The Wetland Inventory Map of Canada using Optical and SAR Remote Sensing data on Google Earth Cloud Computing Platform

A presentation to Association of State Wetland Managers (ASWM) Webinar Series

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Presented by
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Wetlands: Nature’s Kidney!

- **Wetland**: Areas that experience wet conditions at least periodically during the growing season or permanently in all seasons (Tiner, 2015).

- **Wetland Services**:
  - Natural water filtration;
  - Recreational activities (e.g., fishing, hunting, berry picking etc.);
  - Protection from natural hazards (e.g., drought and flood);
  - Habitat for both animal and plant species; And many more
Wetlands are Disappearing!

• It has been frequently stated (but w/o provision of supporting evidence) that 56.0% of North America’s wetlands have been lost since 1700 (Davidson, 2014)

• 70-98% of wetlands near urban centers have been lost or degraded.

• More than 50% of these changes occurred since 1980s (last 40 years)!

• How to act on wetland protection?
Remote Sensing of Wetlands

Protection of wetlands requires info on:
- Where?
- What type?
- How much (area)?

Remote sensing provide:
- Cost-effective methods; Extensive coverage
- Repetitive and frequent coverage (Monitoring changes)

Tag cloud showing the used terms in various frequencies in North American wetland classification papers.
• The effect of different pre-processing steps on wetland classification results
• Feature extraction and reduction
• Feature engineering and optimization
• Object-based vs pixels-based image analysis
• Wetland mapping using ML algorithms
• Wetland mapping using DL algorithms
• Geo-big data analysis (provincial- and national-scale wetland mapping)
• For the list of publication, please visit http://nlwetlands.ca/
Canadian Wetland Inventory (CWI) System

Figure: Jason Beaulieu, 2013
Field data collection

- Visiting more than 800 wetlands within 6 different pilot sites in NL during the last five years
- Collecting field data during summers and falls (2015-2019)
Challenges

• Wetland classification is still a challenging task due to …
  • Similar spectral/backscattering responses;
  • Several small classes without a clear-cut border;
  • Training data.

• These hinder the capability and efficiency of conventional remote sensing tools for wetland classification.
Canadian Wetland Classification System (CWCS)

- Bog
- Fen
- Marsh
- Swamp
- Shallow water
- Urban
- Deep water
- Upland
## Number of training and testing polygons

<table>
<thead>
<tr>
<th>Class</th>
<th>Training Polygons</th>
<th>Testing Polygons</th>
</tr>
</thead>
<tbody>
<tr>
<td>bog</td>
<td>92</td>
<td>91</td>
</tr>
<tr>
<td>fen</td>
<td>93</td>
<td>92</td>
</tr>
<tr>
<td>marsh</td>
<td>75</td>
<td>75</td>
</tr>
<tr>
<td>swamp</td>
<td>78</td>
<td>79</td>
</tr>
<tr>
<td>shallow-water</td>
<td>55</td>
<td>56</td>
</tr>
<tr>
<td>deep-water</td>
<td>17</td>
<td>16</td>
</tr>
<tr>
<td>upland</td>
<td>92</td>
<td>92</td>
</tr>
<tr>
<td>urban/bare land</td>
<td>99</td>
<td>98</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>601</strong></td>
<td><strong>599</strong></td>
</tr>
</tbody>
</table>
Processing of more than 3k satellite imagery

- Sentinel-1 & Sentinel-2 Imagery
- Pre-processing
- Feature Extraction
- SNIC Superpixel Segmentation
- Random Forest Classification
- Wetland Inventory Map
The total number of Sentinel-1&2 observations

**S1: VV/VH**

- # 247

**S2**

**S1: HH/HV**

- # 525

- # 2251
Extracted features (#16) from Sentinel-1&2 imagery
The First Wetland Inventory Map of Newfoundland

The final classification map obtained from the object-based RF classification using the multi-year summer SAR/optical composite (OA: 88.37%, K: 0.85)

<table>
<thead>
<tr>
<th>Classification</th>
<th>Data composite</th>
<th>Scenario</th>
<th>Overall accuracy (%)</th>
<th>Kappa coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pixel-based</td>
<td>SAR</td>
<td>S1</td>
<td>73.12</td>
<td>0.68</td>
</tr>
<tr>
<td></td>
<td>Optic</td>
<td>S2</td>
<td>77.16</td>
<td>0.72</td>
</tr>
<tr>
<td>Object-based</td>
<td>SAR</td>
<td>S3</td>
<td>79.14</td>
<td>0.74</td>
</tr>
<tr>
<td></td>
<td>Optic</td>
<td>S4</td>
<td>83.79</td>
<td>0.80</td>
</tr>
<tr>
<td></td>
<td>SAR + optic</td>
<td>S5</td>
<td>88.37</td>
<td>0.85</td>
</tr>
</tbody>
</table>
The First Wetland Inventory Map of Newfoundland
The Canadian Wetland Inventory Map
# of Sentinel-1 and Sentinel-2 data per province

**Yukon Territory**
- Area: 482,443 Km²
- # Sentinel-1: 718
- # Sentinel-2: 3,586

**British Columbia**
- Area: 944,735 Km²
- # Sentinel-1: 1,620
- # Sentinel-2: 4,550

**Alberta**
- Area: 661,848 Km²
- # Sentinel-1: 1,136
- # Sentinel-2: 3,033

**Saskatchewan**
- Area: 651,036 Km²
- # Sentinel-1: 865
- # Sentinel-2: 2,940

**Manitoba**
- Area: 647,797 Km²
- # Sentinel-1: 717
- # Sentinel-2: 3,084

**Ontario**
- Area: 1,076,395 Km²
- # Sentinel-1: 1,084
- # Sentinel-2: 4,142

**Northwest Territories**
- Area: 1,346,106 Km²
- # Sentinel-1: 11,191
- # Sentinel-2: 5,700

**Quebec**
- Area: 1,542,056 Km²
- # Sentinel-1: 1,968
- # Sentinel-2: 6,655

**Newfoundland & Labrador**
- Area: 405,212 Km²
- # Sentinel-1: 1,441
- # Sentinel-2: 2,441

**Prince Edward Island**
- Area: 5,660 Km²
- # Sentinel-1: 241
- # Sentinel-2: 151

**New Brunswick**
- Area: 72,908 Km²
- # Sentinel-1: 364
- # Sentinel-2: 477

**Nova Scotia**
- Area: 55,284 Km²
- # Sentinel-1: 455
- # Sentinel-2: 418
The total number of Sentinel-1&2 observations

S1: VV/VH

S2

S1: HH/HV
## Sentinel-1 and Sentinel-2 Features Extracted for classification

<table>
<thead>
<tr>
<th>Feature description</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertically transmitted, vertically received SAR</td>
<td>$\sigma_{VV}^0$</td>
</tr>
<tr>
<td>Vertically transmitted, horizontally received SAR</td>
<td>$\sigma_{VH}^0$</td>
</tr>
<tr>
<td>Horizontally transmitted, horizontally received SAR</td>
<td>$\sigma_{HH}^0$</td>
</tr>
<tr>
<td>Horizontally transmitted, vertically received SAR</td>
<td>$\sigma_{HV}^0$</td>
</tr>
<tr>
<td>Span or total scattering power</td>
<td>$</td>
</tr>
<tr>
<td>Ratio</td>
<td>$\frac{</td>
</tr>
<tr>
<td>Spectral bands 2 (blue), 3 (green), 4 (red), and 8 (NIR)</td>
<td>$B_2, B_3, B_4, B_8$</td>
</tr>
<tr>
<td>The normalized difference vegetation index (NDVI)</td>
<td>$\frac{B_8 - B_4}{B_8 + B_4}$</td>
</tr>
</tbody>
</table>
NDVI Map of Canada

Canada

- 0.93

0.98
## Classification Results

<table>
<thead>
<tr>
<th>Province</th>
<th>OA</th>
<th>K</th>
<th>Province</th>
<th>OA</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>BC</td>
<td>77.43</td>
<td>0.73</td>
<td>NS</td>
<td>80.88</td>
<td>0.76</td>
</tr>
<tr>
<td>AB</td>
<td>82.55</td>
<td>0.80</td>
<td>PEI</td>
<td>75.29</td>
<td>0.71</td>
</tr>
<tr>
<td>SK</td>
<td>80.74</td>
<td>0.76</td>
<td>NL</td>
<td>83.67</td>
<td>0.81</td>
</tr>
<tr>
<td>MB</td>
<td>81.36</td>
<td>0.77</td>
<td>YT</td>
<td>74.81</td>
<td>0.70</td>
</tr>
<tr>
<td>ON</td>
<td>82.17</td>
<td>0.79</td>
<td>NT</td>
<td>78.05</td>
<td>0.75</td>
</tr>
<tr>
<td>QC</td>
<td>76.21</td>
<td>0.73</td>
<td>NU</td>
<td>74.32</td>
<td>0.69</td>
</tr>
<tr>
<td>NB</td>
<td>77.91</td>
<td>0.74</td>
<td>CA</td>
<td>78.88</td>
<td>0.75</td>
</tr>
</tbody>
</table>
The first Canadian wetland inventory map with spatial resolution of 10 m
Simple Non-Iterative Clustering (SNIC) Segmentation and Random Forest (RF) Classification
The distribution of wetlands classes in different Canadian ecozones

<table>
<thead>
<tr>
<th>Ecoregion</th>
<th>Wetland area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arctic Cordillera</td>
<td>17,619 km²</td>
</tr>
<tr>
<td>Northern Arctic</td>
<td>8,065 km²</td>
</tr>
<tr>
<td>Southern Arctic</td>
<td>17,448 km²</td>
</tr>
<tr>
<td>Taiga Plains</td>
<td>20,076 km²</td>
</tr>
<tr>
<td>Taiga Shield</td>
<td>290,931 km²</td>
</tr>
<tr>
<td>Boreal Shield</td>
<td>475,568 km²</td>
</tr>
<tr>
<td>Atlantic Maritime</td>
<td>12,128 km²</td>
</tr>
<tr>
<td>Mixedwood Plains</td>
<td>4,723 km²</td>
</tr>
<tr>
<td>Boreal Plains</td>
<td>292,495 km²</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ecoregion</th>
<th>Wetland area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prairies</td>
<td>12,319 km²</td>
</tr>
<tr>
<td>Taiga Cordillera</td>
<td>6,682 km²</td>
</tr>
<tr>
<td>Boreal Cordillera</td>
<td>13,998 km²</td>
</tr>
<tr>
<td>Pacific Maritime</td>
<td>1,371 km²</td>
</tr>
<tr>
<td>Montane Cordillera</td>
<td>14,189 km²</td>
</tr>
<tr>
<td>Hudson Plains</td>
<td>202,109 km²</td>
</tr>
<tr>
<td>Tundra Cordillera</td>
<td>5,495 km²</td>
</tr>
<tr>
<td>Semi-Arid Plateaux</td>
<td>1,172 km²</td>
</tr>
<tr>
<td>Atlantic Highlands</td>
<td>2,781 km²</td>
</tr>
</tbody>
</table>
Bog
Fen
Marsh
Shallow Water
The Winner of ESRI CANADA 2020 Map Calendar Contest!

A high resolution 30-m wetland inventory map of Canada, covering an approximate area of one billion hectares, is generated using multi-year (2016-2018) and multi-source (Sentinel-1 and Sentinel-2) satellite imagery (~550 images) within an object-based random forest classification scheme on the Google Earth Engine cloud computing platform. The whole country is classified with an overall accuracy approaching 80% with individual accuracies varying from 74% to 88% in different provinces, depending on available resources. The resulting nation-wide wetland inventory map illustrates that 15% of Canada's land area is covered by wetlands, most of which are peatlands dominated in the northern ecozones.
Conclusion

Producing Canada’s first detailed categorically-based wetland inventory map at a spatial resolution of 10 m;

Some 190,000,000 ha of Canada is covered by wetlands (19% of Canada’s land area);

Leveraging the computational power of Google Earth Engine and a large pool of high temporal and spatial resolution satellite imagery collected by Copernicus Sentinels;

The Boreal Shield, Taiga Shield, and Hudson Plains comprise much of Canada’s wetlands, whereas wetlands are least common in mountainous eco-zones;

Bogs and fens were found to be the most dominant wetland classes in Canada, especially in the northern eco-zones;

Standard static maps are being replaced by dynamic mapping and monitoring.

Future work

- Wetland inventory of US
- Use of upcoming space-borne RADAR, Optical, LiDAR and Nanosat data

• Extend Partnership!
Shout out to our Sponsors!