WHITE PAPER

Reaching 1 cm (0.4 in) drone survey accuracy

3x higher absolute accuracy with WingtraOne

WingtraOne PPK – 1 cm (0.4 in)[1]

Other fixed wing drones with a 20 MP camera – 3 cm (1.2 in)[2]

Tests in the USA and Switzerland prove that the VTOL WingtraOne drone repeatedly reaches best-in-class 1 cm (0.4 in) absolute accuracy. In optimal conditions even subcentimeter accuracy is possible. This is 3x higher accuracy than what other fixed-wing drones can achieve.

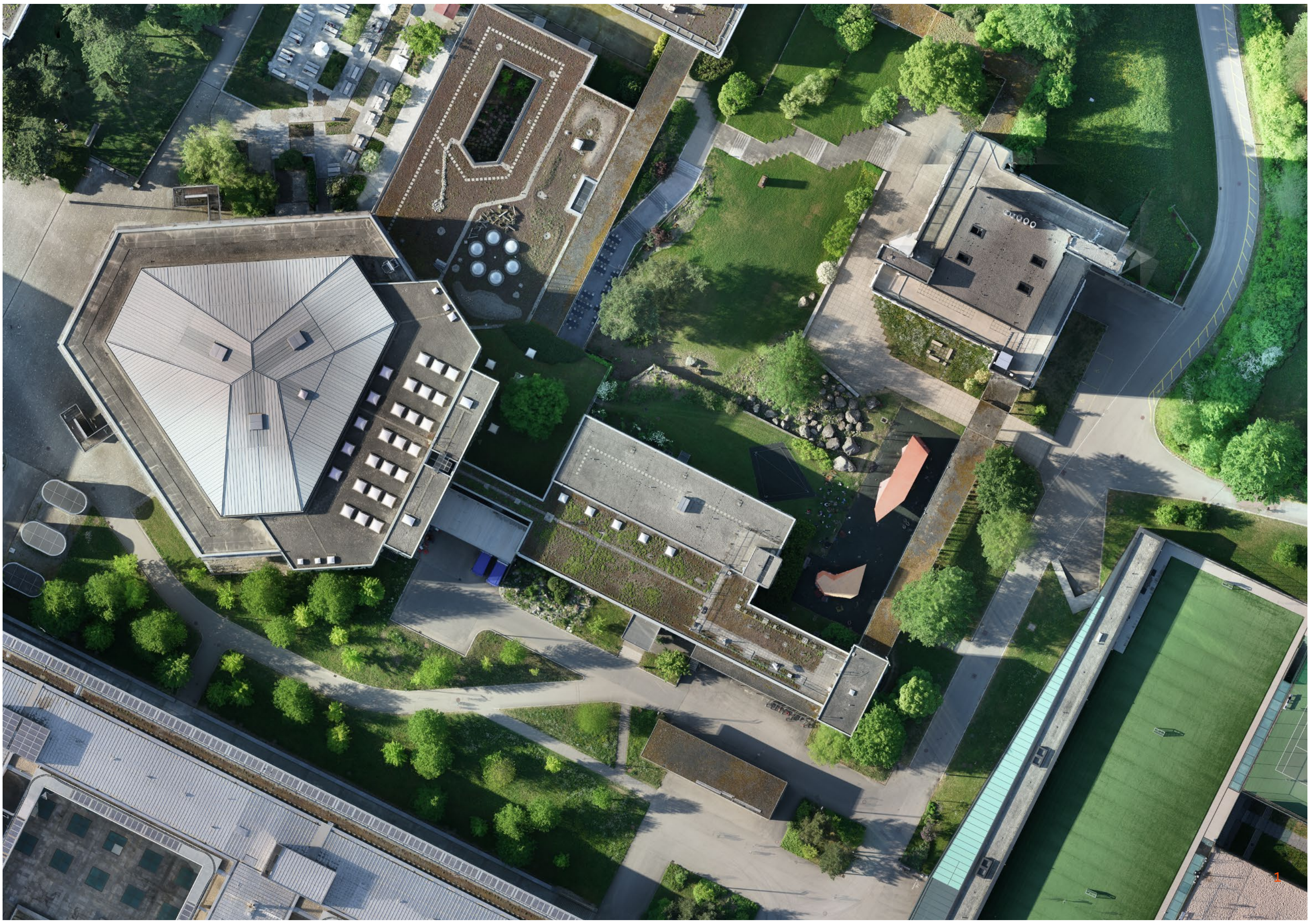
This white paper discusses how WingtraOne sets a new level of accuracy and presents sample data from more than 20 flights. It outlines the key factors influencing accuracy and explains how you can achieve 1 cm (0.4 in) absolute drone survey accuracy in your next mapping project.

[1] Horizontal RMS error measured over 23 test flights in the USA and Switzerland, Summer 2018. RMS error has a standard deviation of 0.4 cm (0.16 in) over all flights.

[2] Best possible results of other market leading drones with a 20 megapixel camera according to the manufacturer's technical specifications.

Content

Orthomosaic map of the ETH Zurich facility where WingtraOne reached its best absolute horizontal accuracy result — 0.7 cm (0.3 in). Switzerland, 2018.



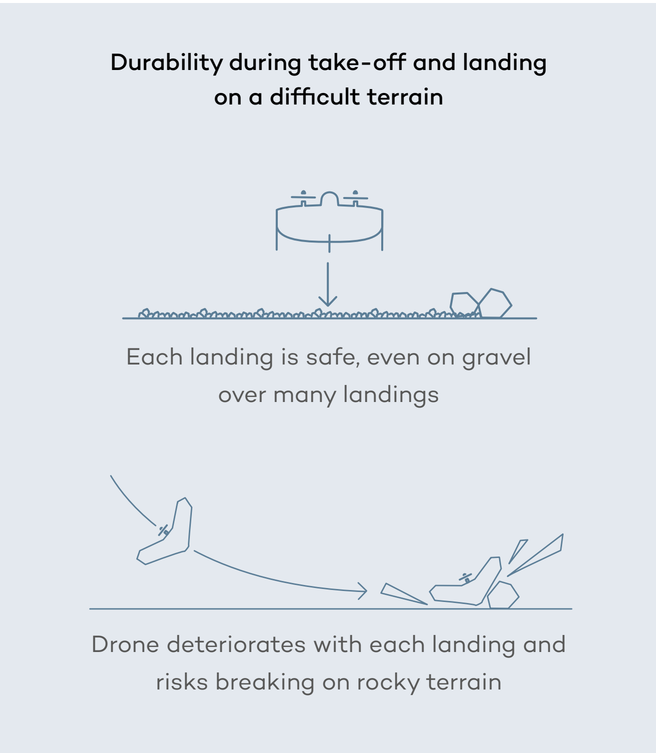
Why VTOL equals better accuracy

VTOL carries better cameras

As a vertical take-off and landing drone, WingtraOne is able to fly in the air as far and stable as a fixed-wing aircraft. Take-off and landing are smooth even on gravel because a VTOL plane can hover like a multicopter. That ensures not only the safety of the drone and its operator but also that of the onboard high-end camera.

In the fixed-wing world, this is not the case. The heavier the sensor, the heavier the drone, resulting in an increased impact energy during a bellylanding. Therefore, most fixed-wing drones are equipped with 20 MP or lower resolution cameras since high-end cameras are too heavy and would require a catapult for take-off.

The VTOL WingtraOne‘s flagship camera is the 42 MP full-frame Sony RX1RII. Such a camera takes high-resolution images as the number of total pixels is more than double that of a 20 MP camera.



Smooth vertical landing guarantees not only the safety of the drone but also of its onboard high-end sensor. Belly landing drones are unable to carry sensors of similar quality due to the increase in weight and harder skid landings.

Higher resolution results in better accuracy and more reliable map generation

High resolution images taken by a 42 MP camera work especially well when reconstructing maps of grass fields, sand, forests or similar homogenous patterns. When using a drone with a lower resolution sensor in these cases, it happens very often that map generation fails.

Along these lines, a high density of pixels greatly affects the accuracy. During the post processing, the coordinates are defined for each pixel on the map. Thus, the more pixels there are, the more accurate the final map or 3D model is. For example, if you fly with a GSD of 3 cm/px (1.2 in/px), 3 cm (1.2 in) is also the best possible accuracy. In contrast, WingtraOne with the Sony RX1RII offers a ground sample distance (GSD) as low as 0.7 cm/px (0.3 in/px) that also allows subcentimeter level absolute accuracy.

Both the accuracy and GSD of a map highly depend on the resolution of the pictures the drone collects. The better the resolution, the more pixels in the image. This leads to better GSD and higher accuracy.

PPK = increased accuracy without GCPs

WingtraOne PPK drone has a built-in PPK GNSS antenna from Septentrio, which ensures best-in-class image geotag correction after the flight. Thus, ground control points (GCPs) are not needed for accurate map reconstruction. They can, however, be used as checkpoints to verify the accuracy of the project. This greatly reduces time spent in the field as up to 30 GCPs would otherwise be needed. For projects needing accuracy assessments, three checkpoints would be recommended when working with the WingtraOne.

Accuracy tests in the USA and Switzerland

Down to subcentimeter level accuracy

No high coverage drone to date has ever been capable of reaching subcentimeter-level accuracy, and many experts were skeptical about these WingtraOne claims. In order to verify them, Wingtra partnered with RDO Integrated Controls, one of the largest Topcon dealers and the largest Wingtra distributor in the US. In Switzerland, Wingtra worked with ETH Zurich, one of the top science universities in the world (Top universities, 2018).

To prove the 1 cm (0.4 in) accuracy claim, Wingtra needed a setup capable of measuring accuracies even lower than that. But as every surveyor will know, it is not that simple to get a global position with an accuracy in the millimeter range. The usual measurement methods using a GNSS receiver in RTK mode are not precise enough. So how could Wingtra overcome this challenge?

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Test setup ETH Zurich, Switzerland

+ 14 flights
+ PPK correction using swipos CORS network
+ Area: 7 ha (17.3 ac)
+ Altitude above takeoff: 62-78 m (203-256 ft)
+ GSD: 0.8-1.0 cm (0.3-0.4 in)
+ Overlap: 80% | 80%
+ 5 checkpoints
+ Checkpoint accuracy (horz/vert): 2/4 mm (0.08/0.16 in)

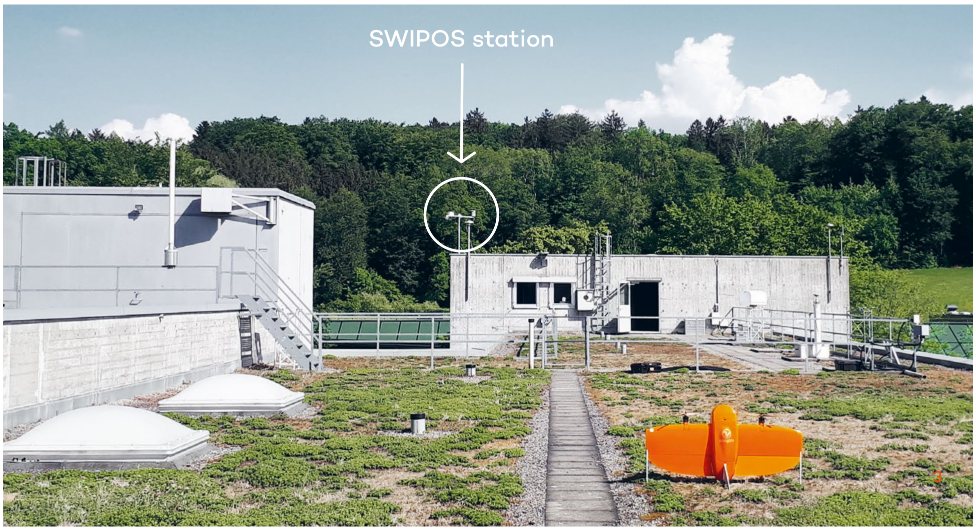
ETH Zurich, Switzerland

The ETH Zurich Honggerberg facility provided two unique setups that were perfect for Wingtra's project:

1. Part of the highly accurate Swiss national continuously operating reference stations (CORS) network (swipos), a continuously measuring GNSS station provided optimal correction data for PPK geotagging and allowed absolute position reading at the centimeter level via GPS and GLONASS.
2. The ongoing research in the field yielded a high-precision fixed-point network that guaranteed 2 mm (0.08 in) horizontal and 4 mm (0.12 in) vertical absolute accuracy (Januth, Guillaume, 2018)!

In this setting, the Wingtra team conducted 14 flights 62 m (203 ft) above home with a GSD of 0.7 cm (0.3 in). The collected images and the raw measurements of the onboard dual-frequency GNSS receiver were automatically saved to the camera SD card after each flight. In addition to the flight data, the raw GNSS measurements of the continuously operating reference station (CORS) at ETH were used to geotag the images in WingtraHub at centimeter-level accuracy.

Because of the high-precision, fixed-point network provided by ETH Zurich, the 14 projects could be compared to checkpoints at the accuracy of 2 mm (0.08 in). The ETH network was used to assess the difference from the point cloud generated within Pix4Dmapper. On average over the 14 flights, the root mean square (RMS) error of the checkpoints was 0.7 cm (0.3 in) horizontally and 2.6 cm (1 in) vertically (values taken from a Pix4D quality report).



The fixed point network at ETH Zurich Honggerberg is so precise (2 mm / 0.08 in) that it is even sensitive to the movements of tectonic plates. Therefore they are fixed in reference to the European tectonic plate to compensate for the movements.

Phoenix, USA

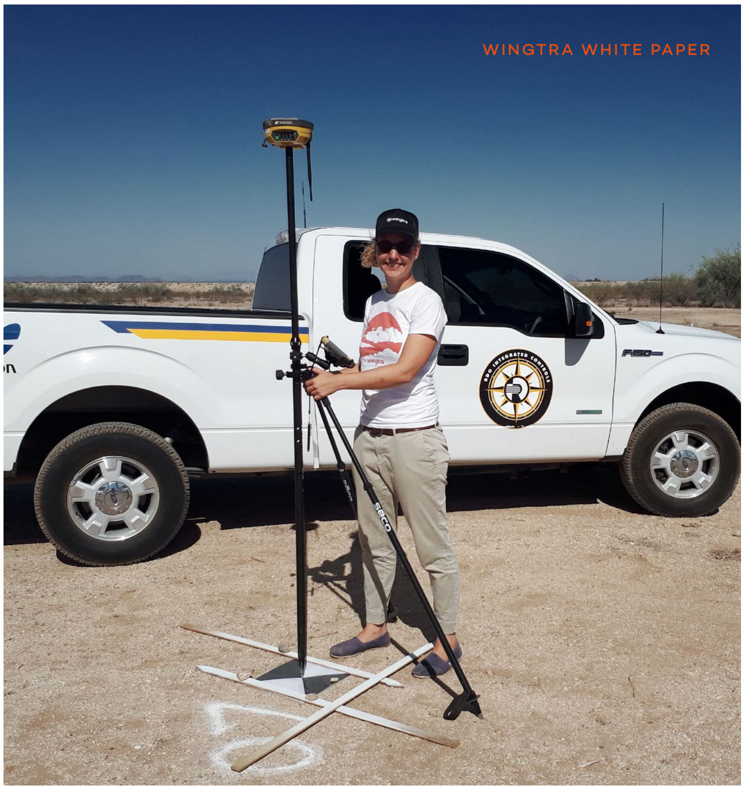
In Phoenix, Arizona, Wingtra and the RDO teams lacked the high-tech infrastructure available at ETH Zurich. Therefore, an individual base station and highly-accurate checkpoints had to be installed manually.

Due to the sparse CORS network, a HiPer V GNSS antenna from Topcon was set out as the base station. It was left on the field to log GNSS coordinates for more than three hours. The logged coordinates of the newly-established base station were later corrected using the US online positioning user service (OPUS), which ensures subcentimeter level accuracy (Ngs.noaa.gov, 2018).

Another HiPer V GNSS antenna was used as an RTK rover to establish nine photogrammetric targets as checkpoints. Their accuracy was measured in RTK mode using correction data from the local base station. These targets were used as checkpoints to evaluate centimeter-level accuracy of the maps generated by the Wingtra team.

In these circumstances, the images collected with the WingtraOne were geotagged in the standard GNSS coordinate system WGS84, using WingtraHub. Data was post processed with Pix4Dmapper to create a point cloud. The same point cloud is the basis to create orthophotos or digital surface models (DSM).

On average over the 9 flights, the root mean square (RMS) error of the checkpoints was 1 cm (0.4 in) horizontally and 2.5 cm (1.0 in) vertically. The value was taken from the Pix4D quality report generated for the point cloud.



A Topcon HiPer V GNSS antenna was used in the Arizona desert, enabling a centimeter accuracy comparison when testing the WingtraOne.

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Test setup Phoenix, USA

+ 9 flights
+ PPK with own base station
+ Area: 17 ha (42 ac)
+ Altitude above take-off: 62 m (203 ac)
+ GSD: 0.8 cm (0.3 in)
+ Overlap: 80% | 80%
+ 9 checkpoints
+ RTK accuracy

RDO Integrated Controls sells and supports positioning and surveying equipment from manufacturers including John Deere, Vermeer, and Topcon. With 78 locations across the United States, RDO is the biggest WingtraOne distributor on the West Coast.

Results

- Tests at ETH Zurich, Switzerland, and Phoenix, Arizona, showcased that in optimal conditions, the WingtraOne drone consistently achieved an accuracy of 1 cm (0.4 in) and below. The very small standard deviation value (see appendix) of 0.6 cm (0.2 in) shows that the high accuracy is repeatable in every flight.
- The millimeter-precision setup at ETH Zurich revealed the best horizontal absolute accuracy result, which was 0.7 cm (0.3 in).
- The resulting horizontal and vertical RMS errors were as expected. These numbers lie within the general rule of thumb for accuracies in photogrammetry, i.e., horizontal 1x GSD and vertical 2-3x GSD.

Such results have never been achieved with a high coverage fixed-wing drone as to the best of our knowledge.

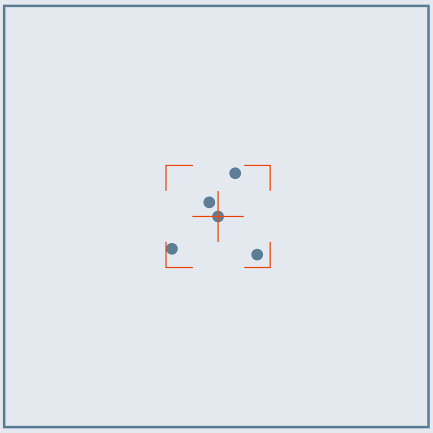
	Number of flights in dataset	Horizontal RMS error	Vertical RMS error
ETH Zurich	14	0.7 cm (0.3 in)	2.6 cm (1.0 in)
Phoenix, Arizona	9	1.0 cm (0.4 in)	2.5 cm (1.0 in)

Horizontal and vertical RMS (root mean square) values illustrating absolute accuracy achieved with WingtraOne when processing the aerial images without using GCPs. Detailed results can be found in the appendix.

3x higher absolute accuracy with WingtraOne

0.7 CM (0.3 IN) ACCURACY [3]

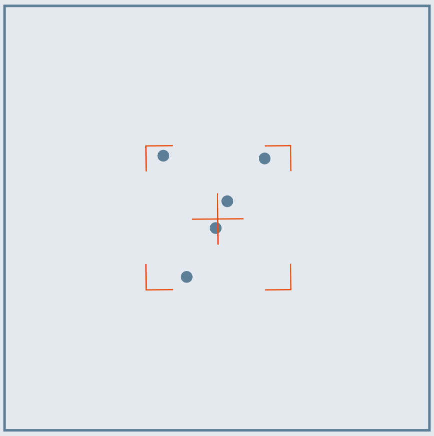
BEST ACCURACY MEASURED



DRONE
WingtraOne PPK
CAMERA
Sony RX1RII

1 CM (0.4 IN) ACCURACY [4]

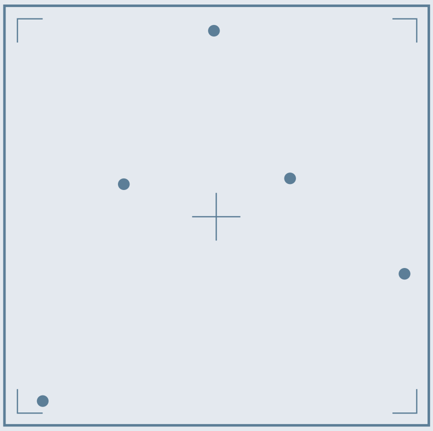
ACCURACY IN OPTIMAL CONDITIONS



DRONE
WingtraOne PPK
CAMERA
Sony RX1RII

3 CM (0.4 IN) ACCURACY [5]

ACCURACY IN OPTIMAL CONDITIONS



DRONE
Other fixed wing drones
CAMERA
average 20 MP camera

[3] Horizontal RMS error over 14 test flights at ETH Zurich in Summer 2018. RMS error has a standard deviation of 0.5 cm (0.2 in) over all 14 flights

[4] Horizontal RMS error over 9 test flights as measured in Phoenix in Summer 2018. RMS error has a standard deviation of 1 cm (0.4 in) over all 9 flights

[5] Best possible results of other market leading drones with a 20 megapixel camera according to their manufacturer's technical specifications

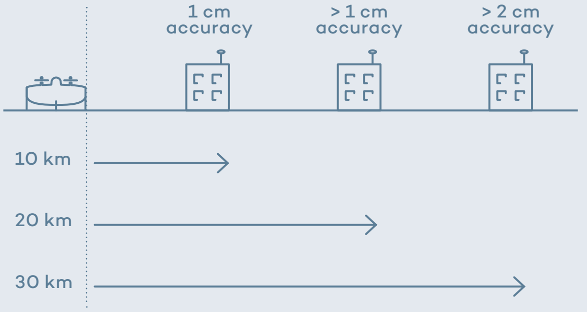
Influencing factors

Distance to a static base station

What happens when the conditions are not optimal? Different scenarios showcased that with intervening factors such as a long baseline—being far away from a base station—the absolute accuracy might vary. As a rule of thumb, every 10 km (6.2 mi) in distance adds 1 cm (0.4 in) to the RMS error. Vertical accuracy suffers greater effect than horizontal accuracy.

In case of a vertical baseline of more than 500 m (1640 ft), horizontal accuracy also becomes notably worse.

The closer the base station, the better the accuracy



Absolute accuracy results decrease gradually when moving away from the static base station. Rule of thumb—every 10 km (6.2 mi) add 1 cm (0.4 in) to the accuracy

The accuracy of checkpoints

While mapping with the WingtraOne PPK, GCPs are not needed to achieve high accuracy results. Instead the same photogrammetric targets usually used for establishing GCPs are used as checkpoints to evaluate the achieved accuracy of the drone.

In Wingtra's case, these checkpoints have to have a subcentimeter accuracy. It is a very complicated task to accurately measure checkpoints at this level, so how do we achieve that? First of all, good photogrammetric targets are needed. The marks should be fixed so that they do not move from the time you measure them, until the flights are finished. They need to be placed on an open area to ensure that they are visible on as many images as possible. The marks should have high contrasting colors and a clearly defined center point.

If you have a highly accurate reference point close by (< 5 km (3 mi), the checkpoints can be measured using a tachymeter or through a differential GNSS measurement system (real-time or post processing). If no reference can be established, long-term static GNSS measurements are needed.

CORS Station (swipos)	Baseline (horizontal)	Baseline (vertical)	RMS error horizontal	RMS error vertical
ETH2	0 km	20 m	0.8 cm	2.6 cm
FRI3	33 km	112 m	0.9 cm	8.3 cm
SCHA	38 km	24 m	1.6 cm	9.2 cm
FALE	86 km	729 m	7.6 cm	11.8 cm
ZIM2	99 km	339 m	4.6 cm	12.2 cm
DAV2	121 km	1030 m	8.7 cm	13.0 cm

RMS errors of check points of an exemplary flight at ETH after geotagging images with different base stations as reference are compared to those in cases of variable horizontal and vertical distance between base station and flight area.

How to achieve 1 cm (0.4 in) absolute drone survey accuracy in your next mapping project

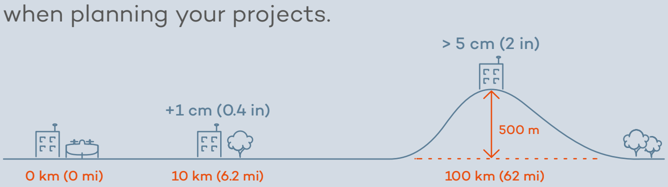
1. Use a WingtraOne PPK drone with a Sony RX1RII payload
WingtraOne PPK is the only broad-coverage drone to date to have achieved subcentimeter (0.4 in) absolute accuracy results.

2. Be aware of the distance to a base station
Achieving absolute accuracy depends on the correction data derived from static base station logging. The closer a base station is to the flight location, the better the corresponding correction data will be to the onboard GNSS logging of the WingtraOne.

When using a continuously measuring GNSS station, make sure it is close enough. The accuracy results will reduce gradually the further you are from the station. Rule of thumb—every 10 km (6.2 mi) adds 1 cm (0.4 in) to the RMS error.

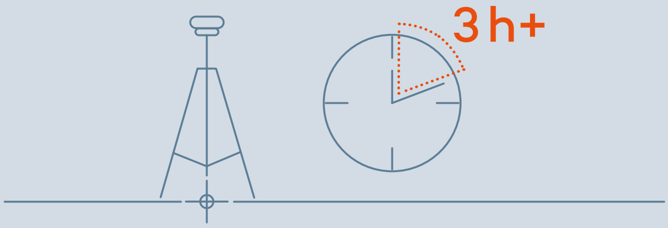
In case the GNSS station is further away, use your own base station.

3. Be aware of elevation influence
A long baseline most of all affects the vertical accuracy. In the case of a height difference between base station and surveying area of more than 500 m (1640 ft), accuracy becomes significantly worse. Take that into consideration when planning your projects.



In case of more than 500 m (1640 ft) elevation difference, accuracy will be worse.

4. Always use a high quality survey-grade base station
When setting up a new base station on an unknown point let the GNSS receiver log the GPS data for a couple of hours, or even better, overnight. Logging GPS data for longer periods will help ensure higher accuracy results.



When establishing a new base station, log GPS data for at least a couple of hours

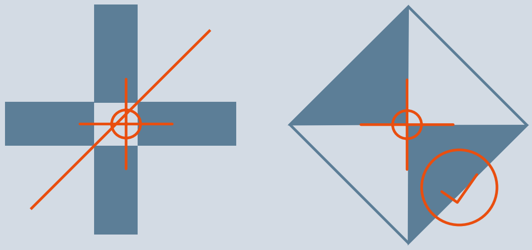
Note that if a new base station is established on a known point, the results depend on how accurately the point was measured before.

Important! Don't forget to check minimum base station requirements, which are:

+ Possibility of continuous logging with logging interval of 15s or faster (1s is recommended for the highest accuracy)
+ Logging at least two frequencies L1 and L2
+ Receiving Constellations GPS + GLONASS (optional for high precision)

Your base station should log both L1 and L2 frequencies and receive data from GPS and GLONASS.

5. Establish checkpoints to prove the accuracy to your customer



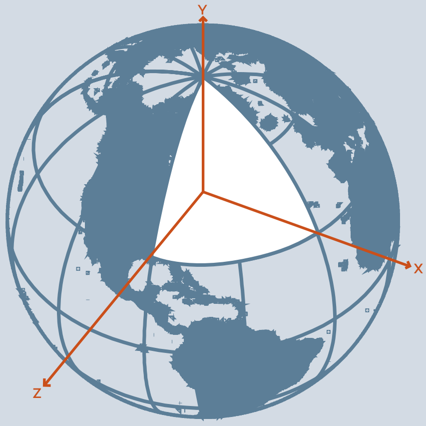
To ensure bulletproof accuracy evaluation, make sure that your checkpoints are measured precisely.

When measuring your checkpoints, make sure to use an RTK or PPK GPS receiver. Common products include Trimble or Leica brands. Using any device other than an RTK or PPK GPS receiver will compromise the accuracy.

Remember to place the tip of your GPS receiver directly on the center of the control point marker. Make sure to calibrate your GPS receiver to be level with the ground. Follow the instructions on the system provided by the measurement device manufacturer. Use a tripod to make sure the receiver is stable and does not move during the measurement process.

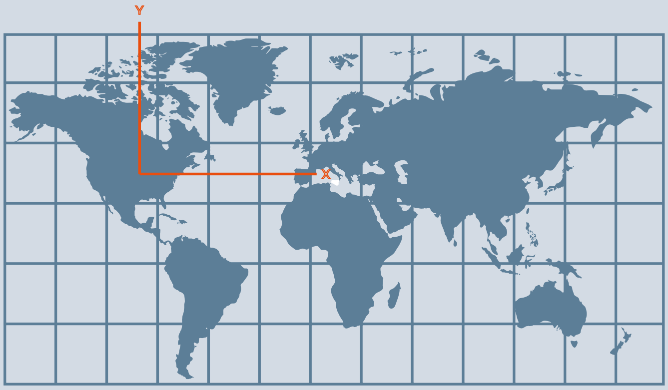
6. Be careful with different coordinate systems

WingtraOne images can be geotagged in any Earth-centered, Earth-fixed coordinate system such as WGS84. When a local projected coordinate system is desired as an output, the transformation can be performed either in the post-processing toolchain or externally using a conversion tool suitable for the desired coordinate system. Be aware that the final results in local coordinate systems are only as good as the provided conversion tools for those systems.



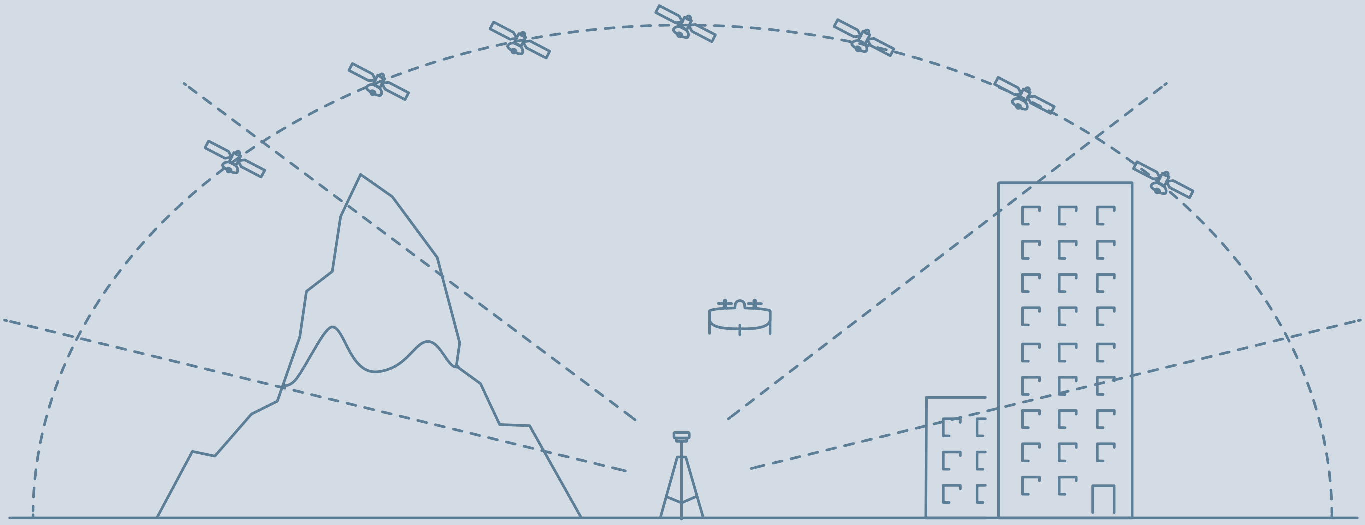
Earth-centered, Earth-fixed coordinate system

Transformation might introduce errors



Projected coordinate system

Transforming final results from one coordinate system to another might introduce some errors. Be aware that the final results in local coordinate systems are only as good as the provided conversion tools.



Environmental obstacles might block the GNSS satellite signal to your GNSS receiver. Such interference would have a negative impact on your accuracy results. Be aware of that when planning your projects in valleys, canyons or next to tall buildings.

7. Avoid environmental obstacles

GNSS satellite signals can be blocked by large obstacles such as tall buildings, mountains or trees. Therefore when using GNSS as a surveying method, carefully choose locations where the surrounding environment does not shelter your receiver from the satellite signals.

8. Contact us

If you have any questions about planning your next project, contact the Wingtra team at sales@wingtra.com and we will make sure to help you out!

To access raw data of the accuracy tests please go to the Wingtra downloads section at https://knowledge.wingtra.com/data-samples-and-maps

Appendix

Table 1: Results of an exemplary flight at ETH Zurich, Switzerland (flight 5). Error of checkpoints relative to the point cloud processed in Pix4D without using GCPs.

Checkpoints	Error X	Error Y	Error Z
Checkpoint 1	0.0 cm	-0.1 cm	1.4 cm
Checkpoint 2	-0.4 cm	-0.5 cm	-2.0 cm
Checkpoint 3	-0.6 cm	-1.0 cm	-2.2 cm
Checkpoint 4	0.0 cm	0.7 cm	-3.2 cm
Checkpoint 5	-0.6 cm	-0.5 cm	-3.5 cm
Mean	-0.31 cm	-0.28 cm	-1.90 cm
Sigma	0.27 cm	0.57 cm	1.74 cm
RMS	0.41 cm	0.64 cm	2.58 cm
RMS horizontal/vertical	**0.76 cm**		**2.58 cm**

Table 2: Comparison of point cloud to check points. Average over all 14 flights at ETH Zurich, Switzerland.

Average of 14 flights	X	Y	Z
Mean	0.26 cm	0.50 cm	-2.09 cm
Standard deviation	0.24 cm	0.31 cm	1.50 cm
RMS	0.36 cm	0.63 cm	2.68 cm
RMS XY/Z	**0.73 cm**		**2.68 cm**

Table 3: Results of an exemplary flight in Phoenix, US (flight 7). Error of checkpoints relative to the point cloud processed in Pix4D without using GCPs.

Checkpoints	Error X	Error Y	Error Z
Checkpoint 1	0.0 cm	-0.9 cm	2.7 cm
Checkpoint 2	1.0 cm	-0.4 cm	2.6 cm
Checkpoint 3	1.6 cm	1.1 cm	1.6 cm
Checkpoint 4	-0.6 cm	1.0 cm	2.3 cm
Checkpoint 5	-0.7 cm	0.6 cm	2.2 cm
Checkpoint 6	0.5 cm	0.1 cm	1.2 cm
Checkpoint 7	0.4 cm	1.0 cm	2.3 cm
Checkpoint 8	-0.8 cm	0.7 cm	1.0 cm
Checkpoint 9	0.7 cm	-0.4 cm	3.1 cm
Mean	0.23 cm	0.31 cm	2.09 cm
Sigma	0.77 cm	0.68 cm	0.65 cm
RMS	0.80 cm	0.75 cm	2.19 cm
RMS XY / Z	**1.10 cm**		**2.19 cm**

Table 4: Comparison of point cloud to check points. Average over all 9 flights in Phoenix, US.

Average of 14 flights	X	Y	Z
Mean	0.22 cm	0.23 cm	2.16 cm
Standard deviation	0.68 cm	0.61 cm	1.07 cm
RMS	0.74 cm	0.68 cm	2.45 cm
RMS XY/Z	**1.02 cm**		**2.45 cm**