 2022

Drone models used in this study

DJI Mavic 3 Enterprise RTK

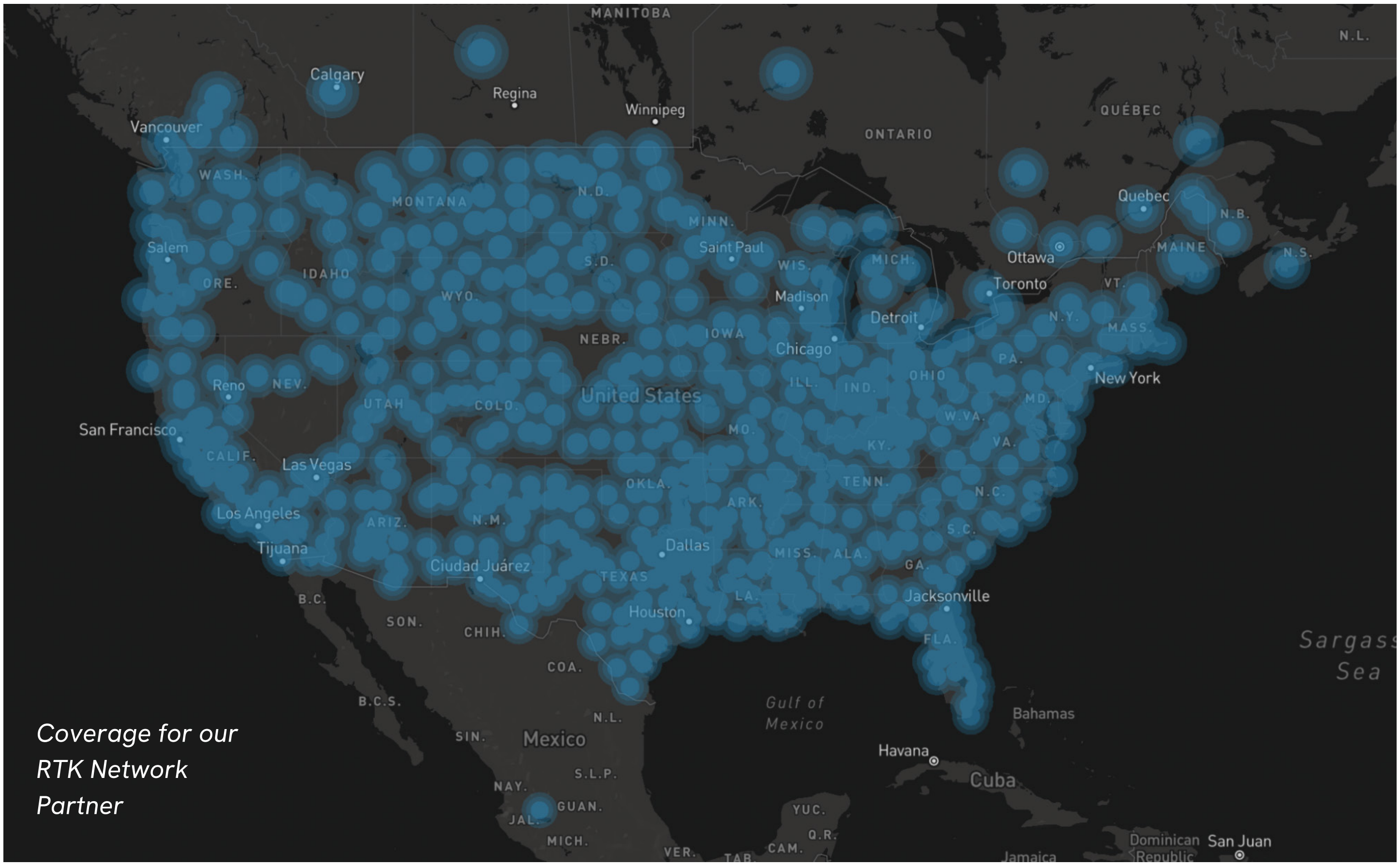
DJI Air 2S

The two drone models used in this study are the DJI Mavic 3 Enterprise RTK and DJI Air 2S.

The Mavic 3 Enterprise RTK (M3E), released in September 2022, uses RTK processing to produce highly accurate aerial maps. DJI claims up to 1 centimeter (cm) R TK horizontal positioning accuracy, and 1.5cm RTK vertical positioning accuracy, depending upon the correction source. The Mavic 3 Enterprise is equipped with a 4/3inch CMOS 20 megapixel mechanical shutter camera that minimizes photo distortion and allows for a fast 0.7 second interval between photos, over a maximum 45 minute rated flight time. Additionally, for inspection purposes (rather than photogrammetry) it has a 56x h ybrid zoom lens, making it a dual-purpose drone.

The Mavic 3 Enterprise is quite portable, weighing in at 2 lbs. It's capable of flying in temperatures between 14 and 104° F with winds of up to 26 MPH. It has a maximum rated flight time of 45 minutes. The M3E kit comes with the drone, smart controller, fast charger, hub charger and hard shell carrying case.

The DJI Air 2S will be used as a control in this study. The DJI Air 2S, released in April 2021, uses standard GPS to geotag its photos. It is equipped with a 1inch CMOS 20 megapixel rolling shutter camera. The Air 2S weighs in at 1.3 lbs and when folded would fit in a 7x4x3 inch box, making it highly portable. The Air 2S is rated to fly in temperatures between 32 and 104° F and winds of up to 24 MPH, and has a maximum rated flight time of 31 minutes.

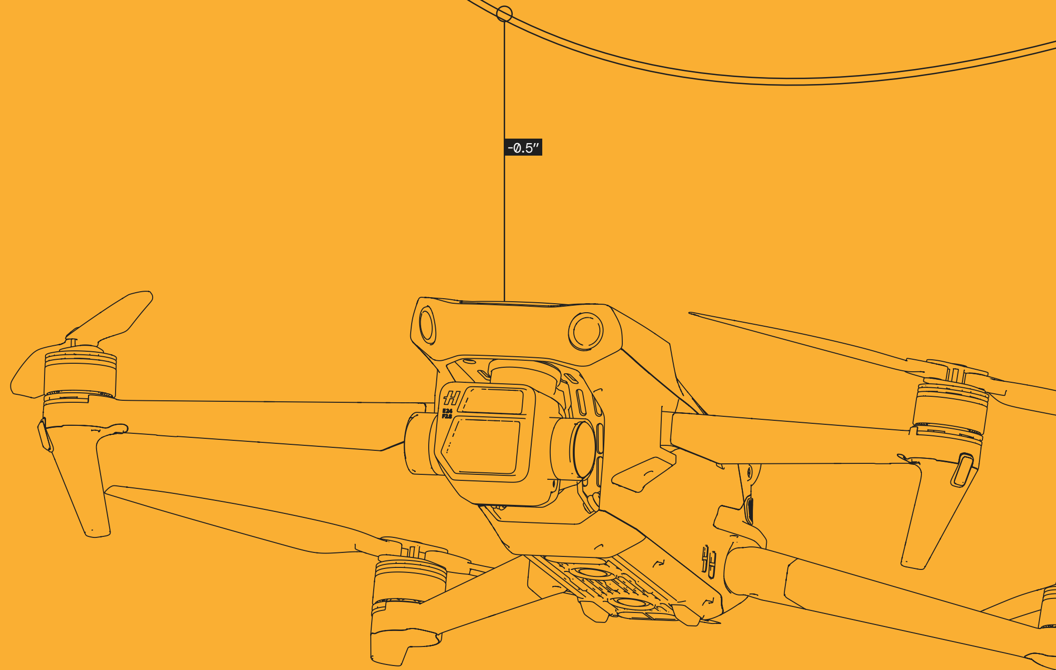


Coverage for our RTK Network Partner

Correction network used in this study

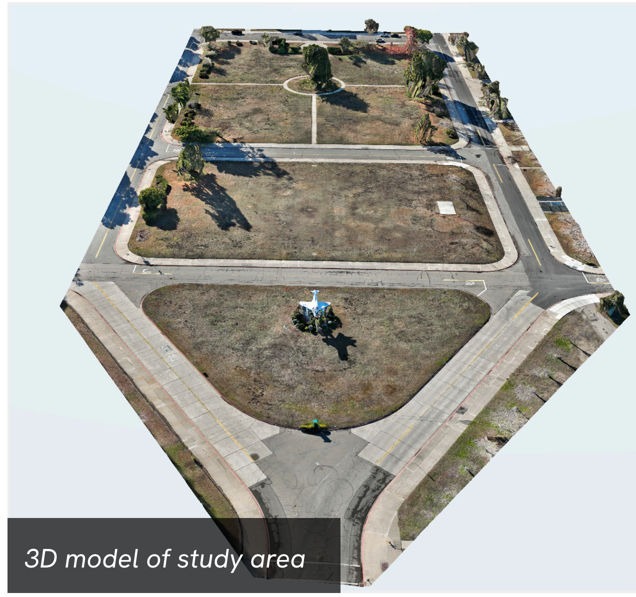
To achieve a centimeter-level geotagged accuracy, RTK drones require a source for corrections data. The M3E has the ability to connect to corrections networks or physical GNSS receiver base stations set up on site. A leading RTK corrections provider was used as the correction's source for the Mavic 3 Enterprise. This uses a dense network of hundreds of high-performance base stations and supports signals from all available satellite constellations, including GPS, Galileo, GLONASS and BeiDou. This workflow only requires an internet connection and that the job site be within the network coverage area.

03 Methodology



Site description

For this study, we selected a 20 acre site in a developed suburban environment. The area contains a mix of streets, sidewalks and grass surfaces. The location has a small elevation change, a moderate amount of trees and is surrounded by 1-2 story buildings. Here is a publicly-accessible share link to the entire set of maps in DroneDeploy.



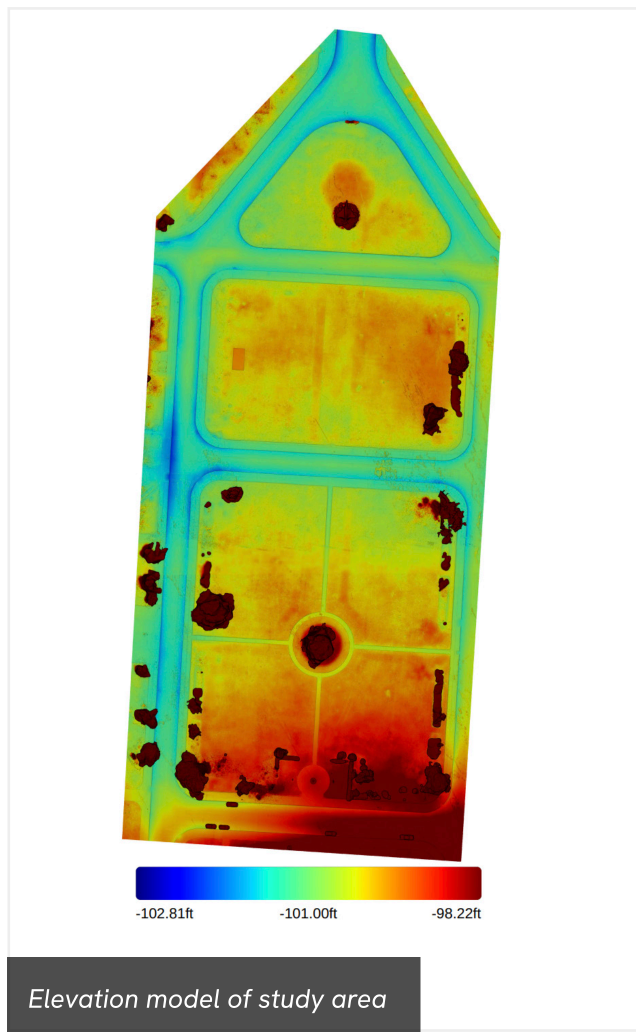
3D model of study area

GCP capture

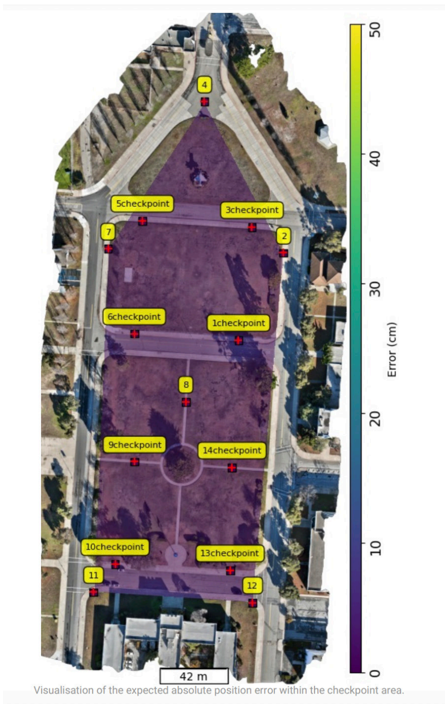
A series of 14 known points were established on hard surfaces across the site to either be used as ground control points (GCPs) or checkpoints. Both GCPs and checkpoints are single physical positions on a site that are measured with survey-grade accuracy.

These points differ in how they're used during the processing of a photogrammetry map. GCPs make your map more accurate, while checkpoints allow you to measure the accuracy of your map. GCPs are the foundation of high accuracy drone mapping, and it's just as important to use checkpoints to validate your map accuracy. You cannot use a GCP alone to measure map accuracy.

GCP placement is very important, as any map region that is substantially less physically constrained by and close to GCPs is at an increased risk for error. Therefore, the six GCPs (shown by markers 2, 4, 7, 8, 11, and 12) were established in an evenly distributed pattern across the job site. If you were to draw lines between the GCPs, you would see a symmetrical mesh of equilateral triangles. This is helpful in evenly reinforcing the accuracy of the map over the entire area.



Elevation model of study area



Visualization of the expected absolute position error within the checkpoint area

Checkpoints, on the other hand, do not impact the geometry of the map whatsoever. They are silent observers of map accuracy, so you cannot add any map error by incorrectly placing a checkpoint. The 8 checkpoints are placed evenly in all cardinal directions of the map to gauge accuracy across the entire area.

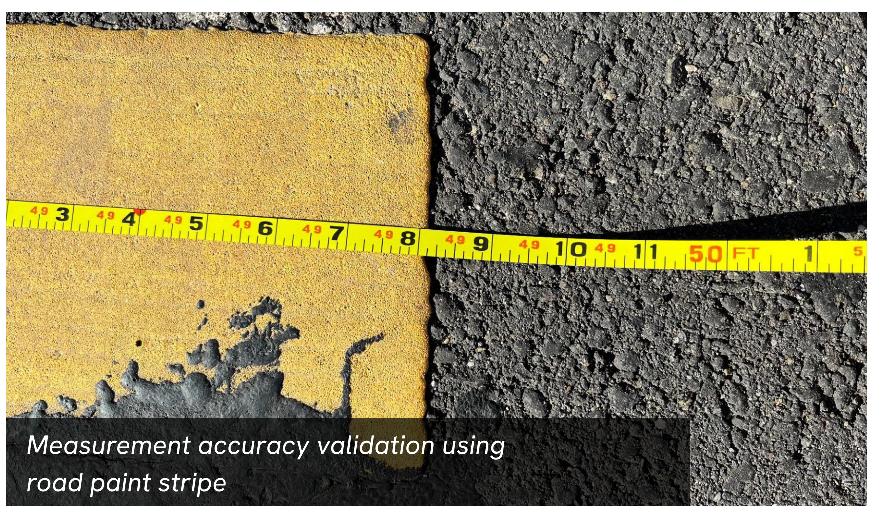
For maps that were processed without GCPs, the 6 noted GCPs were repurposed as checkpoints, creating a total of 14 checkpoints for those maps.

The 14 positions were all measured using an Emlid RS2, which is an RTK GNSS receiver that can be used for GCP surveying. The RS2 (and the newer RS2+) can be used as a base for the Mavic 3 Enterprise RTK, although that was not the workflow used in this study.

After receiving a 'Fix' solution, the measurement value for each GCP was averaged over 30 seconds. The average RMS error across all of the captured points was 1.02 cm.

Surface distance ground measurement

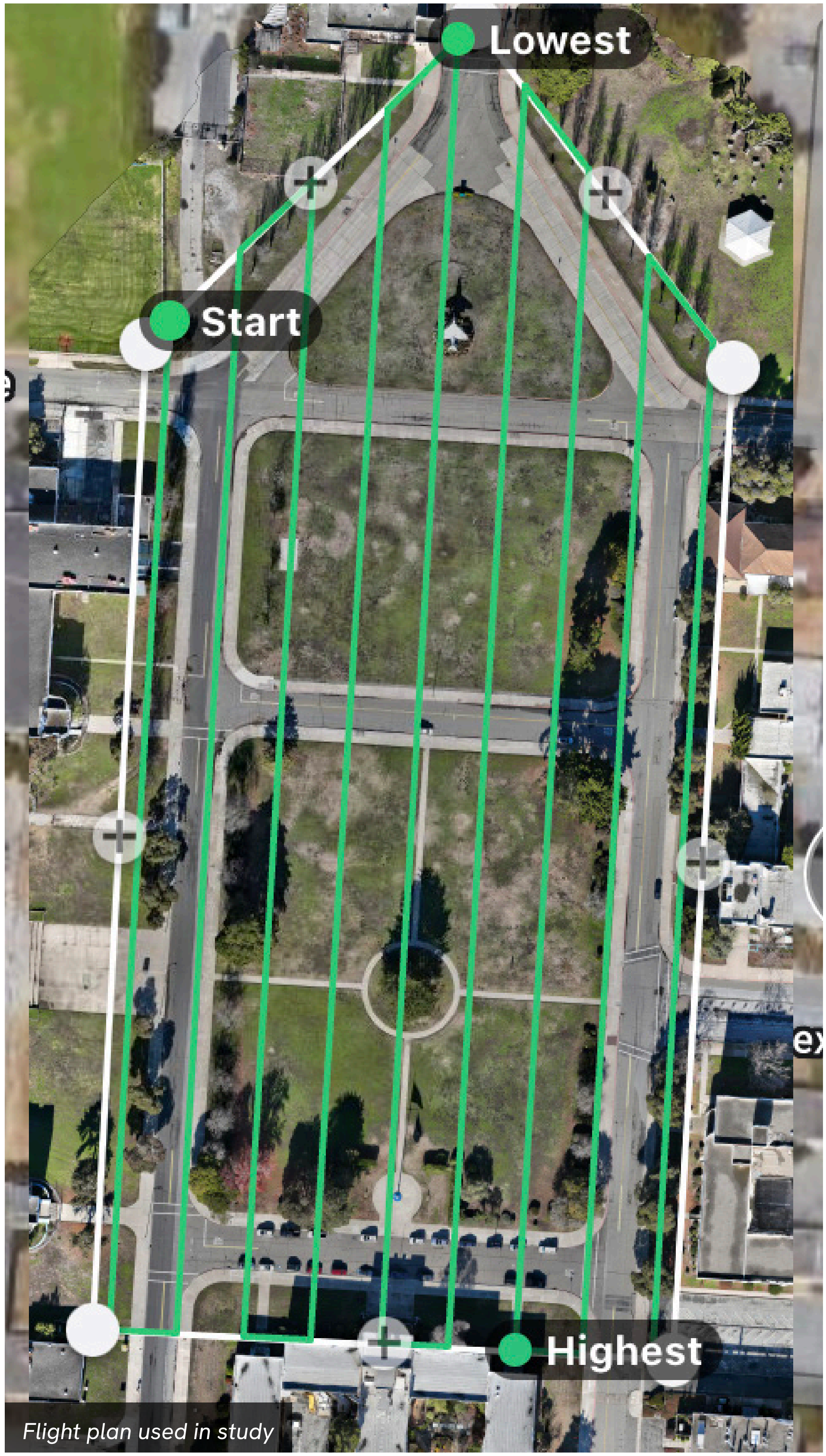
In addition to capturing known points on the ground, which is valuable for absolute map accuracy, linear surface distance measurements were taken to validate relative accuracy. A tape measure was carefully secured to one end of a road paint stripe and pulled to the other end, making sure the tape followed the road surface centered and parallel with the road stripe. The measurement photos are available in the linked project.



Measurement accuracy validation using road paint stripe

Flight plans

Two flight plans of the same boundary were established for this study. One was at 120 ft AGL, the other at 200 ft AGL. These altitudes were selected because they are within a standard range for high accuracy mapping. DroneDeploy's automatic flight settings were used for parameters such as overlap, which was kept at the default 75/65. The flight plans were in a simple lawnmower pattern, capturing all nadir photos which directly face the ground at 90 degrees. This flight plan was chosen because it is time efficient and yields accurate topographic maps. We conducted a total of four flights for each map type to ensure statistically significant findings.



Flight plan used in study

Map processing, GCP tagging and analysis

Over the course of two weeks, we flew a total of 30 drone maps processed with and without GCPs, for a total of 60 maps. You can find the raw data from these flights in this spreadsheet.

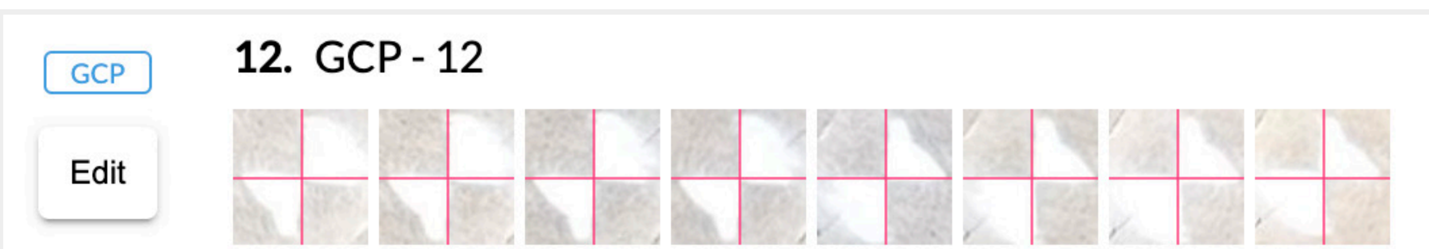
There were no subsequent attempts to improve a map after it was first processed. Below is a breakdown of all of the maps that were processed.

Map Type	Round 1	Round 2	Round 3	Round 4
Air 2S 120 GCP	Nov 27, 2022	Nov 28, 2022	Nov 29, 2022	Nov 30, 2022
Air 2S 120 Non GCP	Nov 27, 2022	Nov 28, 2022	Nov 29, 2022	Nov 30, 2022
Air 2S 200 GCP	Nov 27, 2022	Nov 28, 2022	Nov 29, 2022	Nov 30, 2022
Air 2S 200 Non GCP	Nov 27, 2022	Nov 28, 2022	Nov 29, 2022	Nov 30, 2022
M3E 120 RTK GCP	Nov 27, 2022	Nov 28, 2022	Nov 29, 2022	Dec 2, 2022
M3E 120 RTK Non GCP	Nov 27, 2022	Nov 28, 2022	Nov 29, 2022	Dec 2, 2022
M3E 200 RTK GCP	Nov 27, 2022	Nov 28, 2022	Dec 2, 2022	Dec 2, 2022
M3E 200 RTK Non GCP	Nov 27, 2022	Nov 28, 2022	Dec 2, 2022	Dec 2, 2022
M3E 120 no RTK GCP	Nov 22, 2022	Nov 28, 2022	Nov 29, 2022	Dec 12, 2022
M3E 120 no RTK Non GCP	Nov 22, 2022	Nov 28, 2022	Nov 29, 2022	Dec 12, 2022
M3E 200 no RTK GCP	Nov 22, 2022	Nov 29, 2022	Nov 30, 2022	Dec 12, 2022
M3E 200 no RTK Non GCP	Nov 22, 2022	Nov 29, 2022	Nov 30, 2022	Dec 12, 2022

Dates of each flight used in study

To process both GCP and non-GCP maps, tagging is a required step. Tags are still required for non-GCP maps because all of the points were used as checkpoints for those maps, and checkpoints require tags just as GCPs do. Conceptually, the tagging step in a photogrammetry workflow creates the connection between your images and GCP data.

In DroneDeploy, GCP tagging is a process done partially through automatic computer vision tagging. After the system attempts to auto-tag the GCPs, the user is asked to confirm those tags and adjust if necessary. Below is an example of an accurately tagged GCP. The center of the GCP is precisely marked across all of these views. All GCPs and checkpoints were tagged with at least seven clean views. Once the tags are all submitted, the map will finish processing and complete.



Tagging GCPs in DroneDeploy

Checkpoint Label	X Error (in)	Y Error (in)	Z Error (in)
1checkpoint	-0.5315	0.0945	0.6772
3checkpoint	-0.3150	-0.3740	-0.0433
5checkpoint	-0.4291	-0.4409	0.1890
6checkpoint	-0.2992	0.3780	-0.0906
9checkpoint	-0.0000	-0.5472	-0.1260
10checkpoint	-0.5669	-0.0039	-0.0984
13checkpoint	0.0079	0.3740	0.1969
14checkpoint	0.1417	0.0118	-0.2402
Total (RMSE)	**0.3530**	**0.3401**	**0.2798**

Checkpoint geolocation error from DroneDeploy map processing report

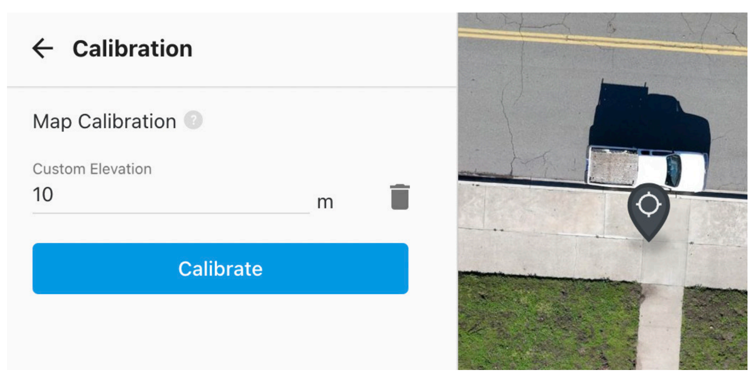
For every completed map in DroneDeploy a detailed map processing report is available in the 'Map Details' section. The map processing report contains checkpoint error values that are automatically computed based on tags. These checkpoint errors (not to be confused with GCP errors) are true measurements of map positional accuracy. You'd find the same errors if you manually checked the values of the known points on the map and compared those numbers to the recorded survey values.

For our major findings section, when we say that the average positional accuracy was a certain value, we are describing the average checkpoint errors across all four rounds for that map type.

For non-GCP maps, the absolute Z values often have a consistent offset from the true value. The Air 2S and M3E non-RTK give elevation values that could be considered arbitrary. The M3E with RTK does give fairly consistent elevation values, but a mediocre RTK connection will typically increase Z errors more than XY.

The issue of low absolute precision in the vertical for non-GCP maps is easily addressed using the Elevation Calibration tool in DroneDeploy. This was used in the map processing workflows.

In the 'Map Details' section, if you calibrate the map to any single known point in the area, you can set the elevation values to what you know they should be. For example, if a position on a map currently reads 100 ft, but you know it should be 150 ft, you would enter '150' into the Elevation Calibration tool. All map elevation values would then increase by the difference - in this case, 50 ft.

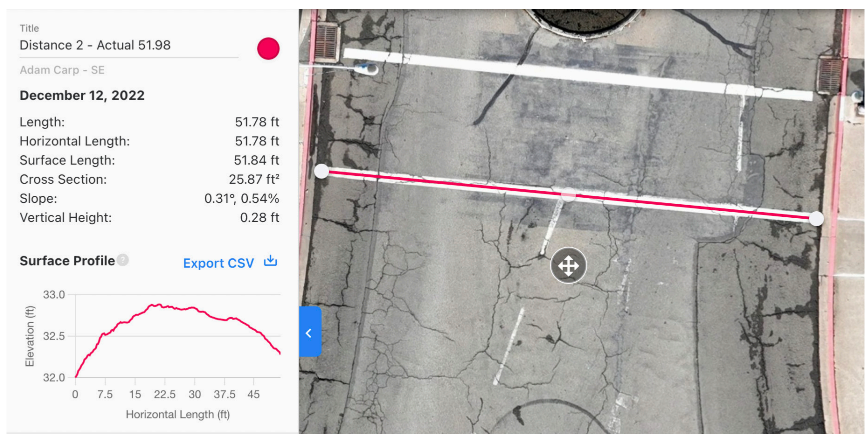


DroneDeploy's elevation calibration tool

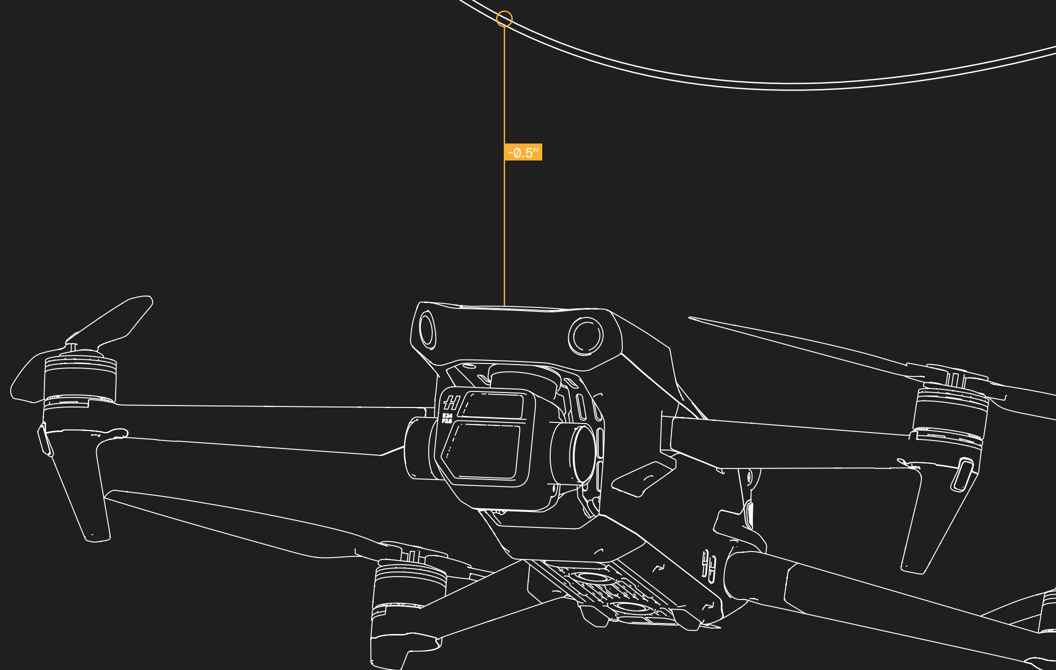
In the ‘Key Findings’ section, if you see a reference to a post-calibration error, this means that the Z error ultimately computed is a post-calibration error. The amount of elevation shift that the calibration created was subtracted from the checkpoint error in the map processing report. The same central calibration point was used for every single map that was calibrated.

Lastly, five manual surface distance measurements per-map were manually clicked to assess the relative accuracy of the maps. Just like the absolute accuracy data, the relative accuracy data is an average of each map type across all four rounds.

Manual surface distance measurements



Example of distance annotation in DroneDeploy



04 Key Findings

Absolute accuracy

Absolute accuracy describes how precisely positioned a map is in the world compared to the site's real-world placement. It is critical for surveying, cut fill and consistent change over time analysis. We explore this topic in this section by providing checkpoint errors to validate map accuracy. Absolute accuracy is less critical for single-date measurement or compare-to-PDF design plans, as that is the domain of relative accuracy. Relative accuracy is fully explored in Graphs 7 and 8.

Highlights:

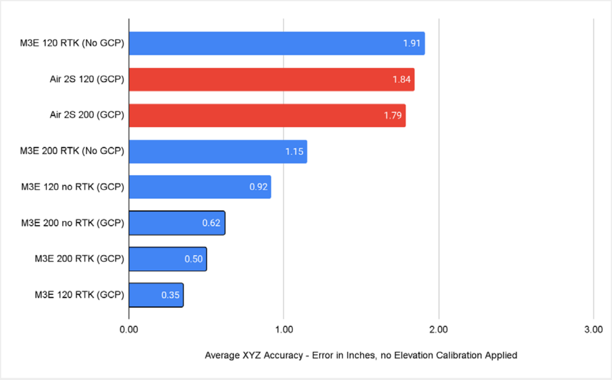
1.1 Using the M3E with GCPs will generate average map error below 1 inch, with or without RTK

1.2 The Air 2S with GCPs showed an average map error below 2 inches

2.1 The Mavic 3 Enterprise generates 3X less map error than the Air 2s

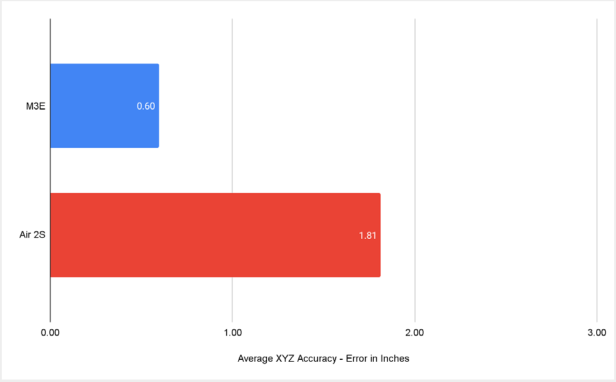
Graph 1: GCP and RTK maps - absolute accuracy

In Graph 1, which includes all maps that use at least GCPs or RTK, the average uncalibrated map error across all four rounds is displayed. This demonstrates how far 'off' an average point on the map is compared to its true position. A smaller value means better accuracy.



Graph 2: GCP maps - absolute accuracy, by drone type

In Graph 2, we focus on a comparison of all Air 2S and M3E maps that use GCPs. The M3E data includes RTK and non-RTK missions, so within the M3E error are multiple capture methodologies, and the Air 2S just includes standard GCP flights at both altitudes.



1.1

Using an M3E with GCPs between 120 and 200 ft results in average absolute errors below 1 inch

Whether RTK is enabled or disabled, and at both altitudes flown, the average map error for all M3E maps that used GCPs was below an inch. Using GCPs is the most reliable method to increase the absolute accuracy of drone maps, provided they are appropriately placed and captured. The camera, telemetry and positioning system on the M3E is designed with high accuracy in mind, so it is logical that using the M3E with GCPs yields quality accuracy.

Using an M3E with RTK and GCPs yields average errors below 0.5 inches

The accuracy that GCPs provide for drone maps is complemented by drone RTK corrections. The closer to a GCP an image was captured, the more confident we can be about where that photo was taken in reality. RTK on the drone allows DroneDeploy to stay more confident about where each photo was taken, even photos that are taken relatively far from a GCP. In this case, high accuracy technology (GCPs and RTK) together yielded errors comfortably under an inch.

Using an M3E with GCPs and without RTK yields average errors below 1 inch

Given a consistent 'mesh' of GCPs throughout the site, even without drone RTK corrections, the map accuracies on average are sub-inch. This shows that the M3E still provides accuracy value even when RTK corrections are not possible. When RTK is not enabled, the M3E generally reported GPS accuracy between 7 and 10 ft, compared to approximately 30 ft from the Air 2S.

M3E RTK non-GCP maps showed average errors between 1 and 2 inches

With a good RTK connection signal, most non-GCP RTK maps show errors close to GCP maps, below 1 inch. When there is a substandard RTK connection, we observe the Z errors increasing by a largely consistent offset. For example, the largest average Z error for RTK non-GCP maps within this whitepaper was 6.83 inches for M3E 120 RTK (Round 2). This error can be almost completely removed, bringing the error down comfortably below an inch, by using an Elevation Calibration in DroneDeploy after processing. Graph 5 will show this in greater detail and provide specific recommendations and analysis on non-GCP RTK map accuracy and calibration.

1.2

Using an Air 2S with GCPs between 120 and 200 ft yields absolute errors below 2 inches

The Air 2S shows an average map error below 2 inches. Given the affordability of the drone, this will still be valuable to many use cases and site teams, particularly for earthworks analysis, compare-to-design and as-built creation.

2.1

The Mavic 3 Enterprise generates 3X less map error than the Air 2S

As shown in Graph 2, when averaging all M3E RTK/GCP and all Air 2S GCP maps into a single statistic, M3E maps have about 3x less map error than the Air 2S. However, that does not mean that your insights and measurements will all be 3x more accurate. Instead, the results will vary depending on the type of measurement or analysis you're conducting, as demonstrated in the next section of this whitepaper, which covers relative measurement accuracy.

Impact of GCPs on accuracy

GCPs are integrated with the drone images within the processing workflow, and are used as known points to position the maps accurately. They are the standard workflow for precision drone mapping, and their impact is explored in this section by providing averaged checkpoint errors.

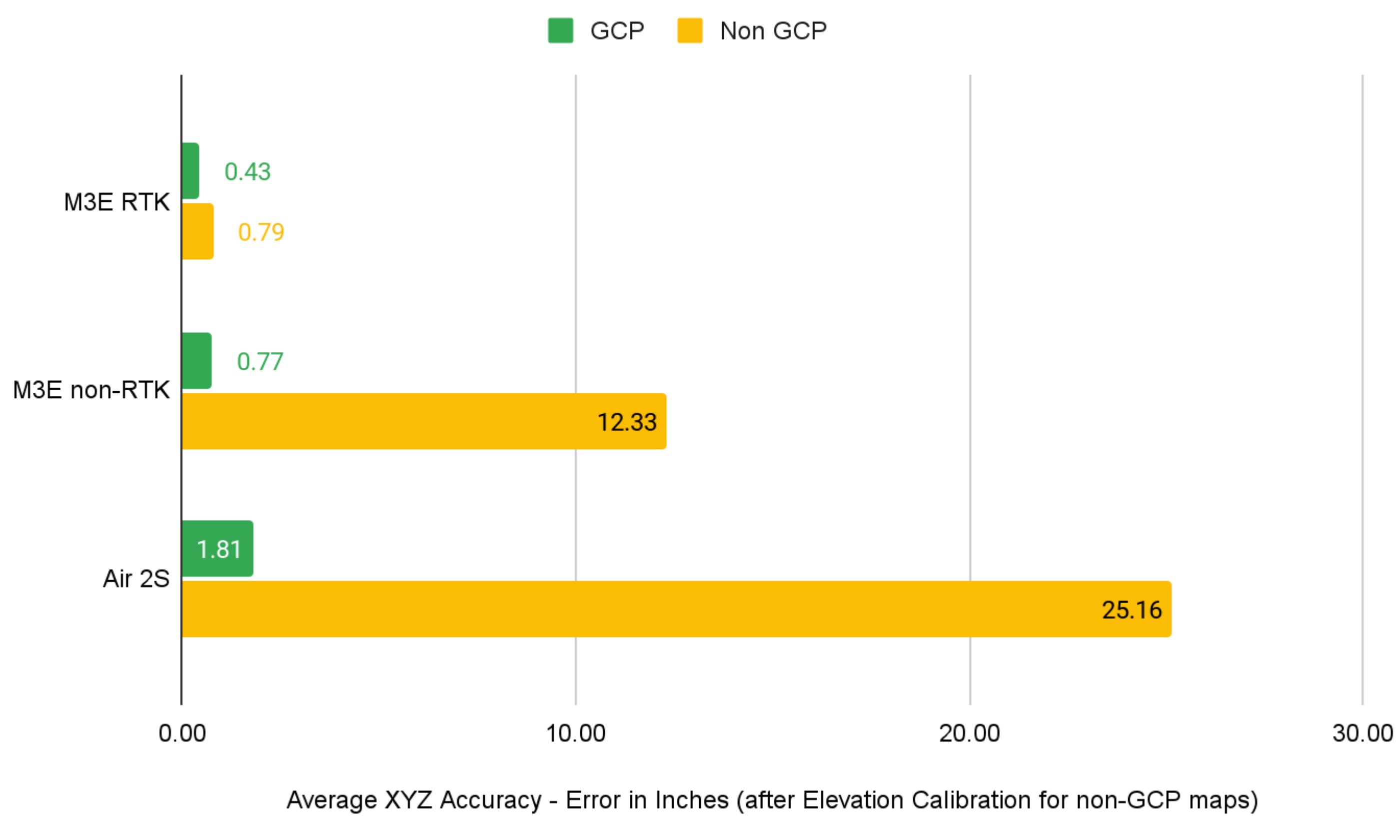
Highlights:

3.1 GCPs improve absolute accuracy for non-RTK maps by over a factor of 10

3.2 GCPs notably improve RTK map accuracy only when RTK corrections are not ideal

Graph 3: All maps - absolute accuracy, by drone type and GCP usage

In Graph 3, for all maps, the average map error across all four rounds is displayed. This demonstrates how far 'off' an average point on the map is compared to its true positions. If a map does not use GCPs, an Elevation Calibration has been applied.



3.1

GCPs improve absolute accuracy for non-RTK maps by over a factor of 10

As expected, GCPs make a substantial improvement in absolute accuracy to non-RTK maps, improving accuracy by over a factor of 10. Air 2S and M3E non-RTK drones report their positional accuracies between approximately 10 - 30 feet. That much error necessitates more precise positional data if high-accuracy analysis is required, and GCPs provide that function, bringing errors down from 1 - 2 feet (after Elevation Calibration) to below 2 inches.

3.2

GCPs notably improve RTK map accuracy only when RTK corrections are not ideal

On average, adding GCPs to M3E RTK maps increased the accuracy by about a third of an inch, which is a small unit of distance, but a large percentage increase. That increase in accuracy is arguably non-impactful to most project teams. However, that statistic is an average. Round #2 M3E RTK at 120 ft was corrected by over 6 inches by adding GCPs. The degree to which GCPs will improve RTK map accuracy is primarily determined by the quality of the RTK corrections on the drone. A poor RTK connection may require GCPs to shift the map by quite a bit, but a strong RTK connection may only mean that GCPs move the map by fractions of an inch. Because RTK connection quality cannot always be predicted, this demonstrates that GCPs should still be used with RTK maps if it is important that the absolute accuracy of the map is as assured as possible. An Elevation Calibration may suffice in lieu of GCPs, which is explored in the next Graph.

With proper GCP Placement, M3E RTK vs non-RTK maps did not have significant accuracy differences

Whether the M3E images were RTK corrected or not, the triangulated 'mesh' of GCPs used within this study provided enough consistent accuracy data to ensure that on average all M3E GCP maps saw errors below an inch. However, the benefit of RTK images would be expected to increase when the GCPs are fewer in number and less consistently placed. GCP map accuracies are especially sensitive to an uneven distribution of the GCPs over the site area. A future analysis exploring the impact of RTK on accuracy when GCPs are set minimally, such as 1 GCP in each corner of the site, would give more clarity into the nuance.

M3E RTK accuracy without GCPs

We receive many questions regarding GCPs and RTK, as RTK calls into question the necessity of GCPs. In this section, we explore the map accuracy of M3E RTK maps without GCPs in order to resolve those questions by providing averaged checkpoint errors.

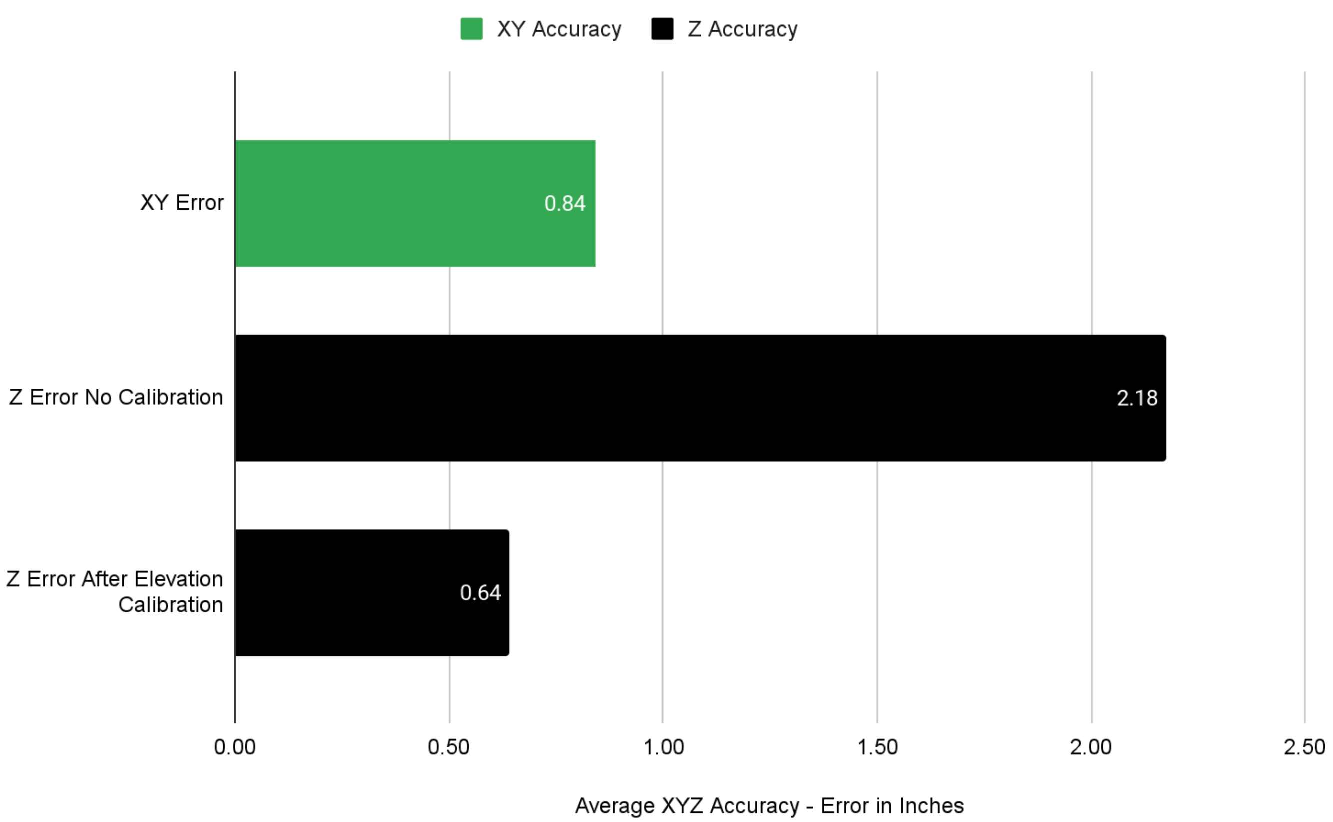
Highlights:

4.1 Non-GCP M3E RTK maps achieved sub-inch error in the XY

4.2 Non-GCP M3E RTK maps achieved sub-inch error in the Z after an Elevation Calibration

Graph 4: M3E RTK non-GCP maps - absolute accuracy, by axis

In Graph 4, we show non-GCP M3E RTK map average error across all 4 rounds. The error is categorized by XY error (horizontal), and Z error (vertical), with and without an Elevation Calibration. This demonstrates how far 'off' an average point on the map is compared to its true positions.



4.1

Non-GCP M3E RTK maps achieved sub-inch average error in the XY

Despite the fact that some of the RTK missions had a mediocre corrections accuracy, M3E RTK map accuracy in the XY was still on average sub inch. The largest average XY error was only slightly over a tenth of a foot, at 1.45 inches. This demonstrates that in similar conditions to the site flown in this study, GCPs will generally not be required to horizontally align the maps within an inch or so.

4.2

M3E RTK non-GCP maps with Elevation Calibration achieve sub-inch average error in the Z

Across all types of GPS-enabled devices, it is common to see more uncertainty in the vertical than in the horizontal, which we saw in this study. Without an Elevation Calibration, on average we saw a little over 2 inches of error in the vertical. Applying an Elevation Calibration brought the average error comfortably below an inch. The Elevation Calibration provides such an increase in accuracy because it accounts for the consistent offset the uncalibrated RTK map vertical errors have. For example, Round #2 M3E RTK at 120 ft, the non-GCP RTK map with the largest errors, showed checkpoint errors only between 5.1 and 7.6 inches. Because the inaccuracy of the map stems from the fact that it is over-elevated by about 6 inches, dropping all map elevation values by 6 inches removes most of the error.

This consistent offset error is not necessarily representative of the type of error you'll always encounter with drone RTK data. This is because there are many different ways to provide RTK corrections that each vary in quality. In our case, with DroneDeploy RTK corrections, an Elevation Calibration solved for the extra Z error. You might find at some point that GCPs are still required to remove the error that your pure RTK maps produce, as you might need an XY calibration, or even some internal relative adjustments if there are inconsistencies within your RTK setup.

Flight altitude and accuracy

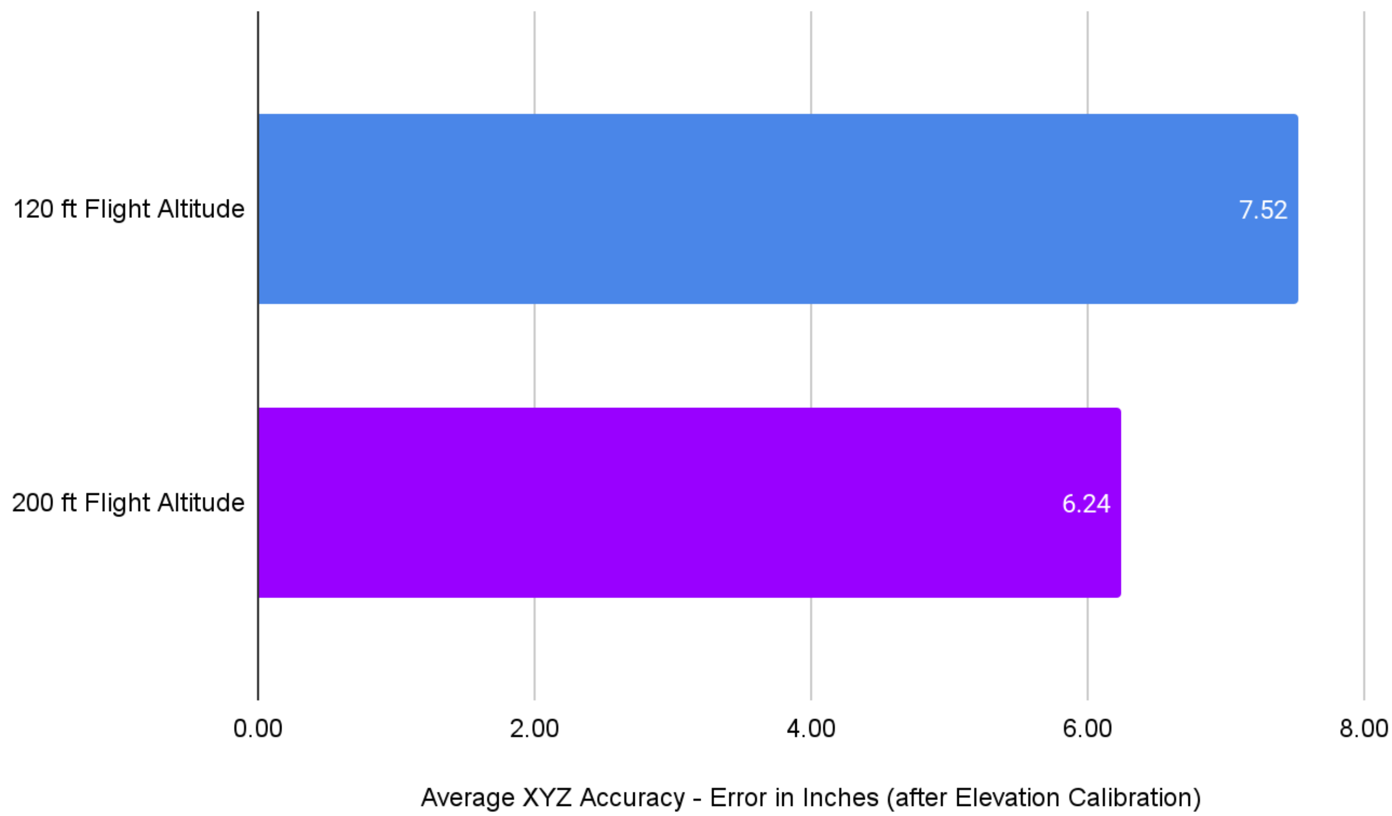
Flight altitude is one of the most important decisions during flight planning. It has an impact on flight time, safety, equipment requirements, map accuracy and map resolution. As many downstream outputs can change given the flight altitude input, we explore this decision specifically through the lens of accuracy by providing averaged checkpoint errors.

Highlights:

5.1 The flights at 200 ft AGL were on average 20% more accurate than flights at 120 ft AGL

Graph 5:
All maps - absolute accuracy, by flight altitude

In Graph 5, the map accuracies are provided, split by the two altitudes flown. Both drones are combined in this average.



5.1

Flights at 200 ft were about 20% more accurate than flights at 120 ft

If all variables remain constant, such as RTK signal strength, lighting, photo quality and GCP count, it is generally believed that flying lower should improve accuracy because the map resolution is increased. In this study, we did not see that pattern. On average, the 200 ft flights had around 20% less error than the 120 ft flights.

It is possible that the 80 ft difference between the two flights and resulting impact on map resolution was not significant enough to cause the 120 ft flights to be substantially more accurate than the 200 ft flights. Other factors such as RTK signal, photo quality, GCPs per image, or number of identifiable objects per photo may together impact accuracy more than 80 feet of altitude difference, causing the 200 ft flights to have more overall accuracy.

With a larger difference in flight altitudes, such as comparing flights at 100 ft AGL vs 400 ft AGL, we would expect to see better accuracy for low altitude missions on average over the long run. But, at altitudes under 200 ft, which are commonly flown altitudes for high accuracy missions, it is not as simple as flying at a lower altitude to gain better map accuracy.

Relative accuracy

Absolute accuracy is not important in use cases such as single-map annotation measurement (distance, volume, height, radius, area, etc), PDF overlay comparison, or basic as-built creation. For those use cases, only relative accuracy is important, which we validate in this section. Each map has five distances for which the drone map value was compared to the ground-based tape measured value. The distance measurement is a surface distance measurement, which means the distance includes the elevation change in the area. This workflow validates the shape, scale and dimensional accuracy of the maps.

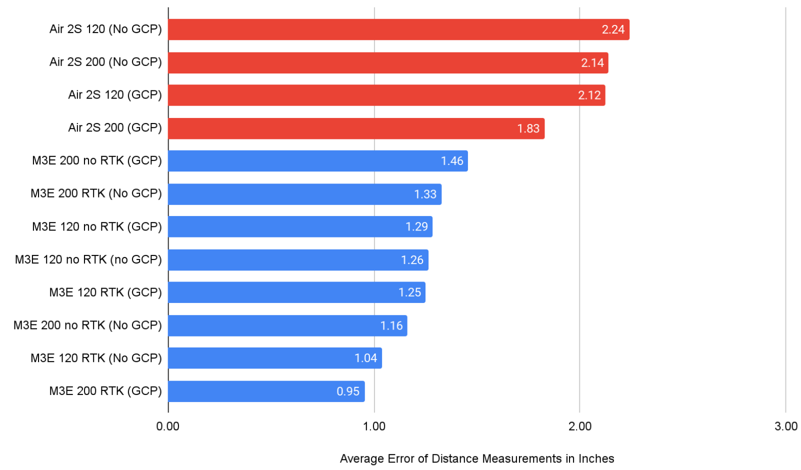
Highlights:

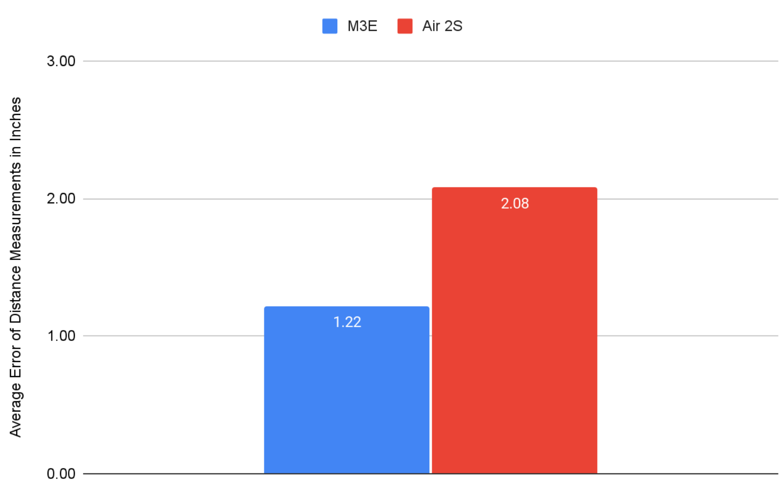
6.1 Both drones show average measurements accuracy to be within approximately 1 - 2 inches

7.1 There is not a clear pattern of impact on relative accuracy beyond the drone model used

Graph 6: All maps - surface distance measurement error

In Graph 6, the average surface measurement error for five distances of approximately 50 ft, per map, is displayed. The ground-based tape measurement was compared to the virtually measured value on the map. As a reminder, each map 'type' error is an average across four unique flights.





Graph 7: All maps - surface distance measurement error, by drone

6.1

Both drones show average distance measurement accuracy to be within approximately 1 - 2 inches

There are some use cases in AEC, energy, and site management that require measurement accuracy better than a couple of inches of error. Those use cases are typically best left to laser scanning or manual measurement, but our findings here demonstrate that for surface analysis where 1 - 2 inches of relative point error is acceptable, even a categorically prosumer-oriented drone such as the Air 2S delivers actionable data.

A surface distance measurement does not only depend on the accuracy of the two ends points of the measurement, but on all points across the distance of the line, since a surface measurement follows the elevation of the site. Therefore, this accuracy check validates not just the accuracy of two points, but provides confidence around the proper scale and size of the entire mesh of the site.

7.1

No clear pattern of impact on relative accuracy beyond the drone model used

It is not evident that measurement accuracy is substantially different between the two different flight altitudes, or with/without GCP and RTK. Relative accuracy is mostly a function of the quality of the photos themselves, with geographic metadata (GCPs, RTK, etc) usually playing a smaller role. With a properly-designed flight mission, relative measurement use cases do not substantially benefit from marginally lower altitudes, GCPs or RTK. It is the drone model that provides for a distinct demarcation between the measurement accuracies. The M3E on average produced about 40% less measurement error than the Air 2S. That is a large percentage, but the increased accuracy in terms of units of distance is relatively small, at about 8/10ths of an inch. That difference in error will only be impactful to project teams if they are scrutinizing analysis to within an inch-level of tolerance.

Drone flight time and efficiency

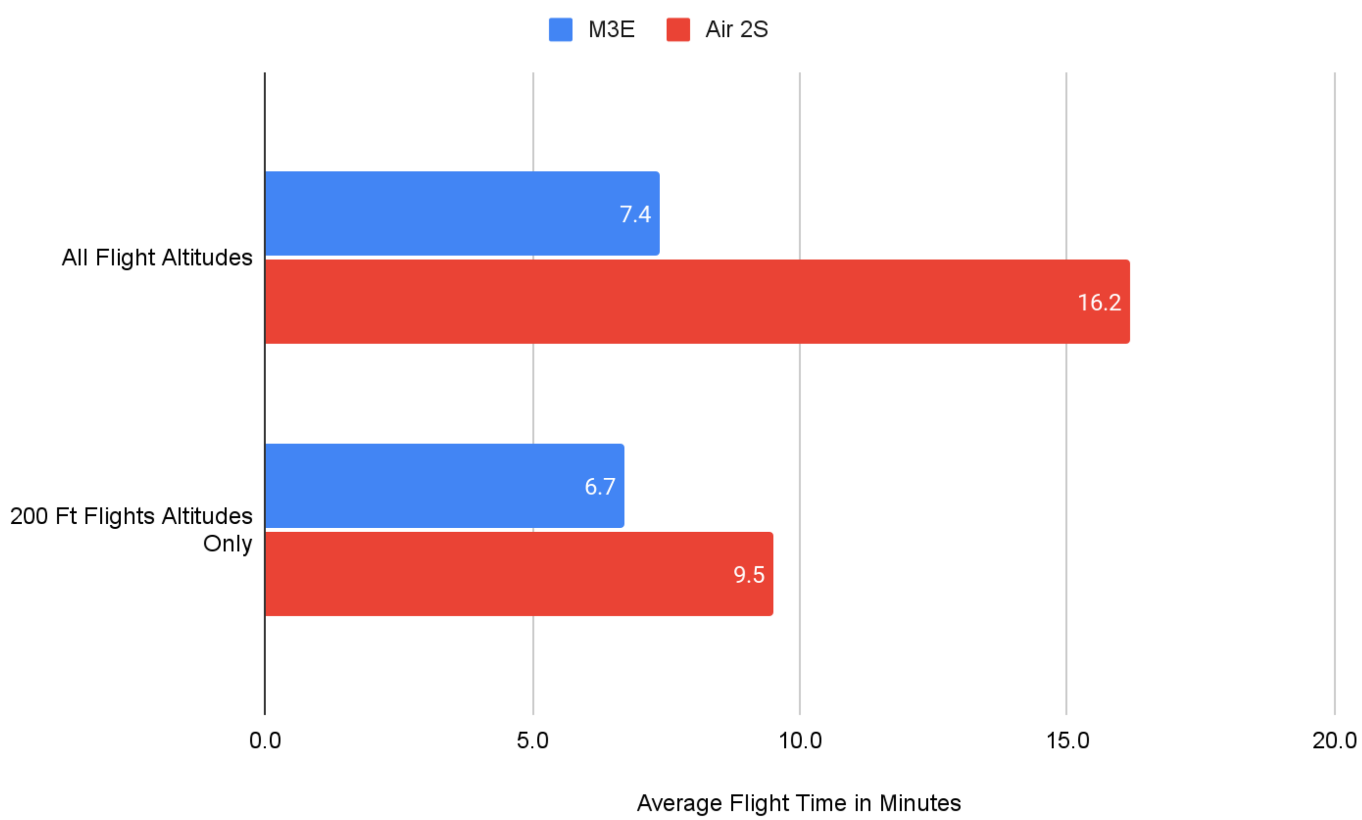
In all industries that leverage drone photogrammetry, time and efficiency is important to maximize a quality result for the customer and for employees. In this last section, we analyze how quickly the Air 2S and M3E RTK can capture data.

Highlights:

8.1 The Mavic 3 Enterprise flies missions at least 30% faster than the Air 2S

Graph 8: Flight time comparison, by drone type and altitude

In Graph 8, we compare the flight time differences between the M3E and Air 2S. Flight time is defined as from the moment the drone takes off, until it lands. Flight time is split between a combination of the 120 ft and 200 ft flights together, and the 200 ft flights only.



8.1

The Mavic 3 Enterprise flies missions at minimum 30% faster than the Air 2S

The Air 2S and M3E both were able to complete the flights at 200 ft AGL within a single battery. At 200 ft AGL, the M3E completed the mission about 30% faster than the Air 2S. It is able to fly quickly and capture photos up to every 0.7 seconds without motion blur due to its mechanical shutter and internal processing architecture.

If you average both the 120 and 200 ft flights, the M3E completed its missions over twice as quickly as the Air 2S. The M3E was easily able to complete the 120 ft missions within a single battery, while the Air 2S required a battery change for its 120 ft AGL flights. The extra time the Air 2S took to return home and back twice, instead of once, is included in the data for that altitude specifically. That time difference does not count the additional time it takes to physically swap the battery and wait for the drone to power on again. That is why the average flight time difference for both altitudes is notably larger than the 200 ft altitudes only. As soon as you have to add an additional battery change to a mission, a notable amount of time efficiency is lost. Therefore, the larger your site/mission, the more time savings you'll gain out of the M3E.

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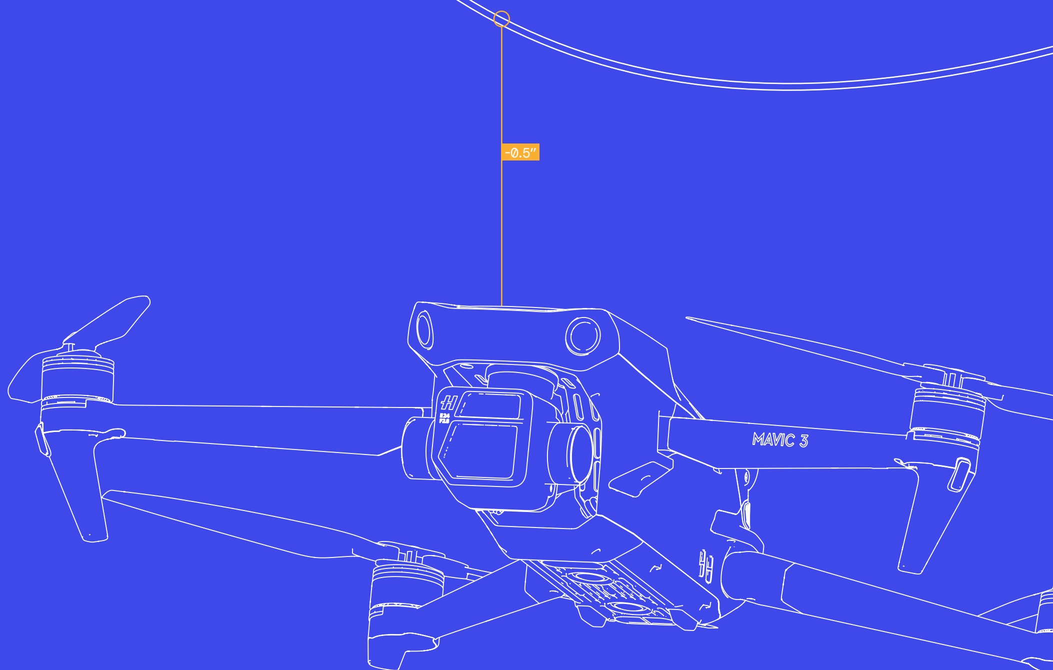

05 Conclusion

Conclusion

The best project decisions happen when teams are equipped with predictable and high quality data capture workflows. Throughout this study, we observed consistently accurate maps using the DJI Mavic 3 Enterprise RTK and we recommend it for inch-accurate, survey-grade aerial mapping.

While the DJI Air 2S will work sufficiently for price-conscious teams getting started, it does not demonstrate the survey-grade levels of accuracy expected by more experienced customers.

For ultimate reliability of absolute accuracy, GCPs and checkpoints should be used. M3E RTK maps without GCPs can also have survey-grade accuracy like GCP maps, however an especially discerning data validation and calibration process should be implemented for non-GCP drone RTK maps. The relative accuracy that the M3E demonstrated through our surface distance measurements indicates easy value potential even before job site teams get more technical with high absolute accuracy workflows. With a fast speed of capture and lengthy battery life, the M3E delivers a strong value proposition at its price point and should be the benchmark for drone hardware considerations.

Given the relative ease of use of all the hardware and software used in this study, as long as beginners are given proper guidelines, it's clear that more widespread survey-grade job site accuracy is upon us.

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