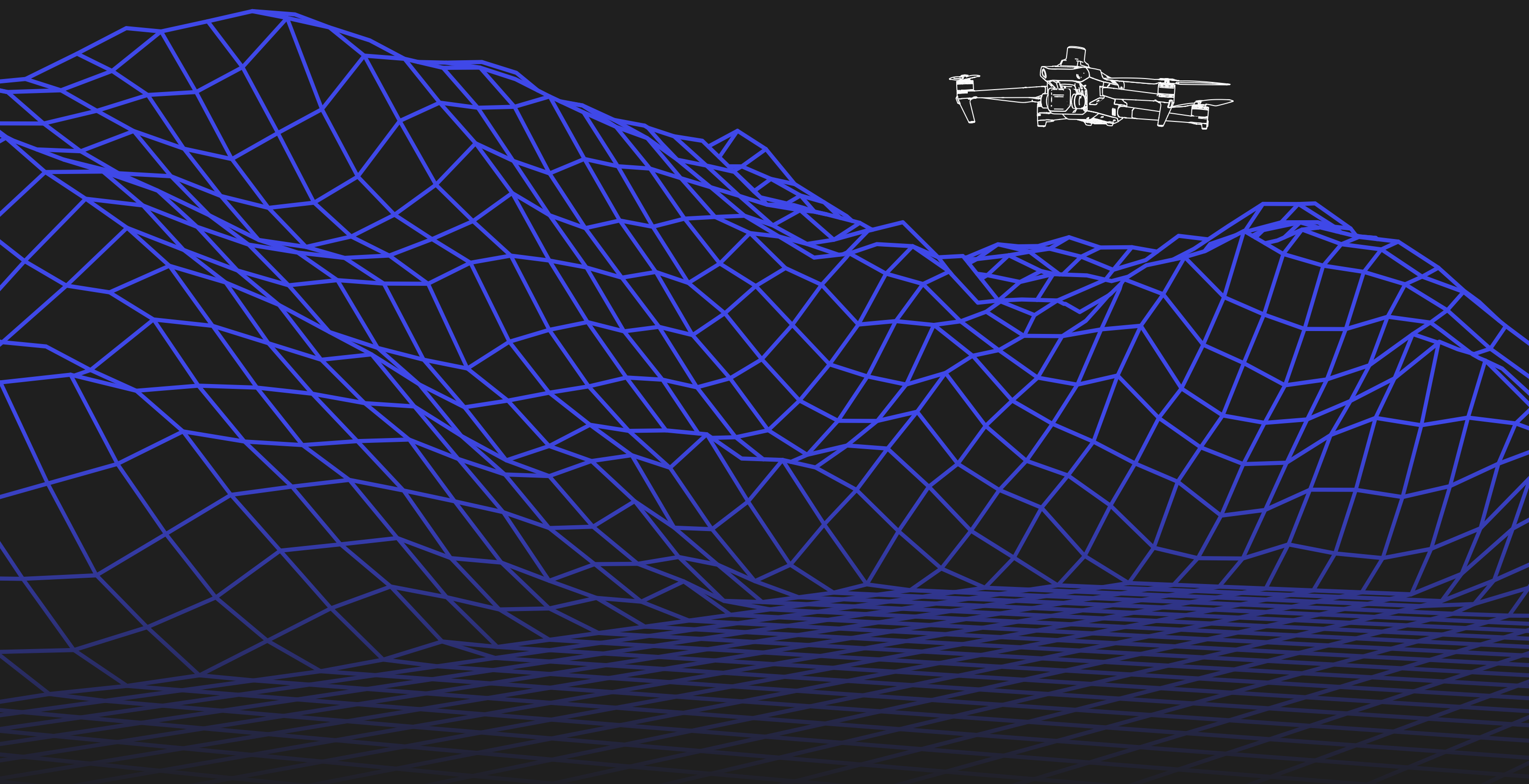
DroneDeploy PPK Whitepaper

Assessing high accuracy surveys and defining where and when to use RTK vs PPK.



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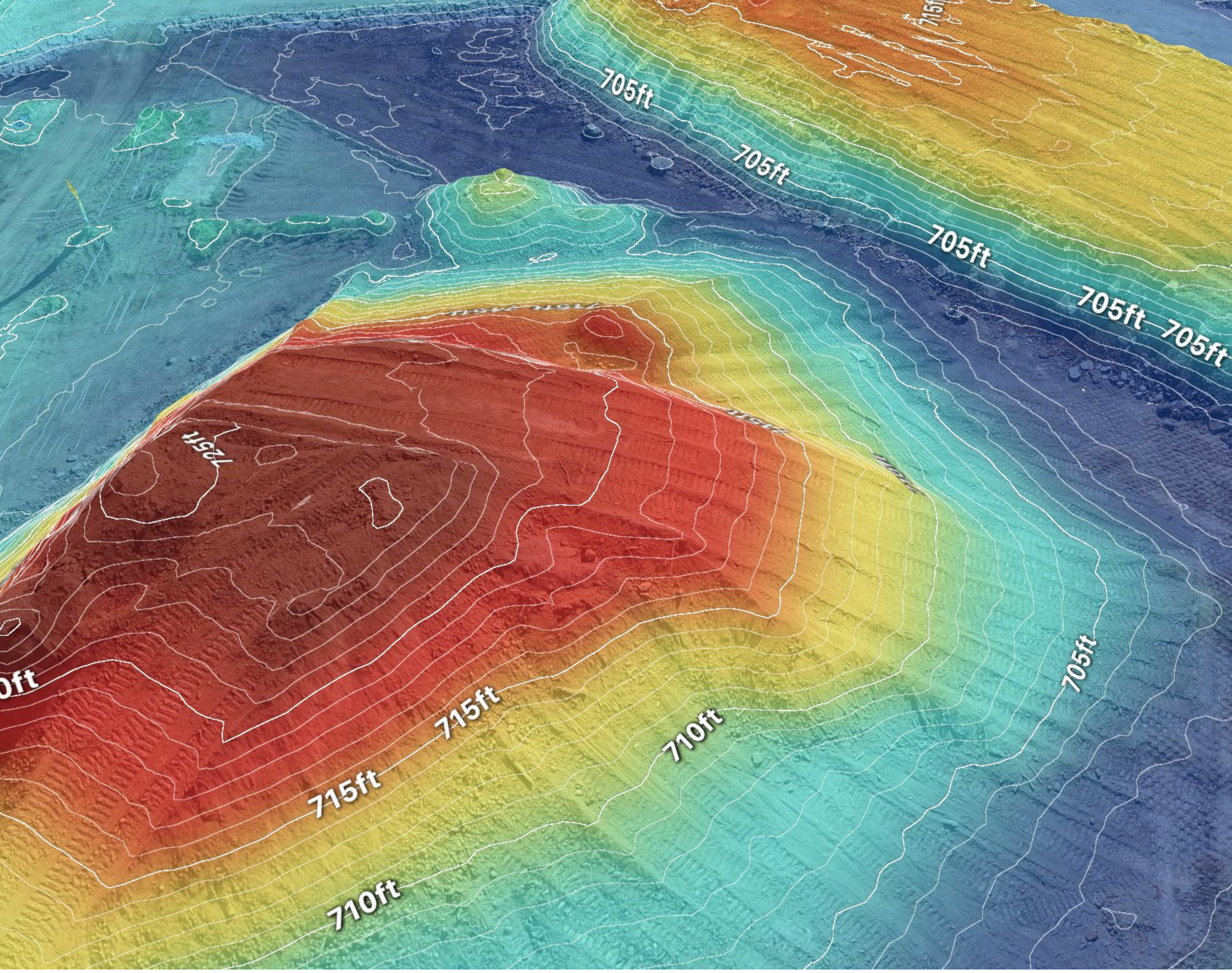
The Challenges of Demanding and Remote Job Sites

Both real-time kinematic and post-processed kinematic processing can capture inch-accurate imagery on your job site. But it's important to know the differences between the two – particularly for teams working in remote locations.



Teams working remote job sites face certain challenges when it comes to drone mapping.

For instance, spotty internet coverage surrounding these remote sites diminish a drone's ability to process data.

This is particularly true with real-time kinematic (RTK) processing, as it demands a consistent signal in order to provide position information (hence the name, real-time).

In contrast to RTK, post-processed kinematic (PPK) corrections are computed after the flight has completed, eliminating the need for an internet connection during the flight.

This is why large civil and mining operations commonly use PPK workflows, as it provides a reliable way for teams to accurately analyze large job sites in remote areas with poor network strength.

Theoretically, PPK produces the highest possible accuracy of the drone trajectory when the proper procedure is followed. Typically, PPK and RTK are the right technologies for drone surveying and the choice is based on the requirements of the job site.

In the months since we released our **RTK whitepaper**, DroneDeploy has partnered with Trimble Applanix to offer PPK processing in response to the needs of teams working at remote sites.

This whitepaper will explore the accuracy of the Post-Processed Kinematic method in its two flavors: 1) using a local dedicated base station and 2) using Trimble Applanix, as well as compare and contrast how DroneDeploy's RTK and PPK workflows work together to provide reality capture programs with a flexible suite of high accuracy workflows to match the requirements of each and every job site.

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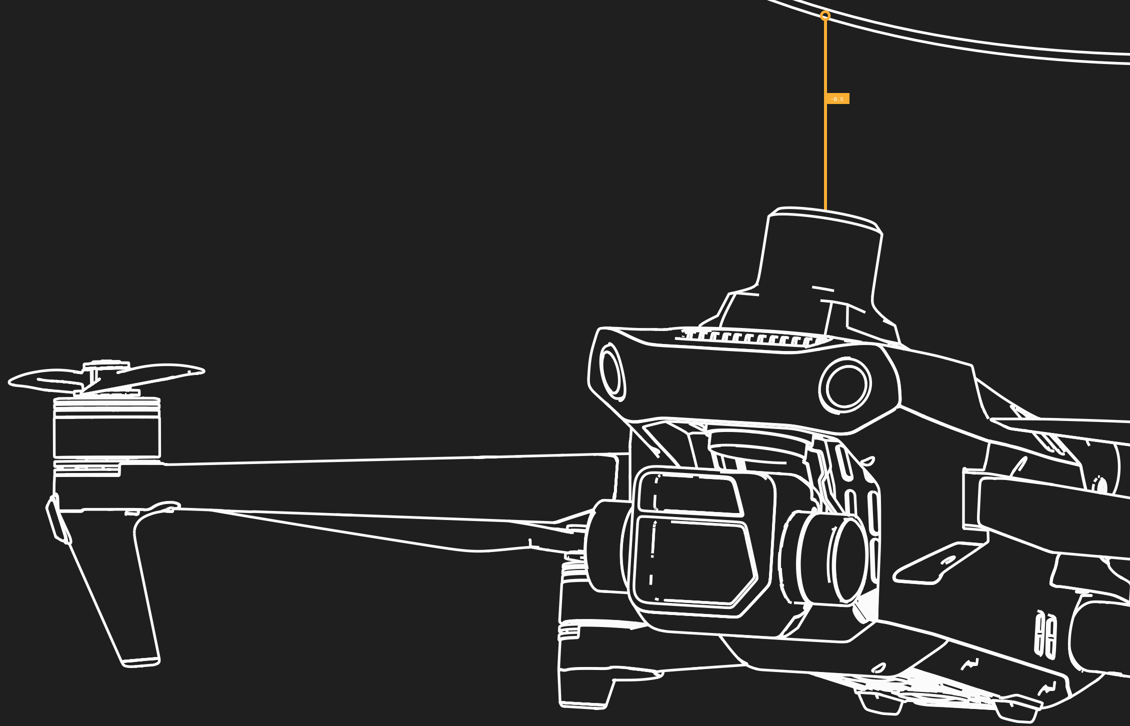


01 Introduction

Recommended prior reading

Consider this whitepaper an addendum to our M3E RTK whitepaper, which defined fundamental information such as absolute and relative accuracy, Ground Control Points (GCPs) and Checkpoints, DroneDeploy's Map Engine, the DJI M3E RTK drone, and our M3E RTK workflow. We recommend that you read that whitepaper before reading this PPK addendum, as those findings will be referenced in this paper as we make workflow recommendations.

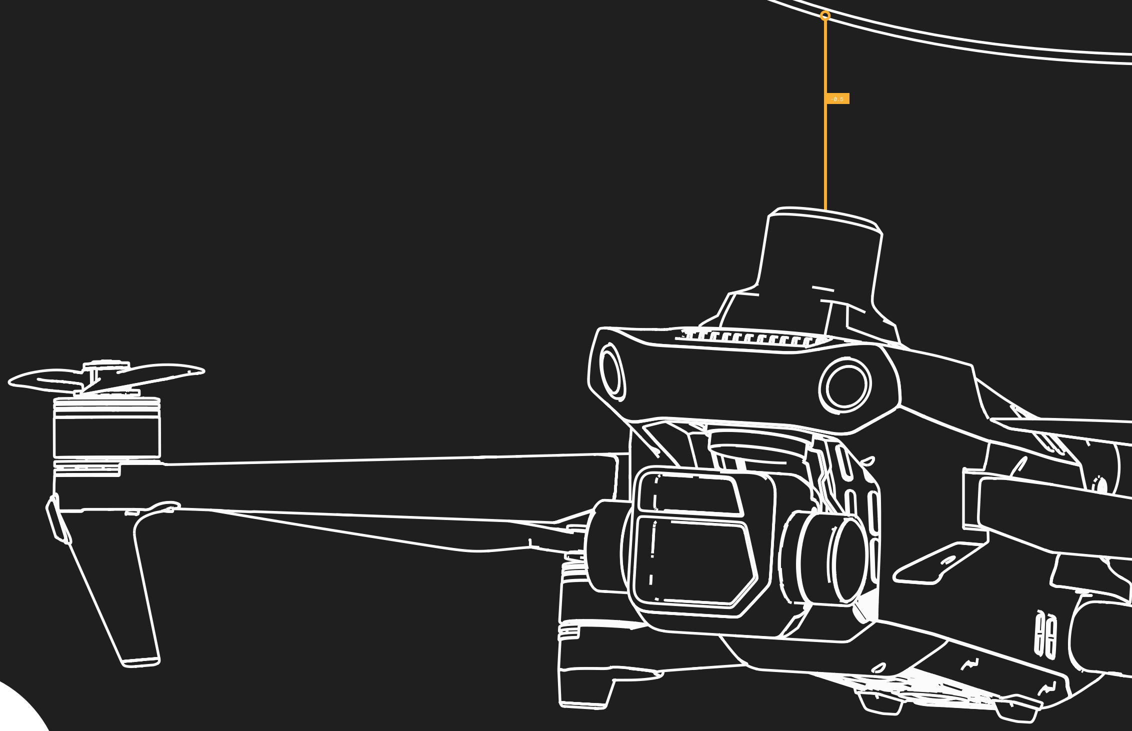
Goals of this study

The primary goal of this study is to measure the absolute accuracy of maps processed with DroneDeploy's PPK workflows on missions flown with the DJI M3E RTK. Within this PPK workflow are some key factors that impact accuracy and efficiency, such as:

- Base station selection
- The number of GCP's
- The flight time

These variables are often asked about when job site teams plan their mapping workflows, and so we will be isolating these variables in the interest of understanding how they impact accuracy.

02 Background



Correcting Drone GNSS Data

Global Navigation Satellite System (GNSS) devices compute their precise antenna location by triangulating the measured satellite ranges between a drone and all visible GNSS satellites.

This allows for computing the precise location of the GNSS antenna onboard any drone at any given moment of time during the drone flight – usually referred to as 'the drone trajectory'.

When a drone trajectory is precisely computed, all mapping products get more accurate and easier to produce.

In a perfect world, a position could be calculated with no error. But our imperfect and varied world means that error is introduced into this calculation because:

1. The position of the satellite is known, but not perfectly because a satellite's orbit varies a small amount.
2. Clocks on both satellites and drones, while high quality, are not perfect.
3. Man-made and natural electromagnetic interference in the upper and lower atmospheres (along with physical obstacles on the ground) add time delays to the transmitted signal.

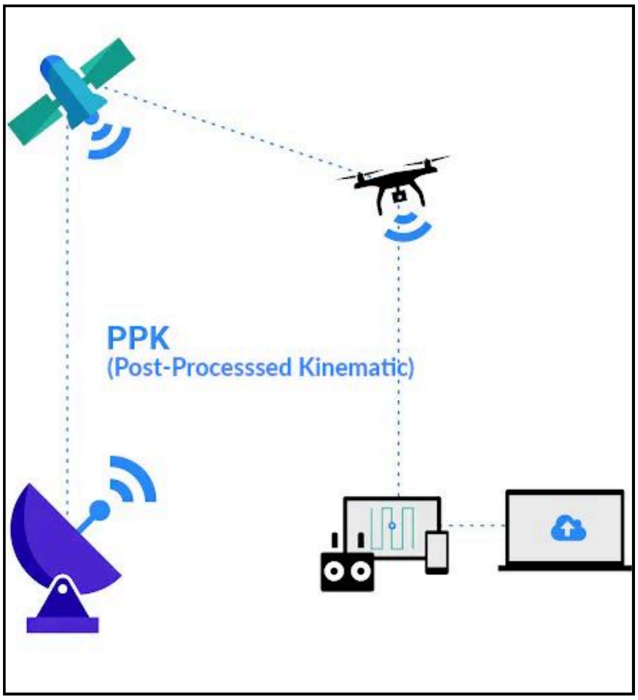
These factors mean that RTK-hardware-equipped drones with no corrections will typically have positional distances of five to ten feet, distances which are far too large for many of its use cases such as cut/fill analysis, compare to 3D design, well-aligned documentation, as-builts and more.

This is where RTK and PPK corrections come into play.

Fundamentally, both workflows track the flight time of at least one base station, which is a GNSS receiver collecting satellite signals at a known point near the job site.

By comparing the base station's known position to the as-reported value during flight, positional errors can be estimated to a very accurate degree.

Where RTK and PPK differ is when and how these corrections are applied to the drone data, with RTK correcting in real time, and PPK computing those corrections after the flight has completed.

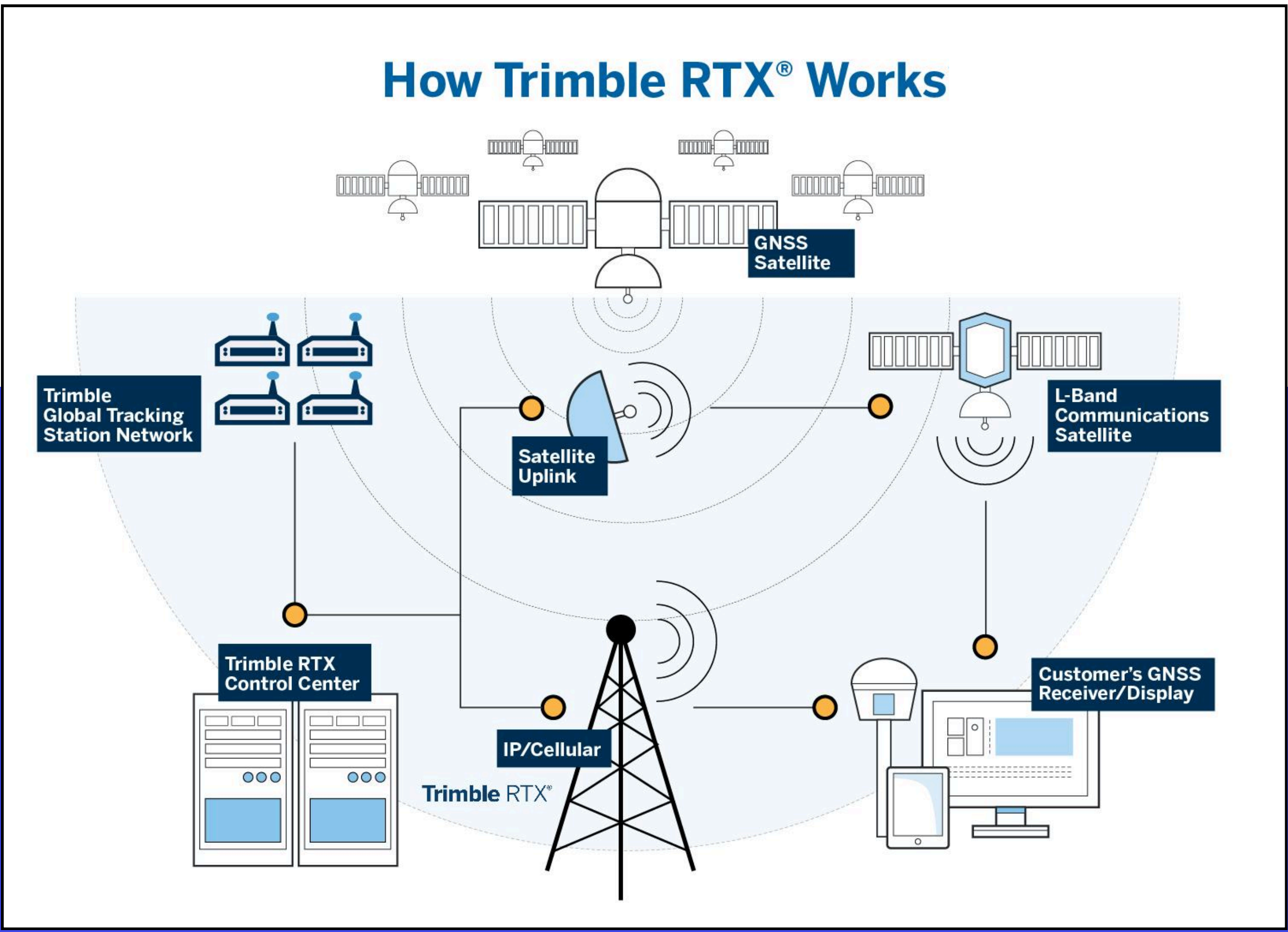


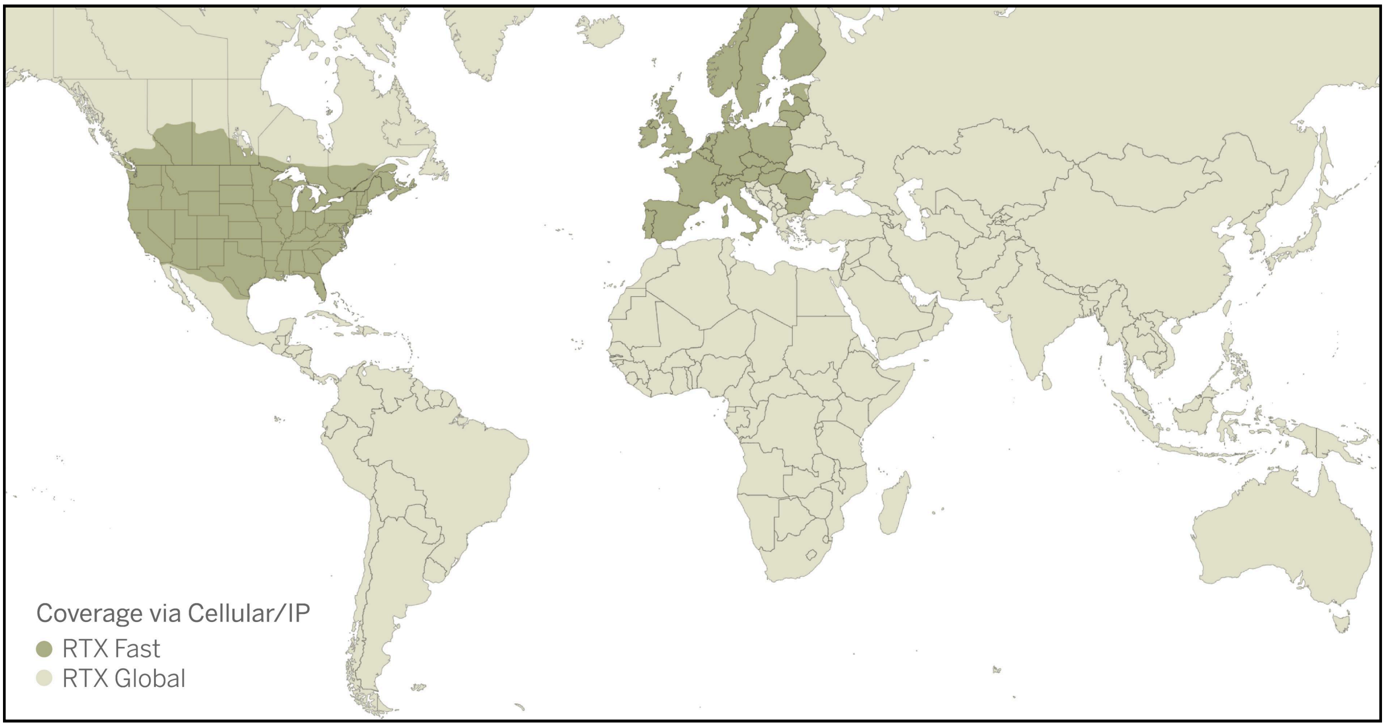
Trimble's Applanix POSPac PPK and Post-processed Centerpoint RTX (PP-RTX)

Trimble's® real-time CenterPoint RTX® service providing centimeter-level positional accuracy for real-time applications. Introduced in 2011, this service relies on the precise generation of orbit, clock corrections, and atmospheric delay models for GNSS satellites (GPS, GALILEO, GLONASS, BEIDOU, QZSS) in real-time.

It is based on a Trimble dedicated worldwide network of permanently tracking GNSS stations.

Trimble's Applanix POSPac PPK with POSPac PP-RTX is a cloud-based service that generates PPK solutions using Trimble's proprietary GNSS PPK engine and Trimble's Centerpoint RTX corrections.





Trimble's CenterPoint RTX services are split into two regions:

- Fast Region (Central Europe and North America)
- Global Region (Rest of World)

Global Region corrections are based on a global ionospheric model, while the Fast Region uses a denser network of reference stations to compute a regional ionospheric model for atmospheric corrections.

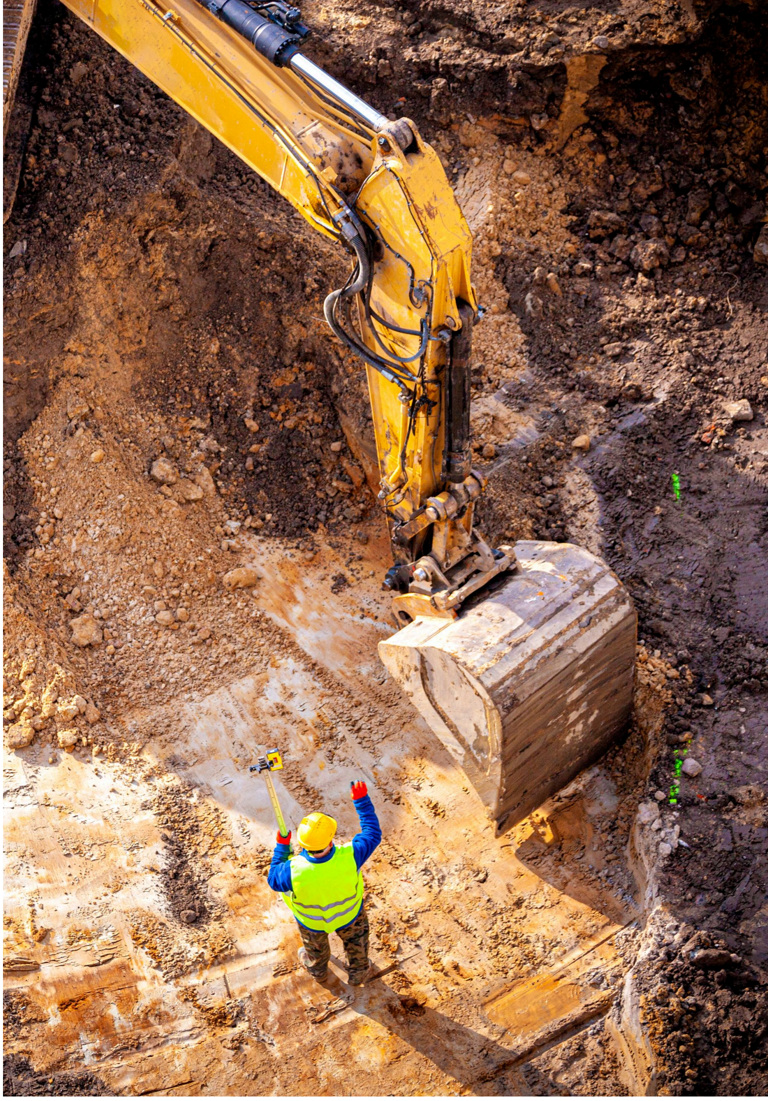
Supported drones and flight workflows

DroneDeploy's PPK workflow is supported for the following drones (with others scheduled to be supported in the future):

1. DJI M3E RTK
2. DJI P4P RTK
3. DJI M300 & M350 RTK
4. Autel Evo II Pro RTK
5. Skydio x10 RTK
6. WingtraOne PPK

In order to take advantage of DroneDeploy's PPK solution, you don't need to fly with **DroneDeploy's Flight App**, or even be connected to the internet during flight.

Simply fly a supported drone for at least ten minutes if you're in an Applanix Fast region, or 20 minutes if you're in the Global Region, then follow one of the two processing workflows laid out below.



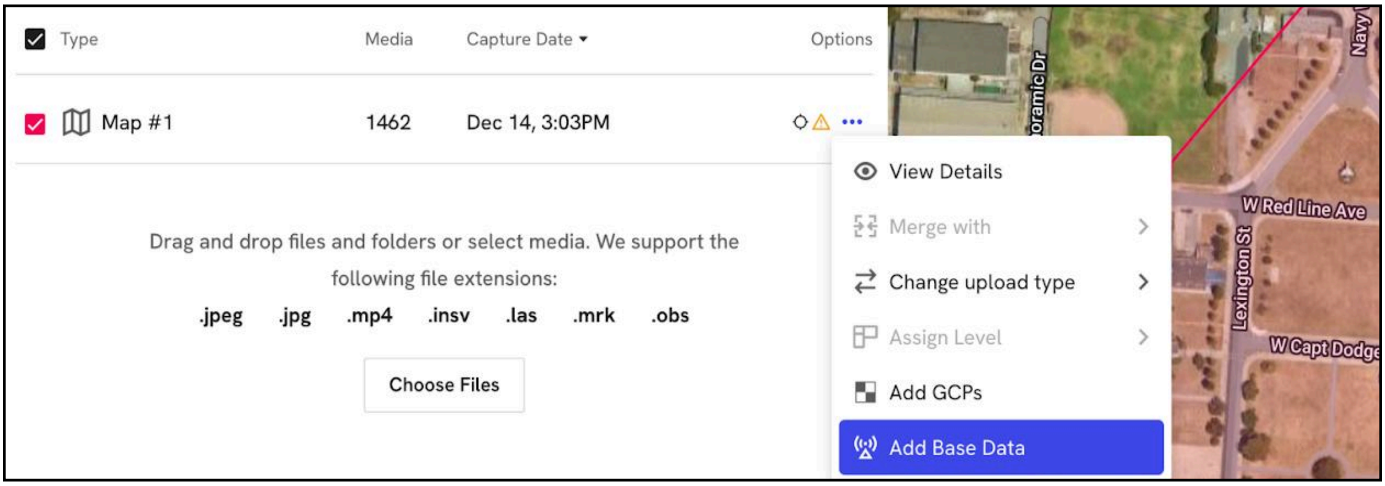
Applanix PPK Processing Workflow

After your flight, be sure to include the MRK and OBS files when uploading the images to DroneDeploy's **Smart Uploader**. These files contain precise photo time stamps and satellite observation data which are compared with the observation data taken from the base station for error reduction.

After adding your drone survey folder, you'll see an indicator showing that your map will be processed using PPK, as DroneDeploy automatically matches up your flight data with the corresponding PP-RTX correction data.

Local Base Station PPK Corrections Processing

If you would like to generate corrections with your own dedicated base station data, you'll want to ensure you have a GNSS base station receiver recording observations for at least an hour during a time that completely overlaps with the flight time of the drone.



Ideally, capital-intensive job sites (e.g. large commercial projects, civil projects, or mines) will run continuous observations so that local base station observations are always available.

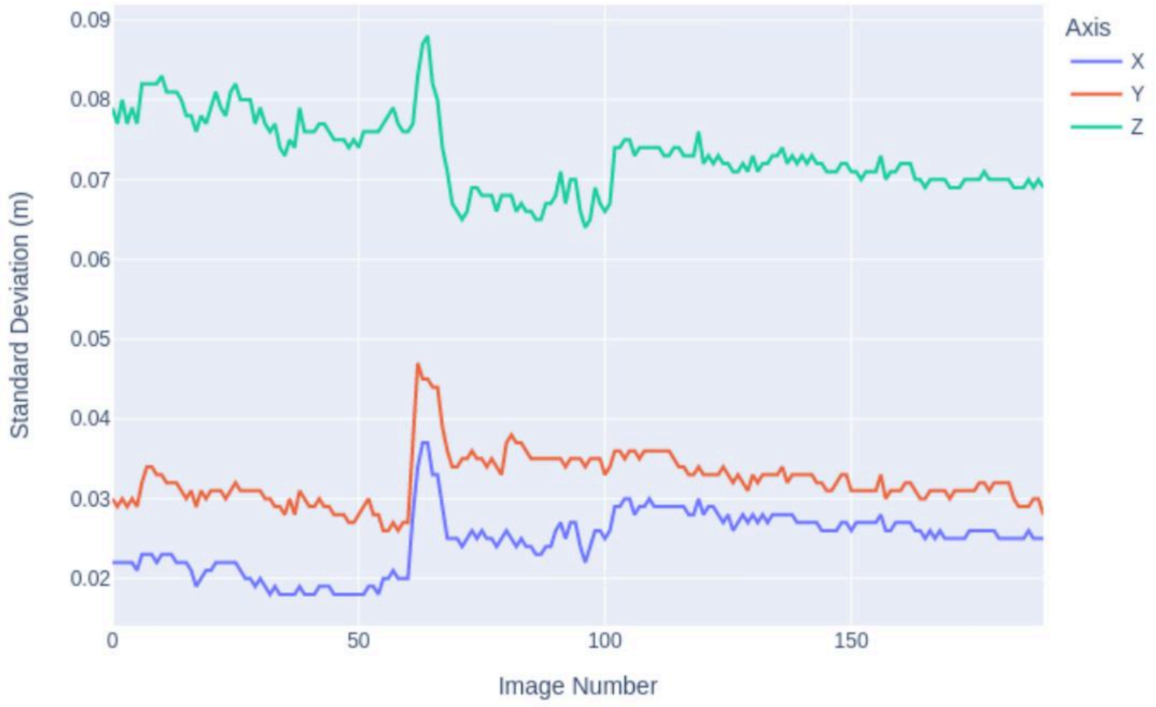
To be clear, the base does not need to be set up on a known point. However the base should be able to export an OBS file or .0-23O file so you can add this base station file to the Smart Uploader before processing your map.

Map Processing Report

When your map finishes processing, the Map Processing Report will indicate if the PPK corrections were successful, and if so, how much variation of correction from standard deviation exists within the X, Y, and Z axes.

You should generally expect the Z standard deviation to be approximately three times the XY standard deviation, as vertical data is usually more uncertain than horizontal data in GNSS applications.

PPK Summary



PPK Status		Success
Datum		ITRF2014 @ 2023.41884
Successful Trajectories		100.0% 1/1
Median Standard Deviation		**X** 0.08ft **Y** 0.10ft **Z** 0.24ft

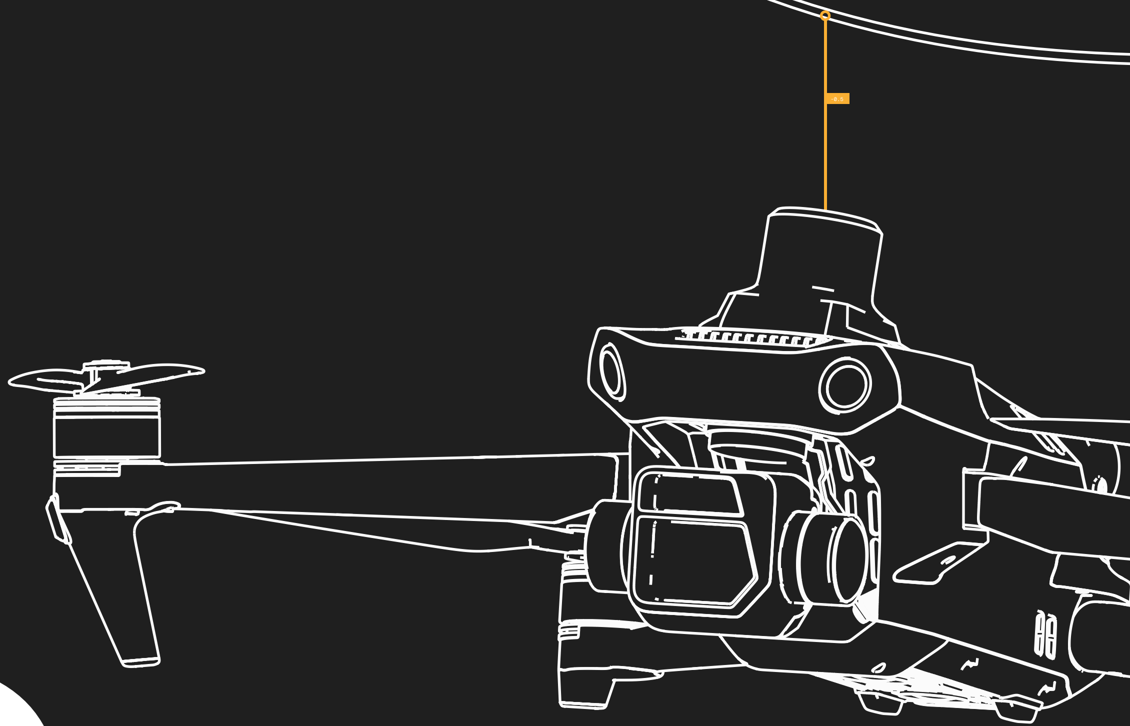
While it is likely that the standard deviation values track closely with map error (in that small standard deviations are generally better than large ones), it is important to recognize that these numbers do not describe map error.

When validating positional map accuracy, there is no replacement for comparing map locations to their respective known ground truths.

The Map Processing report contains automatically computed checkpoint error values based on tagged positions.

These checkpoint errors (not to be confused with GCP errors) are true measurements of map positional accuracy and are the primary means of analysis for this paper.

For reference, you'd find the same errors if you manually checked the values of known points on your map then compared those numbers to the recorded survey values.



03 Methodology

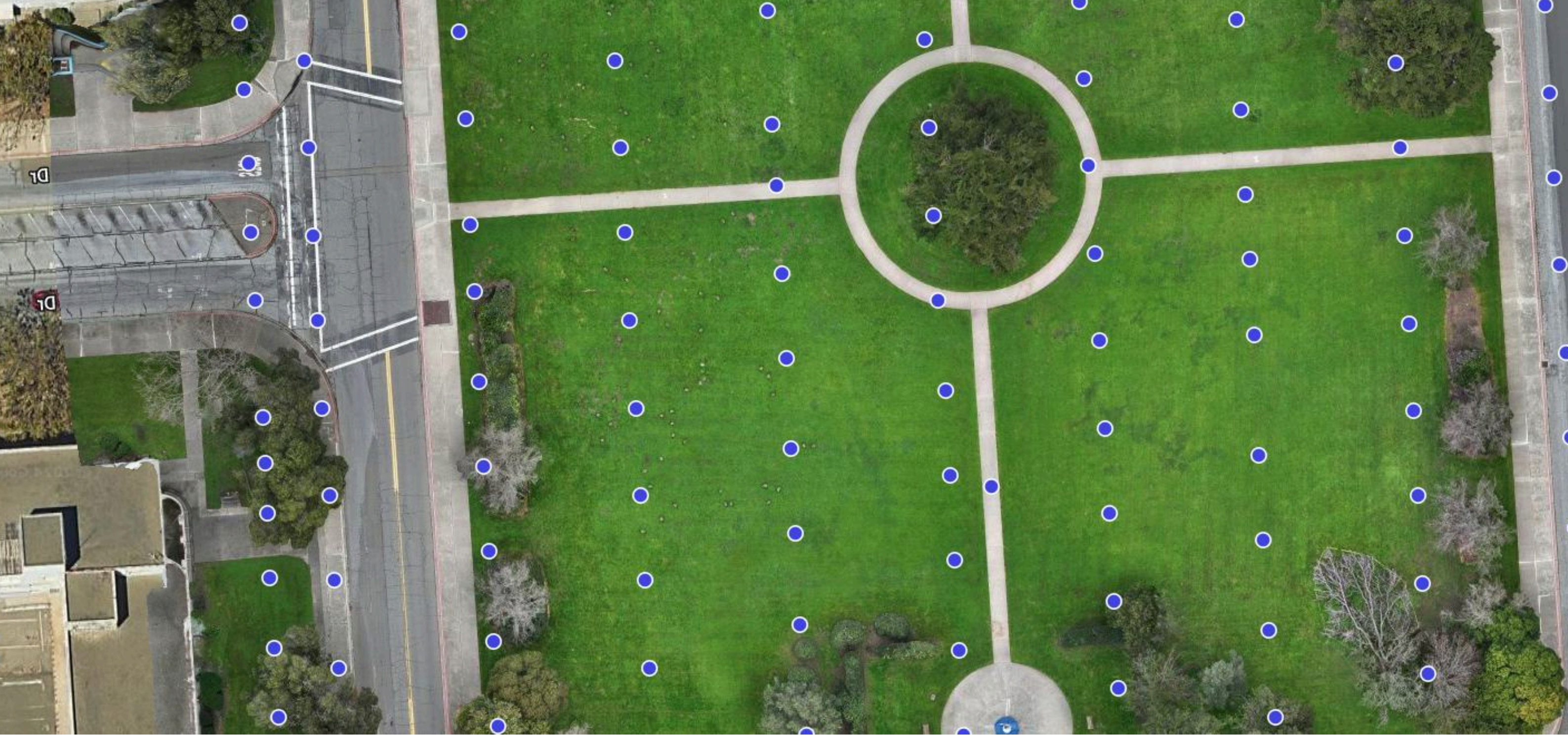
Site description

This study was conducted on the same twenty-acre site as the M3E RTK whitepaper. This area contains a mix of surfaces, and offers small elevation changes, a moderate amount of trees while being surrounded by 1-2 story buildings. Here is a publicly accessible **share link** to the entire map set.

GCPs and Checkpoints

This study used the same known points as in our **M3E RTK whitepaper.** These points are evenly distributed throughout the map area, providing a wide sample of positions for analysis and were remeasured simultaneously with drone flights for epoch (up-to-date) consistency.

Drone captured image of test site



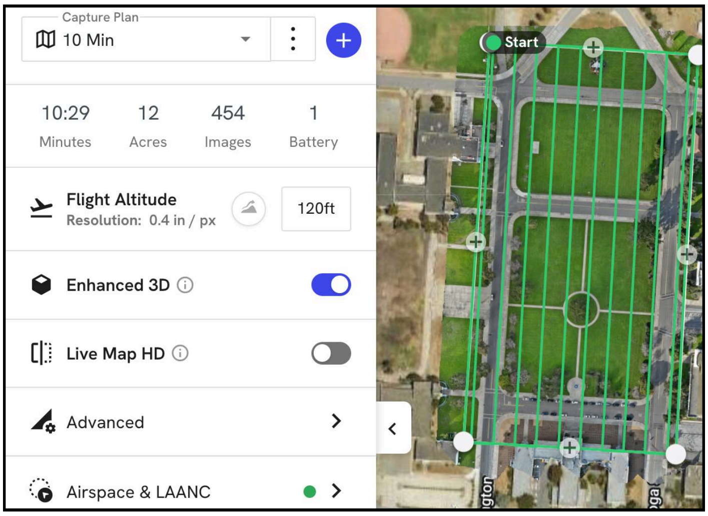
Points were established using an Emlid RS3 GNSS receiver connected to an RTK network for corrections. And each GCP was measured using a 5-minute average: once at the beginning of the day, once at its end, then averaged together for a maximum error of no more than one centimeter.

As we investigated the impacts of the number of GCPs on map accuracy, some maps used a different configuration of GCPs and checkpoints than others:

- For maps with no GCPs, all thirteen points were used as checkpoints for validation.
- For maps with 1 GCP, point 11 was converted to a GCP.
- For maps with 4 GCPs, points 1, 2, 7, and 8 were converted to GCPs.

Drone flights

Each mission flown by the DJI Mavic 3 Enterprise RTK was at 120 feet above ground level. Using DroneDeploy's automatic flight settings, we kept overlap parameters at its 75/65 default.



Flight plans combined a simple lawnmower pattern capturing all nadir photos facing the ground at 90 degrees with oblique orbits of angled photos around the perimeter of the site.

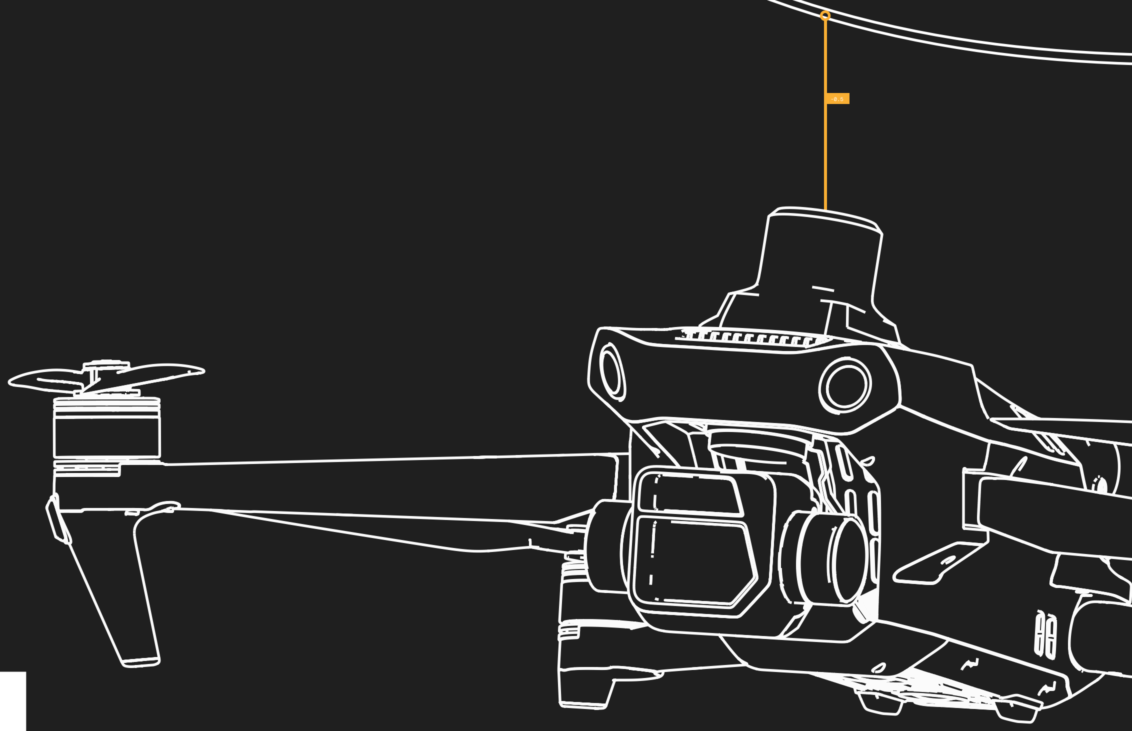
Slowing flight speed was selected as the tool to increase flight speed as it keeps the number and placement of images exactly the same across all flights.

This was done due to the fact that even though the number and location of photos stay consistent across different flight times, this is not the case with flight altitude, overlap, or image angles. Over a single day, we flew nine unique drone flights, with each of the three flight times repeated over three rounds.

Each flight was processed nine different ways, varying the corrections source and number of GCP's, creating a total of 81 maps that were studied for this paper. This matrix shows the nine ways each flight was processed:

PP RTK Corrections	**No GCP**	**1 GCP**	**4 GCPs**
1 hr Local Base PPK corrections set on unknown point (Emlid RS3)	**No GCP**	**1 GCP**	**4 GCPs**
6 Hour Local Base PPK corrections set on unknown point (Emlid RS3)	**No GCP**	**1 GCP**	**4 GCPs**

As explained further in the M3E RTK whitepaper, all GCPs and checkpoints were tagged accurately using a consistent methodology.



04 Key findings

How accurate is DroneDeploy's Applanix POSPac PPK with PP-RTX workflow?

The most important question we answer in this whitepaper revolves around the accuracy of our PPK workflow when using Trimble's Applanix POSPac PPK and PP-RTX service, as the vast majority of our PPK maps will be processed using this method.

Let's break down the checkpoint XYZ errors for all maps corrected using PP-RTX by the amount of GCP's used in each map type:

PP-RTX PPK No GCP:

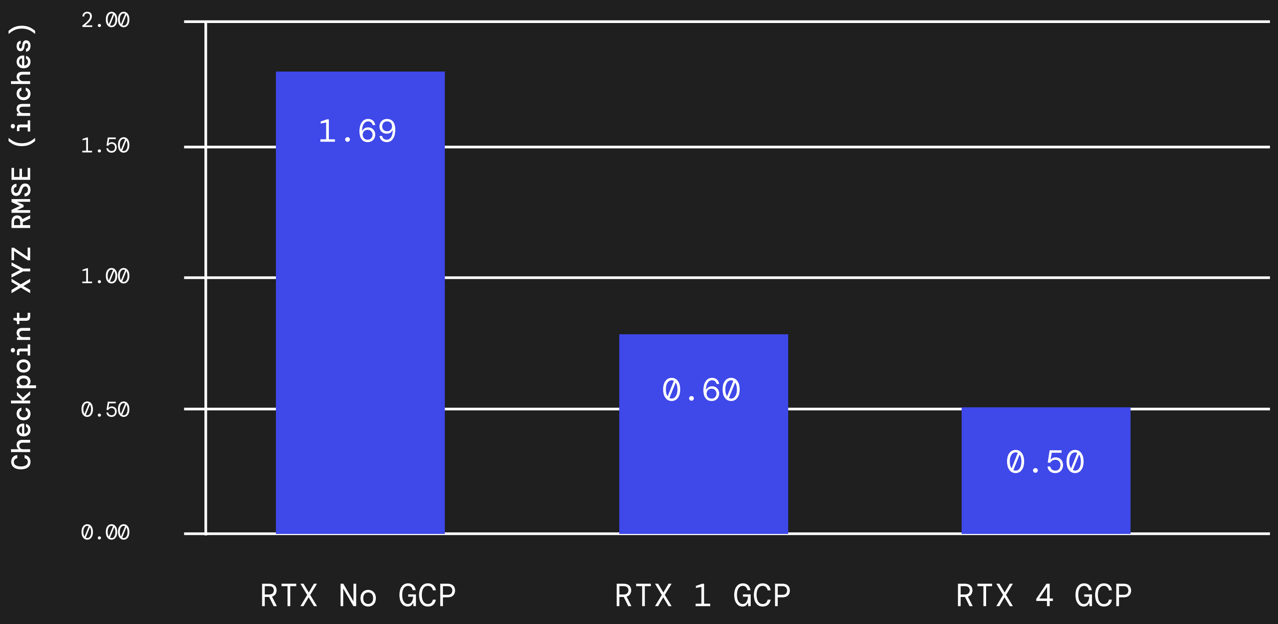
1.69 inch checkpoint XYZ error

PP-RTX No GCP maps are recommended for programs that prioritize simplicity, time savings, and ease of use over sub-inch accuracy.

Let's start with the PP-RTX No GCP maps. This is a pure reflection of the Applanix PPK with PP-RTX service accuracy, as there is no assistance from ground control.

For a significant portion of job sites and use cases (general progress tracking, basic compare-to-design, relative measurements etc.) 1.69 inches of XYZ error is sufficient. This is particularly true given the level of effort, as all you need for this style of mapping is an RTK drone.

DroneDeploy PPK - Trimble RTX Corrections Map Error



It’s helpful to break down this error into its horizontal and vertical components, as there are significant differences between the two:

XY	Z	Total RSME
0.85 in	2.52 in	1.69 in

As noted in the background of this whitepaper, the vertical error exceeding the horizontal error by approximately 3x is precisely within expectations.

If you’re looking to track map over map progress and want your 2D overlays to stay aligned against those maps, look no further. But for more precise survey-related workflows (such as cut/ fill analysis or comparison to georeferenced design surfaces) a 2.52 inch vertical error may be too large. Thankfully, a single ground control point provides a powerful remedy to improve that error.

PP-RTX PPK with One GCP:

0.60 inch checkpoint XYZ error

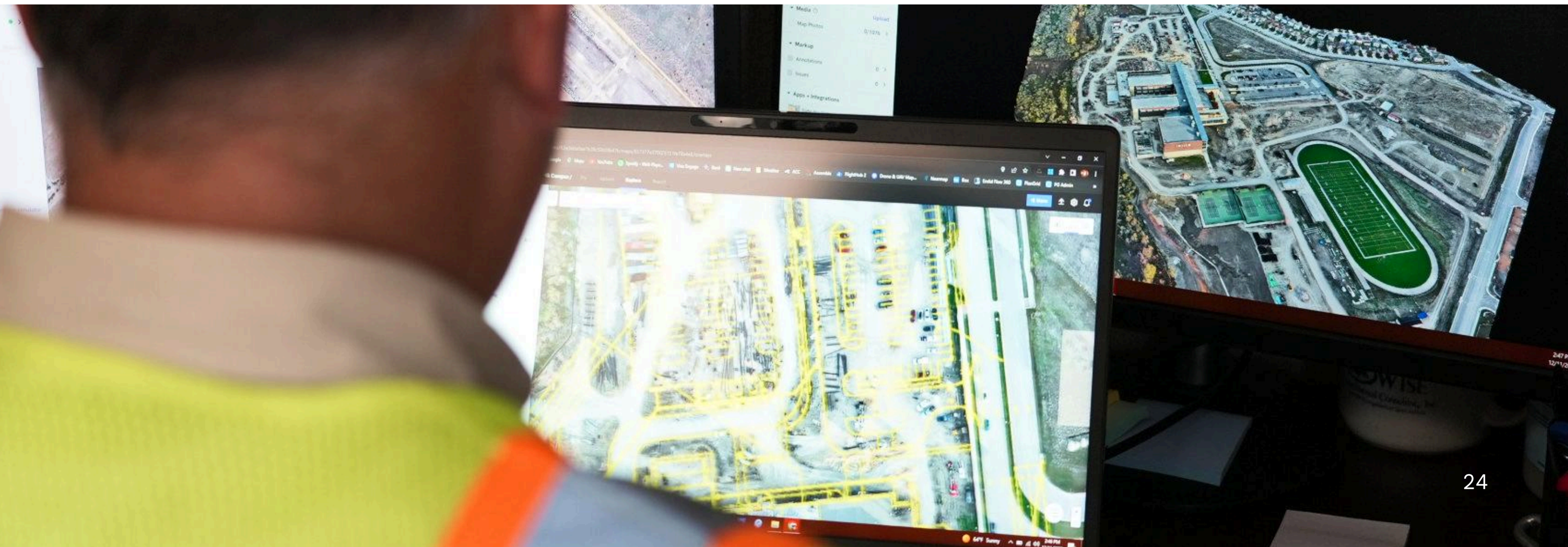
Adding an easy-to-manage GCP to the PPK workflow unlocks the precision required for most compare to design, cut fill, and survey workflows— which is why it's the workflow that best balances accuracy and scalability.

Adding a single known point processed as a GCP with our PP-RTX PPK maps brought our vertical errors comfortably below sub-inch levels on average. A 0.60 inch XYZ error approaches the practical limits of drone photogrammetry, and can be seen as the gold standard for large-scale reality capture.

XY	Z	Total RSME
0.57 in	0.75 in	0.60

What's more, a single known point on a job site is easy for the team to manage and process. Sub-inch accuracy is generally accepted as 'survey-grade' in the drone photogrammetry world; with it, you're able to unlock the world of surveying, cut fill analysis, and detailed 3D compare to design work.

It's why we generally recommend site teams start with one GCP, as it combines a streamlined capture process with an accuracy approximating 4+ GCP maps.



PP-RTX PPK with four GCPs:

0.50 inch checkpoint XYZ error

Recommended for programs that want the best accuracy possible, or who operate on large job sites (i.e. 100+ acres).

While a single GCP can only move the map by a single offset value in each dimension, implementing more than four GCPs allow you to control both map tilt and scale, while also giving you the ability to adjust internal map proportions at each GCP.

That is why adding four or more GCPs to a PP-RTX PPK map – ideally distributed at least around the perimeter of the site – improves map accuracy compared to single-GCP maps.

For this whitepaper, GCPs were placed on the four corners of the site, not in its middle. On average, the difference between one- and four-GCP maps is quite small, with most accuracy gains being on the horizontal plane:

XY	Z	Total RSME
0.36 in	0.70 in	0.50

The difference is more obvious if you set a tight tolerance figure to see how many points float above it. For example, after analyzing what percentage of checkpoint errors stayed under an inch across one- and four-GCP maps, we found that:

- While 95% of all checkpoint errors for the four-GCP maps were under an inch, 88% of all checkpoint errors for the one-GCP maps were under an inch.
- The worst one-GCP map had 66% of its checkpoint errors below an inch, while the worst four-GCP maps had 88% of its checkpoint errors below an inch.

For most sites, the occasional checkpoint floating above an inch is typically averaged out as noise during analysis. But if you require more than 90% of your checkpoints to stay within an inch of error or better, you should use four or more GCPs as it does tighten up the map. For surveyors, engineers, contractors, and site managers who want to get as close to total station data as possible, there is no replacement for consistent ground control over your site.

Additionally, for particularly large job sites, it's probably wise to go beyond one GCP, as the different conditions the drone encounters may require corrections that RTX may not always be able to produce. Meaning if you are on a 100+ acre job site (which is five times the size of the site used in this whitepaper) it's ideal to at least use one GCP per corner of the map.

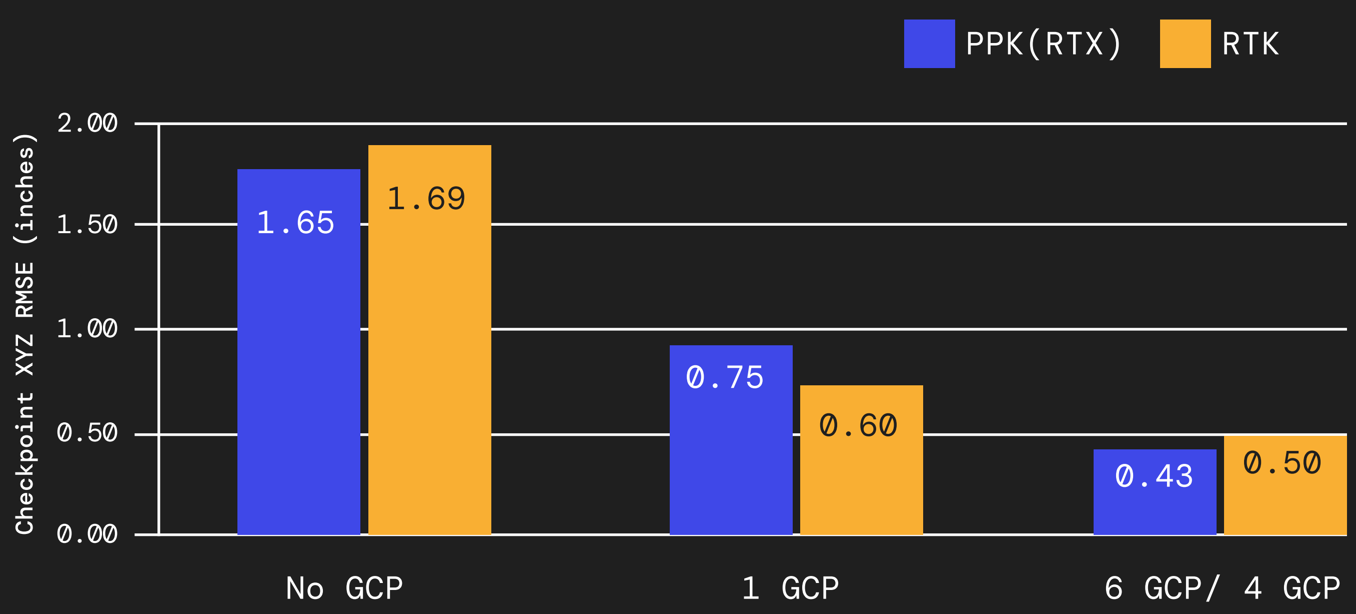
How does DroneDeploy's M3E RTK workflow compare to the PPK workflow?

If you're flying an M3E RTK, we recommend always checking if your site is in a good corrections area and if so, to provide internet access to your controller to receive RTK corrections. Pairing real-time corrections with automatic backups of PPK corrections (if needed) provides you with helpful redundancies in your accuracy workflows, especially if you use GCPs.

The differences in map error between fixed-RTK and PPK maps are negligible.

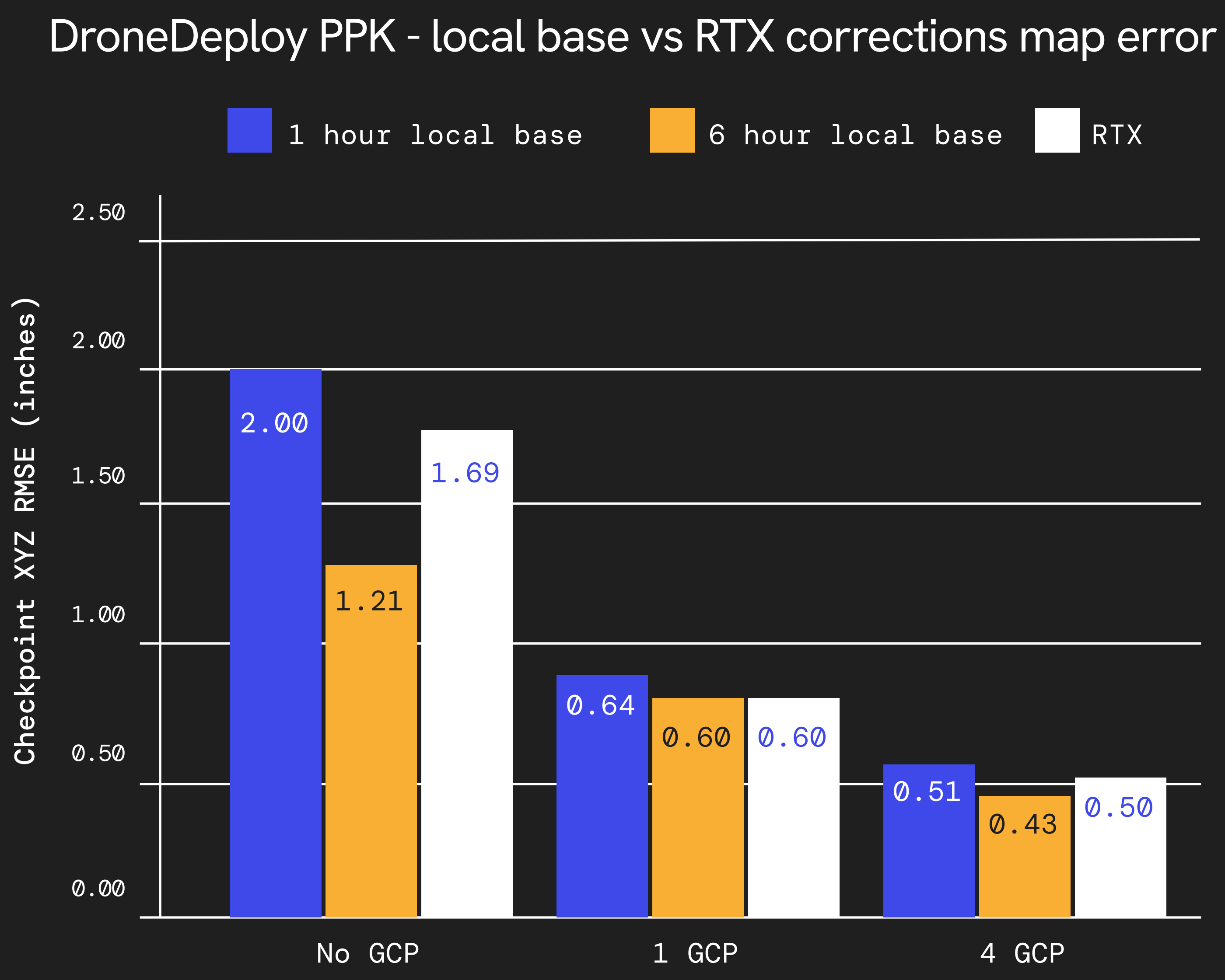
Note that we are comparing vertical elevation calibrated RTK maps to 1 GCP PPK maps, and 6 GCP RTK maps to 4 GCP PPK maps. They are fair comparisons, but not exactly equal in methodology.

DroneDeploy RTK vs PPK map error



How does local base station corrections accuracy compare to PP-RTX corrections accuracy?

DroneDeploy users have the option to upload GNSS observation data from a local base station set up on their job site. For this whitepaper, two Emlid RS3's were set up in the same location during the drone flights. One base station observed continuously for 6 hours during all of the flights, and another observed in 1 hour increments.



With one and four GCPs, the six-hour local base observation was the most accurate, but not by a significant margin. This is due to the fact that adding GCPs heavily influences map accuracy.

With no GCPs, the six-hour local base maps were on average significantly more accurate than the RTX or 1-hour local base maps: this demonstrates where the primary value of local base processing exists when you use no GCPs to still achieve the best accuracy possible.

It is still important to note that whether you use GCPs (and if you do, how many you use) matters more than whether your PPK corrections source is short or long-duration local base station or RTX.

Six-Hour Local Base, No GCP:

1.21 inch checkpoint XYZ error, or better.

Recommended for programs that want the best accuracy possible without GCPs, as error is reduced by ½" compared to PP-RTX no GCP's.

Ultimately, we recommend at least one GCP for all use cases that require nearly maximized change over time precision.

But if programs are looking to accomplish those use cases with no GCPs, we recommend trying local base station processing with Trimble receivers, then validating with checkpoints.

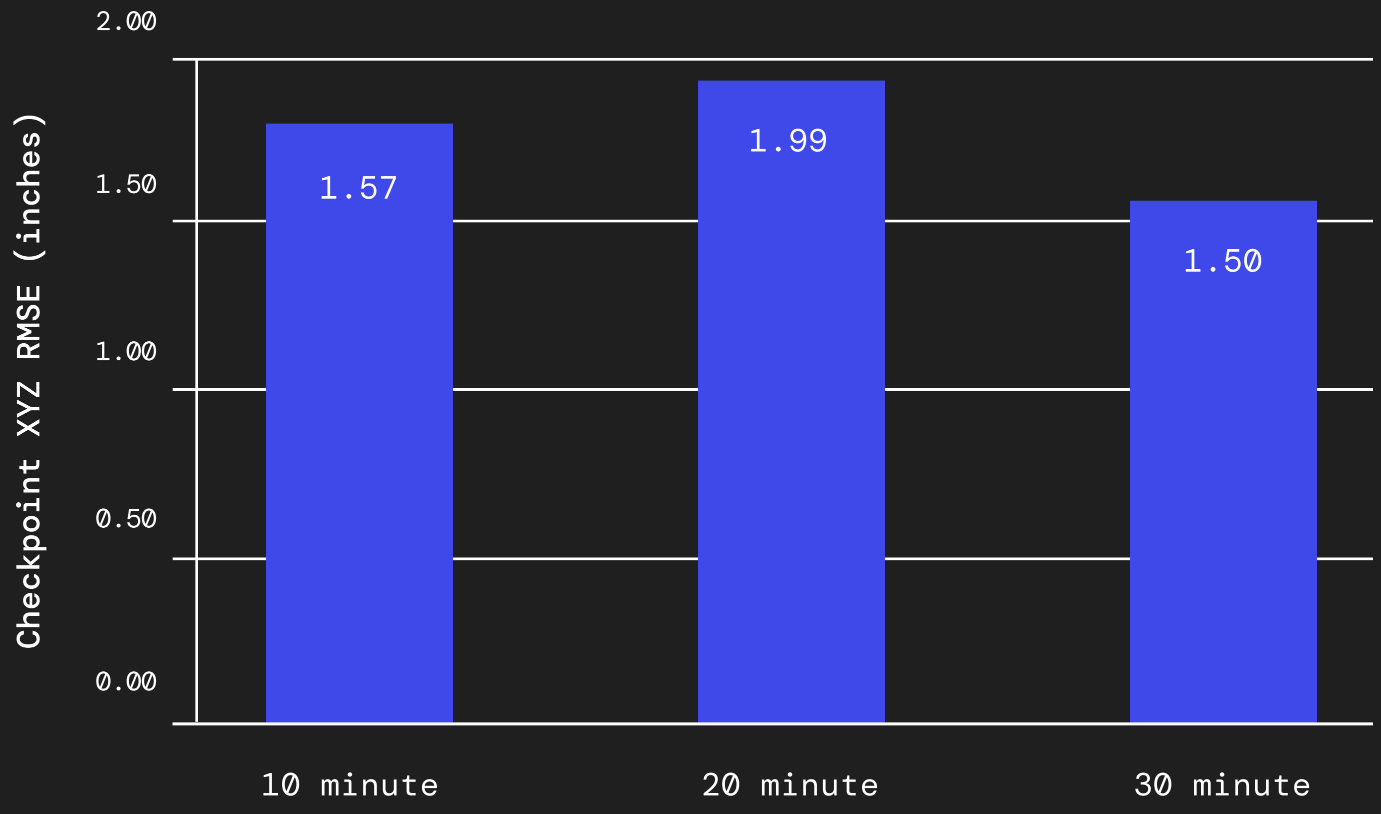
How does flight time influence map accuracy?

No significant difference was found in map accuracy by extending flight time beyond ten minutes in the fast convergence region.

We recommend flying for at least ten minutes in RTX Fast regions (North America and Europe) and twenty minutes in the RTX Global region (rest of world). The whitepaper site is in Northern California in the RTX fast region.

Flight length was varied from ten, twenty, and thirty-minute lengths. The accuracy difference shown below is statistically well within the noise level. Therefore, it's unlikely additional errors in the twenty-minute missions can be attributed to flight time.

DroneDeploy PPK - Trimble RTX map error by flight time



There was a twenty-minute PP-RTX map with an abnormally high error which pulled the average error for that flight time up.

This is a realistic reflection of the nature of GNSS devices and the value of at least one GCP to lock down your maps as atmospheric, solar, or unforeseen technical events are not always possible to predict. In other words, calibrate your data.

In RTX Fast Regions, once you fly for at least ten minutes, there is no need to extend your flight time as a way of increasing corrections accuracy.

The same thing is true about twenty-minute flights in the RTX Global Regions, but that is not included in the scope of testing in this whitepaper.

How close does map accuracy relate to estimated GPS Trust in the Map Processing Report?

Average GPS Trust	0.07ft

A valuable statistic in the Map Processing Report is the 'GPS Trust' value on its first page. Trimble PP-RTX estimates the accuracy of corrections written to all of the images in the map. If the image collection goes smoothly and Trimble's prediction is accurate, it stands to reason that map accuracy should not differ from the GPS Trust figure by a large amount.

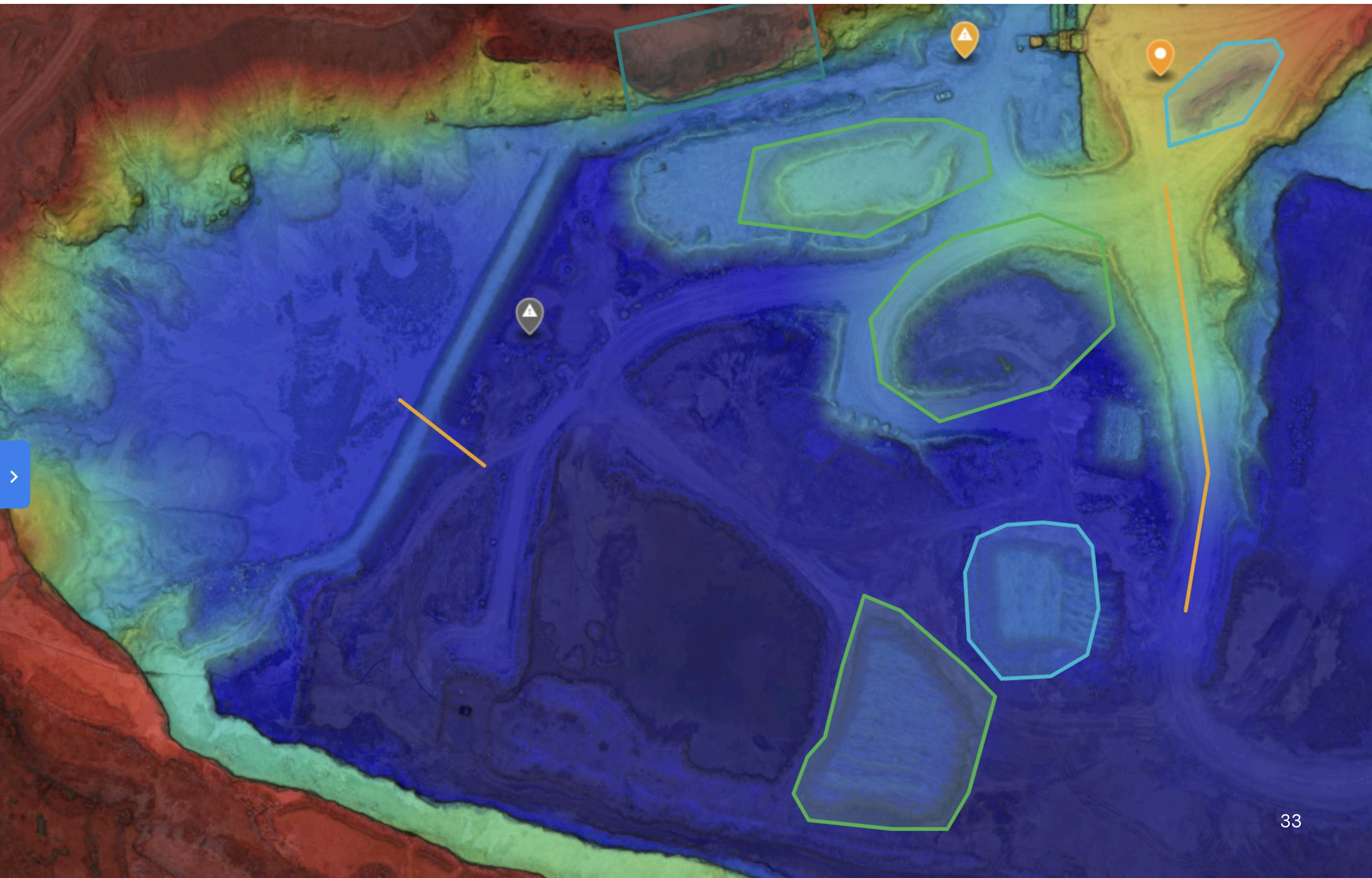
Note: there is an additional error introduced to the final map during the structure-from-motion photogrammetry process, and Trimble's prediction can't be 100% perfectly accurate.

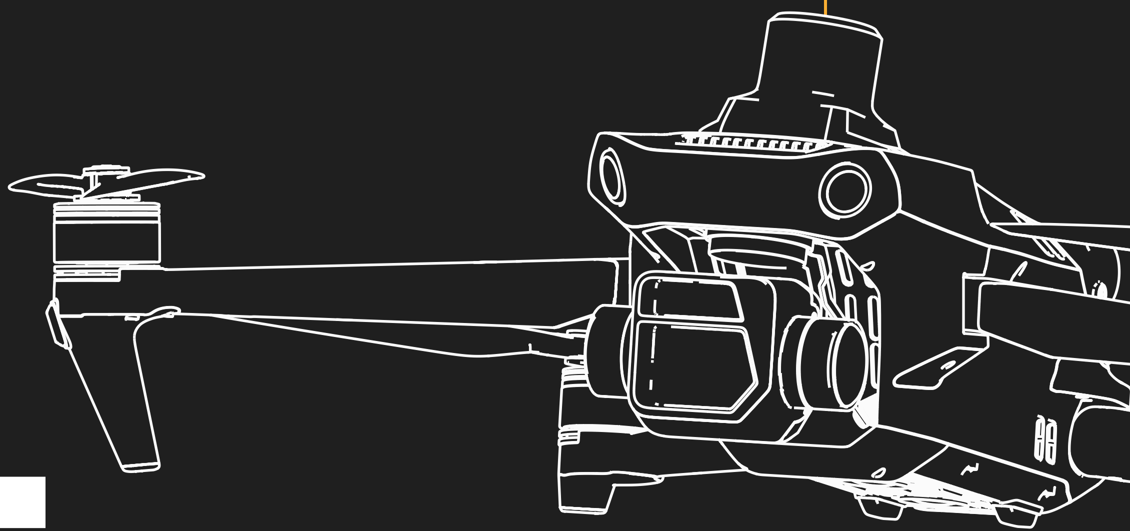
GPS Trust is a useful metric for understanding the estimated global accuracy of your map, but is not a replacement for measuring map accuracy via checkpoints.

GPS Trust figure across the entire whitepaper was very close to the actual map accuracy:

0.82 inches	1.78 inches
Average delta between GPS Trust and Checkpoint RMSE	Maximum delta between GPS Trust and Checkpoint RMSE

This is evidence that the GPS Trust figure is a very useful metric for a quick sanity check on the estimated global accuracy of your map. However, this figure is not an acceptable replacement for checkpoints as a definitive proof of map accuracy.





05 Conclusion

Conclusion

Accuracy depends on the quality of data received, not its quantity. Whether you process that data in real-time or post-flight, there are three quality control choices surrounding your drone flights you need to consider for true accuracy: correction source type (Trimble PP-RTX vs. one- and six-hour local base); number of GCPs used (either zero, one, or 4 GCPs per map); and flight Time (ten, twenty, or thirty minutes).

How you make that choice depends on the size of your site, as well as the needs of your stakeholders.

But given the ease of use of both the hardware and software used in this study – and the unified platform DroneDeploy provides to bridge the two – with these proper guidelines, you can be confident you'll get the most accurate reality capture data possible for your worksite.

How accurate is DroneDeploy's Trimble RTX PPK workflow?

- RTX PPK No GCP:
  1.69 inch checkpoint XYZ error
- RTX PPK 1 GCP:
  0.60 inch checkpoint XYZ error
- RTX PPK 4 GCP:
  0.50 inch checkpoint XYZ error

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