Glacier Surface Segmentation Using Airborne Laser Scanning Point Cloud and Intensity Data

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Aim:
Utilize full information (i.e. geometry and intensity) of ALS point cloud to enable glacier surface classification.
Study Area and ALS Dataset

Hintereisferner

ALS flight campaign
- 12 August 2003
- Optech ALTM 2050 (Topscan)
- 1064 nm laser wavelength

Test site
- 480 x 320 m
- 335,000 last echoes
- 0.7 m average point spacing
Study Area and ALS Dataset

The map illustrates a study area with various ice and snow features, including:

- Snow
- Firn
- Ice
- Crevasses

The map also indicates distances:

- 318 m
- 485 m

The scale at the bottom indicates 500 meters per inch.
Study Area and ALS Dataset

![Graph showing signal intensity vs. distance on profile, with labels for glacier ice, firn, and snow.]
Workflow

Point Cloud $x \ y \ z \ i$

Intensity Correction

Segmentation

GIS Object Building

Segmented Point Cloud

Classification

Segment Polygons

Classified Point Cloud

Classified Glacier Surface
Workflow

- Point Cloud (x y z i)
- Intensity Correction
- Segmentation
- GIS Object Building
- Segmented Point Cloud
- Classification
- Classified Point Cloud
- Classified Glacier Surface
- Segment Polygons
Workflow – Intensity Correction

\[
\rho \propto I \frac{R^2}{R_s^2} 10^{2Ra/10000} \frac{1}{\cos \alpha}
\]

where
\[\rho = \text{reflectance}\]
\[I = \text{signal intensity [digital number (DN)]}\]
\[R = \text{range [m]}\]
\[R_s = \text{standard/normalizing range [m]}\]
\[a = \text{atmospheric attenuation coefficient [dB/km]}\]
\[\alpha = \text{angle of incidence [°]}\]
Workflow

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Workflow – Segmentation

in local neighborhood

- surface normals (plane fitting)
- intensity mode (predominant)
- intensity variation (coefficient of variation)

knn: 25
bin size: 5%
Workflow – Segmentation

- **seed point selection:**
  - ordered by intensity variation
  - starting with most homogeneous points

- **similarity check of candidate points (k nearest neighbors):**
  1) surface normal difference to current seed (e.g. <20°)
  2) max. intensity difference to starting seed (e.g. ±5%)
Workflow

- Point Cloud $x \ y \ z \ i$
  - Intensity Correction
  - Segmentation
  - GIS Object Building
  - Segmented Point Cloud
  - Classification
  - Classified Point Cloud
  - Classified Glacier Surface
  - Segment Polygons
Workflow – GIS Object Building

- Delineation of Segments
- Closing of Gaps

- 2D alpha shapes
- alpha complex is used to construct GIS polygons (connect boundary line segments)
 Workflow – GIS Object Building

- **GIS topology**: neighbors share common boundary

Voronoi diagrams of boundary vertices → intersection of Voronoi with buffer → final removal of small gaps and overlaps
Workflow

Point Cloud $x\ y\ z\ i$

Intensity Correction

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Workflow – Classification

- supervised classification by mean segment intensity
- using manually digitized training areas for extracting rule-base:
  - snow \( \geq 74\% \) of maximum intensity
  - firn 49-74%
  - ice <49%
- “surface irregularities”: areas not covered by any segment polygon
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Results - Segmentation

GIS segment polygons and attributes
Results - Classification

Orthophoto

ALS classification

training areas

Point wise error assessment with manual delineation:

90.9% overall classification accuracy with Kappa=0.80
Conclusion

- **intensity** generates **added value** if corrected

- classification **accuracy >90%** with point cloud segmentation and simple classification

- **better separability in intensity** than in orthophoto (overall accuracy: 86.7%)

- **GIS** implementation offers an **operational tool** for glacier monitoring
Conclusion

Future Work:

- larger test areas with non-glacier classes (e.g. rock, vegetation)
- utilize vector geometry and topology for classification (e.g. neighborhood information)
- object-based error assessment (ground truth!)
- improve intensity correction:
  - individual reflectance models for different surface types
Thanks for your attention!

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