

Persistent Vegetation error in Aerial LiDAR DSMs: Impact on spatial models of inundation risk.

S. Coveney

National Centre for Geocomputation, NUI Maynooth Ireland
Telephone: (00353-1-7086455)
Fax: (00353-1-7086456)
Email: seamus.coveney@nuim.ie

1. Introduction

1.1 Light Detection and Ranging (LiDAR)

LiDAR derived Digital Elevation data are used widely in the Geosciences to model topographically dependent environmental processes. Common applications include modelling coastal inundation vulnerability (Gornitz et al. 2002, Leatherman et al. 2003, Webster et al. 2005) assessment of coastal erosion risk (Woolard & Colby, 2002) and river flood risk (Gomes-Pereira & Wicherson, 1999; Brasington et al. 2000; Cobby et al., 2001).

All of these applications require base data that represent the ground surface accurately. LiDAR generally provides the highest accuracies relative to other Digital Elevation Model (DEM) sources. However, the manner in which LiDAR data are acquired can make it exceptionally difficult to define ground level in areas where ground vegetation prevents laser penetration to the ground surface (ASPRS, 2004). Critically, these conditions often predominate in coastal areas, and can seriously affect the reliability of coastal inundation prediction models. This question is often not fully recognised by data users. The presentation accompanying this abstract will highlight the degree to which vegetation-derived DSM can seriously affect the spatial prediction of coastal inundation risk.

1.2 Removal of vegetation during DSM generation

The classification of first and last laser pulse returns provides a mechanism by which objects close to a LiDAR sensor can be segregated from objects that are more distant from it. This typically corresponds to the segregation of laser-translucent objects that protrude from the surface (trees for example) and the ground surface itself (Lim et al., 2003, Hall et al., 2005; Webster, 2006). The method is effective when laser penetration of vegetation cover is achievable, but it does require the ground surface to be identifiable across a reasonable proportion of the area surveyed.

LiDAR waveform analysis provides a more refined method for the segregation of laser-translucent objects and the ground surface (Nayegandhi et al., 2006, Wagner et al., 2008). However, this method also relies on laser penetration to the ground surface. The identification of a reasonable number (and geographical spread) of ground surface laser return points is often difficult to achieve in naturally vegetated areas, and can be

impossible where dense ground vegetation cover occurs. This issue is not uncommon in natural coastal environments, and is often overlooked when LiDAR DSM data are used to model the spatial extent of coastal inundation risk. This oversight is easy to understand, due to the manner in which DSM elevation error is commonly reported.

1.3 Residual vegetation error in DSM datasets

Typical error ranges quoted by LiDAR data providers fall within the general magnitude range of $\pm 0.2\text{m}$. However, the manner in which LiDAR accuracy standards are framed (FGDC, 1998, ASPRS, 2004, Höhle & Potuckova, 2006) means that quoted elevation errors for natural areas are more likely to be classified relative to ‘compiled to meet’ accuracy statements (ASPRS, 2004) rather than by direct ground validation. Consequently, elevation errors in densely vegetated natural or cropland areas will typically be larger than the level of error that is quoted for an entire DSM dataset. Vegetation-derived elevation errors of the order of 1m have in fact been noted in a number of studies (Paine et al., 2005, Rosso et al., 2006). Errors of this magnitude are sufficient to adversely affect the spatial prediction of short-term flood risk, and the validity of predictions for maximum sea-level rise risk over the next 100 years.

1.4 Principal objectives

The presentation accompanying this abstract will focus on the problem of persistent vegetation error in LiDAR DSM data. The magnitude of this error will be quantified across a range of land-cover types (table 1) using overlapping sections of aerial LiDAR DSMs supplied by three different organisations in three coastal locations along the west coast of Ireland (figure 1). The areas examined support a wide range of natural, semi-natural and anthropogenic land-cover types, providing the basis for the analysis of residual vegetation error across a range of land cover types. The potential impact of these errors on the spatial prediction of rural and urban coastal inundation risk is subsequently discussed.

2. Approach

2.1 Selection of datasets

LiDAR DSM data are used by three separate agencies in Ireland, namely; the national mapping agency, the Office of Public Works, and the INFOMAR (Integrated Mapping for the Sustainable Development of Ireland’s Marine Resources) project. The national mapping agency coverage is incomplete but is growing, the OPW coverage is limited to river courses and limited coastal areas, and the INFOMAR data is a bathymetric LiDAR dataset (with a relatively substantial onshore component) with coverage limited to a few bays on the west coast. Three overlap test areas (figure 1) are used to evaluate DSM error across a range of natural and manmade land cover types (table 1) and to consider the implications of these errors on the reliability for the spatial prediction of coastal inundation risk. Elevation errors are highlighted by external validation with high-accuracy Global Positioning System (GPS) survey data.

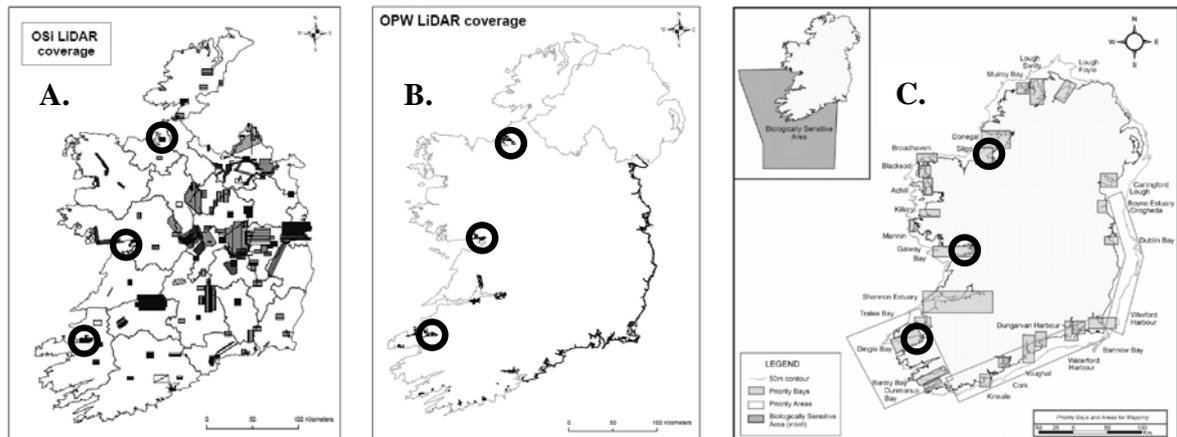


Figure 1. Overlapping sections (highlighted with black circles) that are common to the (a) OSI, (b) OPW & (c) INFOMAR aerial LiDAR coverages.

2.2 External validation data source

Dual frequency (DF) GPS survey is capable of exceptionally high accuracies, and is used widely as a source of external validation data for the assessment of DEM (Lane et al. 2003, Lee et al. 2005, Oksanen & Sarjakoski 2006) and – *to a lesser extent* - for the quantification of DSM error (Huising & Gomes Pereira 1998).

External validation is carried out for this study using DF GPS. High levels of accuracy are achieved with DF GPS due to the sophisticated manner in which it defines location (using two carrier waves) and due to the application of advanced error correction during (or after) data capture. Elevation errors within DF GPS data are corrected using RTK or post-processing correction. RTK (Realtime Kinematic) GPS usually achieves accuracies in the region of 2-4cm for elevation measurements (Ahn et al., 2006; Grejner-Brzezinska, 2005; Mitasova et al., 2004). Even higher accuracies can be achieved by applying post-processing raw DF GPS data against RINEX (Receiver Independent Exchange) correction data (Featherstone & Stewart, 2001).

GPS data are captured for this study using a Trimble R8 DF GPS receiver. Validation data are captured using RTK survey (for densely vegetated areas) and using limited FastStatic survey (and subsequent post-processing) for paved areas. Assessment of the relationship between land cover type and DSM elevation error focuses on five generic land cover classes (table 1).

Generic class	Land cover type
Natural	Open terrain (sand, rock, soil, ploughed fields, lawns, golf courses).
Natural	Brush lands and low trees.
Natural / semi-natural	Tall weeds and crops.
Semi-natural	Forested areas fully covered by trees.
Anthropogenic	Urban areas with dense man-made structures.

Table 1. Land-cover classes evaluated (source ASPRS, 2004).

2.3 External validation approach

External validation is carried out using ArcGIS Geostatistical Analyst. The test land cover types are segregated prior to validation to avoid using a single global kriging model for all land cover types. The external validation process applied includes the following steps for each land cover type:

- Isolation of the spatially autocorrelated trends (Universal kriging)
- Fitting a suitable semi-variogram model for each individual land cover type
- Cross-validation of the optimised interpolations (to isolate interpolation error)
- External validation using DF GPS data

3. Preliminary results and conclusions

Surveying is currently commencing in the three LiDAR overlap areas highlighted in figure 1. These areas are coincident with the hinterlands of Sligo town, Galway city and Tralee town. The methods outlined in section 2 have already been tested and are proving to be effective. RTK elevation accuracies of <4cm and post-processing accuracies of <3cm are being achieved within the GPS validation data, confirming their suitability for the measurement of residual vegetation error. Early test results for tall weeded areas are revealing 95th percentile LiDAR elevation errors of up to 1m, with larger errors occurring within brush lands and low trees. The combined results from the pilot tests highlight real difficulties with the application of aerial LiDAR DSM data for the reliable spatial prediction of inundation risk in densely vegetated coastal areas.

The final results will make it possible to make conclusive statements regarding the suitability of these DSM data for the spatial prediction of coastal inundation risk in the areas studied, and within the wider extents of the individual datasets studied. The general conclusions reached may be of interest to anyone who wishes to consider the potential of LiDAR for the spatial prediction of inundation risk in any coastal location.

4. Acknowledgements

Research presented in this paper was funded by a Strategic Research Cluster grant (07/SRC/I1168) by Science Foundation Ireland under the National Development Plan. The author gratefully acknowledges this support.

7. References

- Ahn, Y.W., LaChapelle, G., Skone, S., Gutman, S. and Sahn, S., 2006, Analysis of GPS RTK performance using external NOAA tropospheric corrections integrated with a multiple reference station approach. *GPS Solutions*, 10, pp. 171-186.
- ASPRS, 2004, ASPRS Guidelines Vertical Accuracy Reporting for LiDAR Data, ASPRS Lidar Committee (PAD), *American Society for Photogrammetry and Remote Sensing*.
- Brasington, J., Rumsby, B.T., and McVey, R.A., 2000, Monitoring and Modelling Morphological Change in a Braided Gravel-Bed River using high-resolution GPS- based survey. *Earth Surface Processes and Landforms* 25, 973-990.

- Cobby, D.M., Mason, D.C., & Davenport, I.J., 2001, Image processing of airborne scanning laser altimetry data for improved river flood modelling. *ISPRS Journal of Photogrammetry and Remote Sensing* 56, 121- 138.
- FGDC (1998), Geospatial Positioning Accuracy Standards Part 3: National Standard for Spatial Data Accuracy, *Federal Geographic Data Committee*, FGDC-STD-007.3-1998.
- Gomes Pereira L.M. & Wicherson R.J. 1999, Suitability of laser data for deriving geographical information: A case study in the context of management of fluvial zones. *ISPRS Journal of Photogrammetry & Remote Sensing* 54, 105–114.
- Gornitz, V., Couch, S. And Hartig, E.K., 2002, Impacts of sea level rise in the New York City metropolitan area. *Global and Planetary Changes* 32, 61- 88.
- Grejner-Brzezinska, D.A., Kashani, I. and Wielgosz, P., 2005, On accuracy and reliability of instantaneous network RTK as a function of network geometry, station separation, and data processing strategy. *GPS Solutions*, 9, pp. 212-225.
- Hall, S.A., Burke, I.C. Box, D.O., Kaufmann, M.R. & Stoker, J.M., 2005, Estimating stand structure using discrete-return lidar: an example from low density, fire prone ponderosa pine forests, *Forest Ecology and Management* 208, 189–209.
- Höhle, J & Potuckova, M. (2006), The EuroSDR Test: Checking and Improving of Digital Terrain Models, in EuroSDR European Spatial Data Research, *Official Publication No. 51, EuroSDR Publications*, Frankfurt, Germany.
- Lane, S.N., Westaway, R.M. & Murray-Hicks, D., 2003, Estimation of erosion and deposition volumes in a large gravel-bed braided river using synoptic remote sensing. *Earth Surface Processes and Landforms* 28, 249-271.
- Leatherman, S.P., Douglas, B.C. & Labrecque, J.L., 2003, Sea Level and Coastal Erosion Require Large-scale Monitoring. *Transactions American Geophysical Union (EOS)* 84, pp 130.
- Lee, I., Chang, H.C. & Ge, L.L., 2005, GPS Campaigns for Validation of InSAR Derived DEMs. *Journal of Global Positioning Systems* 4, 82-87.
- Lim, K., Treitz, P., Wulder, M., St-Onge, B. & Flood, M., 2003, LiDAR remote sensing of forest structure. *Progress in Physical Geography* 27, 1, pp. 88-106.
- Mitasova, H., Drake, T.G., Bernstein, D. and Harmon, R.S., 2004, Quantifying Rapid Changes in Coastal Topography using Modern Mapping Techniques and Geographic Information System. *Environmental and Engineering Geoscience*, 10, 1, pp. 1-11.
- Nayegandhi, A., Brock, J.C., Wright, C.W. & O'Connell, M.J., (2006), Evaluating a small footprint, waveform-resolving LiDAR over coastal vegetation communities, *Photogrammetric Engineering and Remote Sensing*, 72, pp. 1407–1417.
- Oksanen, J. & Sarjakoski, T., 2005, Error propagation analysis of DEM-based drainage basin delineation. *International Journal of Remote Sensing* 26, 3085-3102.
- Paine, J.G., White, W.A., Smyth, R.C., Andrews, J.R. & Gibeaut, J. C. (2005), Combining EM and LiDAR to map coastal wetlands: an example from Mustang Island, Texas. *In Proceedings of Symposium on the Application of Geophysics to Engineering and Environmental Problems*, Environmental and Engineering Geophysical Society, pp. 745-756.
- Rosso, P.H., Ustin, S.L. & Hastings, A. (2006), Use of LiDAR to study changes associated with Spartina invasion in San Francisco Bay marshes. *Remote Sensing of Environment* 100, pp. 295 - 306.
- Wagner, W., Hollaus, M., Briese, C. & Ducic, V. (2008) 3D vegetation mapping using small-footprint full-waveform airborne laser scanners, *International Journal of Remote Sensing* 29, 5, pp. 1433–1452.
- Webster, T.L., 2005, LIDAR Validation Using GIS: A Case Study Comparison between two LIDAR Collection Methods. *Geocarto International* 20, 11-19.
- Webster, T.L., Forbes, D.L., Mackinnon, E. & Roberts, D. (2006), Flood-risk mapping for storm-surge events and sea-level rise using LIDAR for southeast New Brunswick. *Canadian Journal of Remote Sensing* 32, 2, pp. 194-211.
- Woolard, J.W., and Colby, J.D., 2002, Spatial characterization, resolution, and volumetric change of coastal dunes using airborne LIDAR: Cape Hatteras, North Carolina. *Geomorphology* 48, pp. 269-287.