propeller

Accuracy of Stockpile Measurement Using Different Capture Methods

Introduction

In the quarrying and mining industries, it is important to have accurate measurements of your material stockpiles to ensure that you know what quantity of materials you are holding. Specifically, having these accurate measurements ensures that your end-of-month reconciliations are correct and you can forecast your upcoming customer demands.

Historically, stockpiles were, and sometimes still are, measured with land-based surveying equipment such as a GPS rover or terrestrial LiDAR. These methods are not only time consuming, requiring each stockpile to be surveyed individually, but they also pose a safety risk for surveyors who must climb on and around stockpiles and be close to dangerous, heavy machinery.

In recent years, drone photogrammetry has risen in popularity and usefulness, with proven accuracy in measuring earthworks sites and material stockpiles.

The purpose of this whitepaper is to assess various photogrammetry capture methods that can be used to survey stockpiles. Specifically, we will review the accuracy of using a consumer-grade hobby drone (DJI Mavic 2 Pro) compared with an industry-accepted aerial surveying drone (DJI Phantom 4 RTK). Based on the results of this assessment, we will highlight the accuracy that earthworks professionals can expect by using each of these drones, as well as indicate the ease of use and overall financial cost.

Data Capture & Processing Methods

Equipment Used

For the purpose of this whitepaper, stockpile quantity data was collected on Fulton Hogan's Stone Master Quarry in Queensland, Australia. The data was captured by Steve McMurray who is employed by Eltirus and is a registered Mine Surveyor with the Surveyors Board of Queensland. Steve McMurray has extensive experience in drone photogrammetry. The surveyed area was approximately 25,000 m² (2.5 hectares or ~6.1 acres).

Photogrammetry data was captured with both DJI's Mavic 2 Pro (M2P) and Phantom 4 RTK (P4R) that are both remotely piloted aircraft systems (RPAS), commonly known as drones. The Mavic 2 Pro is a hobbyist drone and utilizes a 20MP 1" CMOS sensor with an electronic shutter. The Phantom 4 RTK utilizes a 20MP 1" sensor with a mechanical shutter. This mechanical shutter is used to eliminate the distortions caused by the rolling shutter effect. The Phantom 4 RTK is also equipped with a dual frequency L1/L2 GNSS antenna capable of both RTK and PPK image positioning.

To aid in the photogrammetry process, ground control points were placed and leveraged for data capture. Both Propeller's proprietary AeroPoints as well as spray-painted ground control points were used. The spray-painted ground control points were in the form of white crosses, approximately 1.2m x 1.2m (4ft x 4ft) in size. The position of the ground control points and checkpoints were captured using a Trimble DA-1 antenna, paired with a Samsung Tablet running Trimble Catalyst On Demand High Precision correction through the cellular network.

As a further point of comparison, a Trimble X7 Laser Scanner was used to capture and produce terrestrial LiDAR scans of the stockpiles.

Chosen settings and capture methods

To analyze and compare different accuracies that can be achieved when capturing stockpiles with both drones, a series of settings were chosen when capturing the photogrammetric data. For each drone, a total of three surveys were conducted for each chosen capture method. This was to allow multiple datasets to be produced and for those datasets to be averaged when comparing results. The stockpiles ***did not change*** between captures and the environmental conditions such as wind and ambient light were comparable.

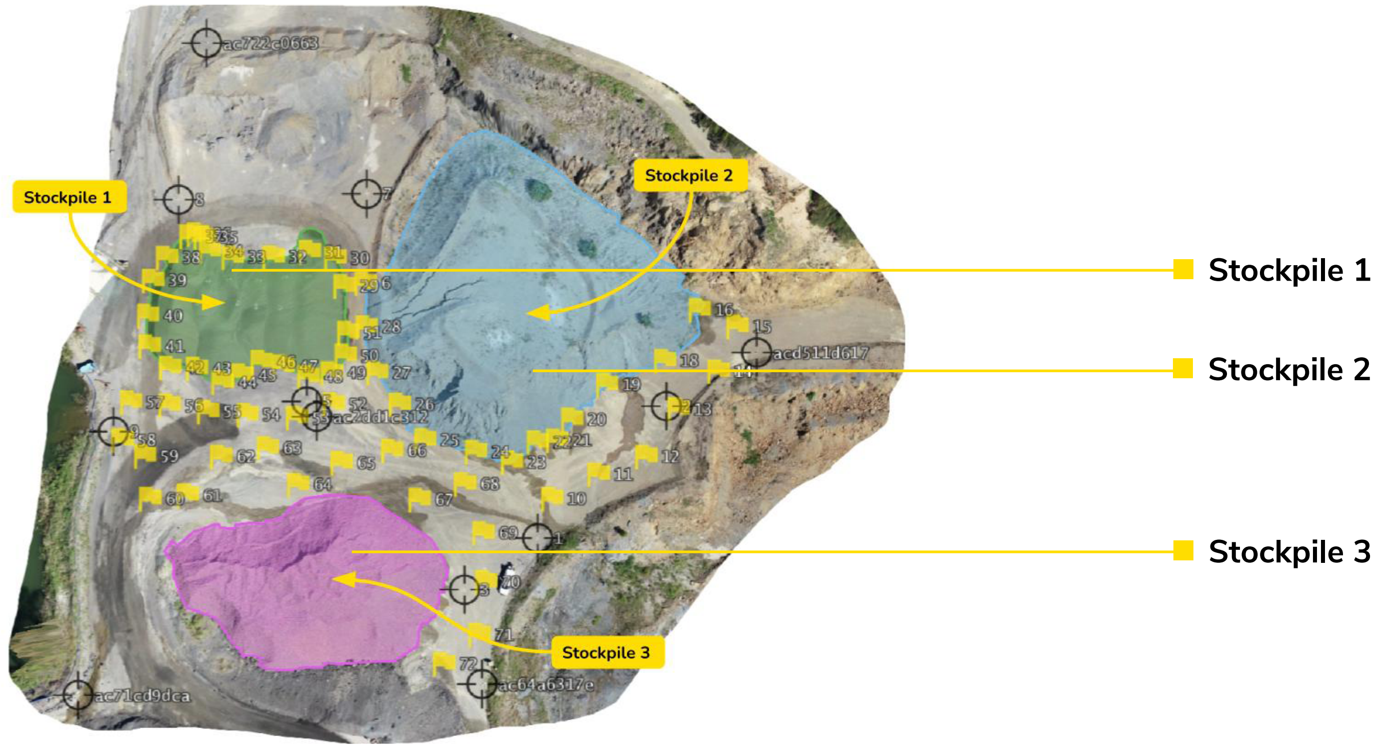


Figure 1: The layout of the stockpiles at the Stone Master Quarry. Flags represent checkpoints and the crosshair marks represent ground control points.

For the Phantom 4 RTK, three sets of data were captured with distortion correction (DC) enabled and another three with distortion correction disabled. The distortion correction feature on the P4R attempts to remove the lens distortion caused when capturing an image using the drone's camera system. When Propeller processes data, the preference is for this distortion to be left unaltered so that it can be rectified more accurately later when the data is processed. All Phantom 4 RTK data was captured using RTK positioning to enable the processing of the imagery with either RTK, PPK, or no GPS correction (i.e., relying on the raw GPS data recorded by the antenna inbuilt to the Phantom 4 RTK).

For the Mavic 2 Pro, three sets of data were captured using both the "hover and capture" and "continuous" shooting modes. Hover and capture causes the drone to stop and take an image, instead of taking an image while flying. The purpose of enabling hover and capture is to remove the distortions caused by the rolling shutter on the M2Ps camera sensor.

A total of 13 different data capture methods were used to produce the dataset of the three stockpiles. As three data captures were undertaken for each of the methods, we are left with 39 different datasets. In addition, the stockpiles were captured using a terrestrial LiDAR. This resulted in 40 datasets from which to compare volumes.

The following table summarizes the data capture methods:

Table 1: Different data capture methods used to measure the stockpiles.

Capture Method	Capture Device	Geotagging Accuracy	Ground Control	Distortion Correction	Hover & Capture
1	P4R	PPK	Yes	No	N/A
2	P4R	RTK	Yes	Yes	N/A
3	P4R	Low	Yes	No	N/A
4	P4R	PPK	Yes	Yes	N/A
5	P4R	Low	Yes	Yes	N/A
6	P4R	RTK	No	No	N/A
7	P4R	Low	No	No	N/A
8	P4R	PPK	No	Yes	N/A
9	P4R	Low	No	Yes	N/A
10	M2P	Low	Yes	N/A	Yes
11	M2P	Low	Yes	N/A	No
12	M2P	Low	No	N/A	Yes
13	M2P	Low	No	N/A	No
14	LIDAR	N/A	Yes	N/A	N/A

A combined total of 75 ground control and check points were surveyed in the general stockpile area to allow for processing and accuracy validation. **From the 75 measured:**

- 5 were AeroPoints
- 7 were surveyed ground control points
- 63 were surveyed checkpoints

The layout of these ground control and checkpoints can be seen in **Figure 1.**

Validating Dataset Accuracy

Choosing a base dataset

To accurately compare stockpile volumes between the differently processed datasets, we leveraged a “base dataset”. Comparisons of the stockpile volumes were made between the base dataset and all other datasets. The stockpile volumes of the base dataset are assumed to be accurate. All other volumes are compared against the base dataset.

For the base dataset, the first capture using method 1 was chosen. This utilizes:

- DJI Phantom 4 RTK with Propeller’s proprietary PPK processing solution
- No distortion correction enabled on the Phantom 4 RTK’s camera
- 2 ground control points for data correction. Note: This is the number of ground control points that Propeller recommends for an area encompassed by the stockpiles when utilizing a PPK or RTK capable drone.

Validating the base dataset against an independently processed survey

To verify the accuracy of the base dataset, Steve McMurray processed a new dataset with the same set of images as the base dataset.

The dataset was processed using the following:

- Imagery with RTK processed geotags
- Five evenly distributed ground control points were used.
- Agisoft Metashape was used to produce a GeoTIFF output for both the orthomosaic and the digital elevation model (DEM).
- No point cloud filtering was used (the same as in the Propeller situation).
- High alignment options were selected in Metashape and a medium density point cloud was used in the creation of the DEM.

When comparing the dataset processed by Steve McMurray to the base dataset processed by Propeller, we found that the accuracy and margin of error for both datasets were similar when referenced to the surveyed check points (see Figure 2). The average checkpoint error for the Eltirus reference dataset was +7.49mm, whereas the average check error for the Propeller reference dataset was -0.12mm. Both datasets produced an average checkpoint accuracy within ±30mm which is typically considered “survey grade”.

All datasets exhibited a higher checkpoint error for checkpoint 48. This will be discussed further in the following sections.

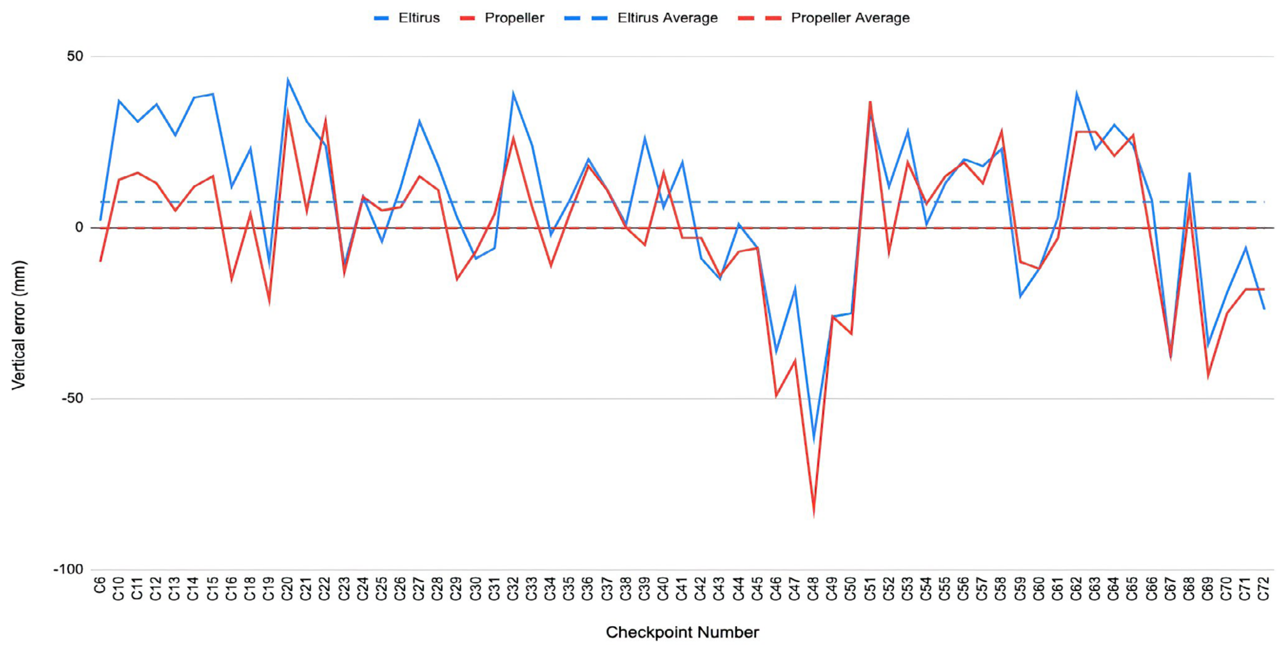


Figure 2: Checkpoint Error in both reference Propeller Dataset and Eltirus processed dataset.

Analysis of error in the various capture methods

The charts provided in the appendix provide heatmaps for the various data capture methods. These heatmaps show the vertical error of each dataset with respect to the checkpoints. Each heatmap uses a fixed scale of +150mm to -150mm, going from blue to red to allow for easy comparison between the heatmaps.

The heat maps show the following:

- Both P4R and M2P processed datasets with low accuracy tags and no ground control points
- P4R processed datasets with PPK geotags and no GCPs
- P4R processed datasets with both PPK and RTK geotags with two GCPs
- P4R processed datasets with low accuracy geotags with five GCPs
- M2P processed datasets with five GCPs

As a general observation, the heat maps show a large checkpoint error when the datasets are processed using low accuracy geotags with no ground control points. In addition, the datasets that use M2P images taken without the hover and capture feature display higher error rates. This is expected due to the rolling shutter effect of the M2P when taking images while in motion.

Although the checkpoint error on some of these datasets is very high, it is not possible to infer the stockpile accuracy from the checkpoint error alone. This high error rate indicates that the dataset is shifted from the accurate checkpoints with respect to a global reference frame. It also may indicate that there is warping of the dataset. For example, warping may have occurred with the M2P processing case when ground control was used but not the hover and capture feature. In this case, the checkpoint error is not consistent in one direction. This is an important nuance to consider, but a full investigation into warping and scaling issues is out of the scope of this white paper.

The datasets that leverage the P4R with low accuracy, PPK, or RTK image corrections, as well as ground control or those using the P4R with high accuracy image corrections (PPK or RTK) are the most accurate with respect to the checkpoints. This is visually evident in the heat maps provided in the appendix.

It should also be noted that all datasets have a higher error on checkpoint 48. This is either due to reconstruction of the model at this point or a human error when measuring the ground; for example, accidentally inserting the GPS rover spike below the ground level at that location. The errors recorded by the GPS rover at that point (0.064mm 3D error and 0.029mm 2D error) are not substantially different from the other checkpoints.

Looking at the individual groups of cases, the following observations were made:

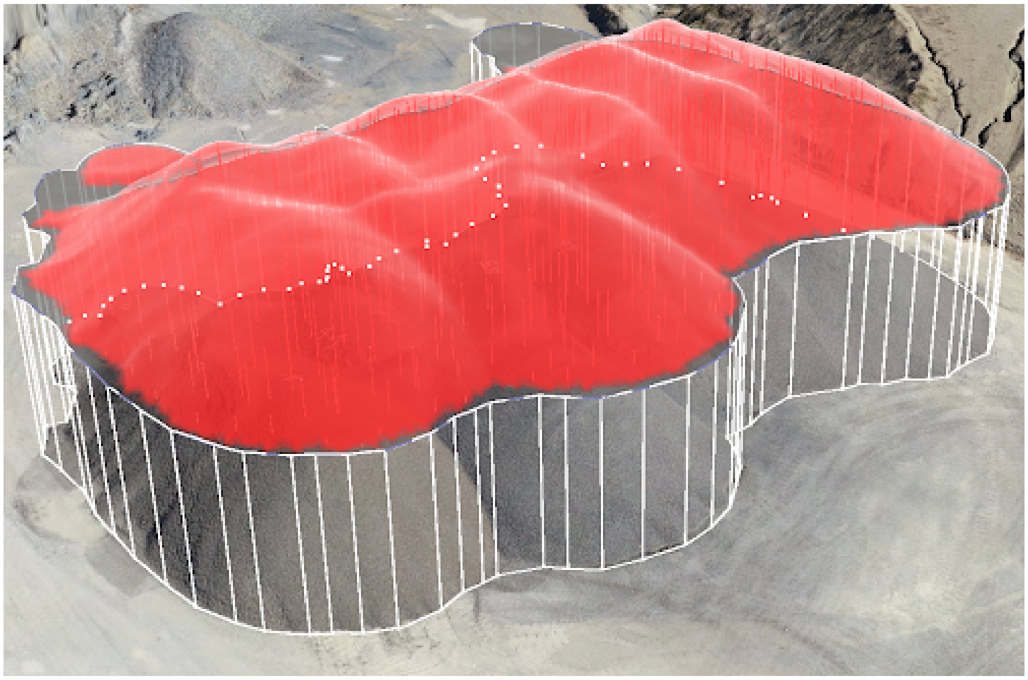
Capture Methods	Observations
M2P without ground control	The checkpoint error is very high. The error on average was 2.259m for both hover & capture and continuous capture.
P4R normal accuracy without ground control	The checkpoint error is high. Potential warping as the error is not consistent in one direction.
M2P with ground control	The error is generally low (<50mm); however there is noticeably higher error in the continuous capture case. Although the average error is not that much different, 50mm (continuous capture) vs 33mm (hover and capture). By inspecting the graph, you can see that the error is much higher in the continuous capture method over certain spots. The error is as high as 140mm for some checkpoints.
P4R with ground control or high-accuracy P4R (PPK or RTK) without ground control	Overall these datasets are the most accurate. By viewing the heatmaps, you can see that the checkpoint error is consistent and small.

Stockpile Volumes & Comparison

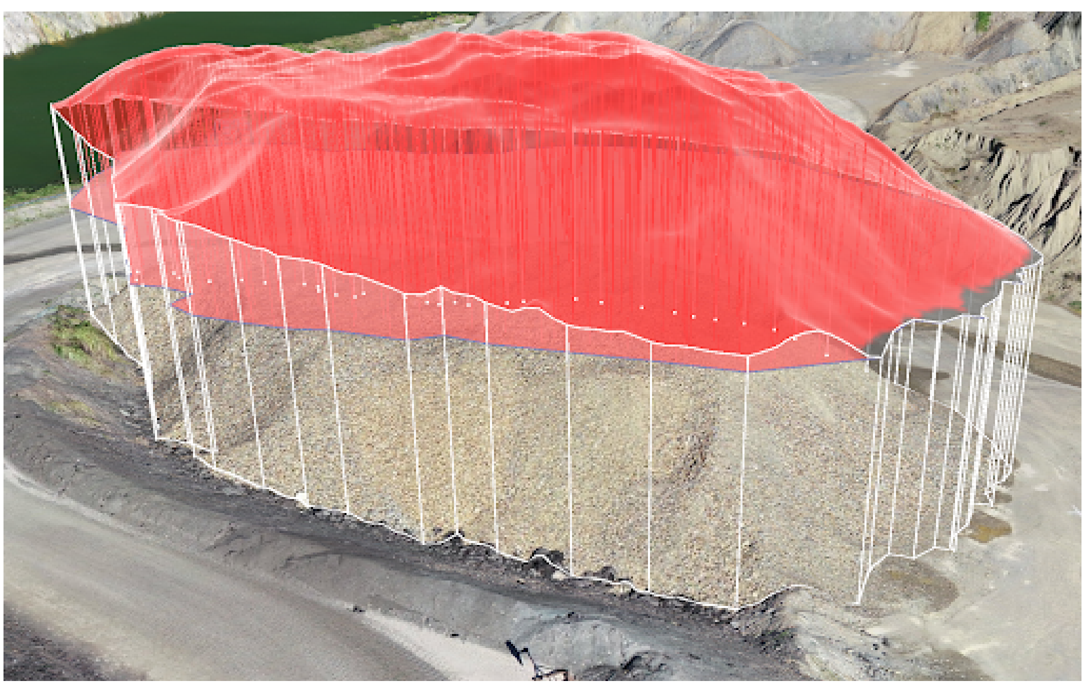
In the area surveyed, there are three separate stockpiles. These stockpiles have been labeled Stockpile 1, Stockpile 2, and Stockpile 3. The positions of the three stockpiles can be seen in Figure 1.

The three stockpiles were measured using the volume tool in the Propeller Platform. To measure the stockpiles, a boundary was created using the base dataset mentioned above. To create this boundary, contours and an elevation map were enabled in the Propeller Platform. This enables the toe of the stockpiles to be clearly defined. To maintain a constant comparison between datasets, the same boundary was used for each data capture type. The position of the boundary was moved to align with the stockpile if there was a lateral shift between datasets. However, no modifications were done to the shape and no major scaling issues were observed.

Stockpile 1 was measured using a smart volume. A smart volume measures the terrain against a base that is created by interpolating a plane between the boundary points selected. As Stockpile 1 sits on a relatively flat surface, this method allows for an accurate calculation of the volume.



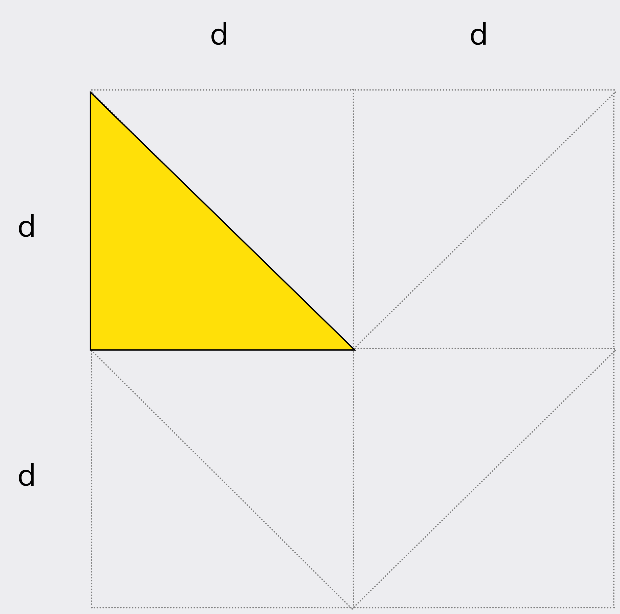
Both Stockpile 2 and Stockpile 3 were measured using a reference level volume. Both of these stockpiles are on non-level surfaces and have been constructed on the side of embankments. By using a reference level, comparisons can be made between datasets. The lowest vertice on the stockpile boundary polygon was used as the reference level. This means that the lowest point in each dataset is used.



Stockpile computation methodology using Propeller

When calculating volumes in the Propeller Platform, the simple vertical prism method is used. The polygon that bounds the volume area is triangulated into right angled triangles. For these samples, an initial sampling distance of 0.5m is used. The polygon is divided into 0.5m sections (see image below). In this division, all triangles are uniformly spaced to coincide with the defined sampling distance.

When using the simple prism method, the volume of each triangle is calculated. The triangle from the surface of interest is projected onto the desired surface to measure against. That surface is then sampled using the positions of each triangle vertice. From there, volume calculations of the individual triangle can be made. By summing the volumes of all triangles in the volume area, it's possible to calculate the total volume change, whether it is a cut or fill volume.



Testing of Propeller's volume method was conducted to see how it compares against other industry leading software platforms such as Trimble Business Center, Autodesk Civil 3D, and Blue Marble Geographics Global Mapper. For the datasets captured for the purposes of this investigation, 39 measurements were chosen to compare the difference between Propeller and other software platforms.

Specifically, all three stockpile measurements were compared from one dataset of each of the 13 drone-based capture methods.

The following table shows the average difference between volumes when measured in the Propeller Platform and other software providers. Propeller's volume calculations show a nominal difference to that of the other software solutions (see Table 2).

Table 2: Comparison of volume measurements using Propeller versus other industry leading software providers.

Software	Average difference between Propeller & software volume (%)	Measurement method
Trimble Business Center	-0.18%	TIN (TTM file) surfaced exported for each stockpile boundary
	-0.85%	Full site point cloud exported and converted to surface
Autodesk Civil 3D	0.84%	Digital Elevation Model (GeoTIFF) exported for full site and converted to surface.
Blue Marble Geographics Global Mapper	-0.12%	Digital Elevation Model (GeoTIFF) exported for full site

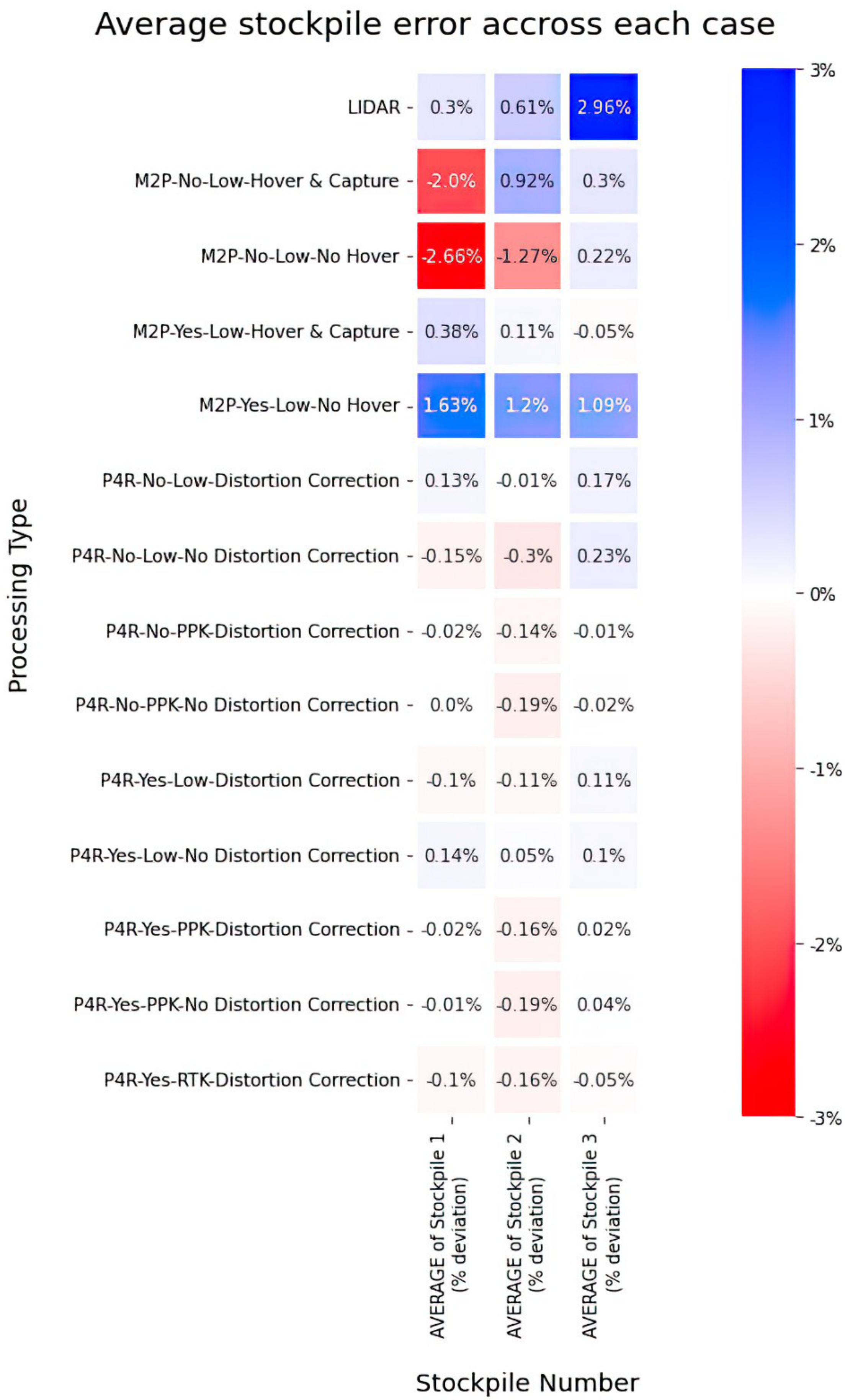
Stockpile volumes

To compare the results of stockpile measurements between datasets, each stockpile measurement was compared against the volume measurement obtained from the base dataset. A percentage deviation, or error, was calculated for each case.

The following formula was used:

$$\text{Error} = \frac{\text{Stockpile volume} - \text{Base dataset stockpile volume}}{\text{Base dataset stockpile volume}} * 100\%$$

The error for each data capture type across the three data captures was averaged to provide a calculation of the error in each data capturing method. This error is displayed in the following heatmap. This heatmap shows the error for each stockpile and utilizes a scale from 3% error (blue) to -3% error (red).


Average stockpile error accross each case
Processing Type
LIDAR
M2P-No-Low-Hover & Capture
M2P-No-Low-No Hover
M2P-Yes-Low-Hover & Capture
M2P-Yes-Low-No Hover
P4R-No-Low-Distortion Correction
P4R-No-Low-No Distortion Correction
P4R-No-PPK-Distortion Correction
P4R-No-PPK-No Distortion Correction
P4R-Yes-Low-Distortion Correction
P4R-Yes-Low-No Distortion Correction
P4R-Yes-PPK-Distortion Correction
P4R-Yes-PPK-No Distortion Correction
P4R-Yes-RTK-Distortion Correction
0.3% 0.61% 2.96%
-2.0% 0.92% 0.3%
-2.66% -1.27% 0.22%
0.38% 0.11% -0.05%
1.63% 1.2% 1.09%
0.13% -0.01% 0.17%
-0.15% -0.3% 0.23%
-0.02% -0.14% -0.01%
0.0% -0.19% -0.02%
-0.1% -0.11% 0.11%
0.14% 0.05% 0.1%
-0.02% -0.16% 0.02%
-0.01% -0.19% 0.04%
-0.1% -0.16% -0.05%
AVERAGE of Stockpile 1 (% deviation)
AVERAGE of Stockpile 2 (% deviation)
AVERAGE of Stockpile 3 (% deviation)
Stockpile Number
3%
2%
1%
0%
-1%
-2%
-3%

Discussion of Results

Based on the dataset analysis, individuals can expect a high checkpoint error when flying the Mavic 2 Pro or the Phantom 4 RTK with low accuracy geotags and no ground control.

Flying a Phantom 4 RTK with RTK or PPK geotags and ground control will produce the most accurate results. When flying a Phantom 4 RTK with low accuracy geotags and ground control points, high accuracy results can also be obtained.

The Mavic 2 Pro is able to produce accurate results with respect to checkpoint error when the hover and capture mode is used in conjunction with ground control points. From the heatmap, it can be observed that when continuous capture is used, there is significantly higher checkpoint error.

While these results are interesting, they cannot be used to make inferences and conclusions on the accuracy of stockpile measurements. Instead, it is necessary to analyze the average stockpile error of each data capture type with reference to the base dataset. This analysis shows us that when using a Mavic 2 Pro with no ground control or using a Mavic 2 Pro with ground control but using continuous capture there is noticeable error.

This error is more prominent with Stockpile 1, which is the smallest stockpile. As the stockpile gets larger, the average error decreases. This higher error on Stockpile 1 may be attributed to its shape. Stockpile 1 is built of smaller stockpiles and has varying height. Both Stockpiles 2 and 3 are more uniform in shape and, therefore, any reconstruction errors may be less prominent.

The following are the average absolute stockpile errors for each case:

- Mavic 2 Pro with hover and capture and no ground control: 1.07%
- Mavic 2 Pro with continuous capture and no ground control: 1.38%
- Mavic 2 Pro with continuous capture and ground control: 1.31%

With regard to Stockpile 3, the LiDAR capturing method has a significant error, due to the use of terrestrial LIDAR and a conical hole that cannot be observed from the ground. Additionally shadowing created from ground based view angles also introduces error.

Both the Mavic 2 Pro dataset using hover and capture with ground control as well as the low accuracy Phantom 4 RTK dataset that did not use ground control had slightly higher error compared to the rest of the capture methods. With an average absolute error of 0.18% and 0.22%, respectively. For all other datasets the average absolute error is 0.09%.

Although these errors seem small, it's important to contextualize them in terms of real-world meaning. For example, a 1.38% error on a stockpile with a volume of 7000 m^3 is 96 m^3. If the material in the stockpile was worth $50/tonne. That would be a $4,800 discrepancy. If you applied this error to multiple stockpiles over a period of time, it quickly adds up.

Conclusion

The type of data capture method has a noticeable impact on the overall accuracy of stockpile measurements. Using a Phantom 4 RTK with ground control will produce the most accurate stockpile measurements. Whether or not RTK or PPK is used creates little impact to the measurement accuracy, provided an appropriate amount of ground control is used. Propeller's help article, How Many AeroPoints Do I Need For My Survey? provides guidance on how much ground control you need, depending on the image correction accuracy and the terrain you are flying over.

Flying a Phantom 4 RTK without ground control and using either no image corrections (low accuracy) or PPK/RTK corrections will allow you to accurately measure stockpiles. However, the downside of doing this is that the overall accuracy of the dataset will be negatively affected.

The analysis shows that decent stockpile accuracy is attainable using the Mavic 2 Pro, provided that ground control is used in conjunction with a hover and capture photography method to counteract the rolling shutter effect. Capturing data with a continuous capture method will lead to inaccurate results, even if ground control is used. It is also worth mentioning that in order for ground control to be used, it must be accurately surveyed by a trained individual using survey equipment. This ground control also must be continuously resurveyed as site operations can cause ground control to be destroyed.

Capturing data using a Mavic 2 Pro without using the hover and capture method or without ground control will lead to stockpile measurements with high error. The margin of error averages between 1.07% to 1.4%, depending on the capture method used, with the highest error indicated when measuring smaller stockpiles. The highest error observed occurred when using the Mavic 2 Pro without the hover and capture feature or ground control, at 2.66% for a 2000 m^3 stockpile.

With this information, the decision really comes down to the level of accuracy you and your team are willing to accept. Can you survey your stockpiles with a cheaper consumer drone and get acceptable results? It all depends on your level of acceptance. If your current method of measuring stockpiles is by truck counts to get a general idea of your stock, then a cheaper consumer drone will yield acceptable results.

However, if you need to be as accurate as possible and ensure your end-of-month figures are accurate or you want to have accurate historical data where comparisons can be made between datasets. Then you should opt for an RTK solution that utilizes ground control.

About Propeller

Propeller Aero unleashes the full power of data for anyone moving or digging the earth to easily, accurately, and instantly track progress and make faster, safer, and more profitable decisions. Propeller empowers customers to collaborate better, regardless of technical knowledge, streamlining the entire process from bid and design through completion.

More than 2,400 customers in heavy civil construction and resource operations settings across more than 14,000 worksites in over 120 countries trust Propeller to track site progress accurately with 3D visual tools that everyone in the organization can use.

For more information, visit:
www.propelleraero.com

About Eltirus

Eltirus are leaders in sustainability improvement through quarry digitalisation.

Working with sites across Australia and New Zealand, we help clients know what's in the ground, extract it viably and ensure compliance.

Active in the use of drones for quarry survey since 2017, we have conducted significant research into "whole of site" drone survey for use in downstream activities such as geological assessment and quarry planning and vertical wall mapping for geotechnical assessment.

For more information, visit:
www.eltirus.com

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Appendix

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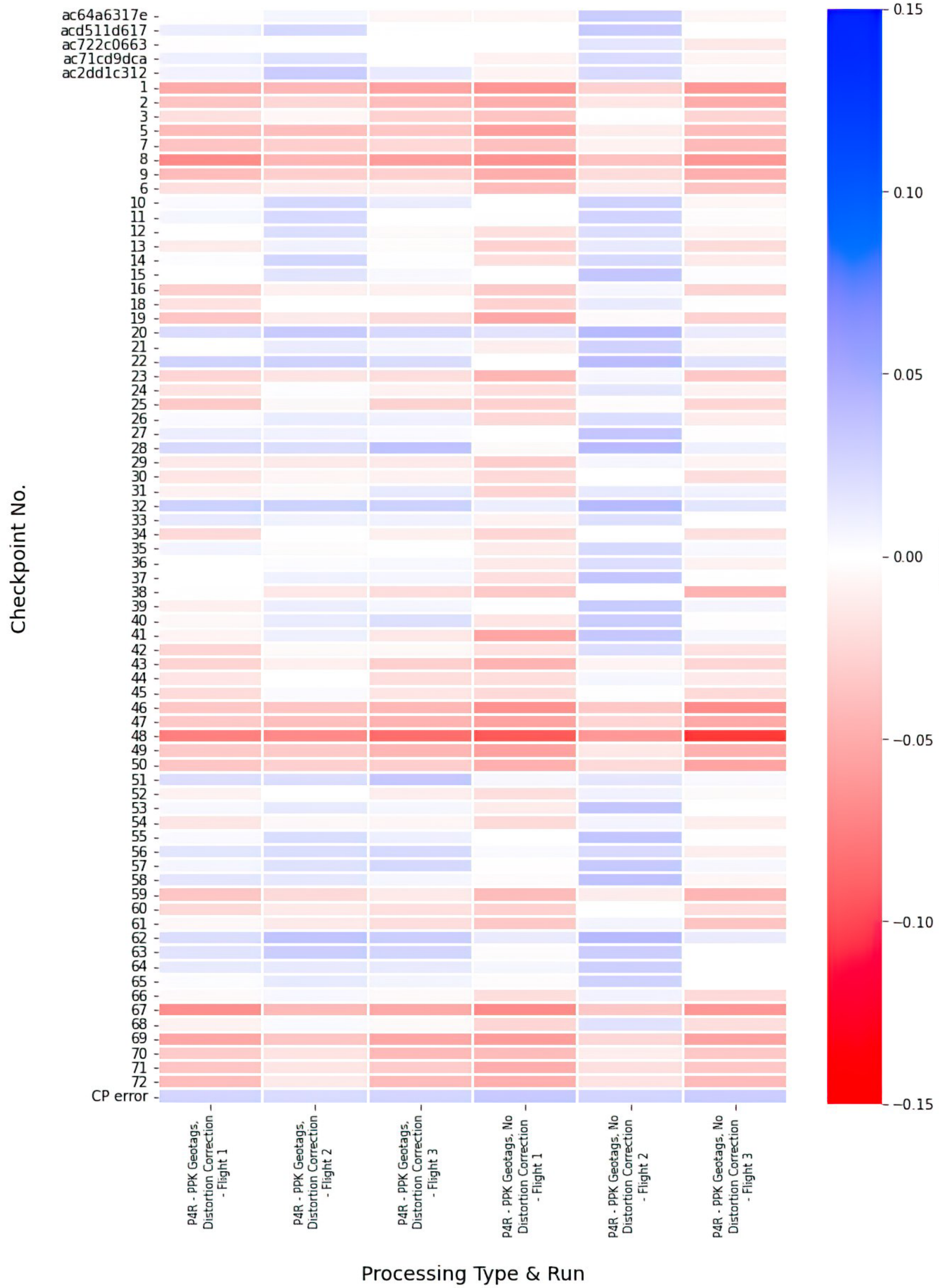
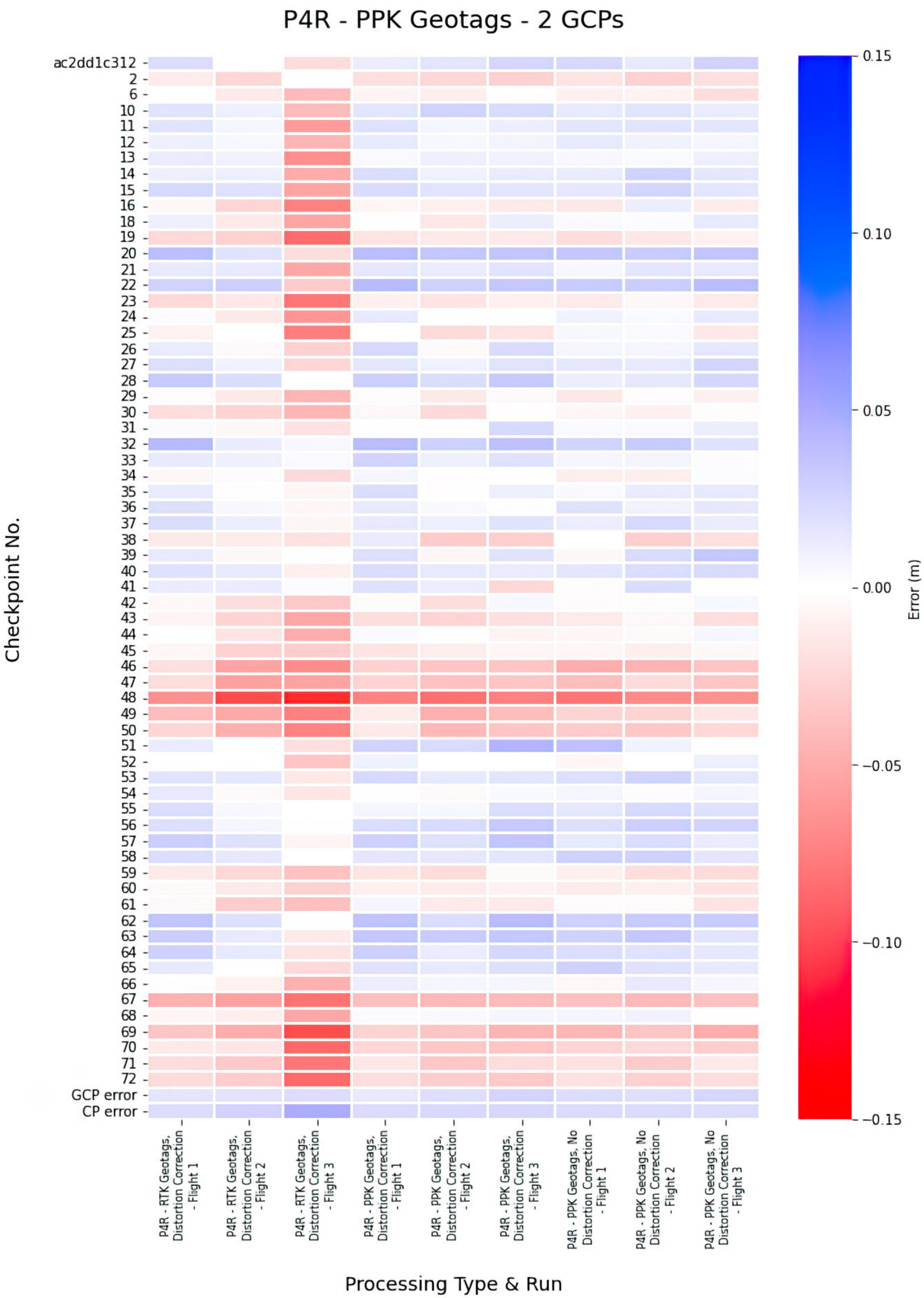
P4R - PPK Geotags - No GCPs




P4R - PPK Geotags - 2 GCPs
Checkpoint No.
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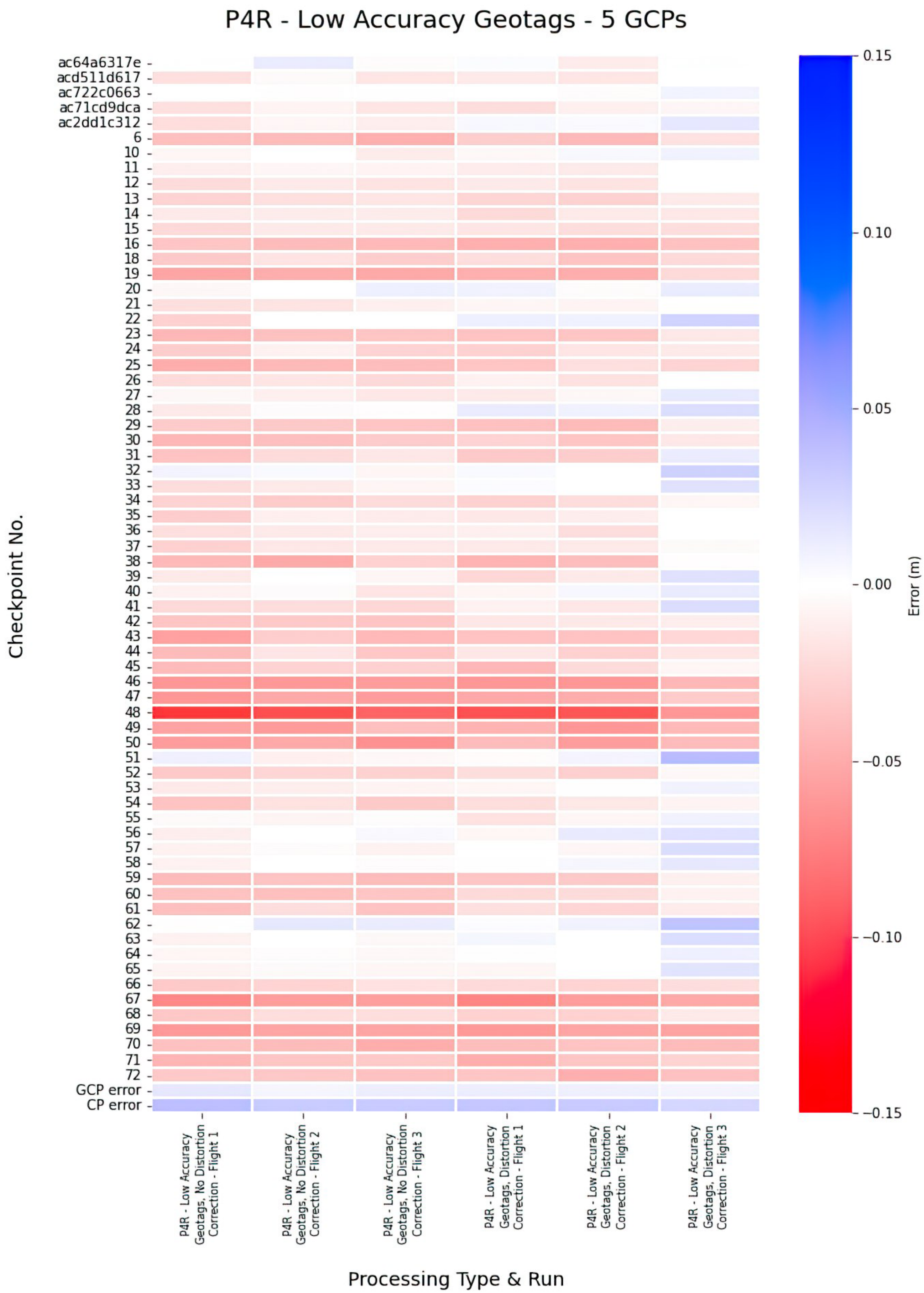
GCP error
CP error
P4R - RTK Geotags, Distortion Correction - Flight 1
P4R - RTK Geotags, Distortion Correction - Flight 2
P4R - RTK Geotags, Distortion Correction - Flight 3
P4R - PPK Geotags, Distortion Correction - Flight 1
P4R - PPK Geotags, Distortion Correction - Flight 2
P4R - PPK Geotags, Distortion Correction - Flight 3
P4R - PPK Geotags, No Distortion Correction - Flight 1
P4R - PPK Geotags, No Distortion Correction - Flight 2
P4R - PPK Geotags, No Distortion Correction - Flight 3
Processing Type & Run
0.15
0.10
0.05
0.00
−0.05
−0.10
−0.15
Error (m)


P4R - Low Accuracy Geotags - 5 GCPs
Checkpoint No.
ac64a6317e
acd511d617
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ac71cd9dca
ac2dd1c312
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GCP error
CP error
P4R - Low Accuracy Geotags, No Distortion Correction - Flight 1
P4R - Low Accuracy Geotags, No Distortion Correction - Flight 2
P4R - Low Accuracy Geotags, No Distortion Correction - Flight 3
P4R - Low Accuracy Geotags, Distortion Correction - Flight 1
P4R - Low Accuracy Geotags, Distortion Correction - Flight 2
P4R - Low Accuracy Geotags, Distortion Correction - Flight 3
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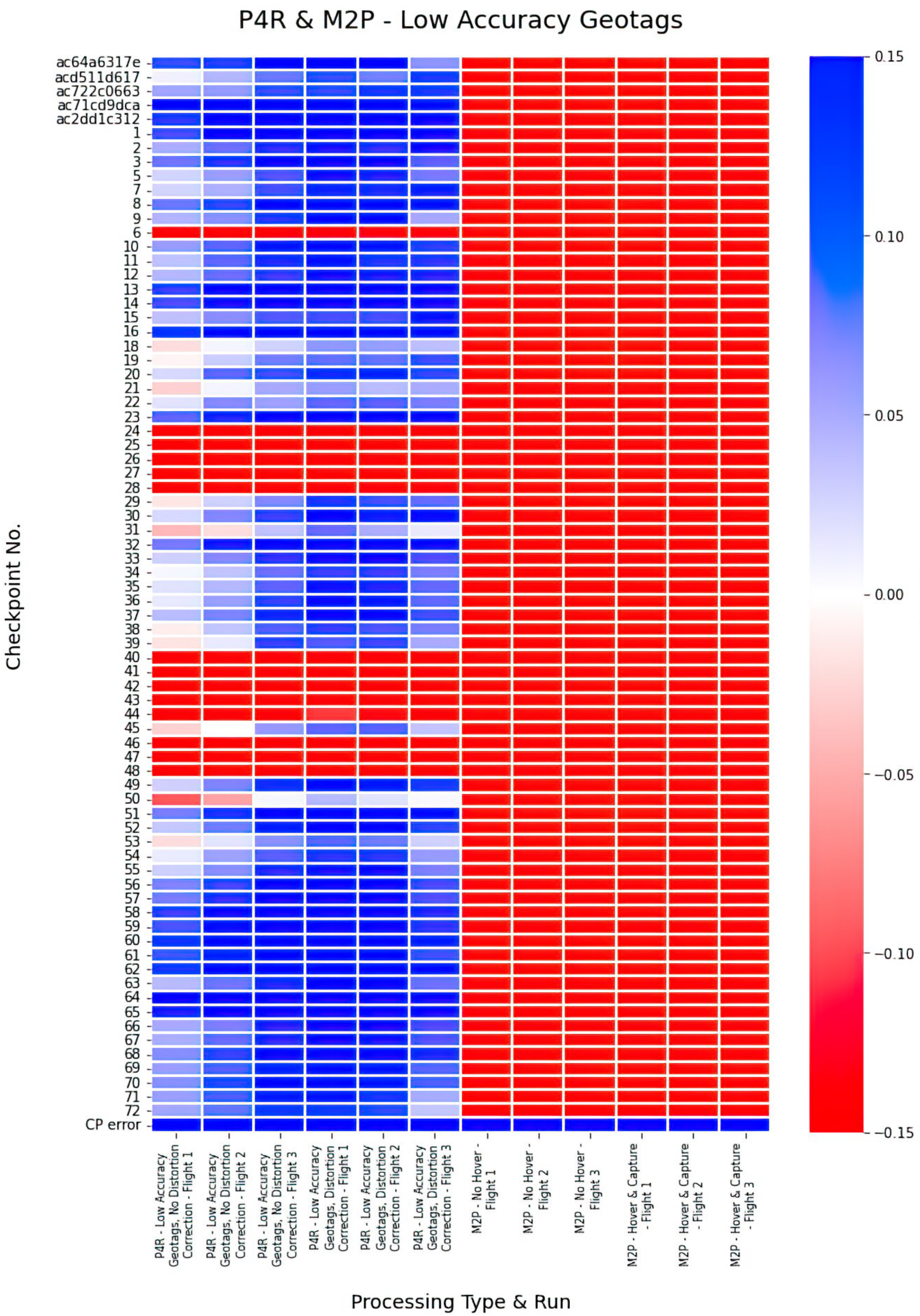
P4R & M2P - Low Accuracy Geotags
Checkpoint No.
Processing Type & Run
Error (m)
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−0.10
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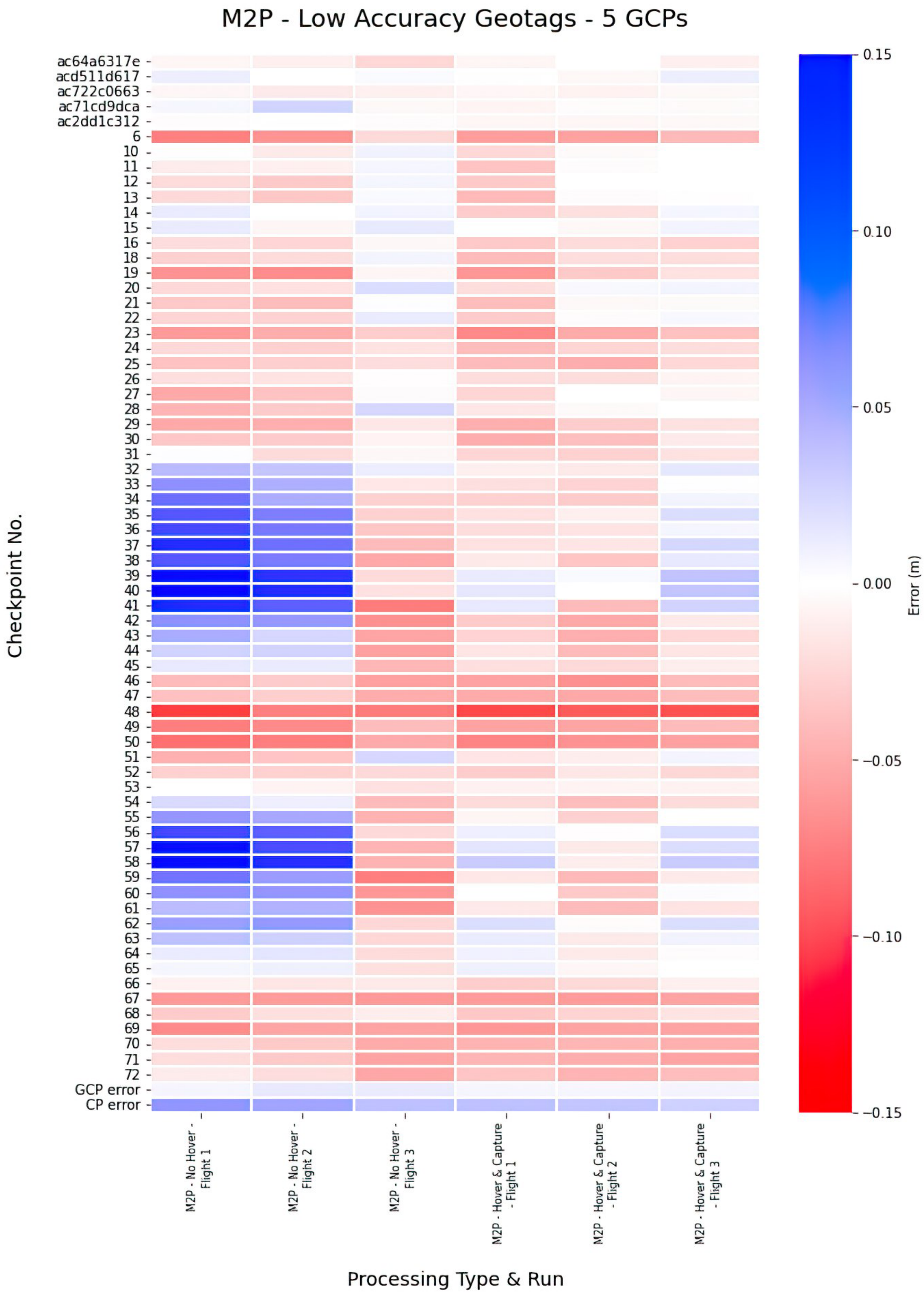
acd511d617
ac722c0663
ac71cd9dca
ac2dd1c312
CP error
P4R - Low Accuracy Geotags, No Distortion Correction - Flight 1
P4R - Low Accuracy Geotags, No Distortion Correction - Flight 2
P4R - Low Accuracy Geotags, No Distortion Correction - Flight 3
P4R - Low Accuracy Geotags, Distortion Correction - Flight 1
P4R - Low Accuracy Geotags, Distortion Correction - Flight 2
P4R - Low Accuracy Geotags, Distortion Correction - Flight 3
M2P - No Hover - Flight 1
M2P - No Hover - Flight 2
M2P - No Hover - Flight 3
M2P - Hover & Capture - Flight 1
M2P - Hover & Capture - Flight 2
M2P - Hover & Capture - Flight 3


M2P - Low Accuracy Geotags - 5 GCPs
Checkpoint No.
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ac722c0663
ac71cd9dca
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GCP error
CP error
M2P - No Hover - Flight 1
M2P - No Hover - Flight 2
M2P - No Hover - Flight 3
M2P - Hover & Capture - Flight 1
M2P - Hover & Capture - Flight 2
M2P - Hover & Capture - Flight 3
Processing Type & Run
Error (m)
0.15
0.10
0.05
0.00
−0.05
−0.10
−0.15