Surface moisture and vegetation influences on lidar intensity data in an agricultural watershed

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Abstract. Airborne laser scanning (ALS) provides more information about scanned surfaces than just elevation. Backscattered laser pulses are visually influenced by surficial reflectance properties of the terrain being mapped, such as the presence of water. In this study the impact of soil moisture and vegetation cover on laser pulse intensity was explored. The study area, an agricultural watershed in the Annapolis Valley of Nova Scotia, was scanned several times over an 18 month period using comparable survey settings. The intensity data for all acquisitions were normalized to account for range bias effects and scaled to an 8-bit range. Tests included comparing raw intensity data with range-normalized intensity data, comparing daily data to assess temporal changes in intensity, and correlating intensity data to spatially coincident soil surface volumetric moisture content measurements. The range-normalized intensity comparison revealed that while normalization removed the majority of systematic bias in the intensity some artefacts remained in overlapping scan areas. Temporal intensity variations were observed in agricultural fields, and while some of this change was attributable to changes in the surface wetness, crop cover and the confounding influence this had on laser pulse attenuation diminished the correlation. Ground sampled volumetric moisture content and intensity were not strongly correlated; however, it was shown that the two methods were measuring similar trends over some of the areas studied. This study concludes that while soil moisture conditions can influence laser return intensity over bare earth, vegetated ground cover has a greater overall control on the signal intensity.

Résumé. Les systèmes laser à balayage aéroportés (SLA) fournissent plus d’information sur les surfaces imagées que les données d’élévation seules. Les impulsions laser rétrodiffusées sont visuellement influencées par les propriétés de la réflectance de surface du terrain sous observation comme la présence d’eau. Dans cette étude, on étudie l’impact de l’humidité du sol et du couvert sur l’intensité des impulsions laser. La zone d’étude, un bassin versant agricole dans la vallée de l’Annapolis en Nouvelle-Écosse, a fait l’objet de plusieurs relevés durant une période de 18 mois en utilisant des paramètres de relevés comparables. Les données d’intensité pour toutes ces acquisitions ont été normalisées pour tenir compte des effets de biais lié au temps de parcours et mises à l’échelle de 8 bits. Les tests incluaient la comparaison des données d’intensité brutes par rapport aux données d’intensité normalisées pour le temps de parcours, la comparaison des données journalières pour évaluer les changements temporels dans l’intensité et la corrélation des données d’intensité par rapport aux mesures de teneur d’humidité volumétrique de surface du sol spatialement co-localisées. La comparaison des valeurs d’intensité normalisées des temps de parcours a révélé que, bien que la normalisation ait éliminé la majorité du biais systématique dans l’intensité, il restait certains artéfacts dans les zones de balayage en superposition. Des variations temporelles dans l’intensité ont été observées dans les champs agricoles et, bien qu’une partie de ces changements étaient attribuables à des changements dans l’humidité de surface, le couvert et l’influence de la confusion ainsi engendrée sur l’atténuation des impulsions laser entraînaient une diminution de la corrélation. Les teneurs d’humidité volumétrique acquises au sol et l’intensité n’étaient pas fortement corrélées; toutefois, il a été démontré que les deux méthodes mesuraient des tendances similaires au-dessus de certaines des zones étudiées. On conclut que, bien que les conditions d’humidité puissent influencer l’intensité des retours laser au-dessus des sols nus, le couvert a une plus grande influence en général sur l’intensité du signal.
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Introduction

Airborne laser scanning (ALS) is a widely adopted method for producing high-quality, remotely-sensed elevation data. ALS has been proven as a powerful tool for many surface modeling studies in a variety of geophysical disciplines (Lloyd, 2002; Wack, 2002; Macmillan, 2003; Hollaus et al., 2005; Boyd, 2007). Compared with the amount of research on lidar’s surface mapping potential, comparatively little research has focused on the utility of laser pulse intensity data and only recently has this topic started to receive serious attention (Coren and Sterzai, 2006; Kassalainen et al., 2005, 2007; Hopkinson, 2007; Mazzarini et al., 2007; Antonarakis et al., 2008; Wu et al., 2009).

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Many ALS systems utilize a light pulse emitted in the near-infrared wavelength of the light spectrum (e.g., 1.064 μm for the Optech ALTM). It is known that because of the absorption properties of water at infrared wavelengths, moisture can affect the reflectance property of soil (Weidong et al., 2002; Whiting et al., 2004; Kaleita et al., 2005). Hopkinson (2007) suggested that relative intensity values could be corrected without the need for an atmospheric attenuation coefficient, surface roughness value, and true angle of incidence value, as the controlling factor in laser pulse return (LPR) intensity will be the amount of energy emitted. Therefore it is assumed that relative intensity fluctuations of the LPR (assuming all else being equal) can be attributed to the spectral reflectance properties of the surface that is being scanned. It follows that backscattered near-infrared light pulses could possibly be used to identify and map areas of surface saturation and potentially moisture content at the ground surface. For the purpose of this research paper the term "surface saturation" is defined as the measureable amount of volumetric moisture at the surface level.

In previous studies gamma radiation (Carroll, 1981), thermal infrared (Price, 1982), and microwave radiation (Jackson et al., 1999) have been used to estimate soil moisture. One of the key benefits of microwave radiation was its ability to penetrate the surface and vegetation at longer wavelengths. This functionality is limited because of resolution; as wavelength increases, penetration through solid objects (i.e., ground and vegetation) increases, but footprint size also increases thus resolution decreases (Kaleita et al., 2005). Remote sensing systems that utilize laser optics and operate in the near-infrared of the spectrum are more spatially accurate than microwave sensors and possess the ability to scan the surface beneath the foliage cover but cannot penetrate the soil surface.

The question remains, to what extent does surface saturation and ground cover alter the intensity properties of ALS data? This case study investigates the influence of soil surface saturation and vegetation cover on reflected intensity data from agricultural fields.

Methodology

Study area and subplot description

The study area for this project was the Thomas Brook Watershed (TBW) located north of the town of Berwick in the Annapolis Valley of Nova Scotia. The TBW study area, a small subwatershed of the Cornwallis River, was chosen based on the overall size of the watershed; it is small enough to collect a diverse set of ground samples and to be accessible for both aerial surveys and ground sampling. The predominant soils in the TBW are glacial till deposits. They range from poorly drained, unsuitable crop land soils to well drained, good crop land soils (Cann, 1965). The majority of the landscape features in the watershed are rural anthropogenic. The Thomas Brook passes through many culverts and artificially straightened sections before reaching the Cornwallis River outflow. The area around the brook is heavily agricultural in the lower reaches with small areas of natural forest and vegetation remaining on the face of the North Mountain. Within the TBW, agricultural land makes up 60% of the overall land use leaving only 40% for nonagriculture land use such as housing, roads, and natural vegetation. The watershed is characterized by two highly differing slope sections. The upper section of the watershed flows down from the North Mountain and has an average slope of 10.5% with an elevation range of 192 m and a mean elevation of 120 m ASL. The lower section of the watershed flows across the valley floor at a much lower gradient and has an average of slope of 3.5% with an elevation change of 34 m and a mean elevation of 20 m ASL.

The criteria for selecting subplots for the field research were different land cover types (i.e., crop type for the 2006 growing season), geographic location in the watershed, topographic condition, and accessibility. Three fields were selected for study because during a typical data collection day it would take the full day to visit the three locations. Each field had a different crop type, corn, barley, and forage (i.e., hay). The vegetation in the fields varied from low grass and bare earth in the spring to knee-high barley, hay, and 2 m tall corn rows in the late summer (**Figure 1**).

The barley field was selected based on its location in the watershed, its ease of access and its short vegetation cover. During the early spring this field's ground cover is low grass, while during the late summer the field is covered with low-growing barley. The corn field was chosen as a study area because it was centrally located in the watershed as it was just off of a main road for easy access. This field was also unique because it was a tilled field with low-level, evenly distributed vegetation cover in the spring and approximately 2 m tall corn rows in the fall. The hay field was chosen for its ease of access, its location in relation to the other subplots, its vegetation characteristics, and it was at the southern most point of the watershed. The hay field had low-level (5–10 cm) vegetation cover in the spring and short hay cover (10–15 cm) in the fall.

Lidar data collection and system settings

The Applied Geomatics Research Group (AGRG) flew lidar missions over the TBW in the Annapolis Valley, Nova Scotia, in 2006 and 2007. The ALTM system settings, the flight operations, and the data processing methods were kept constant so that any observed differences in intensity would be due to differences in ground surface reflectance rather than hardware or methodology. The first dataset, collected on 29 March 2006 (Julian day 088), was used to generate a digital elevation model (DEM). In a temperate climate, collecting lidar data in the spring produces high-quality DEMs because the leaves on the trees are not yet fully

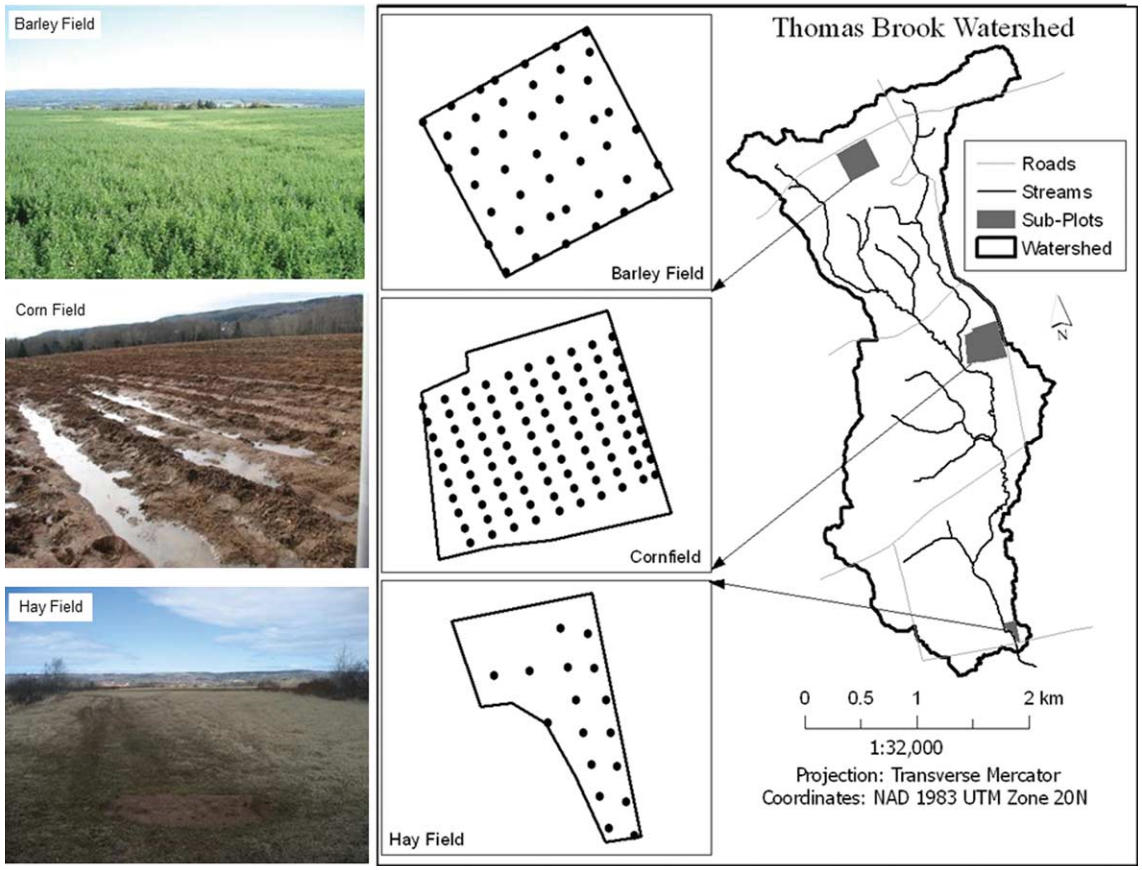

Figure 1. Thomas Brook Watershed subplots. The barley field contained 44 volumetric moisture content (VMC) field survey points. The corn field contained 101 VMC data points. The hay field contained 17 data points.

developed allowing more of the surface under the forest canopy to be visible to the laser. Also, ground foliage is pressed down from winter snow-pack, which means laser pulses have a higher probability of being closer to the actual bare earth surface. The survey consisted of eight flight lines with a 50% sidelap. The Optech ALTM 3100 sensor was set to a pulse repetition rate of 50 kHz, a scan frequency of 30 Hz, and a scan angle of $+/-18^\circ$. The survey was flown using a Piper Navajo aircraft at velocity of 120 knots at an approximate altitude of 1300 m above ground level. The settings and timing were chosen to be optimal for DEM generation.

The remaining datasets from 2006 were collected in August (Julian days 221 and 222), at times of aircraft availability using a three flightline configuration with the same lidar unit and using the same settings. In 2007 more data were collected over the study area. The first dataset was collected in March (Julian day 090) with two more in September and October (Julian days 273 and 274). The data from September and October were also collected using the same ALTM 3100 model but because of servicing to the AGRG unit it was a different sensor. All of the 2006 and 2007 experimental surveys were collected with a pulse repetition rate of 70 kHz, a scan frequency of 39 Hz, and a scan angle of $+/-24^\circ$. The altitude of these surveys was approximately 900 m above ground level at a velocity of approximately 120 knots.

Intensity data normalization

The lidar data were processed twice using Optech's (Toronto, Ontario) REALM software; once without the range correction (non-normalized) option applied and once with the range correction (normalized) applied. Raw, uncorrected, intensity data displayed a clear scan angle and range bias that was evident in the form of weaker returns at the outer edge of scans and at lower elevations in the valley. While flying altitude remained uniform, the ground surface elevation varied by almost 210 m. The intensity of each return was affected by the dynamic range between the sensor and the target. The range correction scaled intensity values to an optimal range (typically the average range for the data collection) to account for the influence of range variation due to changing terrain height and scan angle. The normalized datasets demonstrated a uniform range of intensity values throughout the image, whereas the non-normalized data had greater variation in brightness (**Figure 2**). The normalized image showed more detail and definition and consequently a greater amount of information could be extracted from normalized data.

After the data were normalized, the intensity values were scaled to an 8-bit (1–255) digital number scale to ensure that each dataset was comparable for a change detection analysis. The method for scaling the intensity was a 95th percentile upper and lower bound cutoff. By removing the upper and lower extremes of the histograms of each dataset the means are effectively shifted. While there is the potential to cause some of the subtle intensity variations to be masked out during this scaling procedure this method also removed outlying data that could have been caused by multipath returns or specular reflection off water bodies.

Data filtering

The ALTM 3100 can record multiple returns. Each time the pulse encounters an object a portion of the energy is reflected back to the sensor and is recorded as an echo. The system will record up to four echoes per pulse; the first, the last, and two in-between. This functionality makes the data unique to other remote sensing technologies. Where multiple echoes were returned, the outgoing pulse had been split by encountering more than one object in its path and, consequently, the associated ground-level data point could not be considered to represent true surficial reflectance conditions. The data was filtered so that all multiple echoes were removed.

To ensure that only ground-reflected, single-echo data points were considered for analysis, filtering for data points that were within 1 m vertically of the DEM data collected in March 2006 was performed. Single-echo returns will occur in fields, on roads, buildings, canopies, etc., which means that all of the ‘‘nonground’’ single returns had to be filtered out. The results of the filtering are shown in **Figure 2**. The boxed areas in the figure represent fields where good coverage of single-echo data points was retained. The areas adjacent to the boxed areas have sparse data coverage indicating that the area contained large amounts of multiple returned echoes, or the area contained a large amount of nonground data points (forest or vegetation) and was therefore removed from the analysis.

Data collected off-nadir was subjected to longer travel time to the target and back to the sensor, which led to increased expansion of the laser pulse and therefore a lower peak intensity return. We used overlapping flightline data mosaiced into a single dataset and compared the change in intensity from 2 days of data collection. We then tested single flightline data to mitigate issues with angle of incidence, scan angle signal decay, and footprint size.

Temporal change detection analysis

Two tests were performed on intensity data: one using multiple flightlines of data for a particular dataset and the other using only one flightline of data collected at near nadir to the area of interest. The change in intensity was calculated using the first day of data collection as a base grid, with each subsequent day of data subtracted from it (**Figure 3**). This procedure created a time series that allowed the change in data to be viewed day by day. All else being equal, the change in the intensity between collection dates would reveal patterns of reflectance change on the surface.

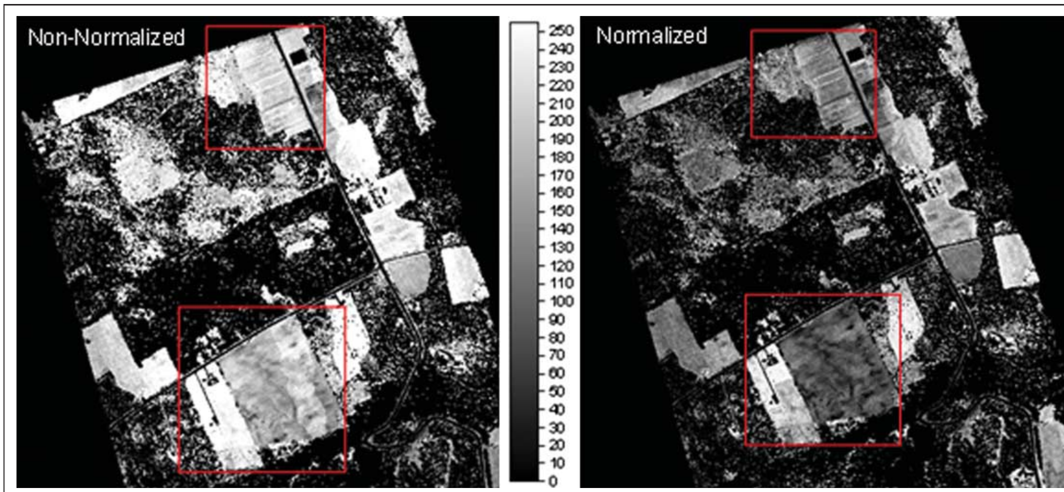

Figure 2. The image displays non-normalized intensity data versus normalized intensity data (8-bit grayscale of arbitrary units). The image on the left shows the intensity of the raw data. The image on the right shows the same data after range and angle of incidence normalization. The boxed areas display areas of good data coverage where the normalization effect can be observed in great detail. The visible area is approximately 1 km wide.

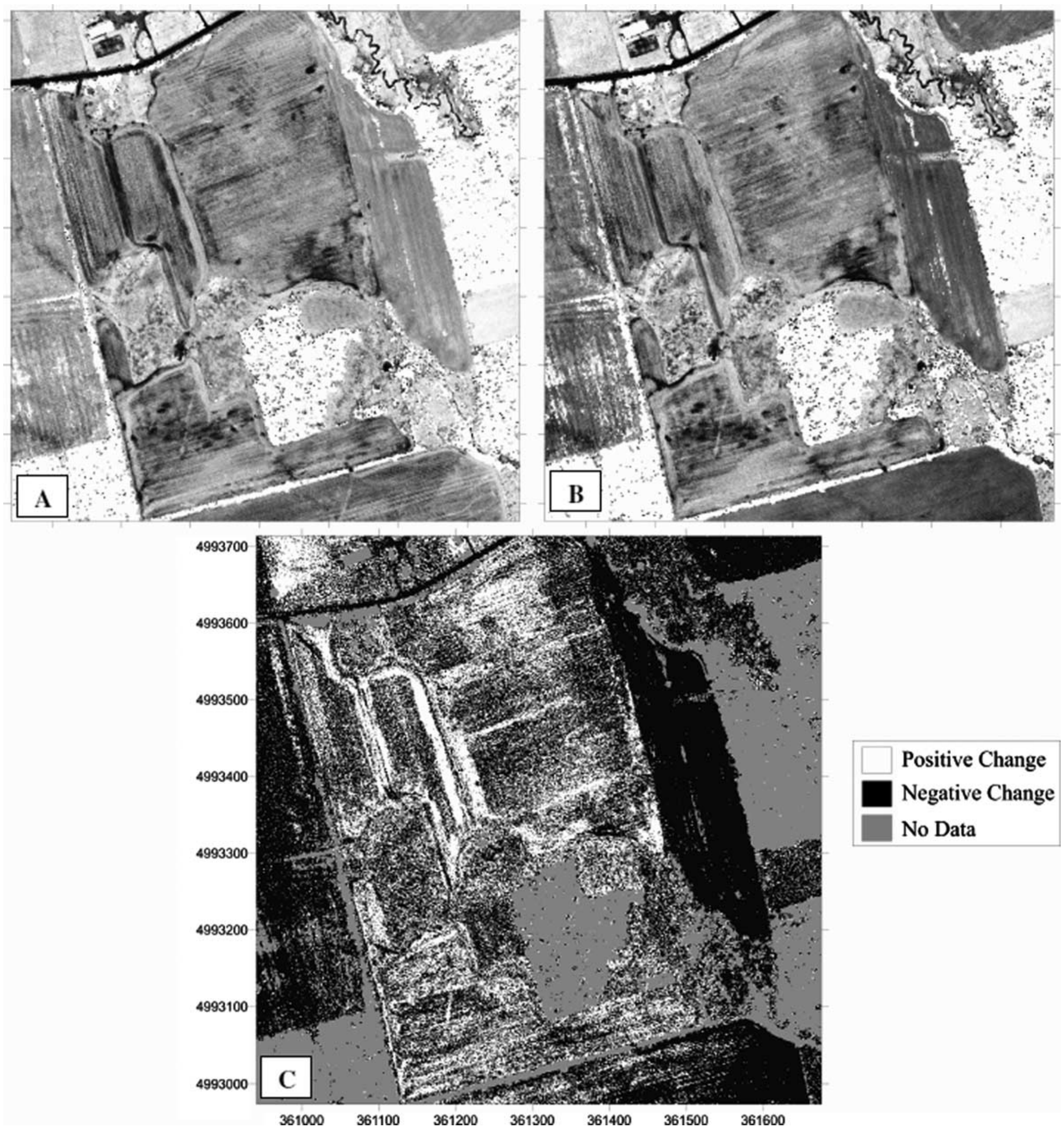

Figure 3. Intensity image change detection example. Darker shades represent lower intensity returns. B is subtracted from A to generate the change image C (A − B = C). C has been coloured so that positive change in the data is white (i.e., higher intensity in B than A). The grey sections are areas of "no data".

Volumetric moisture content data collection

To identify whether wet surface conditions directly affected laser pulse intensity we tested the hypothesis that high values of volumetric moisture content (VMC) would be associated with low intensity values.

Surface saturation was measured simultaneously to two of the lidar datasets in the spring and fall of 2007 (31 March (Julian day 090) and 30 September (Julian day 273)). Only one flightline, collected at nadir to the study area (to mitigate the angle of incidence and footprint size issues), was examined from each collection day. The VMC soil surface saturation data were collected using a Campbell Scientific Hydrosense 10 cm Time Domain Reflectometry (TDR) probe and tracked via GPS (RTK Leica 500 series) on 28–30 March 2007 (Julian days 087, 088, 089) and 30 September 2007 (Julian day 273). The coincident lidar data within a 1 m radius of each GPS point were then isolated. The VMC data were collected throughout three fields within the study area. A total of 162 data points were collected, 44, 101, and 17 in the barley, corn and hay fields, respectively. The same GPS points were used on both data collection dates.

Two tests were conducted: a regression analysis and a paired t test. The rational for using two tests was that if the relationship was systematic we would see the results in the regression test; however, if the relationship was weak it might come out only in comparison of high and low values. If both tests failed then the conclusion would be that there was no influence of surface saturation on laser pulse intensity.

Data classification technique

The VMC datasets were stratified into three categories: low moisture content (LMC) contained all intensity values that corresponded to VMC values less than 20%, moderate moisture content (MMC) contained all intensity values that corresponded to VMC values between 20% and 30%, and high moisture content (HMC) contained all intensity values that corresponded to VMC values greater than 30%. The class-break values were based on stratifying all observed data into approximately equal area classes. The mean intensity values associated with the data points in each of the three VMC classes were extracted. By assuming that the upper boundary of wetness was saturation level (i.e., VMC is approximately 50%) and then creating break values of $< 20\%$ for LMC and $> 30\%$ for HMC, effectively created upper and lower boundaries masking out the midrange moisture levels.

Paired *t* tests were performed on mean lidar intensity values that corresponded with LMC and HMC observations. The MMC data points were excluded because the intention of the test was to identify the difference between the reflectivity of a wet soil versus a dry soil. If the mean intensity of the HMC was consistently lower than the mean intensity of the LMC this would indicate that the data were behaving in accordance with the hypothesis. The *t* tests were performed on the three subplot areas for each collection day. Two of the subplot fields were vegetated (barley and hay fields) while the third was bare soil (corn field).

Results

Temporal change detection analysis

In **Figure 4** the change detection is displayed using the multiple flightline dataset from August 2006. The climate data indicated a period of surface drying between the two collection days. The change image (**Figure 4C**) revealed that there was generally an increase in intensity between the two data collection periods. All else being equal, this suggests that the surface reflectance had increased between Julian days 221 and 222, which would indicate that the surface was drying out and would be consistent with the weather data that showed a storm event on day 219 followed by warm, dry weather (the precipitation that occurred on day 222 was post-data collection).

In **Figure 4A** there was a distinct contrast in intensity values from one flightline to the next that split the study area to the right-centre of the field. In the flightline overlap zone the intensity values varied significantly. This variance displayed prominently in the change image, **Figure 4C**, where the sharp intensity contrast was clearly visible. Despite the control applied during the data collection and data processing the intensity data remained variable in the overlap zone, which highlighted that the range corrected intensity normalization did not fully account for variables such as footprint area change (Hopkinson, 2007) or changing foliage geometry with angle of incidence. However, this visual artifact was easily mitigated by comparing single near-nadir flight lines instead of the multiple overlapping flight lines (**Figure 5**).

In **Figure 5** the sharp contrast in intensity values that was clear in **Figure 4** was eliminated. By isolating the data into single flightlines, one more source of interference was eliminated, and the change in intensity between the two collection days was more likely due to changing surface reflectance than intensity artifacts. There are branches of drainage clearly visible in both images. In **Figure 4C** the intensity change between **Figure 4** and **Figure 4B** indicated that the reflected intensity had decreased in the northern areas of the field while it increased in the southern portion of the field between the two data collection days.

An overall increase in intensity between the 2 days illustrated in **Figure 5** was expected as Julian days 273 and 274 were 2–3 days after a large rain event, and the ground would presumably be drying out. The increase in intensity in the lower (southern) part of the field is also possibly explained by the increasing north-to-south slope angle over the southern half of the field, that would cause the surface moisture to drain more rapidly there than in the northern portion.

Volumetric moisture content

The results of the intensity/VMC regression test are summarized in **Table 1**. There was little direct correlation between the normalized intensity data and the shallow depth integrated VMC data. This suggests that moisture content in the upper soil layers was not a strong influence on reflectance in the near-infrared wavelength of the laser scanner at the scale sampled.

The *t* test results from the corn field revealed that the data were in agreement with expectations for both collection days (**Table 2**). Mean intensity values associated with observed LMC soils were significantly higher (at the 99% level of confidence) than the mean for the HMC observations. This indicated that higher intensity values were, indeed, associated with drier soils in the corn field. While the level of confidence was reduced, this was also true (at the 90% level of confidence) in the hay field.

The barley field results showed that the mean intensity values for the HMC and LMC were not significantly different. This field had short vegetation cover, too low for the data to be discerned and separated during the processing. The short vegetation caused a layer of separation between the laser pulse data and the ground sampled TDR moisture probe data such that the intensity data were more

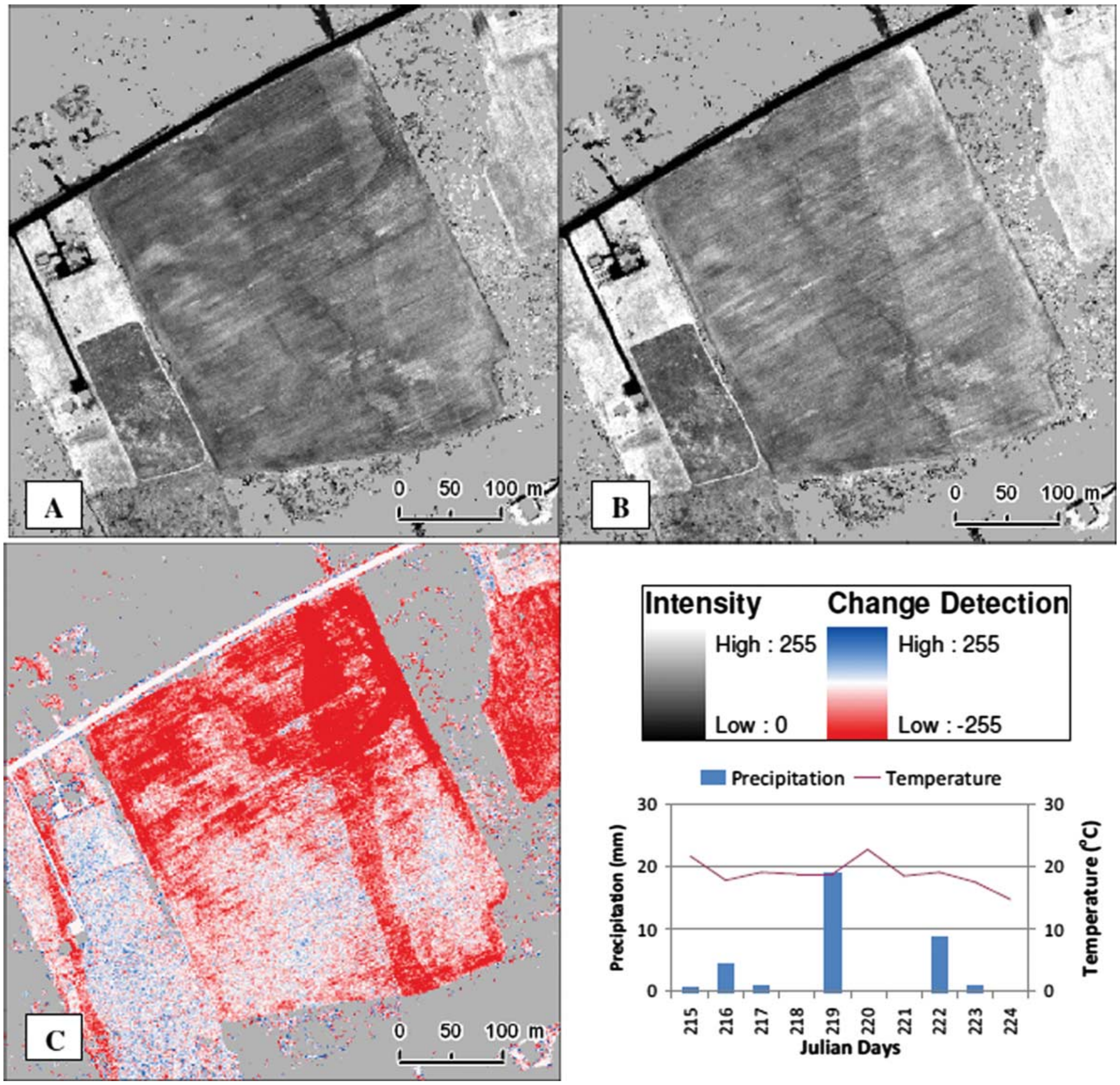

Figure 4. Change detection imagery from August 2006 data (Julian days 221 and 222). (A) Normalized and scaled intensity data collected on day 221, 2006. (B) Normalized and scaled intensity data collected on day 222, 2006. (C) Change detection result displaying the inconsistent change in intensity data from the combined flightlines; the data collected at the edge of the flightline was affected to a higher degree by vegetation attenuation than the data collected directly nadir to the aircraft.

strongly influenced by overlying vegetation than by bare earth level moisture conditions.

Discussion

The range normalization technique used to adjust the intensity values to account for the range bias effect worked to some degree. We demonstrated in the change detection test that despite the normalization process some ground surface reflectance effects could not be accounted for; this led to observations of intensity artifacts in the overlapping areas of multiflightline datasets. The variability of intensity values between flightlines of data was not accounted for in the normalization technique, which should be a consideration when utilizing this type of data for classification and mapping purposes.

In **Figure 4** the climate data between the 2 days of data collection indicated a period of surficial drying, yet the change in intensity between the two collection days (**Figure 4C**) revealed a large portion of the field where the intensity values decreased. There were two potential explanations for this occurrence, one based on the physical ground conditions and the other caused by some systematic influence. A systematic cause could be the scaling of the intensity data to the 8-bit range, which could have artificially

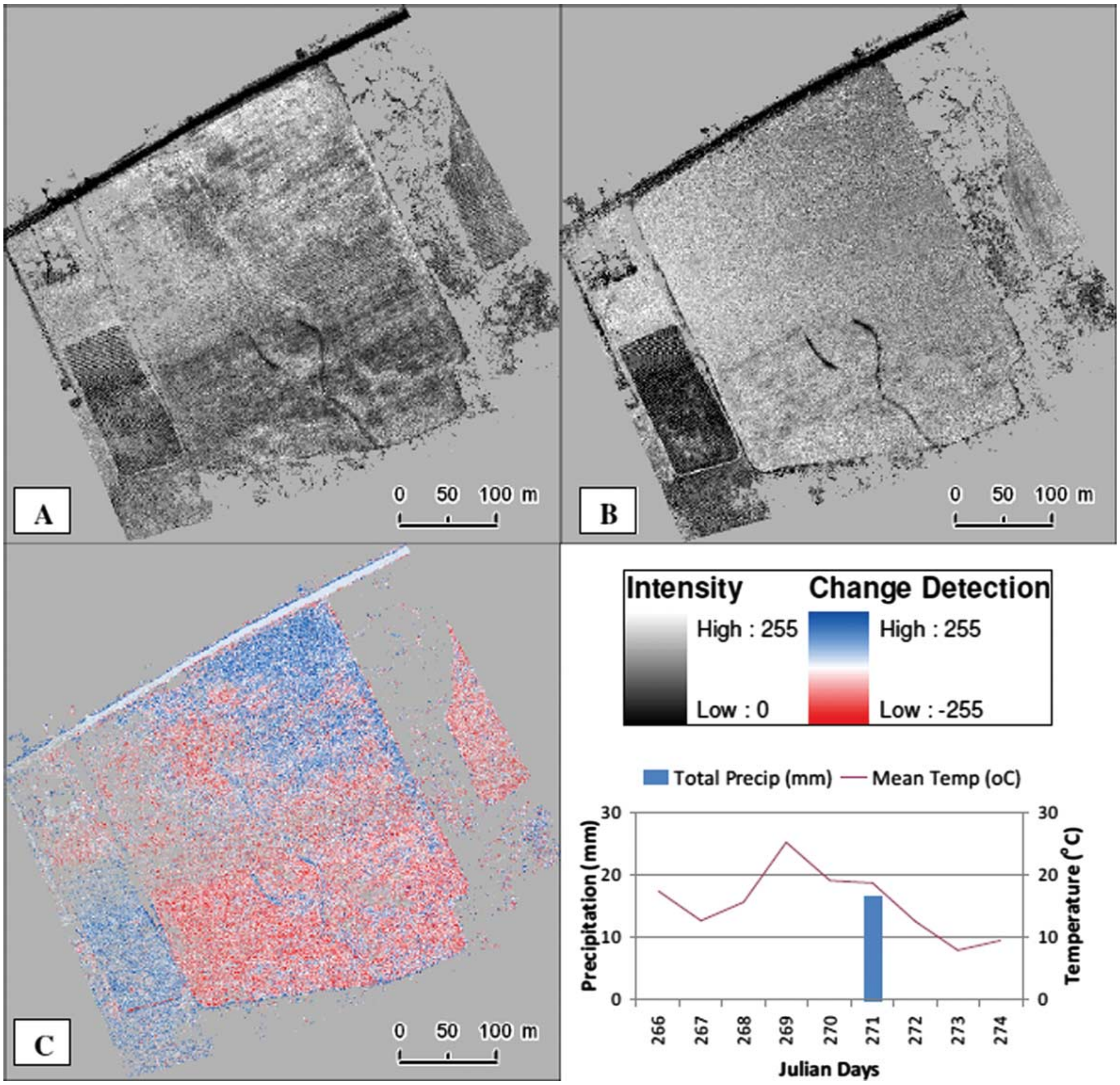

Figure 5. (A) One flightline of data collected on Julian day 273, 2007. (B) One flightline of data collected on day 274, 2007. (C) Change detection image. The harsh intensity artifact was no longer an issue when only one flightline of data was considered for analysis.

amplified low intensity returns in one dataset and not the other. Another explanation could be that while meteorological conditions indicated a drying out trend, the short vegetation in the field (approximately 60 cm tall barley) could have acted to mask and even reverse the soil moisture influence. For example, more return energy is associated with a pulse at a normal angle of incidence (Kaasalainen et al., 2005) such that vegetation cover on appropriate sloped surfaces could lead to an elevated intensity response. This would cause the intensity signal to increase in one portion of the field and not the other. Changes in foliage angle due to wind, rainfall or tress, for example, may also have unknown and confounded influences on the ground level intensity response.

Table 1. Regression analysis summary of laser pulse intensity and VMC for data collection on Julian days 090 and 273.

Field landcover	Collection day (Julian)	r^2	n
Barley	090	0.00	44
Barley	273	0.01	44
Corn	090	0.11	101
Corn	273	0.16	101
Hay	090	0.16	17
Hay	273	0.01	17

In the corn field the ground cover was bare earth, no vegetation, during the first data collection period and was corn stalks (approximately 2 m tall) during the second data collection period. The discrete-pulse return ALTM sensor cannot distinguish split-pulse returns spaced less than approximately 1.5 m apart. This means that some of the data points collected in the corn field will likely be influenced by the corn stalks, which could lead to an elongated laser pulse return with reduced peak amplitude

Table 2. *t*-Test summary table for significant difference of mean intensity values.

		Low moisture content			High moisture content			
Field landcover	Collection day (Julian)	Mean	Standard deviation	*n*	Mean	Standard deviation	*n*	*p* value
Barley	090	20.7	1.6	6	21.0	2.5	382	0.696
Corn	090	9.3	1.8	33	7.9	1.9	185	0.000
Corn	273	8.7	1.5	35	7.2	0.98	11	0.001
Hay	090	15.5	1.2	122	14.9	1.5	33	0.055

Note: The mean intensity data was higher where low moisture content was measured on both data collection days for the corn field and on the first collection day for the hay field. The mean intensity data in the barley field revealed negligible difference between the high and low moisture content. No data for hay and barley fields are reported for day 273 because the data was skewed because of the presence of vegetation cover in these fields.

(**Figure 6**). All else being equal, a pulse encountering tall crop vegetation would most likely display a reduced amplitude return compared to a pulse reflecting off the ground due to the reduced contact area. In **Figure 6C** hypothetical returns from bare ground and vegetated surfaces are compared. The vegetated signal's peak intensity value is reduced compared with the bare ground signal due to foliage structure interference. This phenomenon could lead to systematic intensity signal dampening over surfaces with tall vegetation cover. This will only occur in areas of tall ground-level vegetation (such as corn crops) because short vegetation (such as lawn grass) will not structurally attenuate the signal, but the spectral characteristics of the short vegetation target will increase the amplitude of the return; as observed in the barley field (**Figure 4**).

Despite this complication due to vegetation cover, many laser pulse returns over the corn field still reached the surface and were minimally affected by foliage because of the wide spacing and relatively open foliage structure of the corn rows. This was demonstrated in the comparison between the ground sampled VMC data and the extracted intensity data. In the corn field the mean of the LMC data was higher than the mean of the HMC data, indicating an inverse relationship. This confirmed that low intensity data can be associated with wetter surface conditions, even under certain vegetation cover conditions. However, vegetation cover clearly exerted a controlling influence on the intensity signal in the barley and hay fields.

Intensity can potentially be used for ground surface classification, but such methods cannot be universally

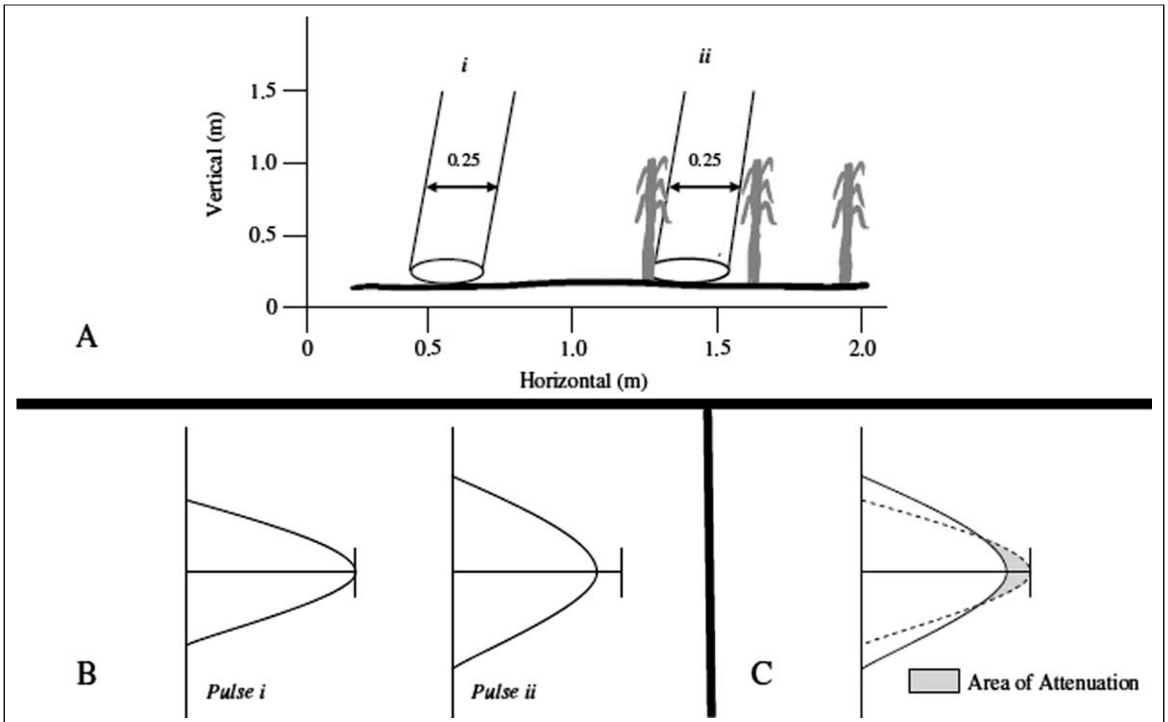

Figure 6. Simplified conceptual diagram of signal return attenuation over unvegetated and vegetated surfaces. (A) Diagram of two laser pulses reaching the ground surface. *Pulse i* is not affected by vegetation whereas *Pulse ii* is affected by short surface vegetation under 1 m in height. (B) The same two pulse's signal as read by the sensor. *Pulse i* signal peaks at maximum return potential whereas *Pulse ii* signal amplitude is reduced due to the influence of ground foliage. (C) A comparison of the two signals.

applied because of the competing influences of spectral and structural controls. Many authors implicitly assume that the surface reflectance characteristics play the dominant role in the laser intensity signal, but we have shown that pulse splitting and attenuation in short vegetation can reduce the intensity even though the surface spectral reflectance of vegetation might be higher. Tall ground vegetation affects the structural properties of the pulse return by elongating the reflecting surface along the travel path, whereas increased moisture conditions affect the spectral response by absorbing the near-infrared energy.

Conclusion

A series of comparative tests were conducted on laser pulse intensity data captured over a number of bare earth and crop-covered agricultural fields. It has been shown that intensity can be influenced by surface reflectance changes over bare soil because of surface moisture conditions. Statistical tests showed that the mean intensity value for LMC soils was significantly higher than that of the mean intensity value of HMC soils.

However, in a field with short vegetation the tests were inconclusive. The mean intensity of the LMC points was not significantly different from the mean intensity of the HMC points. This result meant that the surface reflectance was being affected by some other factor besides moisture. Near ground-level foliage most likely exerted the dominant control on laser pulse intensity. Vegetation influences the signal in two ways; the signal can be spectrally amplified by short vegetation or it can be structurally dampened (or split) by taller vegetation.

The temporal analysis revealed that intensity data were best studied on a flightline by flightline basis, rather than a full mosaiced dataset of overlapping flightlines, because of systematic artifacts at the scan edges in overlapping areas. While data range-based normalization was utilized to mitigate the range bias effect, the technique was not as successful at mitigating the scan angle effect. The change detection analysis also showed that subtle changes in intensity can be masked by the spectral and structural reflectance of vegetation.

This study has shown that factors such as survey configuration, vegetation cover, and soil moisture should be considered if intensity-based change detection or land-surface classification is to be carried out.

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