

3D FLOOD-RISK MODELS OF GOVERNMENT INFRASTRUCTURE

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ABSTRACT:

Simulating and predicting floods and its effects on utilities provides powerful visual representation for decision making on when buildings in the flood zone may be safe for people to occupy. Traditional paper maps and digital maps may not give us the possibility to do a 3D visualization in order to study the detailed effect of a flood situation on utilities.

This research explores LiDAR data and the application of 3D modelling in order to provide an analysis of the risk of floods on government buildings and utilities. LiDAR data provides a cheaper, faster and denser multidimensional coverage of features for 3D mapping. LiDAR data was acquired for the city of Fredericton in 2007. This data was processed to generate 3D maps. By employing accurate coordinate conversion and transformations with respect to the geoid, a Digital Terrain Model (DTM) was created. Flood polygons were created for 0.2m intervals in height for the study area. Initial study allows for this interval to be considered, since little difference in flooding behaviour is noticeable below this interval. To further strengthen visual perception, 3D buildings, infrastructure and utilities were modelled for the study area. The DTM and the 3D models of the government buildings, infrastructure and utilities were intersected. The resulting view does not only register a new scenario but also provides a more realistic outlook of the buildings and infrastructure during floods.

Finally, a flood scene was produced for each of the forecasted flood levels for visualization via Web interface.

1. INTRODUCTION

Media reports reveal devastating effects of the latest floods that hit New Brunswick, Canada in summer 2008. This situation stretched the Province's support facilities available to persons affected by natural disasters. The rising water levels forced the closure of the New Brunswick Legislature, and also resulted in temporary closures of the international bridge that links the Province to the United States of America. It also closed the operation of the Gagetown ferry. Fredericton experienced its worst floods in 1973, when the St John River reached the 8.6 meter mark.

The closure of roads, government buildings and the evacuation of people and their possessions during floods are necessary to avoid the loss of life and property. High-rise in water levels could affect electrical, water and telecommunication facilities. It could also affect the sewage system. The washrooms in such a situation cannot be utilizable. The question now is: when can an office be declared risky to occupy? The decisions to close public utilities require a strong justification. Such decisions have social, economic and political impacts on society.

City Managers will require reliable support to justify the decision to close down government infrastructure. This paper proposes the use of 3D flood modelling coupled with an enriched 3D terrain model including infrastructure (electrical power, water, tele-communications) and buildings to make

decisions on when buildings and infrastructure are declared unsafe to use.

2. PREVIOUS RESEARCH

Since ancient times, humans have developed means to monitor flood levels and to some extent, predict the rate of flood rise. People in medieval times marked animals and push them down the river to see how deep the river was. According to the director of EMO, Ernest McGillivray, his grand-father had a self calibrated stick that he pushes down the river to compare and forecast river flood levels.

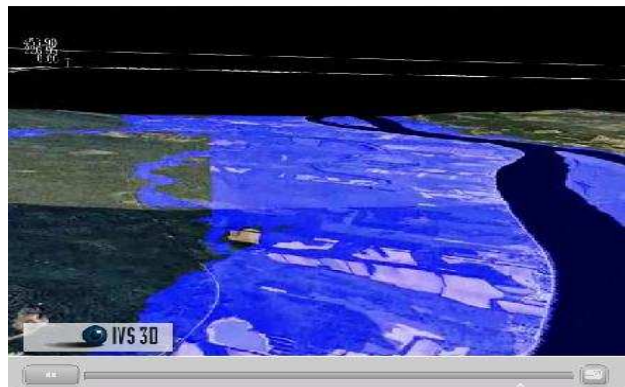


Figure 1. 3D visualization of 1973 flood in Fredericton
 Today, more innovative ways have been developed to study flooding. These include remote sensing techniques such as satellite technology, aerial photogrammetry and LiDAR. Such technologies are combined with computer terrain modelling tools to create scenarios, as in the case of Geographic Information Systems (GIS), for analysis.

The New Brunswick Emergency Measures Organization (EMO) with contribution from the University of New Brunswick, Canada developed flood model (assessable from <http://www.gnb.ca/public/Riverwatch/index-e.asp>) for the area of New Brunswick as shown in Figures 1 (above) and 2 (below).

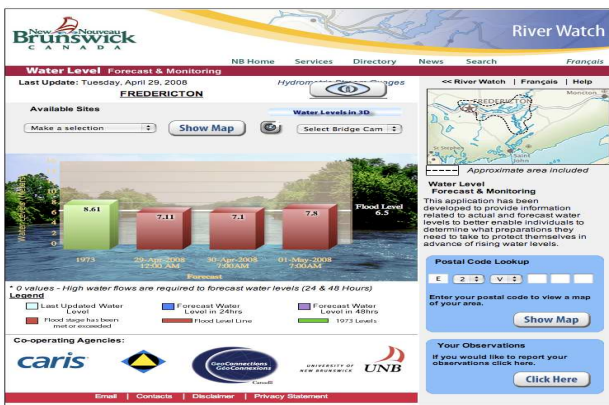


Figure 2. Website for flood warning

However, the current visualization method does not adequately represent the different perspectives of the affected infrastructure. It can be seen that the building models are represented by polygons only and the 3D view of the terrain is nonexistent.

As a result, the public may not have adequate technical or analytical know-how to analyze the polygons. Therefore, they may not find the website very useful.

Alternatively, if the floods and infrastructure were modelled in 3D, the multidimensional visualizations of the floodplain and its effect on utilities can be discussed in more comprehensive terms, among engineers, government executives and the public. To showcase such a possibility, buildings of downtown Fredericton were extruded in 3D and modelled in detail. Figure 3 below shows the processing steps in arriving at the 3D models.

Enriching the 3D models with the utilities and DTM, through the process of modelling different water rise situations, gives different scenarios of flooding, which can be used for analysis. Based on this analysis, the question of what flood level could render utilities unavailable and make the government infrastructure risky to occupy can then be answered.

3. DATA COLLECTION AND PROCESSING

Light Detection and Ranging (LiDAR) is a data collection technique that uses a beam of light to make range-resolved

remote measurement of features within the path of a shot beam of light. The New Brunswick government, through the Department of the Environment and Emergency Measures Organization (EMO), collected LiDAR data from an estimated area of 1880 km², specifically around Fredericton and its surrounding area in 2007.

The intended use of data was to monitor flooding in the area.

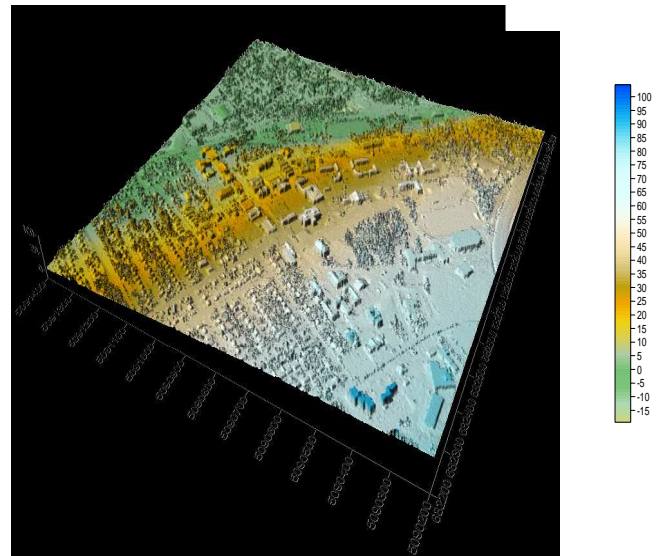


Figure 3. Downtown Fredericton LiDAR data

Figure 3 shows a sample of the 2007 LiDAR data for downtown Fredericton. To extract information from LiDAR data, users will consider the purpose for which the point cloud data is intended to be used for.

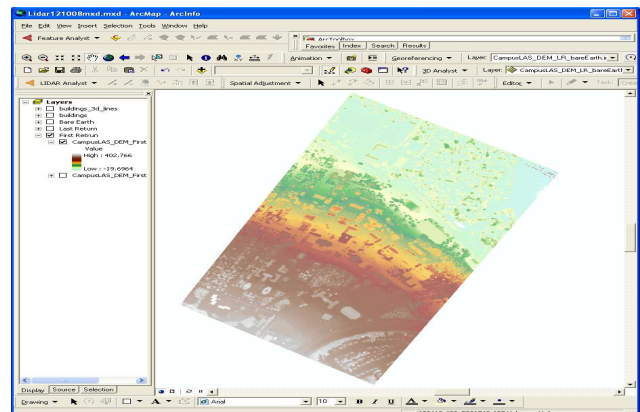


Figure 4. LiDAR data. First Return, part of Fredericton, NB

For the case of this research, accurate planimetry and geoidal height coordinates were sought for the 3D flood modelling. To achieve this feat, the data was processed as follows:

1. Find LiDAR strip for the project area and extract returns of LiDAR beams (Figure 3)
2. Extract Bare Earth i.e. ground DEM of the area of interest (Figure 4)
3. Extract Building Footprints from the returns of the LiDAR data (Figure 5)

- Edit Footprints by comparing with Cadastral data. The cadastral map does not contain height values and is not recent. The LiDAR data contains recent data of the project area, taken during the May 2007 floods. However, based on different defined parameters, the algorithm used to extract the building footprints produces varying results. The best fit is as shown in Figure 6. The results were compared to the digital cadastral map of the study area. Further editing was necessary to correct the planimetry errors from the building footprints obtained from extraction process.
- Proceed with other modelling tasks – adding attributes and other data necessary for analysis (Figure 7). The buildings and utilities, including electrical power, water and telecommunications are all modelled in 3D. Their defining attributes are included in the modelling. The output is intersected with the terrain model produced previously.

LiDAR data is usually collected with reference to ground controlled points using GPS methods. Subsequently, the output coordinates are ellipsoidal. To obtain accurate flood modelling and terrain detail the data was projected to the geographic coordinate system and finally transformed to a Geoidal model, HT2_0, referring to New Brunswick, Canada.

To specifically have a detail for the floods, Geoidal heights above 20m were filtered out, since we did not expect flood levels to go above the height.

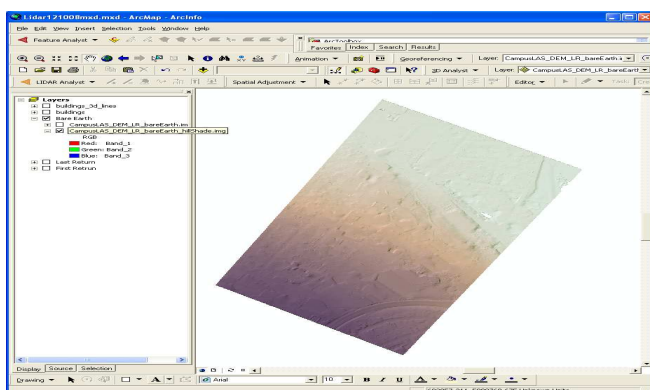


Figure 5. Extracted Bare Earth from LiDAR data

The Geoidal coordinates are input to GIS system to model a Triangular Irregular Network (TIN).

Layers containing flood profiles and polygons were created at 0.5m intervals. 3D buildings and utilities were also modelled. All the models and DTM were then combined under the same coordinate system. To form a decision system, different flood scenarios were modelled for different flood levels.

Existing utilities and buildings in downtown Fredericton were modelled in 3D and geo-referenced to the geoidal model HT2_0 of New Brunswick, Canada. Such technologies abound in commercial and free software available online.

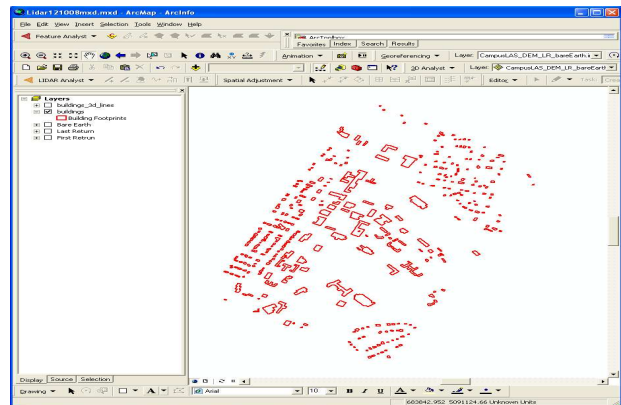


Figure 6. Extracted Building Footprints from LiDAR data

One such tool that was exploited for use in this project was Google SketchUp. Although limited in its interaction with spatial features, Google SketchUp provided the tools needed to model the buildings and surrounding utilities for the test area.

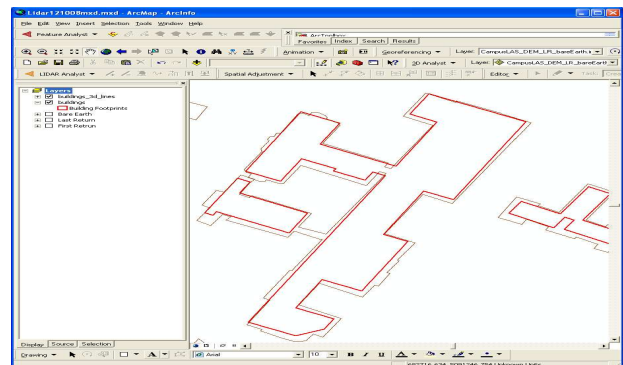


Figure 7. Extracted footprints compared with Cadastral footprints

As part of future work, advanced tools in the CityGML family could be used for more interactive results.

4. PROCESSING STEPS - 3D FLOOD MODEL WORKFLOW

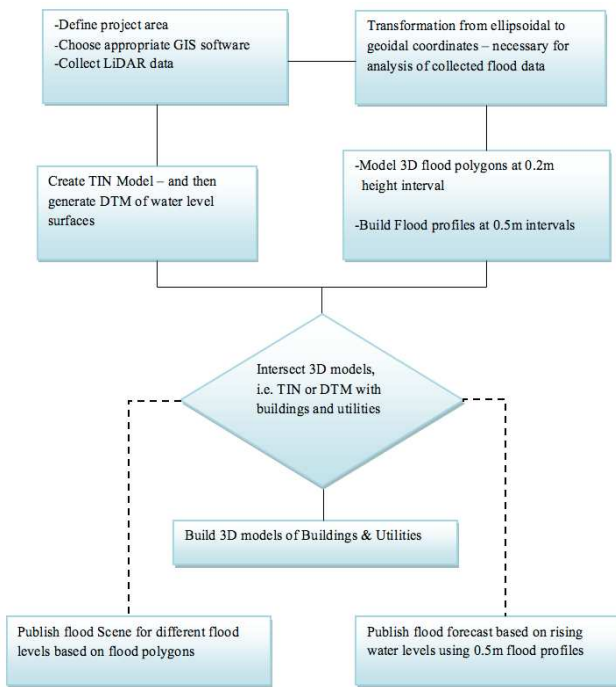


Figure 8. Processing steps for 3D Flood Models

5. RESULTING 3D FLOOD MODELS

Using different extrusion heights to represent different flood scenes, it is possible to simulate different flood events (see Figures 8, 9 10 and 11). The pictorial scene, representation of the building, floods and its effects can be clearly visualized and analyzed.

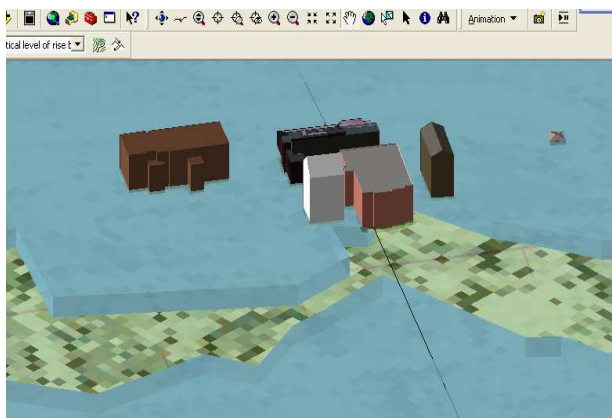


Figure 9. 3D models of selected buildings in Fredericton with infrastructure

Figure 9 shows a 3D view of the flooding in May 2008. The 3D buildings and utilities can be seen consecutively as a result of applying transparency to the layers. In Figure 10, the utility lines are embedded in the 3D models. A rise in water levels

above 1.25m on the utilities will result in electrical power along those routes to be cut off.

Figure 12 shows a visual model of the flooding affecting new built Public Washroom at the Military Guard Square, in Fredericton, Canada. At this level of water rise, the electrical boxes would be flooded. It is visible from the model that during flooding, surrounding areas including the Public Library, the Armory and the Military depots will be out of use and certainly inaccessible. The Triangular Irregular Network (TIN), in Figure 5, shows the natural critical point at which water will begin to flow in the direction of the downward slope. When ground water rises up to this level, waste matter from the sewage system will flow in the upwards, under pressure from rising water from the river.

The washroom facility may not be used under these circumstances.

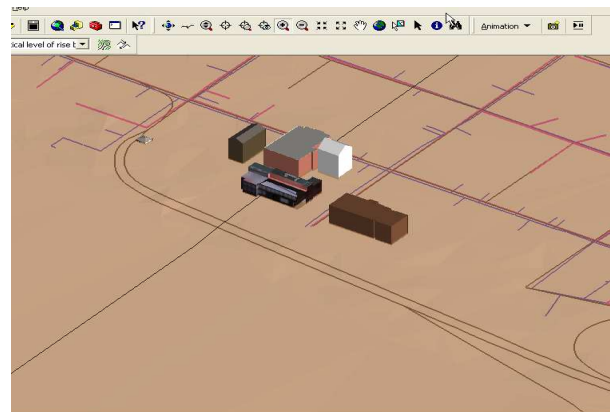


Figure 10. 3D models with transparent utilities

6. RISK ANALYSIS OF PROJECT AREA

Further analyzes of the TIN, showed that many part of Fredericton may have been build on a watery bed. The TIN shows that if ground water rises to its natural terrain height across the city, several homes, offices and utilities will be flooded. The situation is worst in the downtown area, which has the lowest heights. The TIN can also be used to create a DTM to show the natural flow of the water. Priority emergency decisions can be made out of this situation to close the downtown offices and infrastructure first, at the start of rising water levels.

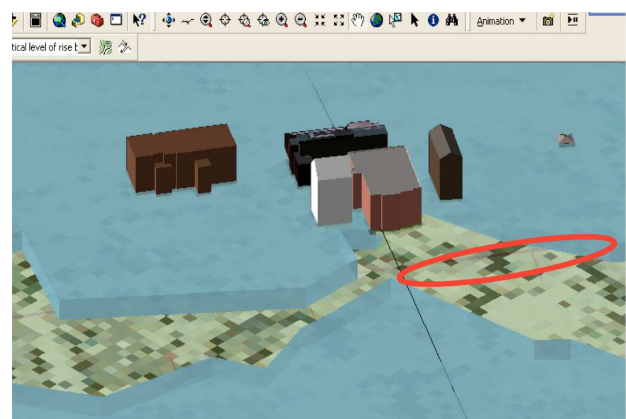


Figure 11. 3D model of utilities and TIN of ground points
Based on the embedding of flood profiles with existing utilities and infrastructure, it can be shown when it is risky to occupy or use the structure (see figures 12, 13 and 14).

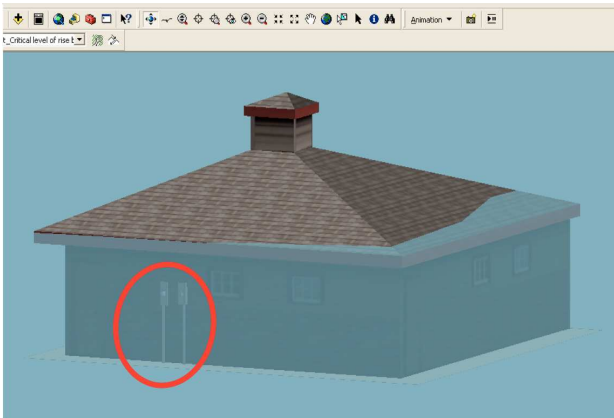


Figure 12. 3D Washroom, with power box, in 1973 simulated flood

Daily automatic generation of flood polygons from the data provided by the existing online River Watch application (see <http://www.gnb.ca/public/Riverwatch/index-e.asp>) can produce an animated 3D video, which can be put on the website to provide updated 3D flood forecast to residents.

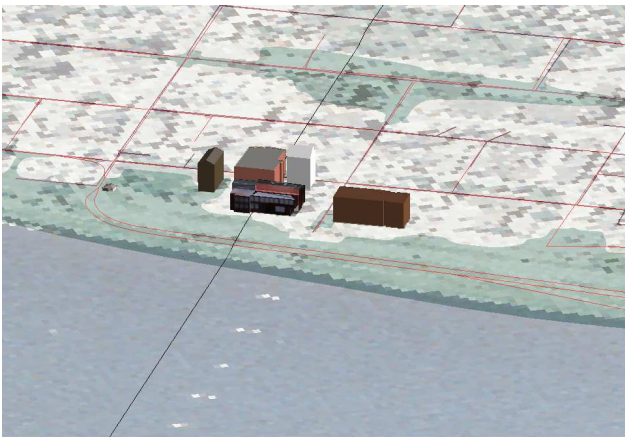


Figure 13. 3D models of selected buildings in Fredericton

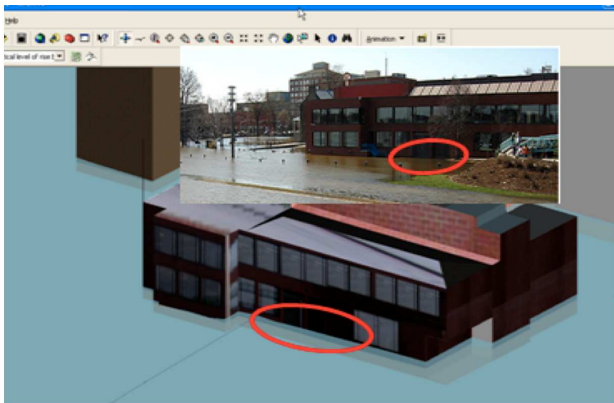


Figure 14. 3D Model compared with Photograph taken during the flood in 2008

7. CONCLUSION

It can clearly be seen from the comparison of the model and the picture captured during the 2008 flood, that the levels of flooding are visually the same. The water just touches the back gates of the Fredericton Public library on both shots. The display accuracy of the flood model is dependent on the vertical accuracy of the geoidal heights, obtained from the LiDAR data. This stood at a best of 15cm, at 95% confidence level.

The 3D GIS application provides a better platform for visualizing flood situations than previously done in 2D maps. All parts of a building could be studied in detail in the event of flooding. This provides a better tool for analyzing and preparing for emergency measures. It also presents a near to reality situation that can easily be understood. Ministers and Heads of Department who may not be familiar with GIS analytical tools of Query Languages can still understand technical discussions on flood analysis through the use of the pictorial nature of models, which are close to reality. It is possible to simulate flooding polygons at different heights to produce different flood scenarios.

Simulation can also be used to trace and analyze underground utilities by making all top layers above them transparent. Flood scene animations can be published to website for public access.

8. BIBLIOGRAPHY

Alharthy, A. and Bethel, J., 2002. Heuristic filtering and 3D feature extraction from LIDAR data. *International Archives Of Photogrammetry Remote Sensing and Spatial Information Sciences* 34(3/A):29-34.

Argal, P.S. and Siga, R. J., 2008. LiDAR, pps 869-900.

Chopra, A., 2007. *Google SketchUp for Dummies*, John Wiley and Sons Ltd, Hoboken, US, pp.3-398.

CTV, 2008. News Headlines, Accessed on May 1, 2008. <http://www.ctv.ca>.

Elaksher, A. F. and Bethel J. S., 2002. Building extraction using lidar data. *ASPRS-ACSM annual conference and FIG XXII congress*. 22 p.

Elaksher, A.F and J. S Bethel., 2002. Reconstructing 3d buildings from lidar data. *International Archives Of Photogrammetry Remote Sensing and Spatial Information Sciences* 34(3/A):102-7.

EMO Fredericton, 2008. Flood Warning website, Accessed December 2008 from: <http://www.gnb.ca/public/Riverwatch/index-e.asp>.

EMO Fredericton, 2008. Online Portal, Accessed from: <http://www.gnb.ca/emo-omu/index.asp>.

ESRI, 2008. Using 3D Analyst, Arc Catalog, ArcMAP and ArcScene, Users manual, pp. 4-208.

Google Earth, 2008. 3D interactive web browser, Accessed on from <http://earth.google.com>

- Google, 2008. Google SketchUp online tutorials, Accessed from <http://sketchup.google.com>
- Hodgson, M.E. and Bresnahan, P., 2004. Accuracy of airborne lidar-derived elevation: Empirical assessment and error budget. *Photogramm Eng Remote Sensing* 70(3):331-40.
- Karnieli, A, Gilad. U., Ponzet, M., Svoray, T., Mirzadinov, R., Fedorina. O., 2008. Assessing land-cover change and degradation in the central asian deserts using satellite image processing and geostatistical methods. *Journal of Arid Environments* 72(11):2093-105.
- Kraus, K. and Pfeifer, N., 2001. Advanced DTM generation from LIDAR data. *International Archives Of Photogrammetry Remote Sensing And Spatial Information Sciences* 34(3/W4):23-30.
- Lindsay, J. and Creed, I., 2005. Sensitivity of digital landscapes to artifact depressions in remotely-sensed DEMs. *PE&RS, Photogrammetric Engineering & Remote Sensing* 71(9):1029-36.
- Lucas, K.L. and Carter, G.A., 2008. The use of hyperspectral remote sensing to assess vascular plant species richness on horn island, mississippi. *Remote Sensing of Environment* 112(10):3908-15.
- MacMillan, R., Martin ,T., Earle, T., McNabb, D., 2003. Automated analysis and classification of landforms using high-resolution digital elevation data: Applications and issues. *Canadian Journal of Remote Sensing* 29(5):592-606.
- MacMillan, R., Martin, T, Earle, T., McNabb, D., 2003. Automated analysis and classification of landforms using high-resolution digital elevation data: Applications and issues. *Canadian Journal of Remote Sensing* 29(5):592-606.
- Marks, K. and Bates, P., 2000. Integration of high-resolution topographic data with floodplain flow models. *Hydrol Process* 14(11):2109-22.
- Popescu, S.C., Wynne, R.H., Nelson, R.F., 2002. Estimating plot-level tree heights with lidar: Local filtering with a canopy-height based variable window size. *Comput Electron Agric* 37(1-3):71-95.
- Priestnall, G., Jaafar, J., Duncan, A., 2000. Extracting urban features from LiDAR digital surface models. *Comput, Environ Urban Syst* 24(2):65-78.
- Service New Brunswick, 2008. Geographic Data and maps, Accessed from http://www.snb.ca/gdam-igec/e/2900e_1.asp.
- Shekhar S and Xiong H., 2008. *Encyclopedia of GIS*.
- Sohn, G. and Dowman, I. 2003. Building extraction using lidar DEMS and IKONOS images. *Proceedings of the ISPRS working group III/3 workshop*.
- Sohn, G. and Dowman, I. 2003. Building extraction using lidar DEMS and IKONOS images. *Proceedings of the ISPRS working group III/3 workshop*.
- Times Colonist, 2008. Headline: Rising flood threaten New Brunswick Legislature, May 1, 2008 Edition.
- Wang, F. and Xu, Y.J., 2008. Development and application of a remote sensing-based salinity prediction model for a large estuarine lake in the US gulf of mexico coast. *Journal of Hydrology* 360(1-4):184-94.
- White, S.A. and Wang, Y., 2003. Utilizing DEMs derived from LIDAR data to analyze morphologic change in the North Carolina coastline. *Remote Sens Environ* 85(1):39-47.
- Zhang, K., Chen, S.C., Whitman, D., Shyu, M.L., Yan, J., Zhang, C., 2003. A progressive morphological filter for removing nonground measurements from airborne LIDAR data. *IEEE Trans Geosci Remote Sens* 41(4 Part 1):872-82.