System and terrain error modeling

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Why do we care about error?

- Allows us to place trust in our products and understand quality of results
- Enables risk assessments for management decisions
- Enhanced LiDAR mission planning capabilities to meet specifications
- Majority of DEM users do not account for errors! (Wechsler, 2003)

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'Accuracy' of Optech Pegasus*

Flying Height (m)	Vertical (cm)	Horizontal (cm)	Confidence Interval
1200	5-20	22	Standard (~68%)
2000	5-20	36	Standard (~68%)
3000	5-20	55	Standard (~68%)

*Dependent on selected operational parameters using nominal FOV of up to 40° in standard atmospheric conditions with 24-km visibility

•Are these the only conditions that we must satisfy to meet the published values?

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Error sources in LiDAR observations

- Hardware components
  - GPS
  - Inertial Measurement Unit (IMU)
  - Laser Ranger
  - Laser Scanner

Best Defined

- Slope of the terrain
- Beam divergence
- Laser beam incidence angle
- Range based intensity biases
- Atmospheric effects
- Vegetative effects

Ongoing Research

Empirically observed RMS errors

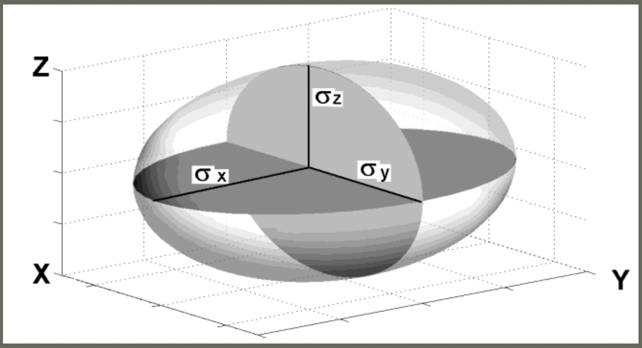
- Huising and Pereira (1998)
  - **Flat sloped terrain - 29 cm**
- Hyyppä et al. (2005)
  - **Slopes above 30˚ - 50 cm**
- Personal experience
  - **High slope alpine environment, errors up 70 cm**
- **Why does this discrepancy exist?**

Error modeling

- Vendor specifications and quality assurance procedures are not designed to provide an estimate of error for the entire survey
- ***Performance analysis of ALTM 3100EA: Instrument specifications and accuracy of LiDAR data*** **– Ussyshkin and Smith (2006)**
- Errors assessed under strict conditions - provide assurance the sensor system was operating correctly
- Not feasible to empirically measure error everywhere
- If errors can be modelled, it can provide overview of error across the survey

Error model results

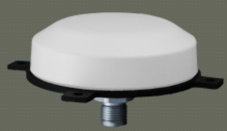
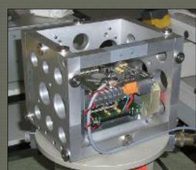
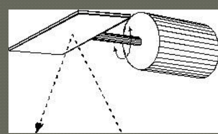
- Error modeling result provides a three dimensional error ellipsoid describing the space which contains the point with statistical confidence



Hardware Errors

Direct Georeferencing of LiDAR

- $(X,Y,Z)_{Ground}$ = ƒ(GPS, IMU, Scanner, Ranger, Integration)
- Produces 3D point coordinate
- Each system component contains error


Global Positioning System

- Satellite Availability } GDOP
- Satellite Geometry } GDOP
- Atmospheric influences
  - Ionosphere
  - Troposphere

Inertial Measurement Unit (IMU)

- Initialization Parameters
  - Direction of local gravity
- Drift
  - Temperature, pressure, vibrations

Laser Scanner

- Angular error
- Related to manufacture of angular encoder
- Caused by variations in temperature and pressure and electronics of the system

Laser Ranger

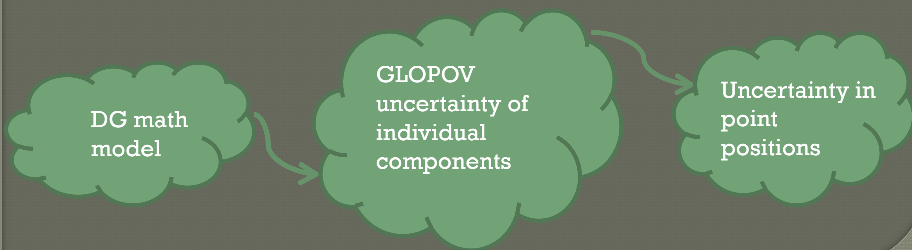
- Internally due to only timing implications
- Externally due to atmospheric effects terrain effects etc.

Approximate individual hardware system errors

HARDWARE SUB-SYSTEM	ERROR MAGNITUDE
GPS	Horizontal: 3-5 cm Vertical : 5 – 10 cm
IMU	Roll / Pitch: 0.005 – 0.01˚ Heading: 0.01-0.02˚
Scan Angle	0.003˚
Laser Range	2 cm

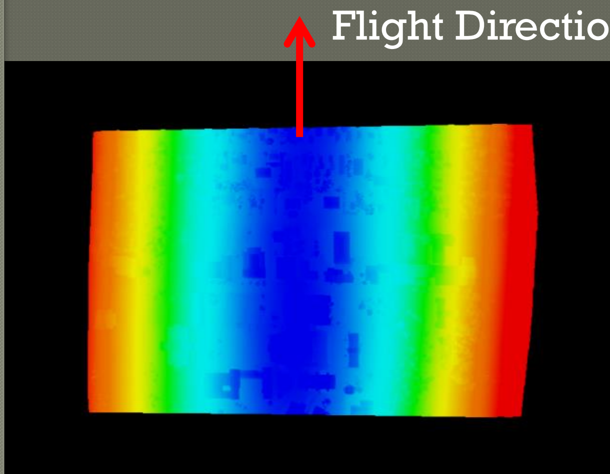
Calculating Hardware Error

- Propagating error of individual components
- Performed through general law of propagation of variances (GLOPOV)
- Assumption : No correlation between system component



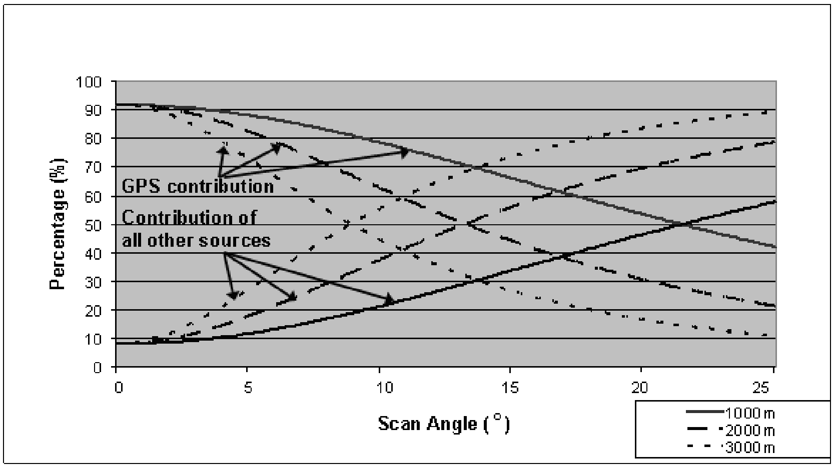
Vertical error results

Flight Direction



Red = 8cm
Blue = 5cm
FH = 1200m
SA = 15˚

Error Proportions

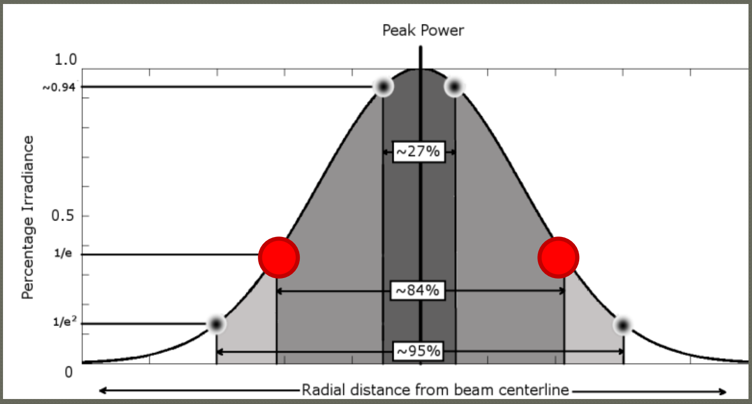


What does this tell us about mission planning?

Terrain Related Errors

Beam divergence

- Several definitions for beam divergence exist. Optech - 0.25 mRad at 1/e, 50 cm footprint diameter at ground w/ 1000 m flying height

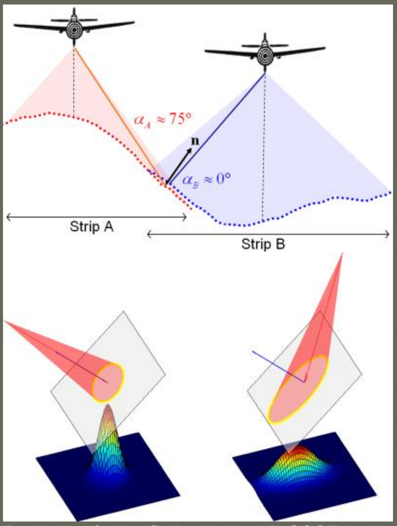


Incidence Angle

•Depends on terrain and scanning geometry

•Creates large 'smeared' footprints

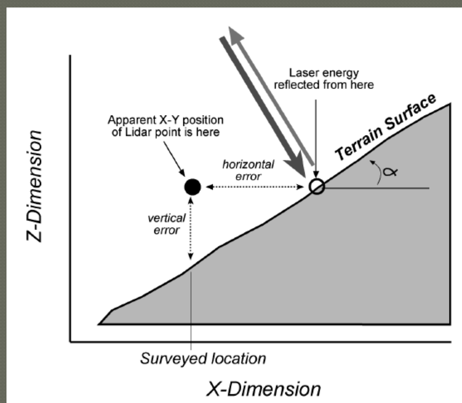
•Vectors perpendicular to terrain cause least error



Images from Schaer et al. 2007

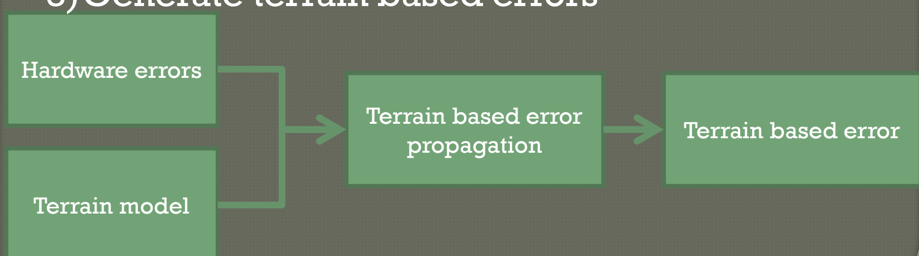
Predicting slope based error

- Horizontal error leads to vertical error – Koppe's formula

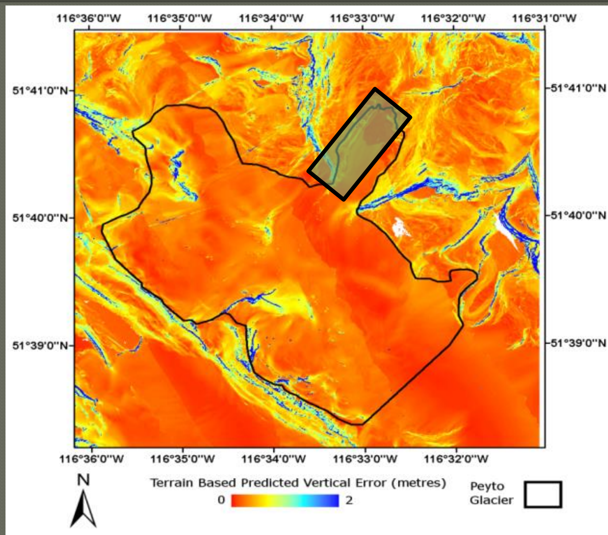


Propagate error based on terrain slope

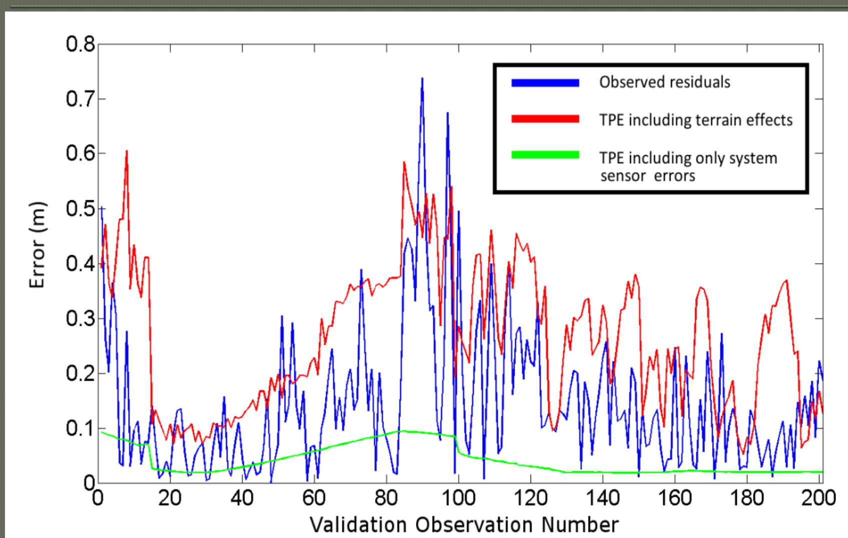
1) Combine hardware errors with a terrain model
2) Supply information to an error modelling algorithm
3) Generate terrain based errors



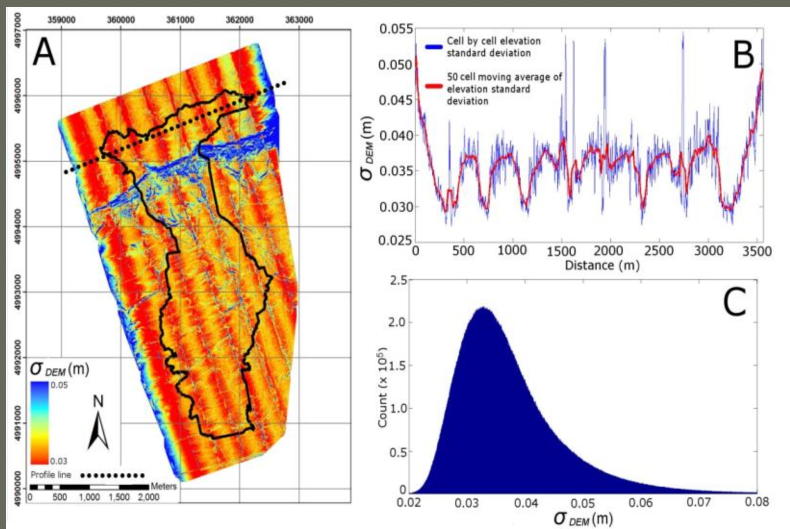
Uncertainty map of alpine area



Terrain error modeling results



LIDAR DEM error



Conclusions

- Manufacturer accuracy specification and quality assurance procedures prove sensor was operating correctly
- Large scan angles, sloped ground, will increase error past specifications
- Error modelling can provide a spatially explicit quantification of error across a survey site
- Can be propagated to further products – such as flood risk assessment maps.
- Future steps require error models based on vegetation