Geomorphologic Mapping by Airborne Laser Scanning in the Antarctic Dry Valleys

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Outline

- Overview of airborne laser mapping and polar applications
- ATM survey of the Dry Valley
  - Data acquisition
  - Data processing
  - Data dissemination
- Examples of geomorphologic mapping from DEM
  - Glacial geomorphology
  - Hydrology
  - Tectonics
  - Volcanism
- Higher level processing
Principles of laser altimetry

- A. Distance between sensor and ground is determined from measurement of laser travel time
- B. Position of sensor is measured by differential GPS
- C. Attitude of sensor is measured by Inertial Navigation System (INS)
- A, B and C are combined with calibration values and correction factors to compute the position of the ‘laser point’ in a global reference system
- Result is a set 3D points
- For many mapping applications grids are computed
- Direct reconstruction of 3D surfaces is possible from the point cloud
Why using LIDAR for cryosphere research?

- Airborne and satellite laser is ideal for polar and alpine research, because
  - fresh snow is almost a perfect Lambertian reflector
  - laser scanning provides simultaneously synoptic coverage, high spatial resolution and spatial accuracy
  - laser systems can map featureless terrain – notorious problem in photogrammetry
  - laser systems have small footprint – problem for radar systems
History and state-of-art

- The beginning: NASA has started a systematic mapping program in Greenland in the early 1990s
- Current status: Laser is applied routinely for mass balance and ice dynamics studies over ice sheets and mountain glaciers
- New sensors: NASA has launched the Ice, Cloud and land Elevation Satellite (ICESat) on January 12, 2003. The sole sensor of the satellite is the Geoscience Laser Altimetry System (GLAS), NASA’s first terrestrial laser altimetry satellite mission. The program is in calibration/validation phase
- New applications: first surveys for glacial geomorphology
Dry Valley airborne laser altimetry survey

- **Goals:**
  - obtain precise elevations for ICESat cal/val
  - assess the use of airborne laser for Antarctic mapping

- **Joint project of NASA/NSF/USGS**

- **Data acquisition:**
  - Sensor: NASA’s Airborne Topopgraphic Mapper (ATM) conical laser scanning system
  - Survey: December 2001
  - Results: coverage of selected site with an average laser point density is 0.1 – 0.5 point/m²
Why did we select Dry Valleys as ICESat calibration site?

- High track density (left)
- Maximum range part of ICESat orbit (right)
Why did we select Dry Valleys as ICESat calibration site? (cont.)

- Small annual and interannual variability
- No vegetation, minimal snow/ice cover
- Minimal cloud cover
- Smooth surface at the scale of the ICESat footprint
- Diverse topography (slope)
- High ICESat track density
- Maximum orbital altitude
- Close to major science targets

Verification and calibration of ICESat is ongoing effort. Results of cal-val and change detection were reported at AGU.
Target areas for testing geological and glaciological applications
Data acquisition system: Airborne Topographic Mapper, NASA/WFF

Installed in Twin Otter aircraft (regularly used in P-3 (Orion) aircraft)

Specifications:

- Green wavelength
- Scan with nutating mirror
- Spectra Physics TFR laser
- 10-20 degree off nadir angle
- 10-15 Hz scan rate
- 5,000-20,000 pulse rate
- Installed in P3-B Orion
- Intensity + passive channel
- 1 meter footprint size
- Digital imagery also acquired
## Data Processing Steps

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Generating Database

- Antarctica laser point data set contains over 1.2 billion points, stored on 23 DVDs in over 300 files, sequentially organized by flight lines
- Database required to perform queries with multiple criteria
- Oracle 9i with spatial option was selected
  - data table contains laser points and auxiliary data
  - index tables help to accelerate queries
  - disk capacity needed: approx. 90 GB
  - multiple queries possible, geared towards spatial criteria
    - find points within a specified polygon
    - find points within a search radius of a given point
Generating DEMs

- Blunder detection
  - unusual large amount of blunders due to rapid change in albedo and atmospheric conditions

- Boundary definition
  - original laser points are organized by flight lines NOT by project sites (one flight line may cover different sites)

- Grid interpolation
  - surface fitting with robust estimator
  - label grid posts based on fitness error and point distribution

- Quality control
  - internal, e.g. fitness error during interpolation, visualization
  - external, e.g. with GPS control points
Blunder distribution and detection

Extreme brightness contrast and atmospheric conditions resulted range errors
DEMs from ATM scanning laser altimetry data around McMurdo Sound, Antarctica

DEM from ATM data with site ID and name; 2 m grid posting (solid line) or 4 meter grid posting (dashed line)

ATM trajectories (colors according to flight missions)

Base map: McMurdo Sound, Antarctica - 1:1,000,000 (USGS, 1974)
DEM compiled from ATM airborne laser altimetry data

Shade

Remote Sensing Data Seminar, OSU
February 4, 2004
Checking absolute accuracy using GPS stations
Accuracy of DEMs and data distribution

- **Accuracy of DEM**
  - Internal accuracy is measured by residual of plan fitting within grid cells, and stored in a “label” matrix. For most DEM cell it is better than 10 cm.
  - Absolute accuracy of 0.1+-0.5 m is estimated by comparison with 80+ ground GPS points.
    - Most of these GPS positions refer to the antenna phase center and its exact height above the topographic surface is not known. Therefore the RMS error of the DEM might be overestimated → accuracy studies are ongoing.

- **Data distribution:**
  - For information on the data set contact Bea Csatho, OSU, csatho.1@osu.edu or visit http://www-bprc.mps.ohio-state.edu/ohglas/glid_icesat.htm
  - To obtain the data contact Cheryl Hallam, USGS, challam@usgs.gov
Mapping glacial, tectonic and volcanic geomorphology at the Dry Valleys, Antarctica
Research interest (several PIs)

- Taylor, Wright, Victoria, McKelvey, Balham, Beacon and Arena valleys, Bull Pass -- glaciology, glacial and periglacial geomorphology; glacier surface models, drainage patterns, patterned ground, rock glaciers, etc.,
- White Island, Mt. Morning, Mt. Erebus, Mt. Discovery -- mapping volcanic cones
- Radian Glacier to The Portal -- relationship between bedrock structure and ice flow
- Denton Hills -- fault structure and landscape analysis
- Wilson piedmont glaciers -- lineaments and bedrock structure
- Cape Royds -- Penguin rockery landscape
- Hut Point Peninsula -- volcanic landscape, McMurdo Base
- Odell glacier -- possible aircraft landing site
Wright Valley

Taylor Valley 1.
(Canada and Commonwealth glaciers)

Taylor Valley 2.
(Lake Bonney)

Beacon Valley

Denton Hills

Mount Morning
Further data analysis and higher level processing

- Tools for mapping geomorphological features
  - Feature extraction
  - Segmentation
  - Surface reconstruction and modeling
  - Data fusion
- Provide quantitative data for landscape modeling
- Can be performed on original point cloud or from DEM
Beacon Valley

Patterned ground, non-sorted polygons,

Jurassic sandstone and dolerite sills

Rock glacier surface

1 2 3

5km
Closer look at the DEM

Feature extraction: polygons, rock glaciers
Canada glacier
Commonwealth glacier
Lake Bonney
An example: Canada glacier, Taylor Valley

Feature extraction: drainage pattern, moraines, crevasses. Coastline, meltwater channels.
Hydrological features, drainage pattern

Evidence of temporary stream flow
S of Lake Bonney

Glacial flutes S of Commonwealth glacier

Feature extraction: drainage pattern, flutes, crevasses, coastline
Glacial geomorphological features.
Bartley glacier in the Wright Valley

Segmentation and feature extraction: Crevasses, moraines, drifts, bedrock outcrops, streams
Denton Hills, fault structure

Shaded relief DEM from laser  Landsat TM mosaic (USGS)
Cross-cutting fault array
S of Joyce glacier

Lineament mapping

(T. Wilson)
Quaternary fault, Garwood valley

Lineament mapping

from Jones, 1996

(T. Wilson)
N slope of Mt. Morning, volcanic geomorphology

Shaded relief DEM from laser alt.  Landsat color composite
Erebus Volcanic Province

NE cone elongation and alignments
Surface signatures of volcanic fissures

Horizontal stress direction

Cone morphology – indicator of fault control

\( S_{\text{Hmax}} \)

\( S_{\text{hmin}} \)

(Tibaldi, 1995)
Close-up of volcanic cones and lava flows

Surface reconstruction and 3D modeling: Parametric form of volcanic cone shapes determined by 3D surface fitting (cone parameter, base, crater rim); delineation of lava flows by texture based segmentation
Conclusion, future work

- Laser mapping provides high accuracy, high resolution, repeat and regional coverage
- Data set is suitable for creating DEMs and for quantitative mapping of geomorphologic features
- Multidisciplinary effort is needed for comprehensive studies
- Techniques of different fields, such as computer vision, artificial intelligence, data fusion are needed to automate the processing steps
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