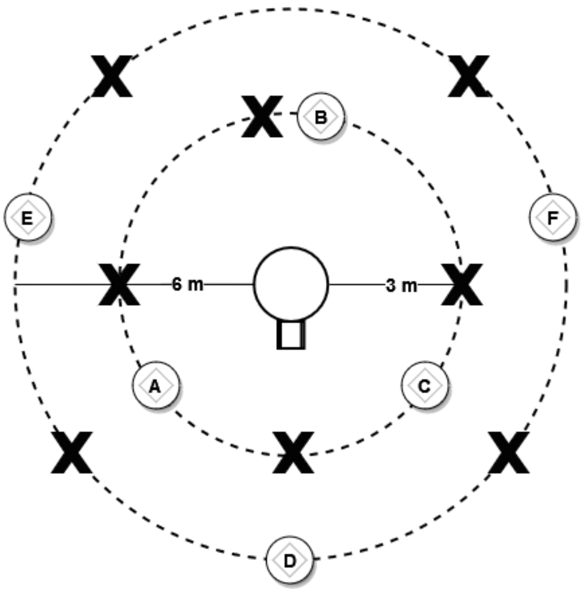
Pre-Processing Report

Sampling

Between **11.07.2023 - 21.07.2023**, we scanned **18 plots** within the **Observatoire Régional des Écosystèmes Forestiers** (OREF). Access to the plots was provided by CNPF. One plot could not be scanned due to access restrictions imposed by the proprietor. Plots are named OREF_PLOTNUMBER, but the naming convention is not fully consistent; OREF_6 is also known as OREF_428 in CNPF documentation.

Each plot was scanned from **eight positions** using a TRIMBLE X7 terrestrial LiDAR device. Scans were conducted on **low-density settings** and centered on two HOBO temperature loggers: one located at ground height and one mounted on a tree at around 1 m height. After each scan, the LiDAR device took photos of each scan position, which we used to color the point clouds.



Sketch of the sampling design. X marks the eight scan positions. Real positions will differ from this sketch, as positions were adaped to ensure line of sight to at least three targets at all times.

Six spherical targets were deployed around the center to aid with registration: three at a radius of three meters and another three at a radius of six meters. Since they were deployed in a clockwise direction, the targets can be recognized by their position. The targets are color-coded as follows:

Inner Targets

A, fully blue

B, from top to bottom; blue-red

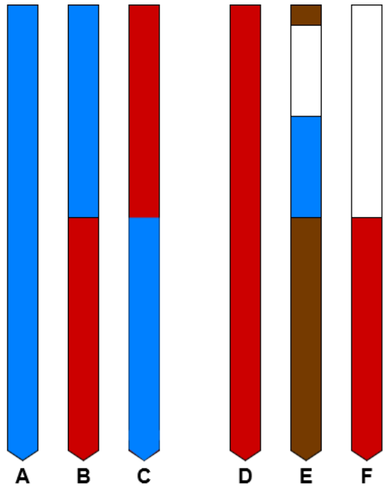
C, red-blue

Outer Targets

D, fully red

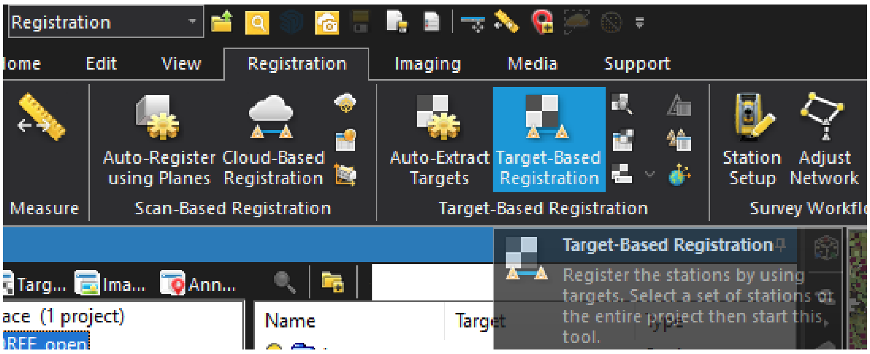
E, wood-blue-white

F, white-pinkish

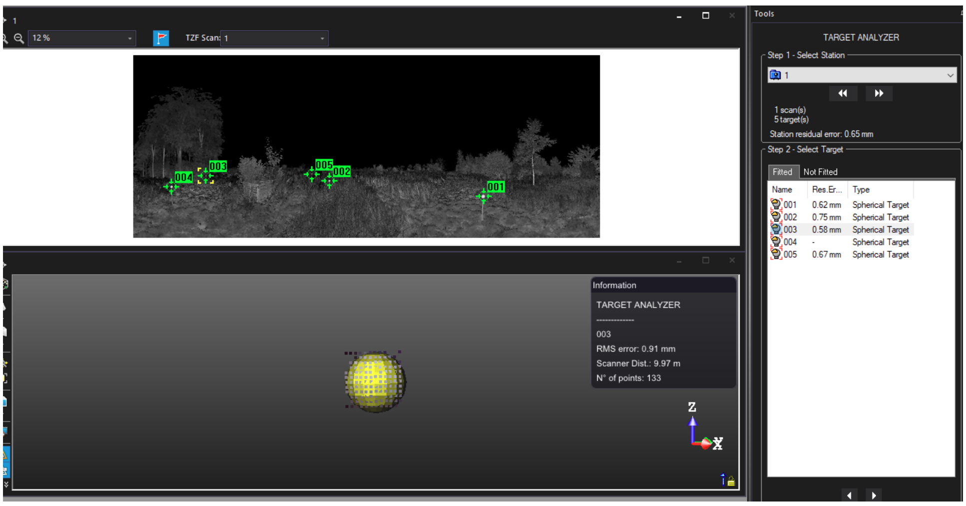


Registration

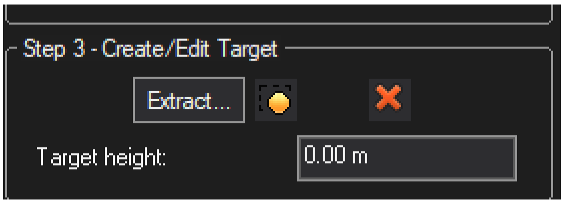
When it comes to registering scans to a shared coordinate system, Trimble's companion software Fieldworks offers several options. Registration is done in the corresponding registration tab. We used target-based registration to register our eight scans.

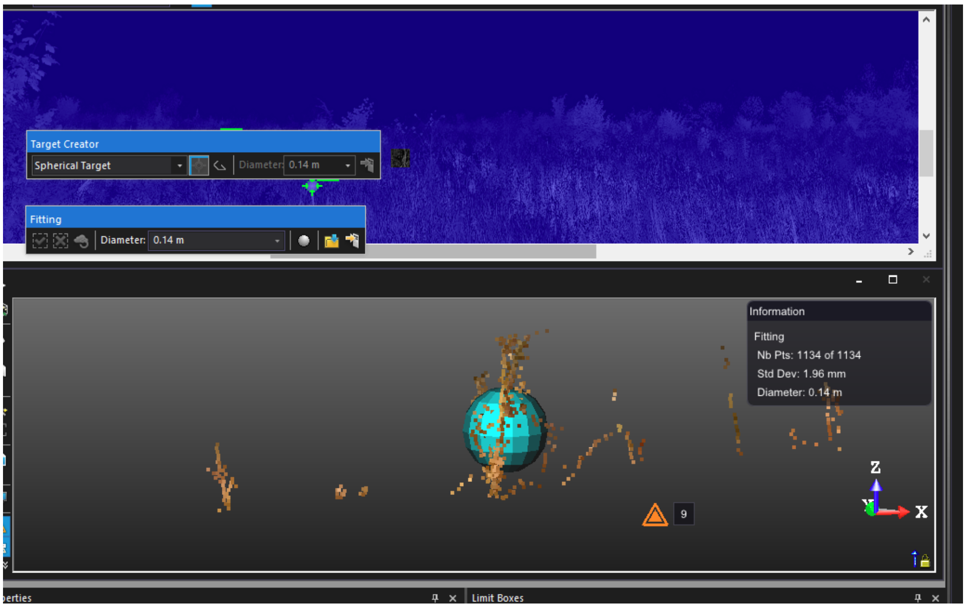


As the name implies, target-based registration requires the deployment of field targets as a reference. When selecting either **Auto-Extract Targets** or **Target-Based Registration**, Fieldworks will try to find and match targets in each selected scan based on point cloud shapes and reflective properties. The automatic algorithm works well for unobstructed targets, but Fieldworks will frequently "find" targets within the canopy and miss partially covered targets.



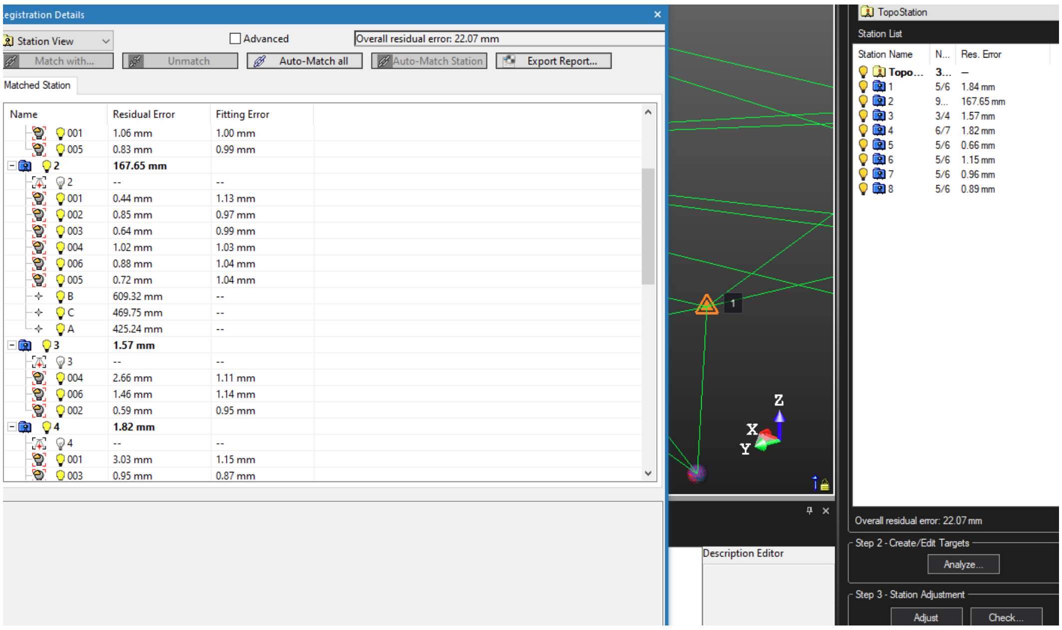
When it finds a target, Fieldworks will create a sphere geometry that aligns with the target surface to the best of its ability using the provided diameter. We checked the standard deviation of distance or RMSE to review the accuracy of the process. We deleted all wrongly identified targets and went through the pictures taken at all scans to find and manually identify any targets missed by the automatic detection. These will usually be targets with partially obstructed line of sight to the scanner. The color images taken by the scanner are immensely helpful in finding missing targets.





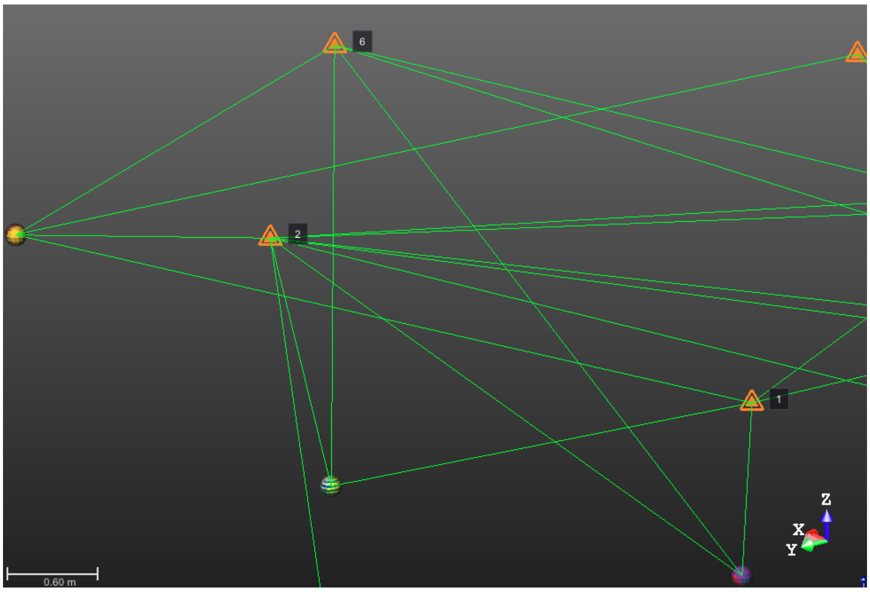
Once we enter the target creator, Fieldworks will isolate the part of the point cloud we clicked on and try to place the target sphere correctly on its own. We can assist the algorithm by adjusting the field of view so that it only includes the sphere. To do this, simply select the sphere by clicking a polygon around it and choose "select inside." Then, Fieldworks will only consider pixels that are inside your selection when placing the sphere. Placement accuracy is determined by the standard deviation of distances between the point cloud and the sphere surface. If the sphere is too far from the target's actual location within the placement, it will negatively affect the registration accuracy. Therefore, the standard deviation of distances should be as low as possible, preferably below 2 mm. Note that Fieldworks displays the standard deviation for all pixels within your selection.

To leave the target analyzer, press "adjust network" once all targets have been found. Fieldworks will then attempt to match each sphere location with one another. However, if targets are matched with a high residual error, they will not align well when stacked on top of each other. This can occur if targets were moved between scans due to external forces (such as being blown over, touched, or placed on an unstable surface) or due to natural geometric distortion introduced by long distances and complex surface geometries. If targets have moved significantly between scans, they should be excluded from certain scans.



Registration detail window. Here, the primary source of uncertainty and residual error are clearly the three point targets added for georeferencing. They are stored in scan two, causing residual errors in this scan to skyrocket. This does not mean that the registration is worthless, its just a relative indicator of how good (or bad) georeferencing worked.

Once the targets are matched, you can check how well they are aligned by examining the visual network. Select all scans and right-click to display the visual network, and disable the point cloud for easier visual comparison. Then, you can see which scans can see which targets and how well the targets are aligned. The quality of registration depends on the density of the visual network and how well the targets are aligned with each other. Residual error and visual inspection can give you an idea of how far apart the targets are. It is also possible to determine which targets should have a line of sight with which scan positions in this view, and we used it to find and add missing targets to the registration.



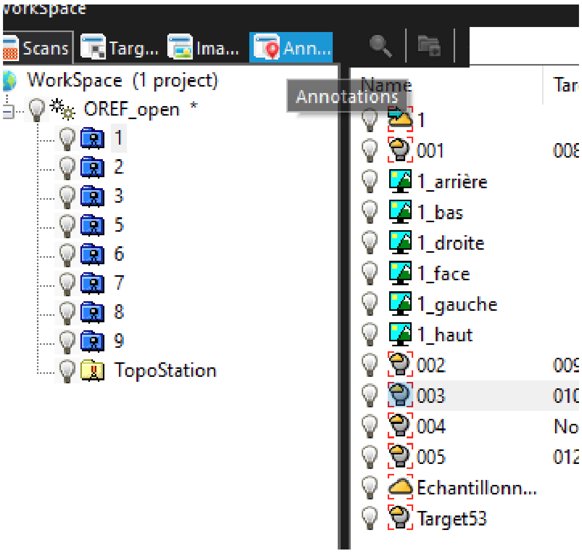
Visual Network of a registered plot with point clouds turned off.

A general rule of thumb is that the more targets each scan position recognizes, the better the registration result will be, provided that the targets did not move between scans. Note that residual errors are merely an indicator of how well targets seen from different perspectives match with each other. If a scan only sees one target and uses it to align with the other scans, the residuals can be negligible, but the registration will still be bad as the point cloud will only be aligned to have a single spot fit perfectly with the others. Targets can also be matched manually by right-clicking and selecting "unmatch" or "match". After registration, it is possible to export a registration error report which includes the residual errors for each target position.

Pre-Processing

▼ Placing Annotation Markers

Next, we added annotations to the inner targets and plot center. Annotations can be set to help with orientation within the point cloud. They can be accessed in the workspaces annotation tab and turned off and on like normal objects;

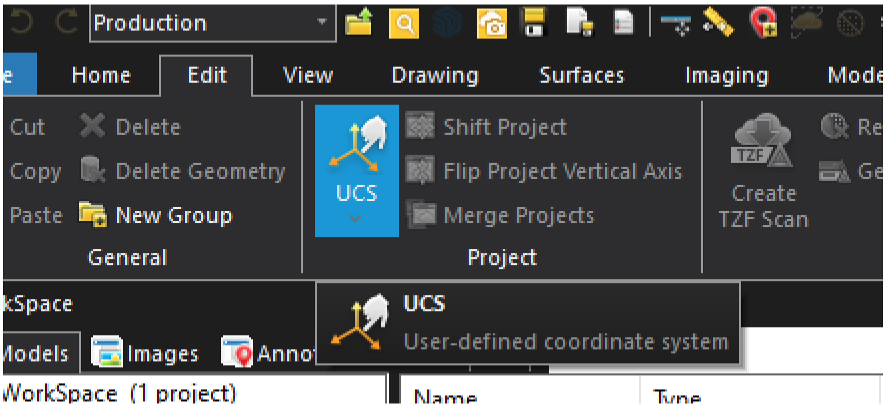


Annotation labels were added to the targets A, B, C, and the plot center. They can be found in the annotations tab and turned on and off like normal objects. In the description, we recorded their coordinates in latlon and **EPSG2154 RGF93 / Lambert-93**.

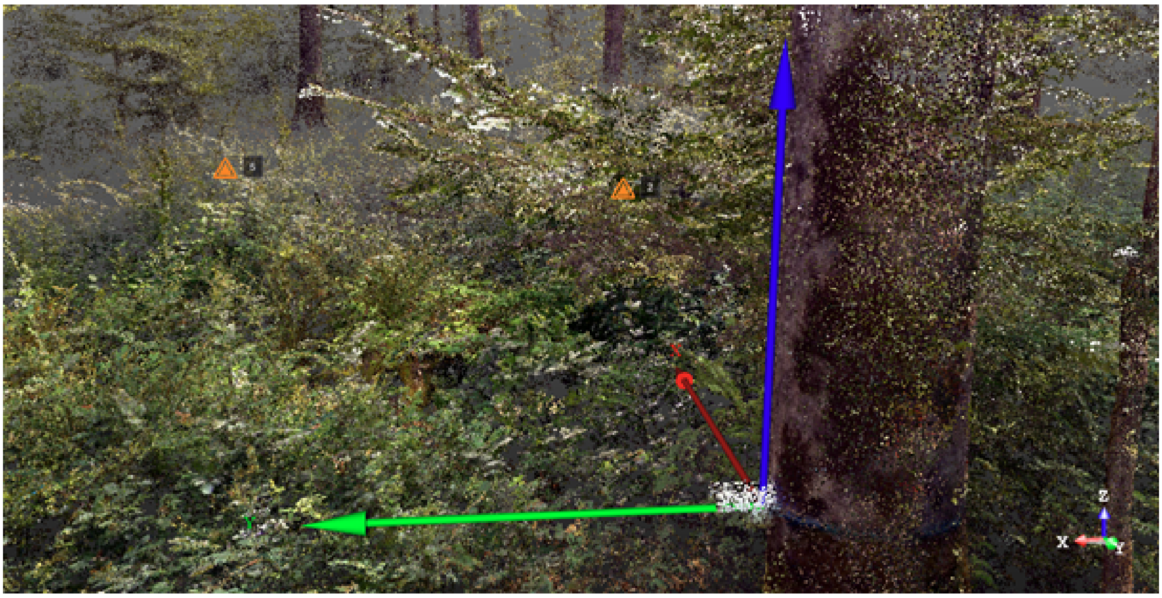
Four annotations for each plots; ABC and center. The other annotations are placed during georeferencing.

▼ Defining a User Coordinate System (UCS)

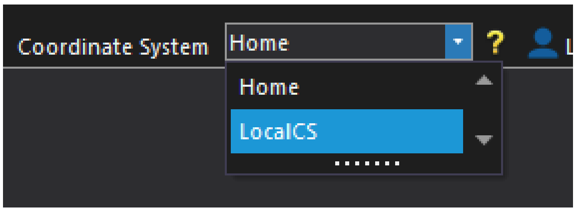
We gave each scan a custom local coordinate system dubbed LocalCS. LocalCS is always centered on the HOBO temperature loggers shield which should be helpful when applying buffers based on the center and such. Custom coordinate systems can be created in production mode → edit tab → UCS.



When defining a new UCS it is smart to first lock the z-Axis so it stays orthogonal to the ground. We wanted LocalCS to have a y-axis which points away from the scanner. After locking the z-Axis, we have to pick an origin point. We used a limit box top view to get a better view of the scanner and placed the origin in its center. We then fine tuned the location to align it as good as we could by manually playing with the coordinates. Then, we used pick axis to define a y axis into the desired direction and adjusted it manually until it sat right. The x-axis will also be placed orthogonal to it automatically



After LocalCS looked correct, we confirmed. Fieldworks will save the new UCS as a file which you can adjust the name of. The project can then be transferred into the new UCS on the top right and Fieldworks will ask in which of the two coordinate system to export the point cloud in.

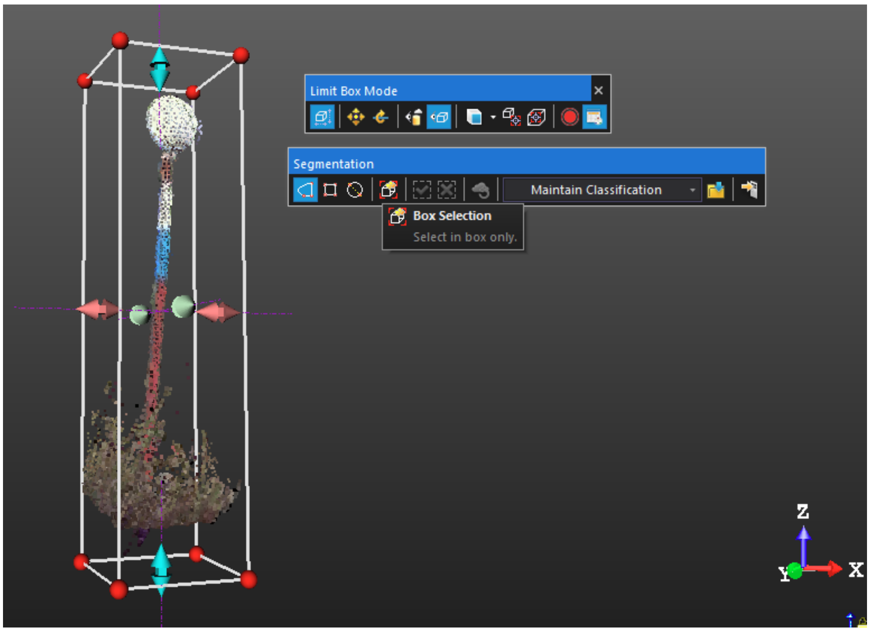


▼ Exporting station positions as CSV

After defining the LocalCS, all the station positions were exported in local CS as a CSV. This is necessary to keep working with them in other software since LAS files do not store station positions. It is a simple export operation. We chose to export the positions in mm to avoid rounding for now since we could still convert to meter later.

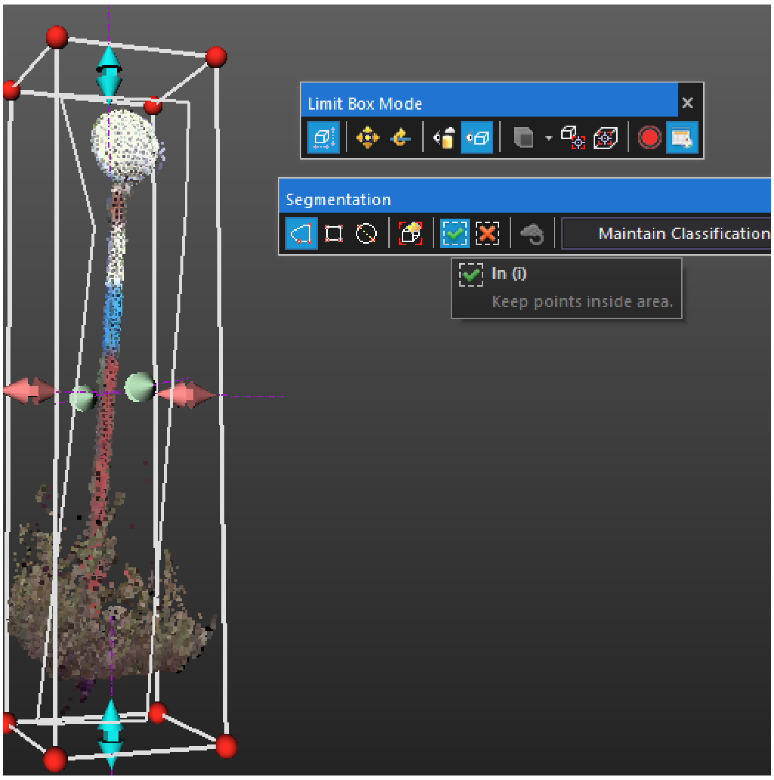
Segmentation

Because targets are very reflective non-vegetation objects, they had to be isolated from the origin point cloud before export. We achieved this by defining a limit box around the target, before entering the segmentation tool in the production tab and activating box selection.

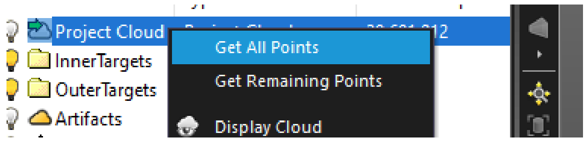


Box selection is absolutely necessary. Without it, you will inadvertently select and segment stuff outside of the limit box without knowing it - the limit box is only a visual helper!

Afterwards, we fenced in the target and only kept points within the selected area. Now, we tried to remove all points that are not part of the target by selecting them and using the out butting.



When only the target and its stand remains selected, we saved the selected point cloud. Fieldworks will then separate the segmented points from the origin point cloud and create a new point cloud from your selection. If you make a mistake during segmentation, you can always get all points back from the origin point cloud. As far as we know, Fieldworks never really deletes points but prefers to mask them out.



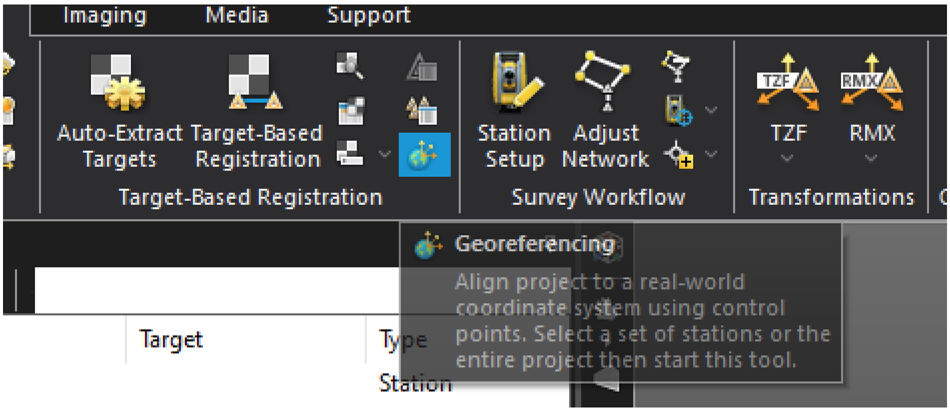
Once we segmented all targets, we grouped them into folders.

Using this workflow, any object can be isolated from the point cloud. Thus, we also removed any apparent isolated returns. Isolated returns are returns that are not recognizable as part of a real feature. TLS will often find isolated returns in the sky in plots that are more open.

Once all the targets and isolated returns were segmented, the trimmed origin point cloud was exported in LocalCS as LAS 1.4.

Georeferencing

We georeferenced point clouds with varying degrees of success using the GPS coordinates recorded in the field. For that purpose, we used Fieldworks georeferencing tool in the registration tab. Make sure you have selected your whole project while clicking it; otherwise, it will attempt to georeference individual scans only.



In the georeferencing tool, we manually selected the base of each target and the base of the center tree and assigned it coordinates from the GPS coordinate table. Coordinates can either be assigned manually or through import; but the letter requires some minor adjustments in the table so Fieldworks can read it correctly.

After defining at least three reference points, Fieldworks can transpose a coordinate system onto the point cloud. Note that this will overwrite the currently selected coordinate system. We georeferenced the home coordinate system to **EPSG2154 RGF93 / Lambert-93**. The quality varies greatly varies depending on two error sources;

1. The GPS in-field precision
2. How close the selected reference point in the point cloud is to the in-field measurement.

Because of point two, it could be preferable to measure the position of the target spheres instead of the ground position if possible because. This way, we would not have to manually estimate ground target points but can simply assign the coordinates to the spheres we already defined for registration. Moreover, the scanner does not always capture the ground surface, introducing unnecessary error.

Fieldworks will create the reference points as topostations and the georeferenced points as point target geometries and try to physically match them as good as possible.

Export

In the end, we exported both all point clouds as LAS v1.4 two times. One time in LocalCS and one time in the georeferenced CS. The files are a total of 55GB. Filesize could be reduced further by exporting as LAZ (LASZip) or filtering and trimming the clouds further.