

— TECHNICAL PAPER

GroundMap FusionTM methodology

How surveys are co-registered, fused and graded point by point, what the grades show and what they do not. Method and results of the Hobart showcase.

Issued for evaluation (v0.10). v1.0 follows technical review. The results in this paper come from a showcase, GroundMap processing of public survey data: Hobart city centre, three surveys flown between 2008 and 2024. It is not client work. Section 10 reports a check of the method against 43 State survey marks held out of GroundMap's processing, with its limits.

Summary

GroundMap Fusion moves every survey of a site into the frame of a reference survey on stable ground, merges their points into one point cloud, and grades every point: how many surveys measured the surface there, and whether they agree within 0.15 m. Where they disagree, the point is flagged: real change, or disagreement between surveys. Surfaces no survey measured are filled by geometric modelling and flagged, and never counted as confirmed.

On the Hobart showcase, adding the 2011 and 2008 surveys to the 2024 survey raised measured ground under tree canopy from 6.71 to 8.16 points per m², and the share of the ground and roof surface confirmed by at least two surveys within 15 cm from 21.4 % with two surveys to 39.4 % with three. Every one of the model's 398,268,618 points carries a grade.

Document control

DOCUMENT	GroundMap Fusion methodology
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01 Scope

This paper sets out how GroundMap Fusion combines several LiDAR surveys, or several passes, of the same ground into one point cloud, and how every point in it is graded. It is written for technical evaluators. This version documents the method as it was applied to the Hobart showcase; every definition follows the processing that built it.

AREA	Hobart city centre: GDA2020 / MGA zone 55 (EPSG:7855). Twelve 1 km cells, 12 km ² .
FRAME SURVEY	Hobart City 2023/24, the newest survey. The older surveys are moved into its frame; it is not moved.
SURVEY	One acquisition campaign, named as its custodian names it.
PASS	One measurement of the ground: in multi-pass capture, a flight line or heading. In the Hobart showcase each pass is a separate survey, so the confidence classes' "passes" are surveys here.
CELL	A square of the processing grid: 0.5 m for the agreement grade, 1 m for density.
MODELLLED POINT	A point no pass measured, generated by geometric modelling and flagged.

02 Inputs and licences

SURVEY	CUSTODIAN	IN THE BOX	AS DELIVERED	ROLE
Hobart City 2023/24	State of Tasmania (theLIST); captured by Fugro; CC BY 3.0 AU	12 tiles 359,257,689 points	LAS 1.4, point format 7 (RGB). GDA2020 / MGA zone 55; AHD heights, stated in the tile names, not in the headers	Frame
Mount Wellington 2011	Mount Wellington 2011 LiDAR via ELVIS; no licence on record	12 tiles 18,442,458 points	GDA94 / MGA zone 55 (EPSG:28355), orthometric heights. Captured 20 to 28 January 2011 according to its own metadata	Older survey
Climate Futures Derwent 2008	ACE CRC (Climate Futures for Tasmania); captured by DiMAP	9 tiles 12,324,674 points	GDA2020 / MGA zone 55, AHD heights. No tiles over the western kilometre	Older survey

Inputs. All three supplied through ELVIS (elevation.fsdf.org.au).

- Every input tile is recorded with its SHA-256 hash; the processing reads the tiles as delivered and never edits them.
- Dropped from every survey: noise (ASPRS classes 7 and 18) and heights outside -10 to 1000 m.
- Classes are taken as each supplier delivered them (section 9).
- Licences: per survey, listed at groundmap.com.au/about/data-and-licences/. Attribution: Hobart City 2023/24 LiDAR from theLIST © State of Tasmania. Licence: CC BY 3.0 AU. Climate Futures Derwent 2008 LiDAR: The LiDAR Dataset was collected as part of the Climate Futures for Tasmania project; a project managed and delivered by the Antarctic Climate & Ecosystems Cooperative Research Centre. The dataset was funded primarily by the State Government of Tasmania through the State Emergency Service and the Commonwealth Natural Disaster Mitigation Program. Licence: ACE CRC licence (Australia wide; commercial use, adaptation and sub-licence). Mount Wellington 2011 LiDAR, flown 20 to 28 January 2011, obtained via ELVIS (Geoscience Australia). Licence: No licence on record.

03 Co-registration on stable ground

Older surveys are moved into the frame survey's coordinates in two steps: a datum transformation, then a registration fitted on ground that has not changed.

Datum

Mount Wellington 2011 is transformed from GDA94 to GDA2020 with PROJ 9.8.1 (pyproj 3.8.0), operation "Inverse of Map Grid of Australia zone 55 + GDA94 to GDA2020 (1) + Map Grid of Australia zone 55": a horizontal shift of about 1.5 m. Climate Futures Derwent 2008 is already on GDA2020. No vertical datum transformation is applied; height differences between surveys are removed by the registration.

Registration

The fusion runs in 3 × 3 km blocks; the Hobart area spans two, south and north. In each block, each older survey's ground (class 2) is compared with a TIN of the frame survey's ground on a stable mask: open ground, slope under 25°, no water, and no significant change between the pair. A model is fitted to those residuals and its shift removed from every point of that survey in the block.

Three models are available: a block translation; a translation per flight line, where lines differ; and a plane (height offset and tilt), where a tilt is measured.

SURVEY · BLOCK	MODEL · SHIFT REMOVED, E / N / H (M)	POINTS	BEFORE: MEDIAN / NMAD / RMSE (M)	AFTER
2011 · south	Block translation +0.112 / +0.005 / -0.080	1,638,000	-0.078 / 0.069 / 0.108	-0.001 / 0.069 / 0.077
2011 · north	Per flight line (lines 12, 15 to 18); block for the others +0.213 / -0.037 / -0.120 (block)	1,656,373	-0.120 / 0.081 / 0.142	-0.003 / 0.064 / 0.072
2008 · south	Translation and plane -0.190 / +0.058 / -0.059; +0.072 offset, tilt E -0.167, N +0.045 m/km	1,696,757	-0.068 / 0.146 / 0.164	+0.001 / 0.122 / 0.138
2008 · north	Block translation -0.017 / +0.091 / -0.084	2,253,117	-0.079 / 0.153 / 0.179	+0.004 / 0.153 / 0.159

Registration of the older surveys to Hobart City 2023/24: residuals of the older ground minus the frame ground on the stable mask, before and after. The shift is the older survey minus the frame; it is subtracted.

Flags recorded by the processing: for the 2011 survey in both blocks, the height offset under forest differs from the open-ground offset by more than 5 cm; the per-line fit for 2011 in the north block found offsets on lines 12 and 18; local disagreements at a few named cells were recorded; no local correction was applied. The 2008 registration in the north block is flagged for spread: its NMAD of 0.15 m stays above the block's threshold after the shift, which removed the offset but not the noise.

Check after alignment

An independent check, outside the registration: every older class 2 return on stable open ground (1 m cells with no frame non-ground class within 1 m, slope 10° or less, frame ground in all four neighbouring cells) is compared with the frame's ground surface at its position (bilinear on the 1 m mean of frame class 2). Returns more than 1 m off are excluded as change.

SURVEY	RETURNS	MEDIAN	NMAD	RMSE	95TH PCT DZ	WITHIN 0.15 M
Mount Wellington 2011	823,751	-0.006 m	0.064 m	0.095 m	0.157 m	94.4 %
Climate Futures Derwent 2008	1,036,026	+0.020 m	0.125 m	0.154 m	0.299 m	73.3 %

Older ground minus frame ground after alignment; excluded beyond 1 m: 0.11 % (2011), 0.21 % (2008).

The 2008 survey is about twice as noisy as the 2011 survey on the same ground, so fewer cells can be confirmed by it.

04 Fusion: which points enter the model

The frame survey keeps every return except noise. An older point enters the model only where it adds to the frame, after its vegetation (classes 3 to 5) and any point inside the pair's significant change are dropped. Three rules decide, on 0.5 m cells:

- **A, surface fill.** Within 0.3 m of the frame's surface (holes in that surface filled with the frame's ground).
- **B, wall fill.** Within 1 m of a frame roof outline stepping more than 2.5 m, between the frame ground less 0.3 m and the local frame maximum plus 0.3 m, and only where the older survey's own roof lies within 1.0 m of the frame's roof.
- **C, hole fill.** In a cell with no frame return: within 0.4 m of the surface at the hole's rim or 0.3 m of the frame ground, and only where the older survey's surface matches the frame on that rim (median within 1.0 m over at least three rim cells).

An older point labelled vegetation that lies within 0.3 m of the frame's building surface is treated as roof: the 2011 survey has no building class and labels most roofs as high vegetation.

Older points kept by rule A outside holes take the height of the frame's smoothed surface at their position (3 × 3 median, bilinear); their position and survey are unchanged and they carry `generated = 1` (11,960,252 points). The agreement grade uses their recorded heights, never the smoothed ones. The result: 348,484,180 measured points, 334,665,829 from the frame survey and 13,818,351 from the older surveys.

05 Agreement scoring

The grade is computed per 0.5 m cell on the frame survey's top surface of ground and buildings, then given to the points on that surface.

```
surface(c) = highest frame return of class 2 or 6 in cell c
ds(c) = smallest |z - surface(c)| over older survey s's non-vegetation returns in c
confirmed(c) = 1 + number of older surveys with ds(c) ≤ 0.15 m
agree_cm(c) = 100 × smallest ds(c), rounded; 65535 when no older return lies in c
```

Class 12 (overlap) is left out of the surface because it also holds trees. Every older point moved into the frame is used, not only those kept in the model. A measured point takes its cell's values when it lies within 0.3 m of surface(c); other measured points (walls, vegetation, ground under canopy) are measured but not checked.

SCORE	CONDITION	CLASS	POINTS	SHARE
100	Both older surveys within 0.10 m	 3 passes agree	5,661,406	1.4 %
90	Both older surveys within 0.15 m	 3 passes agree	3,206,708	0.8 %
85	One older survey within 0.10 m	 2 passes agree	43,924,577	11.0 %
75	One older survey within 0.15 m	 2 passes agree	11,864,354	3.0 %
55	Surface point; no older return in the cell, so only the frame measured it	 Single pass	78,569,123	19.7 %
50	Measured point off the top surface: walls, vegetation, under canopy. Not checked	 Single pass	178,181,957	44.7 %
40	Older returns in the cell, none within 0.15 m	 Change detected	27,076,055	6.8 %
5	Modelled point	 Modelled	49,784,438	12.5 %

Score bands and the five confidence classes, with the 398,268,618 points of the Hobart showcase. The score is stored in the LAS extra byte **accuracy**: a confidence grade score, not an accuracy value.

Results on the surface

On the 4.20 km² of ground and roof surface that all three surveys cover (16,790,248 cells of 0.5 m): 39.4 % is confirmed by at least two surveys (6.1 % by all three), 20.3 % is graded change detected and 40.3 % was measured by the frame alone. With the 2024 and 2011 surveys only, the same cells give 21.4 %, 8.6 % and 70.0 %. Ground is confirmed more often than roofs (42.4 % against 30.0 %).

Reproduction: recomputed independently from the raw tiles, 99.99 % of the surface cells get the same **confirmed** value as the showcase files.

Density score

A second field, **confidence**, is a point-density score from 0 to 100: it scores completeness, not the grade and not accuracy. It counts measured points in the point's 1 m column, 32 or more per m² scoring 100 and 15 less for every halving (16 = 85, 8 = 70, 4 = 55, 2 = 40, 1 = 25, under 1 = 15). Modelled points score 5.

06 Change

- **Before fusion.** Each block maps the significant change between every pair of surveys. Older points inside it are dropped (section 4).
- **In the grade.** A surface cell with older returns but none within 0.15 m is graded change detected (score 40). The frame is the newest survey, so its surface is kept; older returns more than 0.3 m from it are not used to fill it.
- **In deliverables.** Points of a surface that changed between surveys are classed ICSM class 22, Temporal Exclusion: "features excluded due to changes over time between data sources" (ICSM Australian Airborne LiDAR Acquisition Specification v2.0, section 3.12.2). The Hobart showcase files keep each supplier's classes and mark change with score 40.
- **A flag, not a measurement.** Change detected includes real change since 2008 or 2011 (new buildings, earthworks, growth on roofs) and errors in an older survey. Change and volume products are computed separately, on co-registered surfaces, where both surveys are confident.

07 Modelled points and their flags

Airborne passes that look down measure roofs and ground but few walls. GroundMap fills surfaces not pass measured by geometric modelling, and flags every point it makes. In the Hobart showcase, walls are modelled from the measured roof outlines of the frame survey:

- a roof raster (0.5 m) from the frame's building points; its outline split into 4 m roof-height bands, so a tower above a podium gets its own wall, and simplified to straight lines (0.35 m);
- along every line, a flat vertical wall from the surface outside (frame ground, or the lower roof) up to the roof inside, at about 16 points per m² (0.25 m spacing, jittered);
- only where the wall is at least 2 m high, and only where no measured point already lies in the same 0.3 m voxel: 4,070,221 candidate points were not generated for that reason.

Result: 49,784,438 modelled points, 12.5 % of the showcase's points. Every modelled point carries all of these flags, so any software can find or exclude it:

FLAG	VALUE ON A MODELLED POINT
LAS synthetic flag	Set
<code>generated</code>	2 (measured points 0, smoothed older points 1)
<code>survey_year</code>	0
<code>accuracy</code> (the grade score)	5; <code>confirmed</code> 0; <code>agree_cm</code> 65535
Classification	6, building, in the showcase

Modelled points are never counted as confirmed and are left out of every measured count and of the density score. Measured-only outputs are the default; modelled points are delivered when the client asks for them. The project's lineage report names the modelling method. Reserved: points from a trained model, if ever used, are flagged as learned, separately from modelled. Limits of this version: walls are flat and vertical, so balconies, awnings and recesses are absent.

08 Outputs

Point cloud	LAS 1.4, point data record format 7 (RGB), LAZ, 0.001 m scale. GDA2020 / MGA zone 55 with AHD heights, written as OGC WKT.
Fields	<code>survey_year</code> (uint16), <code>generated</code> , <code>confidence</code> , <code>confirmed</code> , <code>accuracy</code> (uint8) and <code>agree_cm</code> (uint16) as LAS extra bytes, beside the standard fields and the synthetic flag. <code>accuracy</code> holds the confidence grade score of section 5, not an accuracy value; <code>confidence</code> holds the point-density score (0–100), not the grade.
Rasters	Fused DTM and DSM (GeoTIFF / COG), coverage, agreement and confidence rasters, and a modelled-area mask.
Documentation	Lineage (input tiles and hashes, transformations, registration per survey and block), QA report, ISO 19115 metadata.
Hobart showcase	The fused point cloud in a web viewer. Sample data on request.

09 Limitations

- **Alignment sets the mean offset.** Older surveys are registered to the frame on stable ground, so their mean offset there is near zero by construction; the Hobart figure is checked on open ground independently of that alignment. Agreement cell by cell is still an independent repeat measurement, but it measures consistency between surveys, not absolute accuracy.
- **The test is an agreement test.** It uses the closest older return in a 0.5 m cell, so on rough surfaces a chance return can agree. It is not an accuracy figure.
- **"None agrees" is not proof of change.** With three surveys, 20.3 % of the surface is graded change detected. On stable open ground, where no change is expected, 16.3 % of cells with a 2011 return fail the grade's 15 cm test (5.6 % of 2011 returns lie more than 15 cm from the frame's ground, section 3), and 26.7 % of 2008 returns lie more than 15 cm from the frame's ground: the class mixes real change with survey scatter.
- **The frame's own error is not detected.** A systematic error in Hobart City 2023/24 moves the older surveys with it.

- **Coverage differs.** The 2008 survey does not cover the western kilometre, where at most two surveys can agree; the comparisons in section 5 use the ground and roof surface (4.20 km²) inside the 6.60 km² that all three surveys cover.
- **The 2008 survey is noisier** (NMAD 0.125 m against 0.064 m for 2011 on stable ground), which lowers the share it can confirm.
- **Classes as delivered.** 55.2 % of the frame's kept returns are in class 12 (overlap), with no ground, vegetation or building class; the surface uses classes 2 and 6 only.
- **Ground counts include changed ground.** Aligned older ground returns are counted even where the ground has changed since; change is flagged separately.
- **Modelled walls are flat** (section 7).
- **Grades are not accuracy.** No accuracy figure may be derived from the grades. Vertical accuracy is checked against held-out State survey marks (section 10); the Hobart model itself has no figure against them.

10 Vertical accuracy against survey marks

Accuracy is measured on every job and stated per job.

The method was checked on 20 October 2026 on GroundMap's finished ground from government aircraft LiDAR, as its processing writes it out, against 43 State survey marks held out of GroundMap's processing: median -3 mm, 33 of 43 within 10 cm, RMSE 0.12 m.

MEASURE	VALUE
Check points	43 levelled State survey marks: 12 flush with the ground, 31 set in rock; third-order (42) and fourth-order (1) levelling; AHD
Median / mean difference	-0.003 / -0.019 m
Standard deviation / NMAD	0.115 / 0.078 m
RMSEz	0.116 m
95 % (ICSM v2.0, 1.96 × RMSEz)	0.23 m
95th percentile of absolute difference	0.25 m
Within 0.10 m / 0.30 m	33 of 43 (76.7 %) / 42 of 43 (97.7 %)
Largest difference	-0.371 m

Finished ground minus mark, 20 October 2026. Non-vegetated, open and relatively flat ground (under 10°, by the rules below); vertical only.

At 0.23 m (95 %), the method check is within the 0.30 m vertical limit ICSM v2.0 sets at 95 % confidence.

Method: a check of the method against held-out State survey marks

- **Held out of processing.** The State's marks were split in two by their State site number, by a rule fixed before any mark was read. The held-out half was never used to align, correct or tune anything, and no height was read from it until the check.
- **Reading rules.** One reading per mark: the median height of the finished ground returns (classes 2 and 8) within 1.5 m of it, minus the mark's AHD height. A mark counts only with at least five ground returns within 1.5 m; no wider window is used. A reading counts on open, relatively flat ground only: slope × 0.30 m within 0.05 m (about 9.5°), under 30 % of the returns within 3 m more than 2 m above the ground, and 3 m or more inside the edge of its 1 km square. Every mark left out is listed with its reason.
- **Levelled marks decide.** Only levelled marks flush with the ground or set in rock decide the figures. Kerb, pit and box marks sit beside a step or below the surface and never decide.
- **Discs excluded by a rule fixed before any figure was printed.** Discs set in concrete, and marks with no description, were to be left out if their median differed from the flush and rock marks' by more than 0.05 m. It did: +0.077 m against -0.003 m. The reading picks up the grass and concrete around a disc rather than the ground, so discs are left out of every figure.
- **The finished ground as output.** The readings were taken on the finished ground exactly as GroundMap's processing writes it out; a sample of readings was cross-checked against a separate export of the same ground, to within 1 mm.

Limits

- **No quality level claimed.** The check tests the method; no ICSM quality level or accuracy class is claimed for it.

- **Not an ICSM-compliant assessment.** The figure is computed in the ICSM v2.0 form, but the number, distribution and photographic record of the check points fall short of section 3.6 for the area the marks span.
- **Not a certificate for any survey.** No source survey holds enough marks to be judged on its own, and the check certifies no survey, area or job. No claim is made against the source surveys' own stated accuracy.
- **Check points.** The State marks serve as historic check points (ICSM v2.0 section 3.6.5): held out of GroundMap's processing, but not surveyed for this purpose and possibly used as control by a source survey's provider, not spread by land cover, and without published height uncertainty. Each reading is the median of ground returns within 1.5 m, not the TIN interpolation of section 3.4.1.
- **Control use not known.** Whether a source survey's provider used any of these marks as control is not known.
- **Not tested:** horizontal accuracy, vegetated ground, slopes over about 9.5°, ground beside structures, and change between the levelling and the flight.

Hobart showcase

The Hobart model has no figure against survey marks: no levelled mark flush with the ground or set in rock, of those held out, lies within its 2024 survey. On stable open ground, checked independently of the alignment, the 2011 survey agrees with the 2024 survey to a median -6 mm (NMAD 64 mm, 95th percentile 157 mm; 94.4 % within 15 cm): relative agreement between surveys, not absolute accuracy. The alignment and its check are in section 3.

Every job

- **Accuracy note.** Every job states its own accuracy: independent check points (ICSM v2.0 section 3.6), rules fixed before reading, each point read from a TIN of single returns (ICSM v2.0 section 3.4.1) and on the delivered surface, both forms (ICSM non-vegetated vertical accuracy at 95 %, and RMSE_v (ASPRS Edition 2)), every point left out with its reason, and what was not tested.
- **Survey sign-off.** A registered surveyor is engaged wherever a job needs survey sign-off.
- **Publication.** The accuracy statement, in its national and international forms: groundmap.com.au/accuracy/.

Survey marks: LIST Survey Control, the LIST © State of Tasmania, CC BY 3.0 AU. Aircraft LiDAR: public surveys published on theLIST (State of Tasmania) and obtained via ELVIS (Geoscience Australia), under the licences recorded with them (theLIST: © State of Tasmania, CC BY 3.0 AU). Processing: GroundMap.

11 Version history

VERSION	DATE	CHANGES
v0.9 draft	16 Oct 2026	First issue for technical review. Method and results of the Hobart showcase (three public surveys, 2008 to 2024). Vertical accuracy against survey control not yet validated.
v0.10	22 Oct 2026	Issued for evaluation. Section 10 reports the check of the method against 43 State survey marks held out of GroundMap's processing (20 October 2026), with its method and limits. Modelled points and their flags restated (section 7); reserved learned class added.

12 References

- ICSM, Australian Airborne LiDAR Acquisition Specification, Version 2.0 (2025): accuracy reporting, sections 3.4 to 3.9; class 22, Temporal Exclusion, section 3.12.2.
- ASPRS, LAS Specification 1.4 R15 (2019): point data record formats 6 to 10, the synthetic flag and extra bytes.
- ICSM, Standard for the Australian Survey Control Network (Special Publication 1), Version 2.2 (2020).
- ASPRS, Positional Accuracy Standards for Digital Geospatial Data, Edition 2 (2023): vertical accuracy reported as RMSE_v.
- Survey marks: LIST Survey Control, the LIST © State of Tasmania, CC BY 3.0 AU.
- PROJ 9.8.1 and pyproj 3.8.0: the GDA94 to GDA2020 transformation in section 3.
- Survey data: Hobart City 2023/24 (captured by Fugro for the State of Tasmania; theLIST; CC BY 3.0 AU), Climate Futures Derwent 2008 (captured by DiMAP for ACE CRC; ACE CRC licence) and Mount Wellington 2011 (no licence on record), via ELVIS. Processing: GroundMap. Alignment, fusion, confidence grading, modelling and visualisation by GroundMap. The data custodians and survey contractors did not perform or review this processing and do not endorse GroundMap. ELVIS: elevation.fsdf.org.au.