Airborne LiDAR for EFI in the boreal: what’s “operational”; what’s “R&D” today

For. Chron.:
87: 512-528
SL2012-033
SL2012-104
SL2012-209

CIF-Manitoba Section “Enhanced Forest Inventory”
Jan. 23, 2013, Winnipeg, MB
Airborne LiDAR for EFI in the boreal: what’s “operational”; what’s “R&D” today

- Background
- LiDAR 101
- Example of operational implementation
- Future directions

CLF-Manitoba Section “Enhanced Forest Inventory”
Jan. 23, 2013, Winnipeg, MB
Provincial Forest Inventories - limitations

- Typical FMU is > 1 M ha
- Strategic (forest-level)
- Serves multiple needs
- Based on manual interpretation of aerial images – broad species, age, height, stocking, sometimes by ecosite. Timber volume is imputed.
Needs today...

✓ Volume of merchantable wood, sawlogs.
✓ Basal area, biomass, stems per ha
✓ Ave. tree size (diameter, height, volume).
✓ Tree-size distribution.
✓ Information to build better, smarter, roads.
✓ Information to reduce costs and maximize profits.

Value chain optimization!
Operational Cruising...

Background...

- Height
- Volume (GTV, GMV)
- Basal area
- Density
- Quadratic mean DBH
- Biomass
- Diameter and Basal Area Distributions

Not spatial!
CWFC National Program; Regional Delivery...

**FPInnovations**: CWFC, Forest Ops., Wood Prod., Pulp&Paper

**CFS**: Luther, Leckie, Gougeon, Wulder, Beaudoin

**Universities**: UBC, Queen’s, Nipissing, Sherbrooke, UQAM, Laval, Sir Wilfred Grenfell

**Provinces**: BCMoFR, ASRD, OMNR, MRNF-QC, NLDNR, NBDNR

**Industry**: West Fraser, Tembec, Foothills G&Y, Corner Brook P&P, J.D. Irving

**Funding partners**: GEOIDE, OCE, FQRNT, ACOA, AIFI, NSERC

...Inventory systems that support VCO by allowing us to send the right wood to the right markets, at the right time!

**Airborne LiDAR**: big part of the Program!
Advanced Forest Resource Inventory Technologies
Team AFRIT...

Murray Woods
Doug Pitt
Dave Nesbitt
Margaret Penner
Forest Analysis Ltd.
Kevin Lim
Lim Geomatics
Dave Etheridge
Paul Treitz
Jeff Dech
Don Leckie
François Gougeon

Great bunch to work with!
What is Light Detection and Ranging?

- **Active** remote sensing technology; transmit & receive ~500,000 pulses of laser light per second
- Each pulse can produce multiple returns (up to 8)
- GPS provides the exact X-Y-Z position of each return
Background...

Basic Products...

Digital Terrain Model (DTM)

Digital Surface Model (DSM)

Canopy Height Model (CHM)
**Huge array of uses...**

- Hazard mapping
- Floodplain/risk mapping
- Landform Classification-ELC
- Corridor/Right-of-way Mapping
- Woodlot Extraction
- Agricultural mapping
- Geological Mapping
- Urban Modeling
- Predictive Hydrology
- Transmission Line corridors
- Wetlands/Riparian areas
- Open pit mining
- Coastal/Shoreline Mapping
- Habitat modeling
- Forest Engineering
- Forest Inventory

**Opportunities for cost-sharing!**
Using the point clouds for area-based estimates...
Using the point clouds for area-based estimates...

\[ S_b \text{ GTV (m}^3/\text{ha)} = 31.46 + 1.78(\text{mean} \cdot p90) \]
Model construction

\[ y = b_0 + b_1 x_1 + b_2 x_2 \]

\[
\begin{align*}
  y_1 &= b_0 + b_1 x_1 + b_2 x_2 \\
  y_2 &= b_0 + b_1 x_1 + b_2 x_3 \\
  &\vdots \\
  y_p &= b_0 + b_1 x_2 + b_2 x_3
\end{align*}
\]

\[ y = e^{b_0} \cdot x_1^{b_1} \cdot x_2^{b_2} \cdot \ldots \cdot x_5^{b_5} \]

RandomForest

(nonparametric approach based on an ensemble of regression tree models)
Model construction

**RF – one “tree”:**

- Sample
  - Variable X1 > threshold
    - Variable X2 > threshold
      - Variable X4 > threshold Yi
        - Variable X6 > threshold Yi
    - Variable X2 ≤ threshold
      - Variable X4 ≤ threshold
  - Variable X1 ≤ threshold
    - Variable X3 > threshold Yi
      - Variable X5 > threshold Yi
        - Variable X7 > threshold Yi
    - Variable X3 ≤ threshold
      - Variable X5 ≤ threshold
        - Variable X7 ≤ threshold Yi
Model construction

**RF – one “tree”:**

- Start with the sample.
- If Variable X1 > threshold, then:
  - Check Variable X2 > threshold.
    - If Variable X2 > threshold, then check Variable X4 > threshold.
      - If Variable X4 > threshold, then check Variable X6 > threshold.
    - If Variable X2 ≤ threshold, then:
      - Check Variable X3 > threshold.
        - If Variable X3 > threshold, then check Variable X7 > threshold.
- If Variable X1 ≤ threshold, then:
  - Check Variable X3 ≤ threshold.
  - If Variable X3 ≤ threshold, then:
    - Check Variable X5 ≥ threshold.
      - If Variable X5 ≥ threshold, then check Variable X7 ≥ threshold.
Model construction

**RF – many “trees” = a “forest”:**
Using the point clouds for area-based estimates...

Background...

Now, we have “spatial” data!
Both tactical AND strategic!
Two Forests ~ 2M ha
Northeastern Ontario

LiDAR data; relatively low-resolution...

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Romeo Malette</th>
<th>Hearst</th>
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<tbody>
<tr>
<td>Sensor</td>
<td>Leica ALS40</td>
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<td>Platform</td>
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<td>Pulse Rate</td>
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<td>Scan Rate</td>
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<td>32 Hz</td>
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<td>H</td>
<td>2,740 m</td>
<td>2,400 m</td>
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<td>Line spacing</td>
<td>900 m</td>
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<tr>
<td>Vert. Accuracy</td>
<td>&lt; 50 cm</td>
<td>&lt; 30 cm</td>
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<tr>
<td>Pulse density</td>
<td>~0.5 /m²</td>
<td>~1.0 /m²</td>
</tr>
</tbody>
</table>

Relatively low pulse densities!
LiDAR predictive models

- Top and Dom/codominant Height
- QMDBH
- Volume (GTV, GMV)
- Basal area
- Biomass
- Density*
- Mean tree volume
- Sawlog volume
- Diameter/volume Distributions

* Derived from DBHq & BA

Proper calibration is essential!
An operational example...

**LiDAR predictive models**

- **Top Height**
  - $TOPHT = 17.2 \pm 0.2 \text{ m}$

- **Average Height**
  - $AVGHT = 12.8 \pm 0.3 \text{ m}$

- **Basal Area**
  - $SUMBA = 20.2 \pm 1.0 \text{ m}^2 \text{ ha}^{-1}$

- **QMDBH**
  - $QMDBH = 14.8 \pm 0.3 \text{ cm}$

- **Gross Total Volume**
  - $SUMGTV = 144.3 \pm 8.1 \text{ m}^3 \text{ ha}^{-1}$

- **Gross Merchantable Volume**
  - $SUMGMV = 102.1 \pm 6.3 \text{ m}^3 \text{ ha}^{-1}$

- **Biomass**
  - $BIOMASS = 85087.3 \pm 4374.0 \text{ Kg ha}^{-1}$

- **Density**
  - $DENSITY^1 = 1187 \text{ stems ha}^{-1}$

---

1 Density was calculated from Basal Area and QMDBH and confidence intervals were not calculated.
Some results...

Feedback from the woods...

Basic products = huge advantages!
Feedback from the woods...

Some results...
Feedback from the woods...

Some results...

LiDAR Information can add more value to our basic image and inventory interpretation

“Virtually” walk every square inch!
Feedback from the woods...

4153376610
PJ9 S0b10
17m – 60 – 0.91
Site Class 2
CC=60%

4153069890
PJ90 Sb10
18m – 60 – 1.0
Site Class 2
CC=60%

4553155270
PJ90 Sb10
18.6m – 60 – 1.0
Site Class 2
CC=60%

Plonski's Normal Yield Table
Jack Pine - Site Class 2

0
50
100
150
200
250

162 m³/ha
15.8 cm

GMV m³/ha
20 40 60 80 100
Stand Age

Some results...
**Feedback from the woods**

**4153376610**
- **PJ90 Sb10**
- 17m – 60 – 0.91
- Site Class 2
- CC=60%
- LiDAR Derived
  - 195.9 +/- 14.6 m$^3$/ha
  - 18.4 +/- 0.7 cm

**4153069890**
- **PJ90 Sb10**
- 18m – 60 – 1.0
- Site Class 2
- CC=60%
- 277.4 +/- 18.1 m$^3$/ha
- 20.7 +/- 0.8 cm

**4553155270**
- **PJ90 Sb10**
- 18.6m – 60 – 1.0
- Site Class 2
- CC=60%
- 190.6 +/- 12.2 m$^3$/ha
- 17.6 +/- 0.5 cm

**Efficiencies in planning!**
Feedback from the woods...

Clearcuts: e.g., Jack Pine, 35 ha

FMP – planned: 4,669 m$^3$
LIDAR – predicted: 7,543 m$^3$
Scaled volume: 7,733 m$^3$

The ultimate validation!

Image and data courtesy Tembec Inc.
Advanced Forest Resource Inventory Decision Support System

Forest-Type strata present:
- Intolerant Hwd – 3 – 20x20m cells
- Mixedwood – 228 – 20x20m cells
- Jack Pine – 540 – 20x20m cells

771 Prediction Units for 30.8 ha
AFRIDS System

Welcome to AFRIDS
Advanced Forest Resource Inventory Decision Support System

Access to the AFRIDS on Lim Geomatics' development server is limited to authorized users. To request a username or password, send an e-mail to info@limgeomatics.com

"The right wood, to the right mill, at the right time."

Tap into the power of LIDAR remotely sensed imagery with AFRIDS! Available as a desktop or web-based program, AFRIDS provides forest managers with industry-leading tools for utilizing LIDAR forest inventories. Redefine your expectations of forest biophysical information with the following features:

LIDAR Derived Imagery
Information on forest structure has never been more accessible. Display millions of hectares of LIDAR derived imagery in a web-based, easy-to-use map.

User Name: [Enter]
Password: [Enter]
Log In
AFRIDS System

AFRIDS Advanced Forest Resource Inventory Decision Support Tool

Some results...
AFRIDS System

AFRIDS Advanced Forest Resource Inventory Decision Support Tool

Select a Basemap
- Streets
- Topo
- Imagery

Add Additional Layers
- Outline
- Roads
- Water
- Hillshade

Select a Forest Attribute
- No Attribute

Map Display
- Zoom In
- Pan
- Zoom Out
- Last Extent
- Full Extent
- Next Extent

Transparency
- 40%

LAT: 48.5440
LON: -83.0155
AFRIDS System

AFRIDS Advanced Forest Resource Inventory Decision Support Tool

Select a Basemap
- Streets
- Topo
- Imagery

Add Additional Layers
- Outline
- Roads
- Water
- Hillshade

Select a Forest Attribute
- No Attribute

Transparency

LAT: 48.2849
LON: -81.4124

Some results...
AFRIDS System

Some results...
AFRIDS System

AFRIDS Advanced Forest Resource Inventory Decision Support Tool

Map Display Tools Export

Create a Block
Import Draw Sketch Delete

Symbology

Edit Existing Blocks

Calculate Block Statistics

FRI Tool
Display: [ ] Fill [ ] Linework
Identify: [ ] Identify FRI Attributes
Add Block: [ ] Add This Polygon

Note: FRI linework will only display when sufficiently zoomed in.
AFRIDS System

Some results...

AFRIDS Advanced Forest Resource Inventory Decision Support Tool

Create a Block
- Import
- Draw
- Sketch
- Delete

Symbology:

Edit Existing Blocks
- Select
- Shape
- Split
- Hole

Symbology:

Calculate Block Statistics

FRI Tool
- Display: Turn on FRI Linework
- Identify: Identify FRI Attributes
- Add Block: Add This Polygon

Note: FRI linework will only display when sufficiently zoomed in.

Press down to start and let go to finish
Forest Unit: SB1
Area: 45 ha

AFRIDS System
Some results...

Block Results

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<th>Metric</th>
<th>Mean</th>
<th>+/-</th>
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<tbody>
<tr>
<td>Average Height</td>
<td>15.1</td>
<td>0.2</td>
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<td>Top Height</td>
<td>21.1</td>
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<tr>
<td>Basal Area</td>
<td>25.7</td>
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<tr>
<td>Biomass</td>
<td>108</td>
<td>6.15</td>
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<tr>
<td>Quad Mean DBH</td>
<td>17.9</td>
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<td>Gross Total Vol.</td>
<td>194</td>
<td>104</td>
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<tr>
<td>Gross Merch. Vol.</td>
<td>154</td>
<td>3.71</td>
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<tr>
<td>Mean Tree GMV</td>
<td>169.6</td>
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Total
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<tr>
<td>Biomass</td>
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<td>Gross Total Vol.</td>
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<tr>
<td>Gross Merch. Vol.</td>
<td>14.2</td>
<td>0.527</td>
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Press down to start and let go to finish
AFRIDS System

Some results...
Operational Feedback

Cost-benefit...the Romeo Malette example

e.g., LiDAR Cost Savings

1) Inventory acquisition and processing (6 items)  -$0.10/m³
2) Forest operations (20 items)  $1.40/m³
3) Mill operations (4 items)  $0.30/m³

Total savings: $1.60/m³

X 500,000 m³/year: $800,000/year

Payback 1.3 years

Informed decision making pays off!
OK, so where is the research taking us?

Advances in technology ~ HI-resolution!
Semi-auto Species ID

Augment spectral classifiers with data from

- LiDAR DTM; CHM;
- SGM for crown resolution; as a classifier.

Can LiDAR support ITC?
The future...

Aiding photo interpretation...

LiDAR Predicted GMV Raster

LiDAR Predicted Dbhq Raster

Photo Interpreted Stand Boundaries

Photo Interpreted Stand Boundaries

Use LiDAR rasters to create polygons?
### Semi-auto Species ID

- **n = 346 plots; 86 used for validation:**

#### Predicted (%)

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<th>CH</th>
<th>C</th>
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<td>9</td>
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<td>C:</td>
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#### Actual (%)

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<th>Bw</th>
<th>Ce</th>
<th>Pb</th>
<th>Pj</th>
<th>Po</th>
<th>Sb</th>
<th>Sw</th>
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#### Fraction correct

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**Species directly?**
The future...

Wet Areas Mapping...

Using the Cartographic Depth-to-Water Index to Locate Small Streams and Associated Wet Areas across Landscapes

Barry White, Jae Ogilvie, David M.H. Campbell, Douglas Hiltz, Brian Gauthier, H. Kyle Chisholm, Hua Kim Wen, Paul N.C. Murphy, and Paul A. Arp

First step in mapping productivity!
The future...

... driving towards ecosite,

Add slope, aspect, species preference...
The future...

... and soil productivity

- Participants: Clement Akumu, John Johnson, Peter Uhlig, Sean McMurray, David Etheridge (OMNR); Murray Woods (SSIS); Doug Pitt (CWFC); Doug Aspinall (OMAFRA); Paul Arp (UNB); linked with work in AB, NL, and NB,

Time to get excited?
• EFI+productivity = view of the future (what mill infrastructure is needed; what impact will silvicultural investment have on the outcome?)

• Explore successive LiDAR/SGM to quantify change

GROWING the inventory

Spatially predict the future?
Adding FIBRE Attributes

- Participants: Jeff Dech (Nipissing U); Bharat Pokharel (Nipissing U); FPInnovations; Art Groot, Doug Pitt (CWFC); Murray Woods (SSIS) > linked with work in AB, QC, and NL.

The future...

Predict wood density, MOE, MOR?
The business of managing our forests depends on sound forest inventory...

“We need a spatial inventory, and we need it now!”

Thank you!
The business of managing our forests depends on sound forest inventory.

Thank you!

“We need a spatial inventory, and we need it now!”

murray.woods@ontario.ca
dpitt@NRCan.gc.ca
What is Individual Tree Crown classification?

- Semi-automated image analysis based on digital imagery
- Identify crown edges by following shadows
- Species training & automated classification of each crown

Francois Gougeon and Don Leckie, CFS
Two Forests ~ 2M ha

Northeastern Ontario

- ADS40 imagery; provincial coverage...

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<td>Sensor</td>
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