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GEOMATICS CANADA
OPEN FILE 60

EO Baseline Data for Cumulative Effects Year End Report (FY 2019/20)

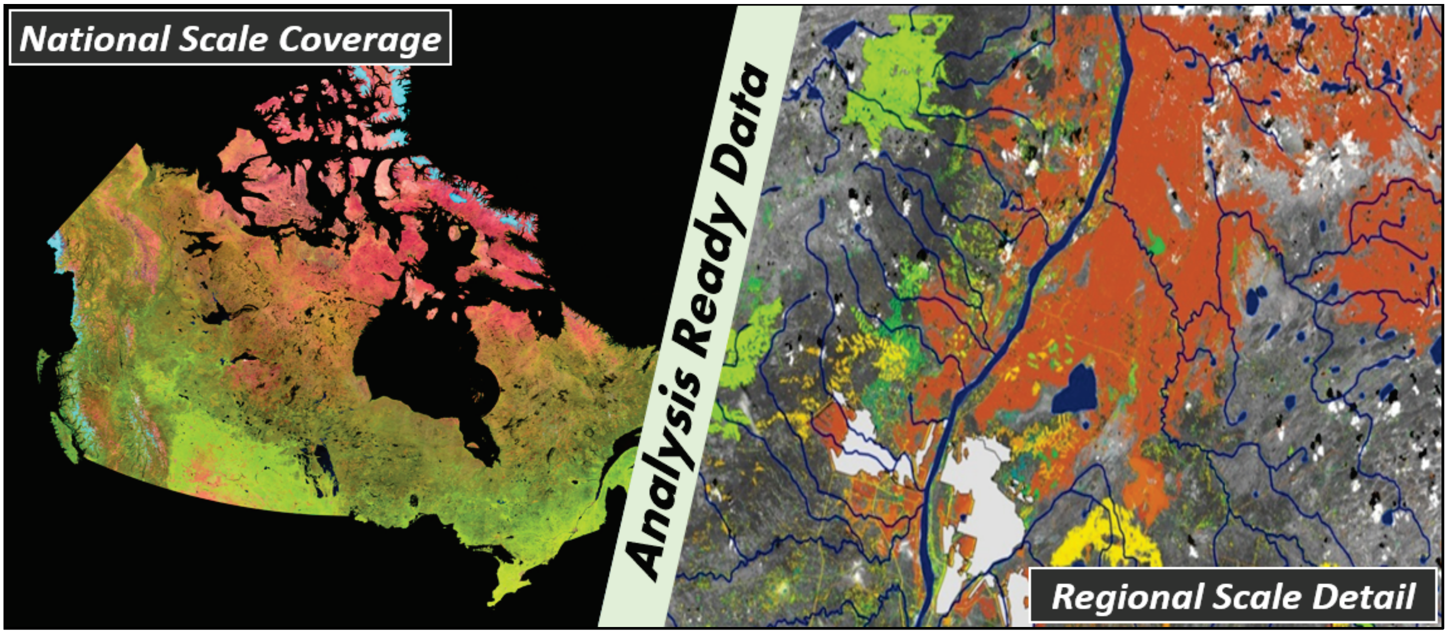

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Table of Contents:

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Executive Summary:

Environmental instability may prove to be the greatest threat Canada will face over the next several decades. Across the country, Canadians are adapting to a ‘new normal’ that is difficult to prepare for. Does this new normal include more frequent catastrophic floods like Calgary in 2013 and the 100-year Ottawa floods in 2017 and 2019. Is there an increase to the frequency and impact of forest fires like ‘The Beast’ in Fort McMurray 2016? Are crop and orchard failures going to continue to increase? How many major resource development projects can the landmass support? These questions are challenging to answer and the cost of not answering them is massive.

This environmental instability is being fueled by a combination of abrupt change drivers including human activity, forest fires, and floods, as well as gradual change drivers like climate change, pollution, and species adaptation. Together, these change drivers can be complex and interactive; where gradual changes cause abrupt changes and vice versa. Effective management of any region in Canada must start with a demonstrated understanding of how these change drivers are impacting the status and trends of that region.

Ensuring that Canadians are able to thrive in Canada’s changing environment requires an intimate understanding of how the landmass is changing. To support the development of this knowledge, the Canada Centre for Mapping and Earth Observation (CCMEO) of Natural Resources Canada (NRCan) has implemented the ***Status and Trends Mapping Program*** (STMP). The STMP will identify, develop, disseminate and analyze critical geospatial datasets for describing a changing Canadian landscape to inform evidence-based decision-making.

The 5-year project ‘***Earth Observation Baseline Data for Cumulative Effects***’ (EO4CE) is the key launch effort for CCMEO’s STMP. The project, currently in its second year, will develop a wide range of status and trends variables (primarily terrestrial) and demonstrate their capabilities within regional assessments of cumulative effects. In fiscal year 2019-20 (April 2019 – March 2020), the EO4CE project has exceeded expectations as articulated within the project plan.

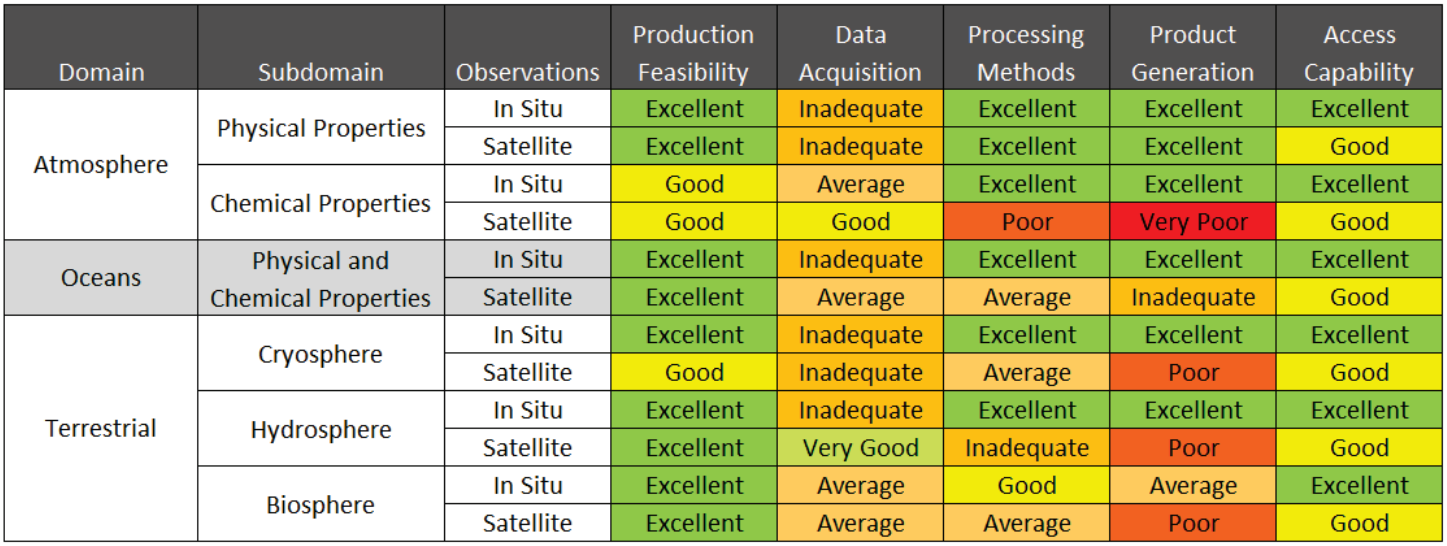
- Significant data products have already been developed and released, including land cover, a wetlands inventory, snow/ice extents, vegetation indices, and imagery mosaics. A schedule of data products to be developed and released over the course of the EO4CE project has been developed *(figure 1.5)*.
- Development of innovative scientific knowledge, methods, datasets, and tools, some highlights include:
    - Local optimization methods (moving windows) for improving regional accuracy of classifiers in national mapping applications
    - Development of a 200 year daily climate record at national scale (historical & forecast)
    - Discovery of freezing temperature controls in aquifer discharge in cold region watersheds
    - Discovery of the impact of water storage on ground surface subsidence in Southern Ontario
- Leadership and expertise has been demonstrated within NRCan and with other government departments and agencies through workshop development and participation, and provision of advice on regional selection.
- Collaborative activities have been established with numerous organizations including within the federal government (Environment and Climate Change Canada, Agriculture and Agri-Food Canada, Public Safety Canada), with provincial/territorial governments (NL, QC, NWT), academia (U-Ottawa, McMaster-U, U-Sherbrooke, Memorial U, U-Lethbridge, U-Waterloo), and non governmental organizations (Ducks Unlimited Canada).
- 10 scientific publications have been produced and a further 6 have been developed and/or submitted for journal review. Although not all journals maintain real-time readership figures, those that do have already demonstrated in excess of 1,500 readers over the short time these publications have been available.

Collectively, these efforts are enhancing Canada’s capacity to conduct regional assessments of cumulative effects. These data and science outputs will enable not only assessment processes, but also the ongoing monitoring programs required to support the integrity of Canada’s communities and ecosystems alongside industrial development.

Status and Trends Mapping Program – Overview

The importance for continuous, reliable and high-quality geospatial data describing Canada's changing landmass has been demonstrated for numerous current Canadian priorities, including climate change mitigation and adaptation, public safety and emergency response, and environmental assessment and monitoring. Presently there is no coordinated development of the critical datasets required and available data are insufficient to properly inform decision-making.

The decisions that these data would support are typically implemented at local and regional scales. However, the timelines required for providing that data prohibit a request-response delivery. As such, it is necessary to develop analysis ready data with national scale coverage and regional scale detail. This format of data development for priority datasets across the federal government is currently highly distributed and often fragmented. A whole of government workshop (60 participants across 9 departments) was held in 2017 to assess the state of Canada's geospatial data records describing Canada's landmass and waters. The workshop documented significant gaps in the production of systematic data describing parameters in the cryosphere, hydrosphere, biosphere, and chemical composition of the atmosphere (see figure 1.1).



Domain	Subdomain	Observations	Production Feasibility	Data Acquisition	Processing Methods	Product Generation	Access Capability
Atmosphere	Physical Properties	In Situ	Excellent	Inadequate	Excellent	Excellent	Excellent
		Satellite	Excellent	Inadequate	Excellent	Excellent	Good
	Chemical Properties	In Situ	Good	Average	Excellent	Excellent	Excellent
		Satellite	Good	Good	Poor	Very Poor	Good
Oceans	Physical and Chemical Properties	In Situ	Excellent	Inadequate	Excellent	Excellent	Excellent
		Satellite	Excellent	Average	Average	Inadequate	Good
Terrestrial	Cryosphere	In Situ	Excellent	Inadequate	Excellent	Excellent	Excellent
		Satellite	Good	Inadequate	Average	Poor	Good
	Hydrosphere	In Situ	Excellent	Inadequate	Excellent	Excellent	Excellent
		Satellite	Excellent	Very Good	Inadequate	Poor	Good
	Biosphere	In Situ	Excellent	Average	Good	Average	Excellent
		Satellite	Excellent	Average	Average	Poor	Good

Figure 1.1 – Essential Climate Variables Workshop – Canadian Development 'Report Card'

To ensure that Canadians have access to the data they need for evidence-based decision-making on Canada's priorities it is imperative that the federal government drive the development of status and trend variables. CCMEO has implemented the Status and Trends Mapping Program (STMP) to address this requirement.

To better inform evidence-based decision-making, the STMP will identify, develop, disseminate and analyze critical geospatial datasets for describing a changing Canadian landscape. This program will ensure that the foundational data required by Canadians is available on the Federal Geospatial Platform (FGP). The structure and delivery of the STMP will allow the FGP to deliver temporally continuous data for critical variables that are changing dramatically over time. The objectives of the STMP include:

- Establish sustainable production value chains within CCMEO for numerous status and trends variables
- Establish a collaborative and cooperative approach across the Government of Canada, and other partners, to respond to the needs for data development and dissemination
- Create the programming structure and organizational commitment that will support investment in:
  - data development governance,
  - data development research, innovation, and implementation, and
  - source data assets and analytical platforms.

Supporting Canadian needs for STMP data requires a strong understanding of the challenges at all stages of the geospatial value chain. In the past decade, the geospatial sector has seen an exponential increase in geomatics and Earth Observation (EO) science related data acquisition systems, data analytics and data delivery systems which has been simultaneously matched by open-access policies, cost-reductions, and user-driven data demand (see figure 1.2). However, consultation efforts have shown that the increased uptake that should have resulted from these improvements has not occurred in numerous domains. This indicates substantial persistent barriers that have been identified as: (1) data availability, (2) technological solutions and associated awareness, and (3) analytics expertise and capacity. The STMP has aligned its programming structure (see figure 1.3) to simultaneously address all three barriers to ensure Canadian end-user communities are able to make use of STMP deliverables.

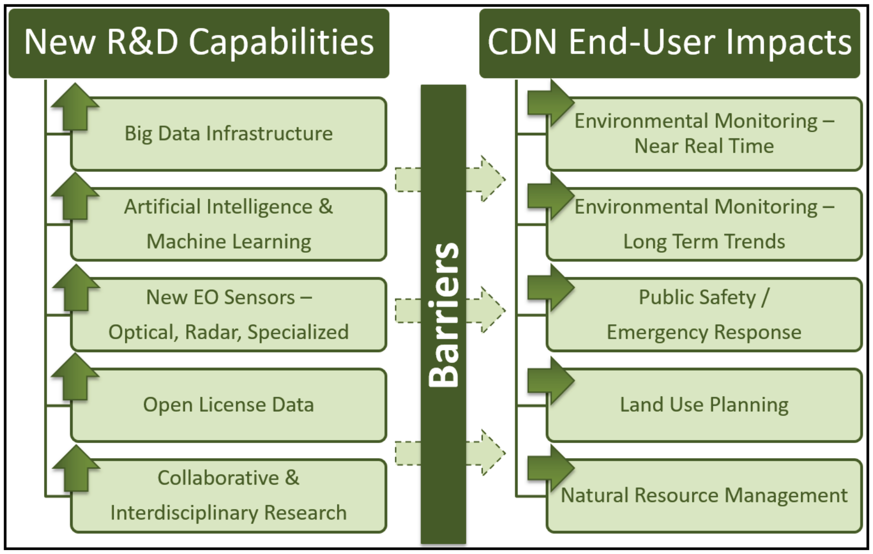


Figure 1.2 – Increasing capabilities in the geospatial sector have not translated well into Canadian end-user impacts due to persistent barriers.

The STMP will result in the development of critical geospatial data and analytics necessary to deliver across numerous current priority policy areas. These include environmental impact assessment, cumulative effects assessment, public safety and emergency response, climate change mitigation and adaptation, and infrastructure investment and risk assessment. While future priorities may be difficult to anticipate, they will undoubtedly rely on a detailed understanding of the changes occurring across Canada's landscape.

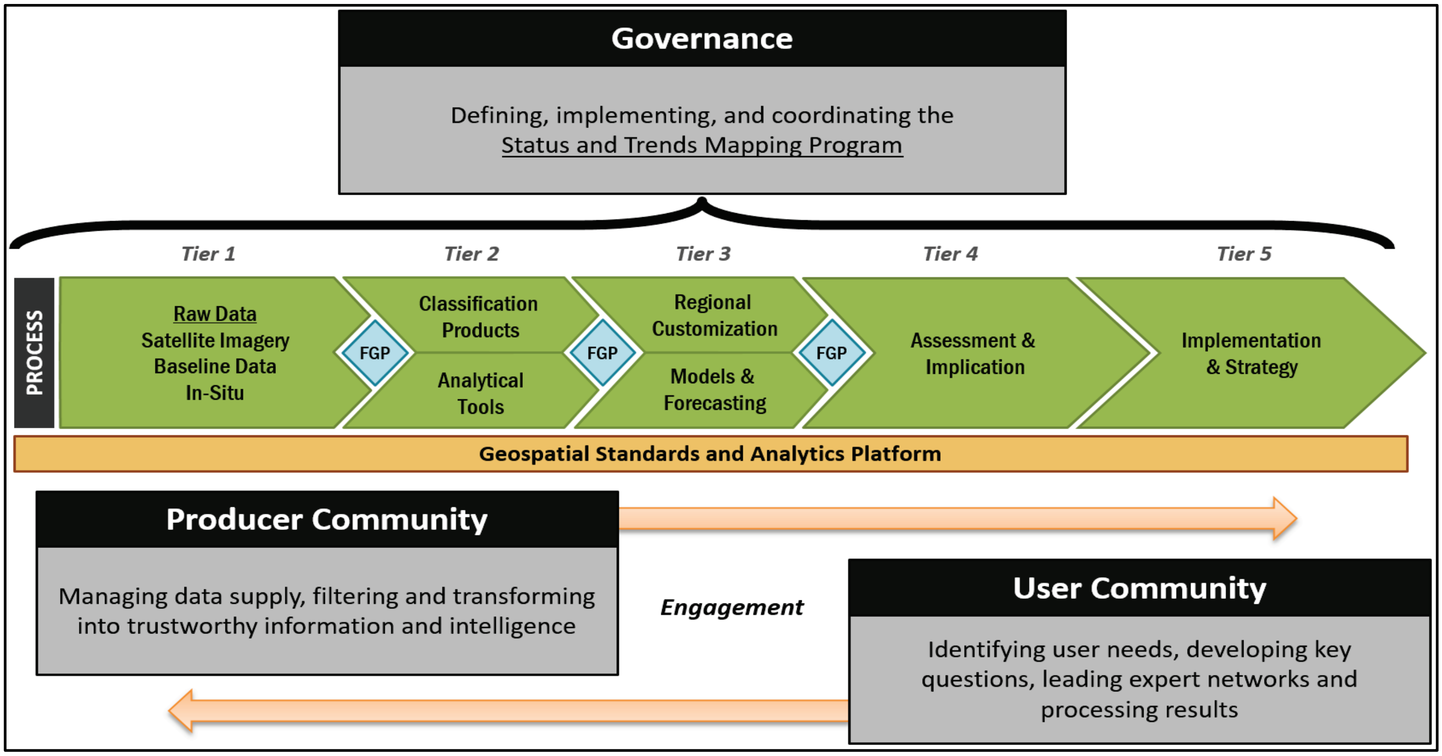


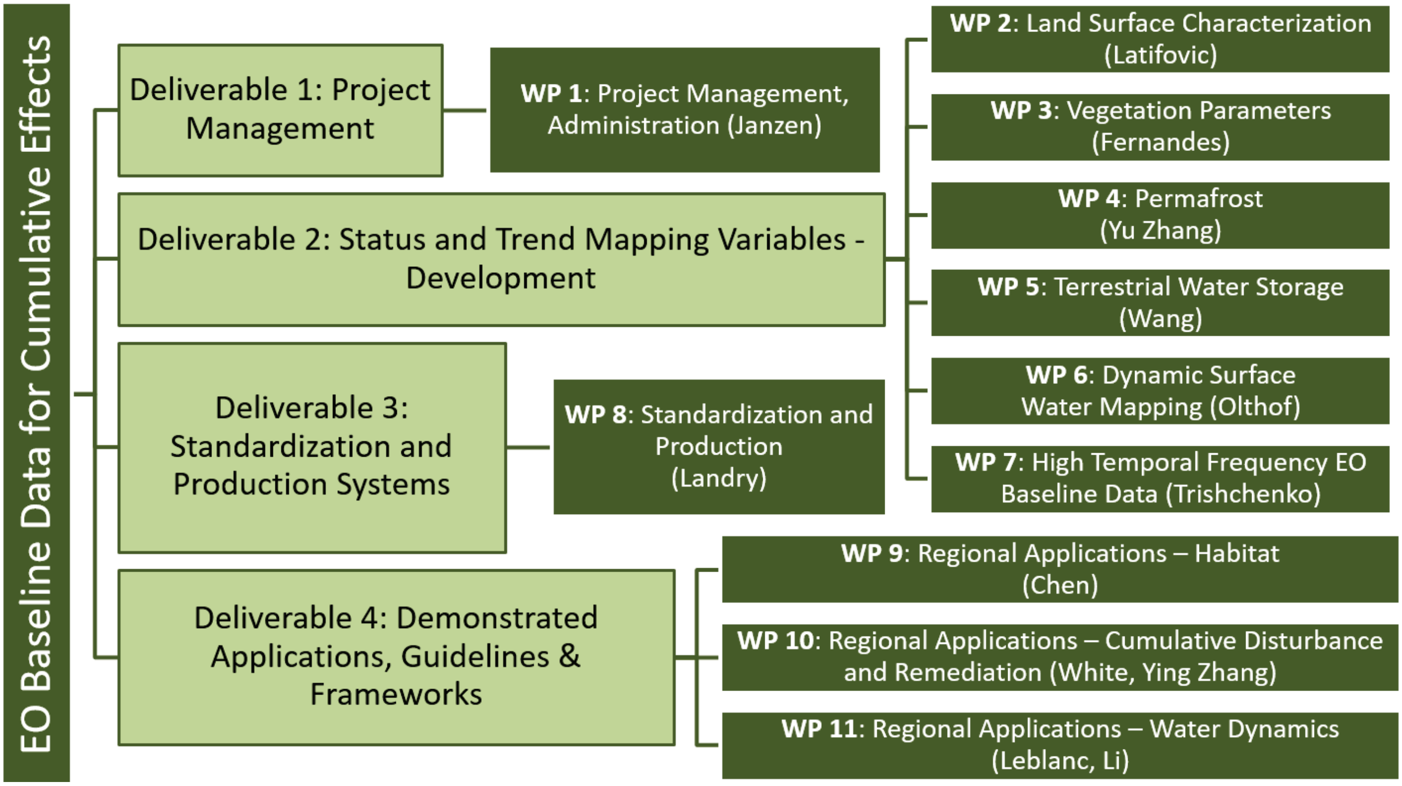
Figure 1.3 – Status and Trends Mapping Program Structure

Project Overview – EO Baseline Data for Cumulative Effects:

Implementation of the STMP will be accelerated through the EO4CE project which is part of Canada's investment in the Impact Assessment framework. Under this framework, the Government of Canada will take a deliberate approach to the assessment and management of cumulative effects, working collaboratively with provinces, territories and Indigenous Peoples. CCMEO's contribution to the approach will be to develop EO baseline data to support cumulative effects assessments. The production of these data will be operationalized to support currently planned cumulative effects assessments, future assessments, and ongoing monitoring. Application of developed datasets will be demonstrated in targeted regional assessments in partnership with other agencies and regional practitioners and experts.

A series of eleven work packages have been identified (see figure 1.4) in support of these cumulative effects assessments. Work packages (2-8) will establish national scale baseline datasets of broad use for cumulative effects and environmental impact assessments. Work packages (9-11) will develop and demonstrate the application of national baseline data for regional applications. Collectively, these work packages will:

- Improve capacity to conduct regional impact assessments through the development of national baseline data
- Improve the capacity of practitioners to customize national scale baseline data for regionally specific issues
- Improve the timelines for delivery of regional impacts assessments and the capacity to update these assessments
- Provide mechanisms to continually monitor regionally identified valued ecosystem components



Project Plan – EO Baseline Data for Cumulative Effects - https://gcdocs.gc.ca/nrcan-rncan/llisapi.dll/link/32992506
CCMEO Internal Workshop (2019/5/9) – Work Package Descriptions - https://gcdocs.gc.ca/nrcan-rncan/llisapi.dll/link/39220726

Figure 1.4 – Project Structure – 'EO Baseline Data for Cumulative Effects'

Two supplemental work packages have been added to the EO4CE project. The first (WP 12) is the Canadian Wetland Inventory, under Deliverable 2, producing national scale wetland datasets. The second is for Status and Trends Visualization (WP 13), under Deliverable 3, which will be an online application aimed at improving capacity for users to access status and trends data.

Accomplishments Overview (FY 2019 – 20):

Product Outputs & Scheduling – This year saw the development and release of several core datasets (see figure 1.5). Most notably this included a Land Cover dataset for the 2015 time period. This land cover dataset describes every area of Canada through a categorization system (e.g. urban, glacier, grassland, cropland, temperate forest etc). It is a foundational dataset that makes it possible to understand both the abrupt and the long-term changes occurring to the extents and spatial structure of Canada's natural and developed lands. Communication efforts to announce this data release demonstrated broad public interest for the dataset with over 500 reactions and/or comments on social media.

Canadian land-managers ability to characterize wetlands has been dramatically improved with the release of a beta-version of a Canadian Wetland Inventory. This dataset, produced in a systematic and consistent fashion, represents a dramatic improvement in data availability for Canada's wetlands and will improve capacity to manage and understand wildlife habitat, carbon cycling and flood hazards, amongst other needs.

FY 2019/20		Product	Coverage	Resolution	Time Period	Frequency
Q3	WP 2	Land Cover	National	30 m	2015	--
Q3	WP 2	Land Cover Change	National	30 m	2010-2015	--
Q4	WP 7	Snow/Ice probability maps, Min snow/ice extent (MODIS)	National	250 m	2000-2019	Warm season (Apr-Sept)
Q4	WP 7	Snow cover, NDVI (VIIRS)	National	250m,500 m	2017-2019	Daily
Q4	WP 7	TOA Mosaics - MODIS	National	250m	2000-2019	10-day
Q4	WP 7	TOA Mosaics - VIIRS	National	250m, 500m	2017-2019	10-day
Q4	WP 12	Wetland Classification (beta ~ optical only)	National	10 m	2018	--

FY 2020/21		Product	Coverage	Resolution	Time Period	Frequency
Q4	WP 2	Land Cover	National	30 m	2020	--
Q4	WP 2	Land Cover	Regional	10 m	1990-2020	Semi-Annual
Q3	WP 3	Vegetation Parameters (LAI, FAPAR, fCOVER possibly albedo	National	100 m	2019	Peak growing season
Q2	WP 4	Long-Term Daily Climate Dataset	National	1 km	1900-2100	Daily (calc on-demand)
Q4	WP 5	Total Water Storage	National	5 km	2002-2016	Monthly
Q4	WP 6	Dynamic Surface Water	Regional	30 m	1990-2020	Presented as Trend Product
Q4	WP 7	TOA Mosaics (VIIRS / MODIS)	National	250 m	2000-2020	10-Day Interval

FY 2021/22		Product	Coverage	Resolution	Time Period	Frequency
Q4	WP 2	Land Cover	Regional	30 m	1985-2020	Annual
Q2	WP 3	Vegetation Parameters (LAI, FAPAR, fCOVER possibly albedo	National	100 m	2000-2015	Growing season: monthly
Q2	WP 3	Vegetation Parameters (LAI, FAPAR, fCOVER possibly albedo	National	100 m	2016-2020	Growing season: 10 days
Q4	WP 3	Vegetation Parameters (LAI, FAPAR, fCOVER possibly albedo	Regional	30 m	2000-2020	Growing Season: Monthly
Q4	WP 3	Vegetation Parameters (LAI, FAPAR, fCOVER possibly albedo	Regional	30 m	2016-2020	Growing season: 10 days
Q4	WP 4	Permafrost	National	250 m	2020	--
Q4	WP 5	Total Water Storage	Regional	5 km	2002-2016	Daily
Q4	WP 6	Dynamic Surface Water (beta ~ optical only)	National	30 m	1990-2020	Presented as Trend Product
Q4	WP 7	SRF -level BRDF corrected data (MODIS&VIIRS)	National	250 m, 500 m	2021	10-day
Q4	WP 12	Wetland Classification (final ~ 90% accuracy)	National	10 m	2020	--

FY 2022/23		Product	Coverage	Resolution	Time Period	Frequency
Q4	WP 2	Land Cover - Reference Database	National	--	*varies*	--
Q4	WP 3	Vegetation Parameters (LAI, FAPAR, fCOVER possibly albedo	National	30 m	2000-2015	Growing season: monthly
Q4	WP 3	Vegetation Parameters (LAI, FAPAR, fCOVER possibly albedo	National	30 m	2016-2020	Growing season: 10 days
Q2	WP 4	Permafrost	National	30 m	2020	--
Q2	WP 4	Permafrost Predictions	National	30 m	2030-2100	Decadal
Q4	WP 5	Total Water Storage	National	5 km	1980-2021	Daily
Q4	WP 6	Dynamic Surface Water (Optical + Radar)	National	30 m	1990-2020	Presented as Trend Product
Q4	WP 7	SRF -level BRDF corrected data (MODIS&VIIRS)	National	250 m, 500 m	2017-2022	10-day

Figure 1.5 – Schedule and specifications of products being developed through the EO4CE project.

Finally, this year also saw the development and release of a series of datasets detailing minimum snow/ice extents and vegetation indices at a coarser resolution but with very frequent temporal resolution. These datasets inform characterization of long-term change processes, timing of surface water movements, and climate modelling.

Science Outputs – The EO4CE project began, for the majority of work packages, in September 2019. Science outputs, in the form of journal publications typically occur in the latter stages of project cycles. However, the EO4CE work being conducted leverages existing expertise and thus the project has already resulted in 10 publications as well as 6 additional manuscripts prepared for submission to scientific journals.

Publications:

DeLancey, Evan, R. John Simms, Masoud Mahdianpari, Brian Brisco, Craig Mahoney, and Jahan Kariyeva, "Comparing deep learning and shallow learning for large-scale wetland classification in Alberta, Canada", Remote Sens. 2019, 12, 2. https://doi.org/10.3390/rs12010002

Li, J., S. Wang, C. Michel, H. A. J. Russell, 2020, Surface Deformation observed by InSAR shows connections with water storage change in Southern Ontario. https://doi.org/10.1016/j.ejrh.2019.100661

Masoud Mahdianpari, Eric Gill, Bahram Salehi, Laura Bourgeau-Chavez Fariba Mohammadimanesh, Brian Brisco, and Saeid Homayouni, "Big Data for a Big Country: The First Generation of Canadian Wetland Inventory Map at a Spatial Resolution of 10-m Using Sentinel-1 and Sentinel-2 Data on the Google Earth Engine Cloud Computing Platform Canadian Journal of Remote Sensing, https://doi.org/10.1080/07038992.2019.1711366

Meisam Amani, Brian Brisco, Majid Afshar, S. Mohammad Mirmazloumi, Sahel Mahdavi, Sayyed Mohammad Javad Mirzadeh, Weimin Huang & Jean Granger (2019) A generalized supervised classification scheme to produce provincial wetland inventory maps: an application of Google Earth Engine for big geo data processing, Big Earth Data, 3:4, 378- 394, https://doi.org/10.1080/20964471.2019.1690404

Olthof, I. (2019). Automated surface water extraction from RapidEye imagery including cloud and shadow detection. Geomatics Canada Open File 52. 20 pp. https://doi.org/10.4095/315176

Rainville, T. and Olthof, I. (2020). Evaluating simulated compact polarimetry for Emergency Geomatics Services flood mapping. Geomatics Canada Open File 55. 59 pp. https://doi.org/10.4095/321454

Trishchenko, A.P. 2019. Clear-sky composites over Canada from visible infrared imaging radiometer suite to continue MODIS time series. *Canadian Journal of Remote Sensing*. 45(3-4), pp. 276-289. https://doi.org/10.1080/07038992.2019.1601006

Trishchenko, A.P., L.Garand, L.D.Trichtchenko, 2019: Observing Polar Regions from Space: Comparison between Highly Elliptical Orbit (HEO) and Medium Earth Orbit (MEO) Constellations. *Journal of Atmospheric and Oceanic Technology*, Volume 36 No. 8, pp. 1605–1621. https://doi.org/10.1175/JTECH-D-19-0030.1

Trishchenko, A.P., Trichtchenko, L.D., Garand, L. 2019: Highly elliptical orbits for polar regions with reduced total ionizing doze. *Advances in Space Research*. 63(12), pp. 3761-3767. https://doi.org/10.1016/j.asr.2019.04.005

Wang, S., 2019. Freezing temperature controls winter water discharge for cold region watershed. Water Res. Res., 55, https://doi.org/10.1029/2019WR026030

Prepared Manuscripts:

Brown, L., Morris, H., Fernandes, R., Djamai, N., Canisius, F., Hong , G., , Dash, J. 2020. Validation of baseline and modified Sentinel-2 Simplified Level 2 Prototype Processor leaf area index retrievals over the North American continent.

Burke, E., Y. Zhang, and G. Krinner. 2020. Evaluating permafrost physics in the CMIP6 models and their sensitivity to climate change.

Djamai, N. and Fernandes, R., 2020. Active learning regularization increases clear sky retrieval rates for biophysical variables using Sentinel-2 data.

Fernandes, R., Djamai. N., Brown, L. and Dash, J., 2020. Uniform priors are sufficient for well posed retrievals of canopy structure variables over crops using Sentinel-2 Multispectral Imager Data.

Zhang, Y., B. Qian, and G. Hong. 2020. A 1-km resolution long-term daily meteorological dataset for modelling and mapping permafrost in Canada.

Zhang, Y., R. Touzi, W. Feng, G. Hong, T. C. Lantz, and S. Kokelj. 2020. Landscape-scale variations of near-surface soil temperature and active-layer thickness measured at multiple sites in northwestern Canada.

Workshops – Cumulative effects are a new application domain for the majority of CCMEO science teams. However, much of the science and data requirements are firmly rooted in aspects of CCMEO expertise. To prepare staff for the implementation of the EO4CE project, an internal CCMEO workshop was organized on May 3, 2019 (figure 1.6) to:

- describe the current state of environmental assessment and cumulative effects assessment in Canada,
- outline the commitments that CCMEO will be expected to contribute
- overview the scientific programming structure to achieve these commitments

CCMEO science teams also participated in a departmental committee to develop a department-wide workshop on cumulative effects (figure 1.6). CCMEO staff delivered a presentation outlining their programming structure and led two breakout sessions (cryosphere science/data requirements, and communications).

Finally, CCMEO staff were invited to an ECCC departmental workshop to present the EO4CE project in order that science teams within that department would be better able to collaborate on their science/data development efforts within their expertise (e.g. atmosphere, wildlife habitat).

Broadly, development and participation in these workshops has improved departmental awareness and uptake of CCMEO science/data outputs as well as helped to form collaborative activities across science teams. Workshop reports have also been generated outlining future science/data requirements and communications expectations.

Figure 1.6 – CCMEO Staff organized and held an internal workshop on cumulative effects (left) and helped to organize and deliver a department-wide workshop on cumulative effects (right).

Collaborations – CCMEO staff have contributed to Government of Canada efforts to identify potential areas for regional selection. In addition to participating in a whole of government effort to identify regions of interest, CCMEO staff have provided contextual geospatial mapping and analysis to support decision-making on requests for regional assessments received under section 9.1 of the *Impact Assessment Act.*

Additionally, a large number of collaborations have been established both internal and external to NRCan.

- *Collaborative research on caribou habitat characterization* – Canadian Forest Service, Environment and Climate Change Canada, Government of Newfoundland and Labrador, Government of Quebec, Government of Northwest Territories
- *Field data collection for Canadian Wetland Inventory* – Environment and Climate Change Canada, Ducks Unlimited Canada, Northeast Avalon Atlantic Coastal Action Program, Memorial University of Newfoundland, and the University of Lethbridge
- *Development of long-term daily climate dataset (1900-2100)* – Agriculture and Agri-food Canada
- *Implementation of long-term inundation frequency mapping* – Public Safety Canada

- *Partnership for field data collection supporting water characterization at Turkey Point* – McMaster University
- *Partnership to evaluate Permafrost melting impacts* – University of Ottawa
- *Partnership to evaluate remote sensing tools for river water management and mapping* – University of Sherbrooke

WP 2: Land Surface Characterization

Rasim Latifovic, Morgan McFarlane-Winchester, Francis Canisius, Lixin Sun

Overview:

National scale Land Cover and Land Cover Change (LULCC) information are required for studying land-surface processes that characterize environmental, social and economic aspects of sustainability. LULCC information includes fundamental Earth surface attributes shaped by geologic, hydrologic, climatic, atmospheric, and land use processes occurring at a range of space-time scales. LULCC, in turn, affects these processes through feedback mechanisms such as plant respiration, which both absorbs and releases carbon, water, oxygen and other biochemical elements from or to the environment. Therefore, knowledge of LULCC is essential to understand Earth surface processes that are relevant for land management and preservation of natural environments that may influence ecosystem and human health. In response to this need, this work package has generated a 30 m Land Cover Map of Canada for the base year 2010 as part of planned series of maps updated at least every 5 years. The purpose of these national scale data products in relation to cumulative impact assessments is to provide a starting point for generating LULCC information required for specific regions of interest.

Evaluation of cumulative impacts and supporting related decision-making requires accurate measurements of LULCC parameters as changes observed in these parameters determine the hydrological and ecological processes taking place in affected environments. However, despite its importance, the availability of appropriate LULCC information required for impact assessment is limited and many user needs remain unsatisfied. Studying different environmental aspects requires different LULCC information particularly in terms of the number and type of classes, frequency of updates, and spatial resolution; meeting such varied needs with general LULCC datasets is difficult. Generating land cover datasets is a demanding process that requires significant human and financial resources. Furthermore, coordination between user and producer communities is limited, impeding progress in addressing these shortcomings. This range of user needs and other complications presently make it impractical to address all requirements with a single national dataset. A new approach to generating and providing LULCC information is needed that can both meet such varied user requirements and still be operationally practical and sustainable. General user needs could be categorized into the following three aspects: 1) classification system and thematic resolution, 2) spatial and temporal resolution, and 3) accuracy and consistency. With these basic users' needs in mind a sustainable and operational system that can generate LULCC datasets according to specific user requirements is the objective of this project. Such a system will be capable of generating consistent datasets on a regular basis; when appropriate input data are available it provides an overall accuracy of greater than 80%.

Outcomes (FY 2019/20):

A rigorous mapping approach as a fundamental part of the LULCC mapping system is one of the WP 2 outputs. The approach is employed for generating land cover datasets for Canada for 2010 and 2015 from TM, ETM+ and OLI Landsat sensors observations. The process incorporates innovative approaches for local optimization of the land cover classifier resulting in significant increases in spatial consistency and accuracy. Training and classifying with locally confined reference samples over large number of partially overlapping areas is performed using moving windows to ensure optimization of the classifier to a local land cover distribution and to decrease the negative effect of signature extension. A weighted combination of labels determined by the classifier in overlapping windows defines the final label for each pixel. The approach requires extensive computation; therefore, it has been developed and deployed on the Government of Canada's High-Performance Computing Center (HPC). An accuracy assessment based on randomly distributed samples shows that land cover data products with this new approach has achieved 79 % accuracy with no marked spatial disparities.

Data Products:

- Land Cover Maps of Canada at 30m spatial resolution
    - 2010: https://open.canada.ca/data/en/dataset/c688b87f-e85f-4842-b0e1-a8f79ebf1133
    - 2015: https://open.canada.ca/data/en/dataset/4e615eae-b90c-420b-adee-2ca35896caf6 *(figure 2.1)*

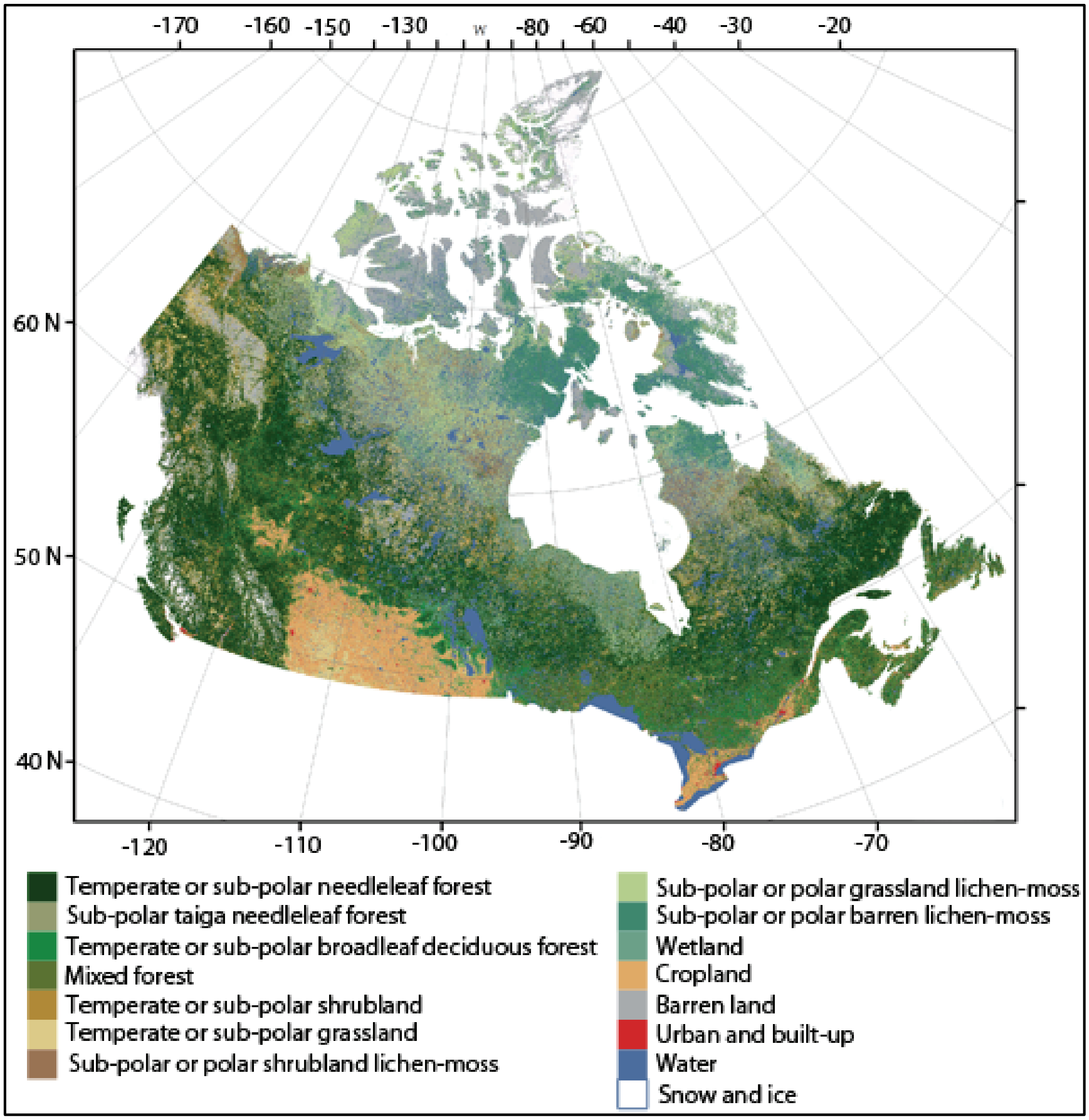


Figure 2.1 – 2015 Land Cover product with land cover class structure; see appendix 1 for image of Land Cover Poster

Risks / Challenges:

Labor intensiveness: Most LULCC datasets require very large amounts of manual labor, making them expensive to produce, especially at national scale. This results in infrequent or widely spaced updates, making change assessment difficult. Automated processing approaches have been undertaken as a practical solution to this issue. However, while the accuracy of automatically generated datasets continues to improve, these approaches may not yet be fully up to the level provided by manual methods and the requirements of user communities.

Data availability: Although multispectral datasets like Landsat and Sentinel 2 are now widely available the number of classes they can accurately support is limited by the information content of the data. Complementary data sources would add additional information and thus be able to support a greater number of classes and/or more accuracy. Some key data sources are remote-sensing-based, such as hyperspectral, radar, and lidar sensors, while others could include a wide range of data including socio-economic information.

Additional References:

Latifovic, R, Pouliot, D and Olthof, I. Circa 2010 Land Cover of Canada: Local Optimization Methodology and Product Development. Remote Sensing 2017, 9, 1098; https://doi. org/10.3390/rs9111098

WP 3: Vegetation Parameters

Richard Fernandes, Francis Canisius, Gang Hong, Najib Djamai

Overview:

The goal of this work package is to provide national scale data products for key vegetation biophysical variables, together with uncertainty information, and software tools to produce regional scale products on demand. These key variables (Table 1) have been identified, together with goal and threshold performance requirements, as essential climate, biodiversity or agricultural variables by international and intergovernmental panels. Additional variables (Table 3.1) will also be mapped on an experimental basis.

Variable	Threshold Requirement			Goal Requirement		
	Spatial (m)	Temporal (d)	Thematic Units,%	Spatial (m)	Temporal (d)	Thematic Units,%
Fraction of Absorbed Photosynthetically Active Radiation	500	30	Max(0.05,10%)	50	10	Max(0.05,10%)
Fraction of Vegetation Cover	250	30	Max(0.1,15%)	50	10	Max(0.05,10%)
Leaf area index	250	30	Max(1,20%)	50	10	15%
Albedo	250	30	Max(0.0035,5%)	50	10	Max(0.0035,5%)
Canopy Cholorophyll Content	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Canopy Water Content	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

Table 3.1 – Product requirements. Shaded rows indicate optional products. N.S. indicates no consensus requirement.

Following recommendations from the Global Climate Observing System Implementation Plan, the Landsat Science Plan, and the SEN4SCI Plan, all variables will be mapped using medium resolution (10m to 100m) satellite based optical imagers. Considering the need for long-term stability and to reduce costs, the Landsat and Sentinel Imagers (Table 3.2) will be used for generating products although other commercial and scientific imagers will be used for product assessment.

Satellite, Imager	Extent	Resolution	Revisit	Notes
Landsat 5, Thematic Mapper	1984-2012	30m	14d	Only for NRCan processing.
Landsat 7, Enhanced Thematic Mapper	1999-2017	30m	14d	Only for NRCan processing.
Landsat 8, Operational Line Imager	2013-present	30m	14d	Both NRCan and Google Earth Engine processing.
Sentinel 2A, Multispectral Instrument	2015-present	20m	5d	Only Google Earth Engine processing
Sentinel 2B, Multispectral Instrument	2017-present	20m	5d	Only Google Earth Engine processing

Table 3.2 – Available relevant input satellite data records.

Two solutions for product generation will be implemented. Canada wide products will be generated on an annual basis for peak season conditions at <=100m resolution using NRCan computing facilities and available NRCan input data (currently limited to Landsat imagey). These products will be disseminated by the Federal Geospatial Platform. Regional production (<5000 product granules per request) will be enabled by providing the Landscape Evolution and Forecasting (LEAF) toolbox to users within Google Earth Engine. This toolbox, developed under the GEODE GRIP project, is capable of near real time product visualization and production using a generic interface running within Google Chrome.

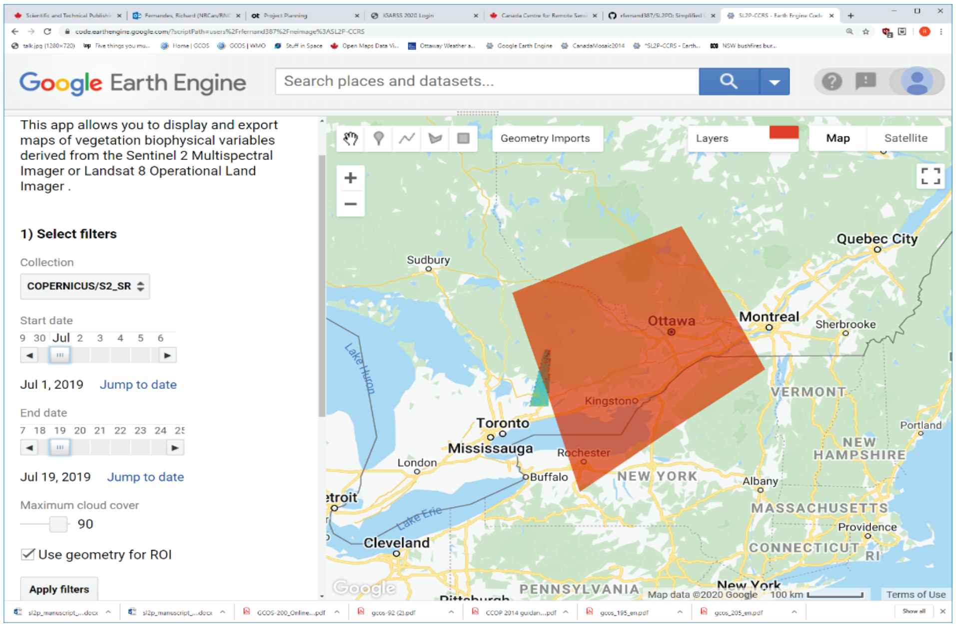
A three-stage approach will be used to implement algorithms within both the NRCan and Google Earth Engine solutions.

-Version 0 - corresponds to the Simplified Level 2 Prototype Processor (SL2P) developed for Sentinel 2 product generation and adapted for Landsat 8 product generation by INRA France. This processor in known to satisfy user requirements for crops but has mixed performance over forest conditions.

-Version 1 - corresponds to SL2P with calibration datasets tuned for regional conditions across Canada. The tuning corresponds to both changes to the simulation physics, to address heterogeneous canopies such as forests, and calibration dataset specifications, to address regional variations in canopy conditions.

-Version 2 - corresponds to an active learning algorithm (Djamai and Fernandes, 2020) applied to refine the SL2P retrieval strategy based on conditions specific to each retrieved product.

Uncertainty assessment of products is based on a three-stage approach. Firstly, all products include theoretical uncertainty estimates based on cross-validation against simulated datasets. Secondly, data acquired using global validation efforts (the Global Validation of Satellite Products project and P2P Agriculture and Forests projects funded by the EU) and thirdly, *in situ* data acquired by regional work packages are processed systematically by WP 3.



This app allows you to display and export maps of vegetation biophysical variables derived from the Sentinel 2 Multispectral Imager or Landsat 8 Operational Land Imager .

1) Select filters

Collection: COPERNICUS/S2_SR

Start date: Jul 1, 2019

End date: Jul 19, 2019

Maximum cloud cover: 90

☑ Use geometry for ROI

Figure 3.1 – Landscape Evolution and Forecasting (LEAF) Toolbox running Version 0 algorithm.

Outcomes (FY 2019/20):

1. The Version 0 algorithm was implemented in both NRCan and Earth Engine Platforms (e.g. Figure 3.1).
2. The Algorithm theoretical basis for the Version 1 algorithm was published (Fernandes et al., 2020) together with code (https://github.com/rfernand387/SL2PD).
3. A database of Canada wide forest *in situ* measurements for canopy structure was acquired and processed. This consists of 7 regional sites with a total of 82 peak season plots and one site with 40 plots spanning an entire year.
4. The Version 0 and a prototype Version 1 algorithms were validated internally (Fernandes et al. 2020) and in collaboration with GBOV (Brown et al., 2020).
5. The Version 2 theoretical basis was submitted for publication (Djamai and Fernandes, 2020).

Risks / Challenges:

The primary risk for this work package is obtaining highly qualified personnel (HQP). Within Canada's current job market, the skillsets desired are difficult to obtain. Mitigation approaches could be adopted such as:

- improving staffing scheduling to facilitate long isolated time periods for core teams to focus on deliverables, and
- finding approaches to streamline hiring processes, especially student coop terms.

Uncertainty assessment of supplementary products, especially those related to biochemistry, is challenging due to lack of lab facilities and the need to network with wide-ranging expert communities. Collaboration with Canadian university groups and with European Union teams is being explored.

Product uncertainty may not meet user requirements at Version 0 or Version 1. We plan to provide users with a facility to specify their own empirical algorithms within the LEAF Toolbox to mitigate this issue.

Additional References:

Fernandes, R., Djamai. N., Brown, L. and Dash, J., 2020. Uniform priors are sufficient for well posed retrievals of canopy structure variables over crops using Sentinel-2 Multispectral Imager Data, submitted to Rem. Sens. Env.

Djamai, N. and Fernandes, R., 2020. Active learning regularization increases clear sky retrieval rates for biophysical variables using Sentinel-2 data. submitted to Rem. Sens. Env.

Brown, L., Morris, H., Fernandes, R., Djamai, N., Canisius, F., Hong , G., , Dash, J. 2020. Validation of baseline and modified Sentinel-2 Simplified Level 2 Prototype Processor leaf area index retrievals over the North American continent, submitted to Rem. Sens. Env.

WP 4: Permafrost

Yu Zhang, Ridha Touzi, Gang Hong, Xiping Wang

Overview:

About half of Canada's landmass is underlain by permafrost. Permafrost is thawing due to climate warming, which has significant impacts on ground stability, infrastructure, hydrology, ecosystems and the climate system. This work package will leverage optical and radar data to improve the spatial resolution of the current permafrost map and will lead to effective incorporation of permafrost information into land-use planning, environmental impact assessments and infrastructure development.

This work package will use a remote sensing-based spatial modelling approach to quantify permafrost conditions and changes with climate. This work package will also develop new methodologies for integration of radar and optical data for enhanced characterization of subsurface permafrost conditions.

This work package will develop national scale coverage, regional scale detail permafrost maps at 250m to 30m resolutions, which will leverage land surface characterization, vegetation parameters, permafrost modelling and climate data for impact assessments.

Outcomes (FY 2019/20):

1. A 1-km resolution long-term daily meteorological dataset (Met1km)

Long-term spatially detailed climate data are essential for modelling permafrost distribution and changes. We developed a long-term (1901-2100) 1-km resolution daily meteorological dataset (Met1km) in Canada for modelling and mapping permafrost at high spatial resolutions. Figure 4.1 and 4.2 shows examples for air temperature. The dataset includes seven climate variables (daily minimum and maximum air temperature, precipitation, vapour pressure, wind speed, solar radiation, and downward longwave radiation). The dataset is generated based on a historical climate record represented by four coarser gridded meteorological datasets. The future climate scenarios are from the outputs of a newly developed Canadian regional model under two Representative Concentration Pathways (4.5 and 8.5). These datasets were down-scaled using a 1-km resolution climate dataset as the spatial template (re-baselining using the monthly averages from 1970 to 2000). We assessed the dataset by comparing with climate observations across Canada. The accuracy of the Met1km is similar to or smaller than coarser gridded climate datasets.

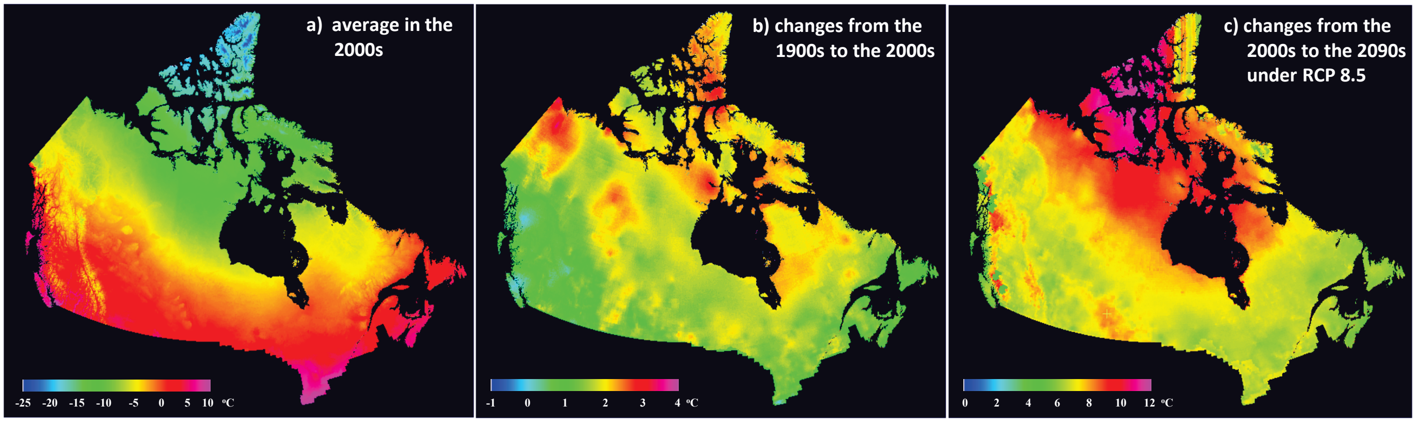


Figure 4.1 – The spatial distributions and temporal changes of air temperature generated by the Met1km dataset. The dataset includes daily minimum and maximum air temperature, precipitation, vapour pressure, wind speed, solar radiation, and downward longwave radiation at 1-km resolution from 1901-2100 with two future scenarios.

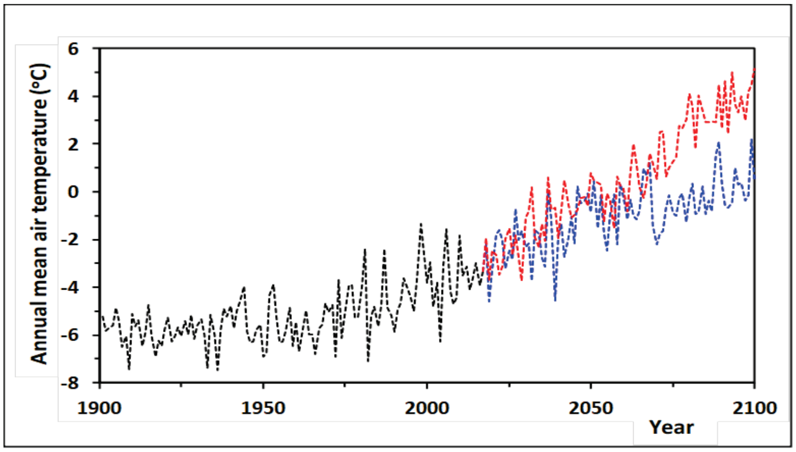


Figure 4.2 – Grid based mean air temperature values extracted from the Met1km dataset for Yellowknife, NWT.

2. Field observations of near-surface permafrost conditions for permafrost mapping

Understanding the local-scale variations of permafrost conditions is essential for mapping permafrost at high spatial resolutions. We conducted fieldwork to measure near-surface ground temperature, active-layer thickness, soil and vegetation conditions at multiple sites across Canada (Inuvik, Tuktoyaktuk, Hay River, and Labrador areas). Detailed field data were collected at nearly 200 sites. These data will be used to understand permafrost conditions at local-scales, calibrate our permafrost model (NEST), and validate high-resolution permafrost maps.

3. Mapping and monitoring discontinuous permafrost using long penetrating radar

Mapping and monitoring discontinuous permafrost using long penetrating radar at 20 m resolution Japanese satellite ALOS equipped with a long penetrating radar is considered for mapping discontinuous permafrost distributed within wooded palsa bogs and peat plateaus near the Namur Lake (Northern Alberta)**.** Very promising results are obtained (Figure 4.3).

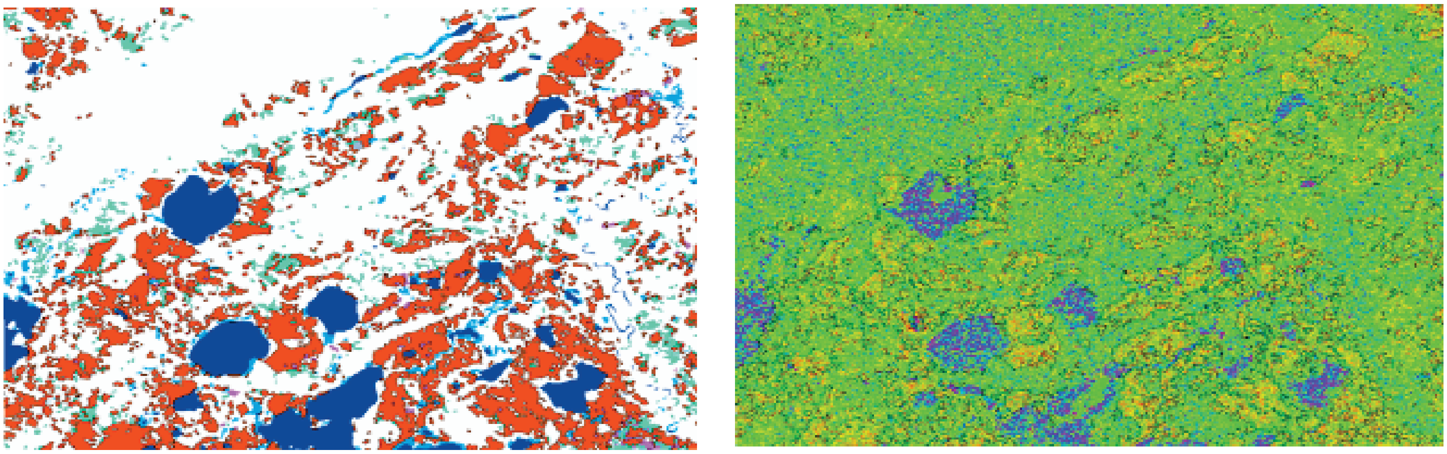


Figure 4.3 – Discontinuous permafrost (pink) in the Lidar image (left) is well identified in the radar image (orange). The results show that the long penetrating radar is promising to detect and map permafrost accurately.

Additional References:

Zhang, Y., B. Qian, and G. Hong. A 1-km resolution long-term daily meteorological dataset for modelling and mapping permafrost in Canada (manuscript).

Zhang, Y., R. Touzi, W. Feng, G. Hong, T. C. Lantz, and S. Kokelj. Landscape-scale variations of near-surface soil temperature and active-layer thickness measured at multiple sites in northwestern Canada (manuscript).

Burke, E., Y. Zhang, and G. Krinner. Evaluating permafrost physics in the CMIP6 models and their sensitivity to climate change, The Cryosphere (submitted).

Touzi, R., S. Pawley, and M. Husseini. Polarimetric L-band PALSAR2 for discontinuous permafrost mapping in peatland regions, Proc. of IGARSS`19, Yokohama, Japan, 28 July- 2 Aug. 2019

WP 5: Terrestrial Water Storage

Shusen Wang, Junhua Li, Zhaoqin Li, Stefan Nedelcu

Overview:

Terrestrial Water Storage (TWS) is all the water present in a terrestrial ecosystem. It includes soil water, groundwater, surface water (e.g., rivers and lakes), snow, glaciers, and water contained in plants and organisms. TWS and its dynamics determine water resources availability and sustainability. It is a key dataset required to support NRCan's mandate for sustainable development of natural resources and the health and safety of Canadians. Access to water is considered a universal human right (UN Committee on Economic, Social and Cultural Rights, 2003), but water resources are under increasing pressure in many parts of the world to meet demands due to population growth and climate change. Cumulative effects from human disturbances on TWS are largely unknown.

TWS change for a terrestrial ecosystem is determined by the water cycle which includes water inputs such as precipitation, and outputs such as evapotranspiration, surface runoff, and groundwater discharge. These processes can be significantly affected by human activities.

The GRACE mission has enabled TWS to be observed for the first time from space. The first GRACE mission collected 163 months data in 2002-2017, followed by the GRACE Follow-On mission launched in 2018. GRACE has significantly contributed to water and climate studies including the characterization of TWS climatology and water budgets for Canada (Wang et al., 2014; Wang and Li, 2016; Li et al., 2016), the quantification of glacier melts for the Yukon Basin and Arctic Cordillera, and water recovery process after the severe drought in 2000-2003 for the Canadian Prairies (Wang et al., 2015).

Further applications of TWS derived from GRACE, particularly for cumulative effects studies, are facing several major challenges, including an insufficient GRACE record length for constructing TWS baseline conditions, coarse spatial resolution (>300-km) and temporal resolution (monthly), and limitations for quantifying TWS components such as groundwater, soil water, and surface water.

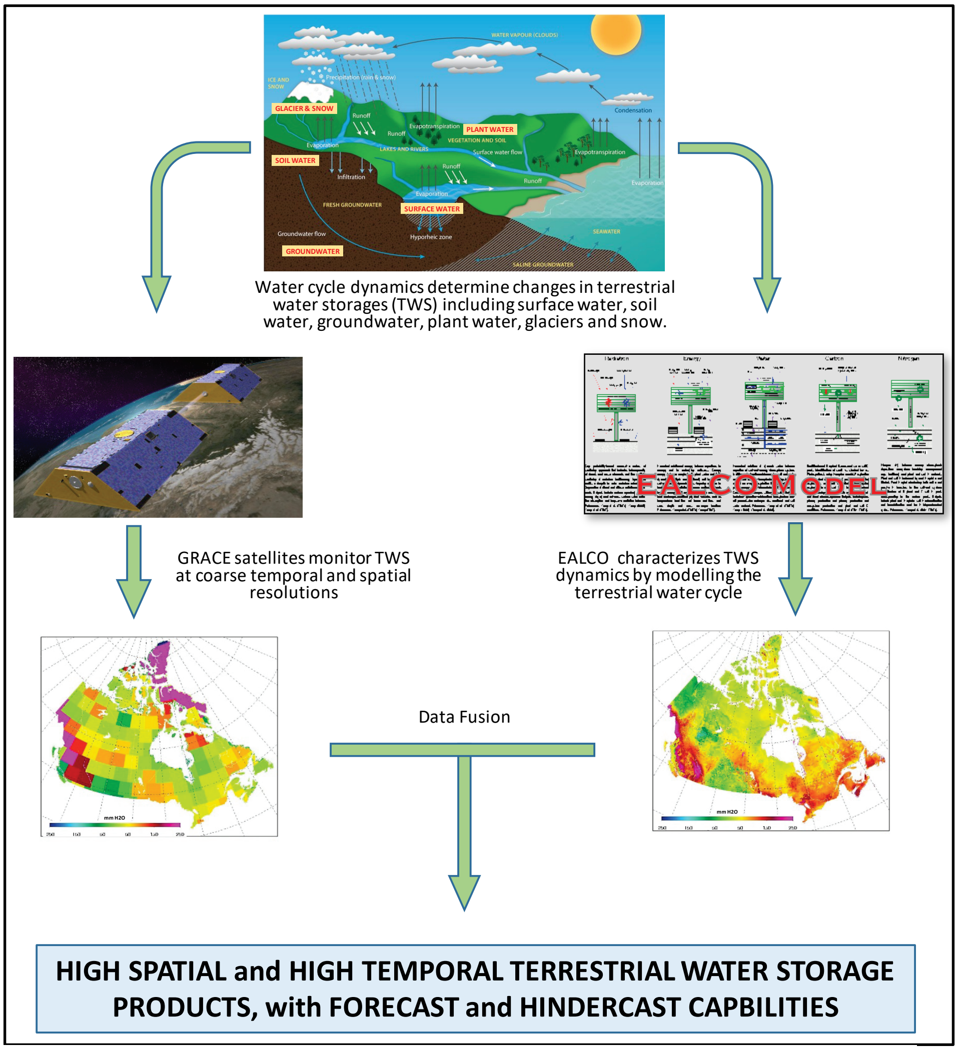


Figure 5.1 – Flow chart for terrestrial water storage work activities

The objectives of WP 5 are to develop methods to construct the TWS baseline, to produce high spatial (5-km) and temporal (daily) resolution datasets, and to solve the TWS components of soil water, groundwater, and snow water equivalent. The major outputs from WP 5 for TWS will meet the requirements for cumulative effects assessment for Canada's landmass.

The methods include data fusion techniques using datasets from GRACE and the EALCO model. EALCO is an EO-based land surface model developed in NRCan for simulating the Earth System processes including the terrestrial water cycles, such as land surface evapotranspiration, dew and frost formation, snow dynamics, surface infiltration and runoff, soil water transfers, groundwater recharge and discharge. EALCO will provide the terrestrial TWS dynamics at high spatiotemporal resolutions which will be integrated with the GRACE coarse resolution TWS data to produce high resolution TWS datasets. Models for predicting TWS will be built to construct the long-term historical TWS datasets prior to the GRACE mission.

Source datasets used in WP 5 include a wide range of geospatial datasets from remote sensing, *in situ*, and climate model outputs. Besides GRACE data, optical and microwave EO products for vegetation and soils are used as inputs for the EALCO model. Data from field UAV campaigns and in situ observations are used for model calibration and validation. Partners include Land Minerals Sector of NRCan, University of Waterloo, McMaster University, among others.

Outcomes (FY 2019/20):

Activities have focused on initial data processing, intermediate data production, and methods development. Major data outputs include (see figure 5.1):

1) 5-km resolution datasets (daily, monthly, annual):
- Evapotranspiration
- Dew/frost formation
- Surface runoff
- Groundwater recharge
- Soil water content
- Soil ice content
- Snow water equivalent
- Potential evaporation
- Soil temperature

2) 1.0-degree TWS datasets from GRACE spherical harmonics solution (monthly).
3) 0.5-degree and 0.25-degree TWS datasets from GRACE mascon solution (monthly).

The datasets and knowledge produced in WP 5 have contributed to a number of innovations in water and climate change studies, such as the discovery of freezing temperature control in aquifer discharge (Wang 2019), and the impact of water storage increase on ground surface subsidence in Southern Ontario in the past decade (Li et al., 2020).

Wang, S., 2019, Freezing temperature controls winter water discharge for cold region watershed. Water Res. Res., 55, https://doi.org/10.1029/2019WR026030

Li, J., S. Wang, C. Michel, H. A. J. Russell, 2020, Surface Deformation observed by InSAR shows connections with water storage change in Southern Ontario. J. Hydrol.: Regional Studies, 27, 100661. http://doi.org/10.1016/j.ejrh.2019.100661

Risks / Challenges:

Challenges persist in finding highly qualified personnel with the skillsets required for terrestrial water storage modelling.

Additional References:

Wang, S. and J. Li, 2016, Terrestrial water storage climatology for Canada from GRACE satellite observations in 2002-2014. Can. J. Rem. Sens., 42, 190-202, doi: 10.1080/07038992.2016.1171132.

Wang, S., J. Huang, J. Li, A. Rivera, D.W. McKenney, and J. Sheffield, 2014, Assessment of water budget for sixteen large drainage basins in Canada. J. Hydrology, 512: 1-15, doi: 10.1016/j.jhydrol.2014.02.058.

Wang, S., J. Huang, D. Yang, G. Pavlic, J. Li, 2015, Long-term water budget imbalances and error sources for cold region drainage basins. Hydrol. Proc., 29, 2125–2136, doi: 10.1002/hyp.10343.

Li, J., Wang, S. and Zhou, F., 2016, Time Series Analysis of Long-term Terrestrial Water Storage over Canada from GRACE Satellites Using Principal Component Analysis. Can. J. Rem. Sens., 42, 161-170, doi: 10.1080/07038992.2016.1166042.

Wang, S., Zhou, F., Russell, H. A. J., 2017. Estimating snow mass and peak river flows for the Mackenzie River basin using GRACE satellite observations. Rem. Sens., 9, 256, doi: 10.3390/rs9030256.

Wang, S. and H. Russell, 2016, Forecasting snowmelt-induced flooding using GRACE satellite data: A case study for the Red River watershed. Can. J. Rem. Sens., 42, 203-213, doi: 10.1080/07038992.2016.1171134.

WP 6: Dynamic Surface Water Mapping

Ian Olthof, Tom Rainville

Overview:

Surface water has traditionally been mapped as a static layer, while water is truly dynamic and its effects on ecosystem processes and land use activities is dependent on where water is located in both space and time. By not understanding the full range of surface water extents, poor land use decisions have been made in the past (e.g. development on floodplains), that now cost millions annually due to flood damage. Among addressing other issues around water resources (e.g. ecosystem integrity), a dynamic surface water map layer will better inform land use and associated financial and policy decisions going forward.

The methodology is derived from Emergency Geomatics Service's (EGS) current flood mapping tools that exploit knowledge and information imbedded in existing water maps to generate new maps from different satellite data (figure 6.1). Previous iterations of the methodology have been demonstrated during EGS flood monitoring and mapping activations since 2017 and published in Olthof (2017) and Olthof and Tolszczuk-Leclerc (2018). The method uses existing surface water maps to sample scene-specific signatures representing permanent land and permanent water that are input into a machine-learning algorithm to generate a binary land / water map. Because signatures are scene-specific, the methodology is sensor-independent and has been demonstrated to work well on a range of fine to moderate resolution optical and radar data. Several demonstrations have been conducted over flood-prone areas in Canada using Landsat, RadarSat-2, Sentinels 1 and 2 and RapidEye (figure 6.2), and we intend to use a multi-sensor approach to generate national-scale water maps. The Landsat archive is available to the public free of charge through the USGS, while Sentinel-1 and 2 are similarly available through the ESA. RadarSat-2 is available through the EODMS to the Government of Canada free of charge. As much best available historical satellite data will be used across Canada within the project timeframe to generate products.

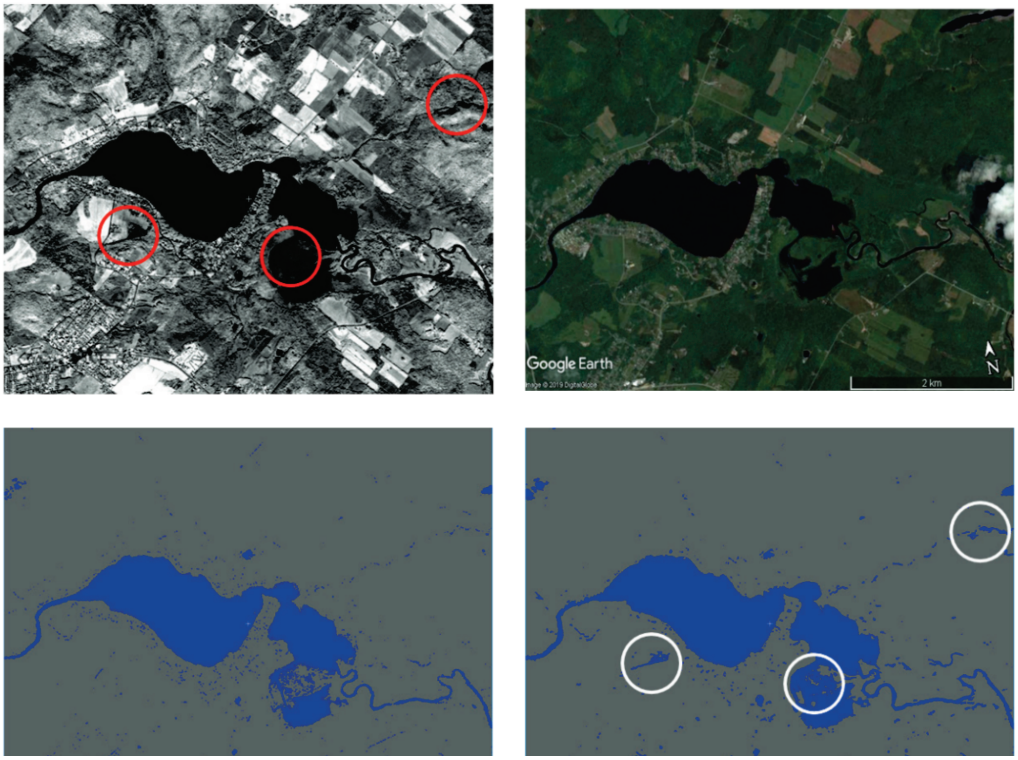


Figure 6.1 – Satellite image depicting inundation (top left), corresponding non-inundation (top right), initial water classification (bottom left) and final classification after region growing with infilled areas circled in white (bottom right).

Dynamic surface water maps will be created from a database of historical surface water maps generated using some of the above satellite archives. Individual surface water maps will be stacked to form a time-series, from which the frequency that each location has been inundated will be calculated and depicted spatially on a map. Inundation frequency portrays permanent land where standing water was never observed, permanent water where water was present in all observations and ephemeral water where water was occasionally present according to its frequency.

Partners / clients include Public Safety Canada, and NRCan (GEOBASE, Floodplain Mapping, and Emergency Geomatics).

Outcomes (FY 2019/20):

- ~11000 RadarSat-2 scenes from 2008 to present have been downloaded through EODMS
- For six of 26 land cover tile extents covering Canada, RadarSat-2 surface water maps have been produced and inundation frequencies calculated.
- Landsat 5, 7 and 8 data from 1985-present represent ~194000 scenes. Processing has been deployed on the Amazon cloud by scaling and testing on one to multiple instances. Landsat Paths 1-13 extending from Eastern Canada to Central Quebec have been processed to date. Inundation frequencies still need to be generated from input maps.
- Olthof, I. (2019). Automated surface water extraction from RapidEye imagery including cloud and shadow detection. Geomatics Canada Open File 52. 20 pp. https://doi.org/10.4095/315176
- Rainville, T. and Olthof, I. (2020). Evaluating simulated compact polarimetry for Emergency Geomatics Services flood mapping. Geomatics Canada Open File 55. 59 pp. https://doi.org/10.4095/321454

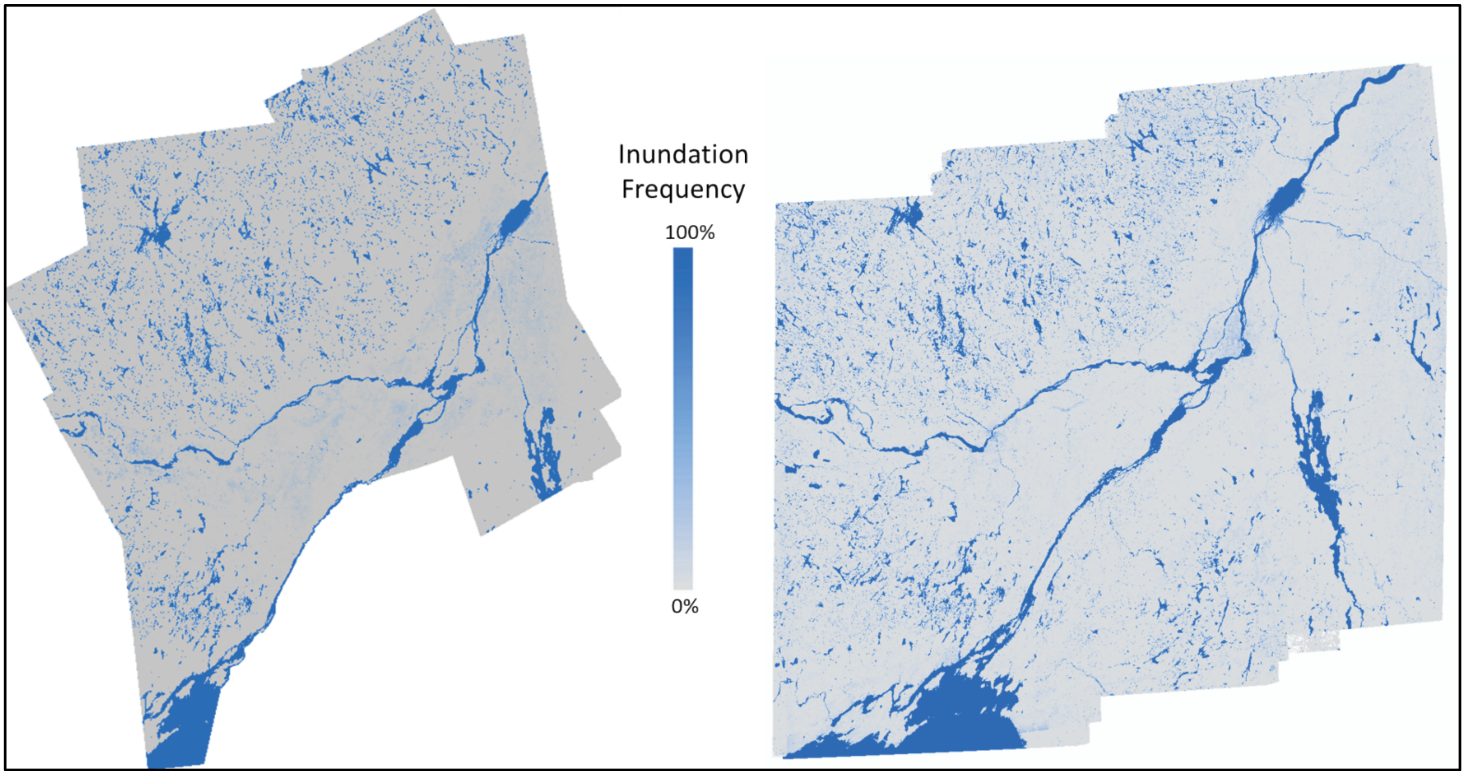


Figure 6.2 – Inundation frequency from 253 RadarSat-2 scenes between years 2008-2019 over the Ottawa to Lac-St-Pierre region, Quebec (left) and 1943 Landsat 5, 7 and 8 scenes between years 1985-2019 (right).

Risks / Challenges:

Processing of such large data volumes remains a challenge. Methods have been developed and optimized for certain regions in (primarily) Eastern Canada, and their application in the prairies (e.g. pothole region) with agriculture is challenging due to confusion with fallow fields with dark or wet soils, and certain arid natural grasslands.

WP 7: High Temporal Frequency EO Baseline Data

Alex Trishchenko, Calin Ungureanu

Overview:

This project is focused on advancing and applying the remote sensing science and technology for generating and analyzing high temporal frequency (daily to 10-day) EO baseline data from moderate resolution sensors (MODIS and VIIRS).

The national scale mosaics (figure 7.1) derived at coarse to moderate resolution (0.25-0.5km) from MODIS and currently VIIRS sensors are baseline data used as inputs for many subsequent high-level products, such as albedo/BRDF, land cover, vegetation, snow, surface water, change detections and others. The archived data for these sensors once combined with historical AVHRR time series allow assessment of these parameters from 1982 to the present and potentially can be extended to 2038 or even further. This creates an opportunity to extend time series information for 50 + years.

Methodology:

- Acquiring all satellite images (Level 1) over Canada territory from MODIS and VIIRS sensors
- Clear-sky pixel identification, atmospheric and BRDF correction, remapping to a standard grid
- Product generation (snow/ice, NVDI, albedo): temporal resolution 1 to 10-days, as well as seasonal aggregates. Spatial solution 0.25km-0.5km depending on product, sensors and spectral band.
- Joint time series analysis of EO baseline data, climate data and other ancillary datasets

Source datasets:

- Satellite data from MODIS and VIIRS sensors
- Reanalysis and surface climate data

Partners/clients:

- NRCan programs and Sectors (CCGP, GWGP, LMS, GSC, CFS, others)
- OGDs: ECCC, AAFC, StatsCan, Parks, INAC, DND, DFO, Polar Knowledge Canada, CSA, TC
- Industry and Academia: C-CORE, Ottawa U, UBC, UofT, Lethbridge U. Queen's U. others

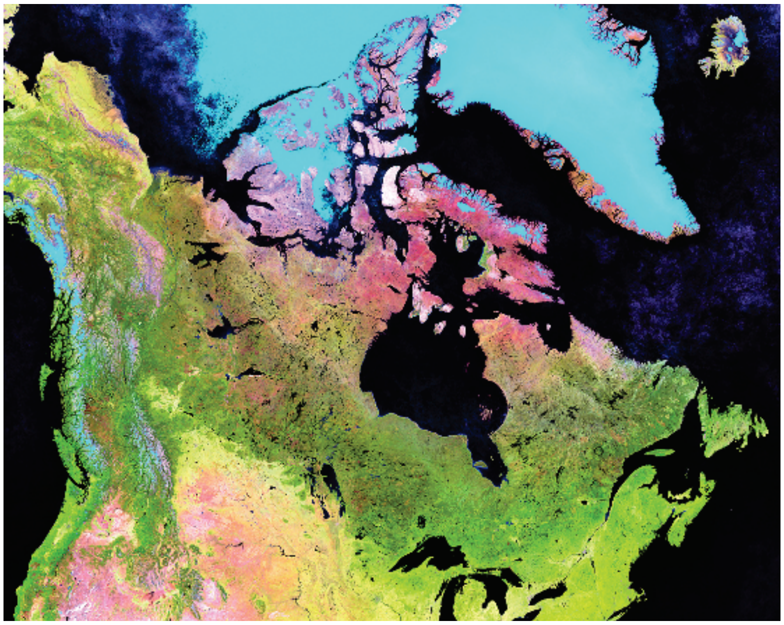


Figure 7.1 – False color warm season (April – September) clear-sky composite over Canadian landmass corresponding to minimum snow/ice cover for 2019 at 250-m spatial resoltion. MODIS/Terra.

Main objectives are:

- Develop and demonstrate the national scale capacity for environmental monitoring of Canada's landmass and coastal regions from space;
- Generate baseline EO data suitable for quantitative, objective and timely assessment of spatial and temporal dynamics of landmass and cumulative environmental impacts;
- Contribute to the "open government" concept by providing EO baseline data for public access.

Outcomes (FY 2019/20):

Data products

- MODIS/Terra and VIIRS/SNPP 10-day clear-sky composites are being generated in near-real time
- Seasonal Snow/Ice probability maps for warm season (April-September) have been updated to include 2019 season (see figures 7.2 and 7.3)

- Monthly maps (Apr-Sept) of landfast ice for Beaufort Sea region have been generated for 2000-2019 period

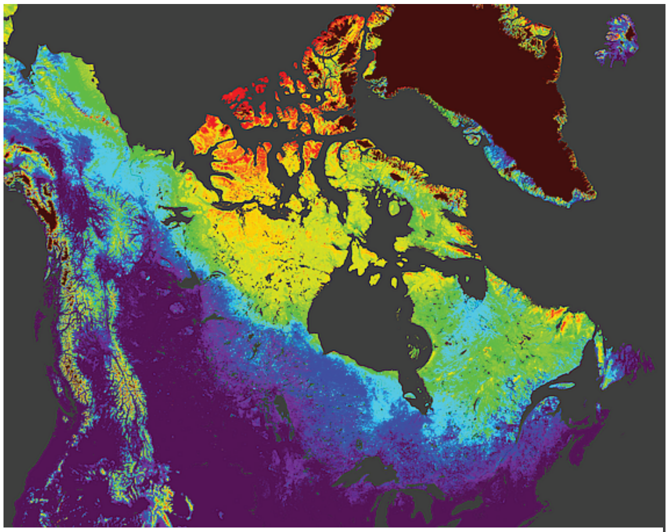


Figure 7.2 – Snow/Ice warm season (April – September) probability map over Canadian landmass for 2019 at 250-m spatial resolution derived from MODIS/Terra.

Journal publications

1. Trishchenko, A.P. 2019. Clear-sky composites over Canada from visible infrared imaging radiometer suite to continue MODIS time series. *Canadian Journal of Remote Sensing*. 45(3-4), pp. 276-289. DOI: 10.1080/07038992.2019.1601006.
2. Trishchenko, A.P., Trichtchenko, L.D., Garand, L. 2019: Highly elliptical orbits for polar regions with reduced total ionizing doze. *Advances in Space Research*. 63(12), pp. 3761-3767. DOI: 10.1016/j.asr.2019.04.005.
3. Trishchenko, A.P., L.Garand, L.D.Trichtchenko, 2019: Observing Polar Regions from Space: Comparison between Highly Elliptical Orbit (HEO) and Medium Earth Orbit (MEO) Constellations. *Journal of Atmospheric and Oceanic Technology*, Volume 36 No. 8, pp. 1605–1621. DOI: 10.1175/JTECH-D-19-0030.1

Conference/Workshop Presentations

1. Trishchenko, A.P., Minimum Snow/Ice Cover Extent over Northern Circumpolar Landmass at 250-m Spatial Resolution from MODIS and VIIRS: Climatic Trends and Suitability for Annual Updates of Glacier Inventory since 2000. 9th EARSeL Workshop on Land Ice and Snow. Bern. Switzerland, Feb 2020.
2. Trishchenko, A.P., C. Ungureanu, J. Li, D. Whalen, V. Kostylev, Yi Luo, 2020: Coastal Sea Ice in the Beaufort Sea Region from CCRS MODIS Composites Products Since 2000. 9th EARSeL Workshop *(as above)*.
3. Trishchenko, A.P., C.Ungureanu, V.Kostylev, D. Whalen, 2019: Coastal zone ice regime in the Canadian Arctic Archipelago during warm season from MODIS and VIIRS multi-year satellite data records. Oral presentation. 27th IUGG General Assembly, July 2019. Montreal .Canada.
4. Trishchenko, A.P., 2019: Clear-sky composites over Canada from Visible Infrared Imaging Radiometer Suite: Development and assessment against MODIS time series. Poster presentation. 27th IUGG General Assembly *(as above)*.
5. Trishchenko, A.P., 2019: Warm season radiation budget and snow/ice extent in Canadian Arctic since 2000. Oral presentation. 27th IUGG General Assembly *(as above).*
6. Trishchenko, A.P., 2019: VIIRS Processing at CCRS/NRCan. Invited presentation at AAFC. July 31, 2019

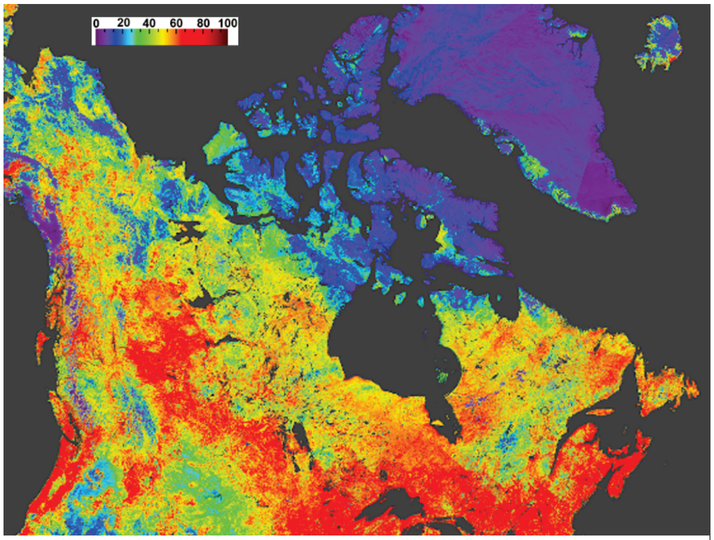


Figure 7.3 – Maximum weekly NDVI Top of Atmosphere composite from VIIRS/SNPP. 2018/07/30-2018/08/05.

Client Services

1. AAFC. Weekly VIIRS composite product have been generated for vegetation season and transferred to AAFC crop monitoring group. Dec 2019. 4 TB
2. Quebec. Ministère de la Forêt de la Faune et des Parcs. Consultation on satellite albedo of forest.
3. Trishchenko, A.P. 2019: TOA Clear-Sky Composites over Canada from Visible Infrared Imaging Radiometer Suite (VIIRS): Data Format. 9pp. Technical report prepared for AAFC.

WP 9: Regional Applications: Habitat

Wenjun Chen, Robert Fraser, Sylvain Leblanc, Christian Prevost, Julie Lovitt, Liming He

Overview:

Among various "valued components" to be assessed, caribou stand out as one of the top priorities because of their importance to the economy, culture, and way of life for indigenous peoples. Previous caribou dietary studies indicate that lichens are the most important food for woodland caribou, especially during the winter and fall. Despite many efforts over the years, information on lichen distribution within the caribou ranges of Canada remains unreliable or unavailable. To fill the information gap, this work package aims to map and detect temporal and spatial changes in lichen distribution for selected caribou ranges in Canada. This is a joint effort by scientists from the Canada Centre for Remote Sensing, the Canadian Forest Service (CFS), Environment and Climate Change Canada (ECCC), provincial & territorial governments, and other partners. Landsat imagery has been widely used by previous researchers to generate lichen distribution maps with low reported accuracies. The main challenge for producing lichen maps from this moderate (30m) resolution sensor is the mixture of lichen with other land cover types (e.g., trees, rocks, shrubs, etc.) within the 30m pixel footprint. To address this, we are designing and testing a new scaling-up approach. We start with sub-millimeter resolution plot photos and scale them up using centimeter resolution UAV data, half-meter resolution WorldView satellite data, and finally to the 30m Landsat imagery. In this way, we expect to substantially increase the size of our "ground truth" database, and improve the overall accuracy of lichen distribution and change maps that we generate from these data. Additionally, we will develop innovative approaches for mapping lichen cover (abundance) and biomass, and producing related change detection products using cutting-edge technology (e.g., artificial intelligence, big data analytics). Finally, lichen accessibility during the winter can be significantly affected by snow properties (e.g., hardness or density). We will document the temporal changes in snow properties using remote sensing time series.

Outcomes (FY 2019/20):

- Given that the final selection of the two terrestrial regions to be assessed is pending, we took a proactive approach by developing and testing methods over pilot caribou habitats. These pilot caribou habitats include the Red Wine Mountain Range in Labrador, Manicouagan Range in Québec (Figure 9.1), and Bathurst Range in Northwest Territories. Once regional selection is complete, these methods will be adopted to caribou habitats in these regions.
- We selected the pilot regions through consultations with partners/users, including Environment and Climate Change Canada, CFS (Atlantic, Laurentian), Government of Newfoundland and Labrador, Government of Québec, and Government of the Northwest Territories (Figure 9.2).
- We conducted field surveys of lichen cover and biomass for these pilot caribou habitats, including a transect from Québec to Labrador (Figure 9.1) and areas near Yellowknife. A fieldwork report was prepared (Chen et al., 2019, Summary report of fieldwork: July 22 to August 2, 2019, pp. 110) and circulated with partners and users. Managers and researchers from the government of Québec, Government of Newfoundland and Labrador, and CFS indicated that this report was very informative and useful.

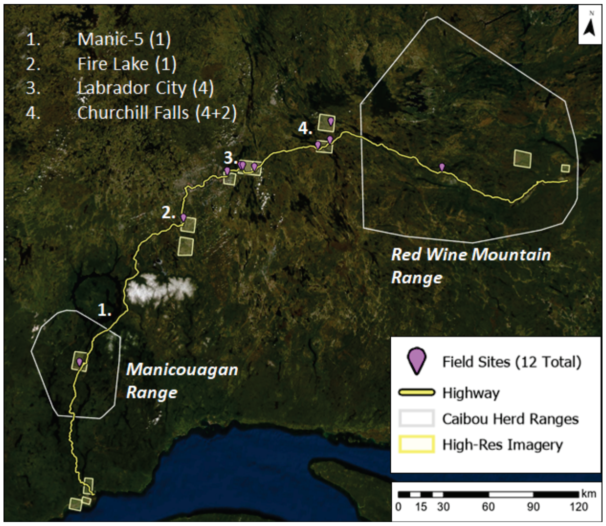


Figure 9.1 - Pilot caribou ranges and field survey of lichen along the Québec-Labrador transect in the summer of 2019.

Figure 9.2 – Consultations between remote sensing scientists from CCMEO and caribou researchers and managers from CFS, the Gov't of QC, and the Gov't of NF at the Laurentian Forestry Centre (July 22, 2019).

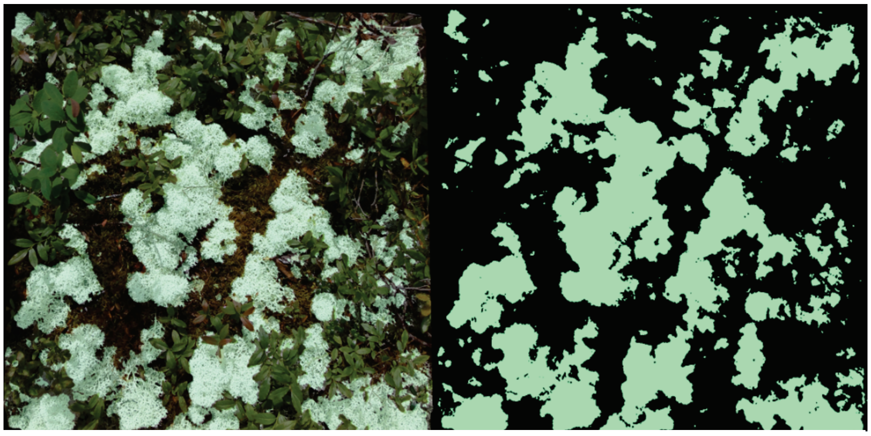


Figure 9.3 – An example plot digital photo (~50 cm by 50 cm) (left panel) and lichen classification (right panel) for a site along the Québec-Labrador transect in the summer of 2019.

- Our initial results indicate that the use of down-looking plot digital photos and UAV imagery can greatly improve the accuracy of lichen cover and biomass at the plot and site level (Figure 9.3). The UAV and WorldView imagery can also greatly increase the size of the ground truth database, by 100s to 10,000s times (Figure 9.4). The increase in the size of ground truth data will improve the lichen map accuracy for these habitats, and facilitate the development of innovative approaches for mapping lichen using artificial intelligence and big data analytics.

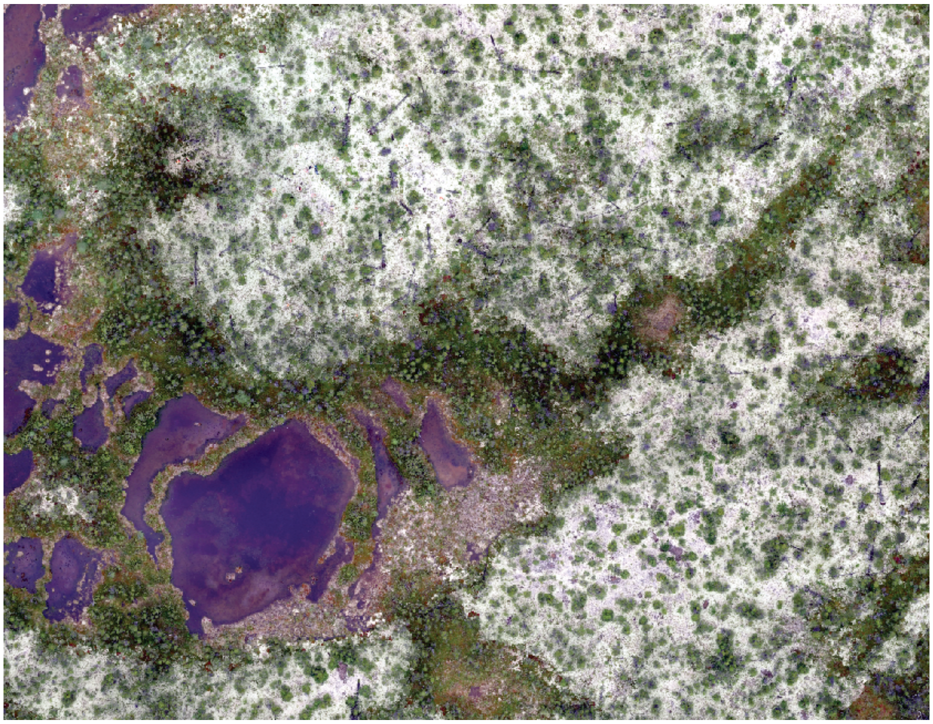


Figure 9.4 – An example of mosaicked UAV imagery for a site along the Québec-Labrador transect, acquired during the summer of 2019.

Risks / Challenges:

- Analyses of plot digital photos, UAV, and WorldView imagery, can be time-consuming, and thus need adequate human and computing resource support.
- Different images tend to have different view angles for the same objects, as well as different mixture issues. Furthermore, shadows cast by trees impact both UAV and optical satellite imagery by obscuring lichen and making satellite estimates of fractional lichen cover more difficult. Better understanding and minimizing the error propagation through the up-scaling process will be the key to the success of our proposed approach.

WP 10a: Regional Applications: Land Disturbances

Ying Zhang, Julie Lovitt, Matthew Roffey

Overview:

Land disturbances related to mining activities, such as removal of soil and vegetation, waste storage in facilities, and infrastructure development for production/transportation, leads to cumulative impacts on the environment at both the local and regional scale. The sustainability of mineral exploitation relies on successful management of the environmental impacts. The identification, mapping, and monitoring of land disturbances and potential risks/impacts related with mining development at local and regional scale becomes a significant requirement for sustainable mining development.

Often, field observations in remote mining sites are not available. Earth Observation imagery data and technologies, has become an effective approach of extracting information for mining sites/areas to support environmental assessment and risk analysis. In this project, the research focus is on local/regional cumulative land disturbances related with mining development. The objectives of the research are, in collaboration with partners:

a. to assess the capability and effectiveness of remote sensing data from diverse sensors (on platforms of regular/small satellites, UAV and airplane) with different spectral and spatial resolutions in monitoring and extraction of information on land disturbances related with mining activities;

b. to assess and develop automated information extraction methodologies towards operational mapping of mining land disturbance footprints using high resolution imagery;

c. to investigate risks and potential impacts of mining related infrastructure (such as tailings ponds) and land disturbances on the environment;

d. to assess sensitivities of EO-based land disturbance risk analysis tools with consideration of future federal environment assessment applications.

Outcomes (FY 2019/20):

In FY 2019/20, the activities of this work package focused mainly on definition of research scope, developing partnerships, technology review and preliminary tests, as well as data collection from diverse sources for future case studies. Major accomplishments include:

a. Collection and preprocessing of imagery data before and after the Mount Polley 2014 breach event

High-resolution imagery and Digital Elevation Model (DEM) maps are the key data layers for extraction of the information as inputs for mining site risk analysis. Since the mining site is located in a remote area, the pre-event data are very limited in national/provincial archives. A data set including imagery of high-resolution optical satellites, aerial LiDAR and a derived DEM was collected from diverse sources globally. Additionally, UAV-based post-event DEM data (Figure 10.a.1) was collected from the field in the summer of 2019 through a contract. Pre-processing of these raw imagery data collected has been on-going.

b. Preliminary tests of extracting fine features in Alberta oil/gas mining areas

For future development of automated methodologies to extract the land disturbances from high-resolution imagery with different resolutions have been on-going. The test sites are selected in the oilsands mining region in Alberta. The land disturbances due to mining in the tests are production sites, seismic lines and other fine features related with mining. Figure 10a.2 below demonstrates an example result of linear feature (seismic line) extraction and inference based on image processing and spatial modeling.

Risks / Challenges:

Challenges persist in finding highly qualified personnel with the skillsets required for image-processing and mapping of mining related small feature disturbances over large areas.

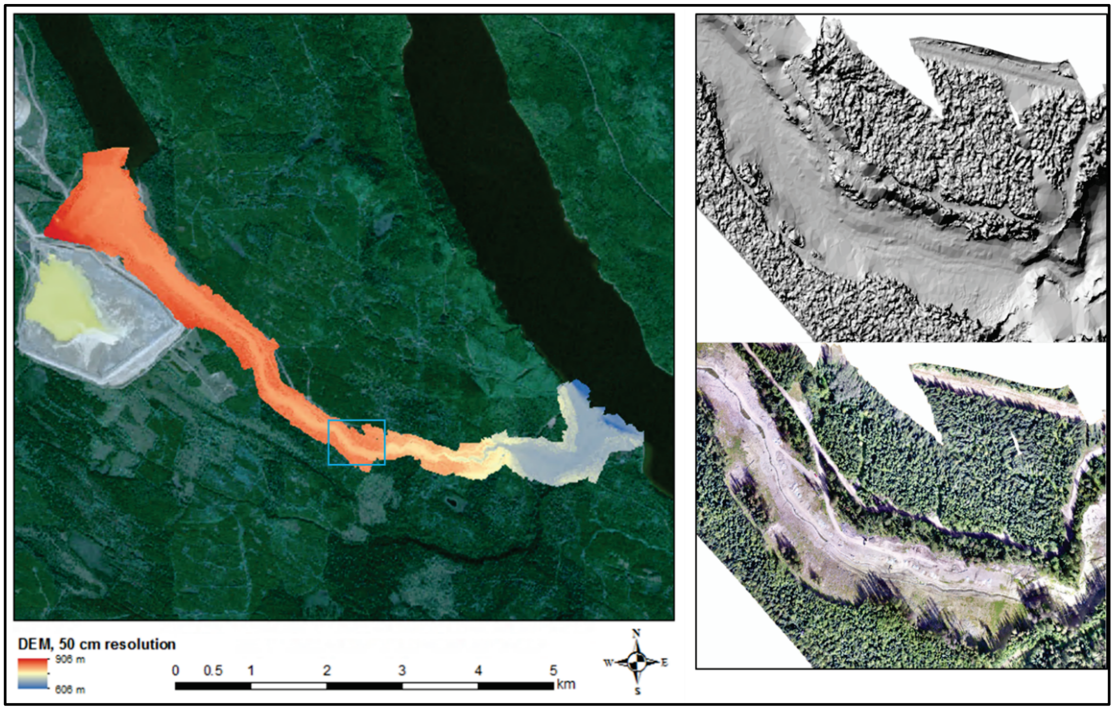


***Figure 10a.1** – High-resolution DEM (preliminary) and raw imagery samples at 50 cm resolution collected with a UAV over the Mount Polley mining spillway.*

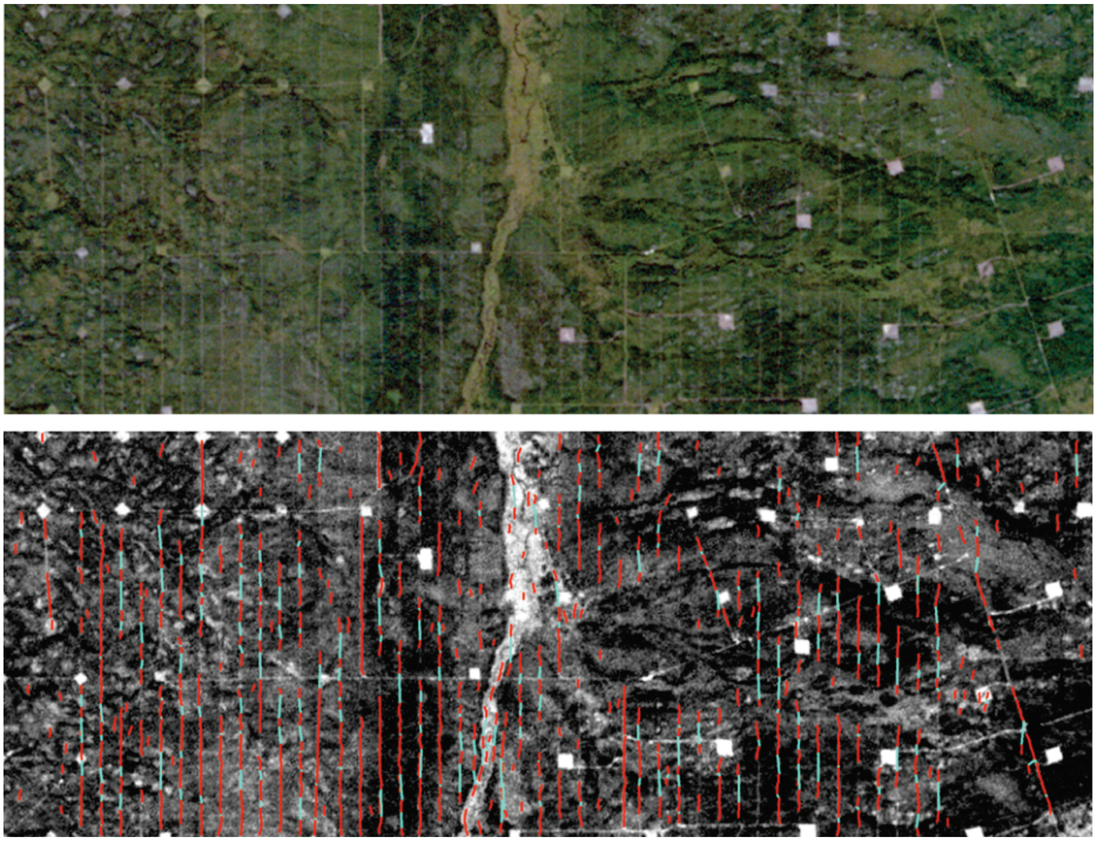


***Figure 10a.2** – (Top) RapidEye image with 5m resolution showing seismic lines (as well as in situ wells) in Alberta oilsands area. (Bottom) Red lines are those delineated through line-extraction. Blue lines are generated through inference to fill gaps between line segments.*

WP 10b: Regional Applications: Site Monitoring & Remediation

H. Peter White, Julie Lovitt, Christian Prevost, Sylvain Leblanc, Wenjun Chen

Overview:

Over a century of natural resource development in Canada has resulted in numerous sites (active, closed or abandoned) that require constant surveillance and management. Many are remote (such as in Canada's North) requiring regular expensive visits. These sites can directly impact communities if not adequately monitored (such as the Mount Polley breach into Quesnel Lake, BC; or downstream erosion of tailings in NS). Successful remediation take several decades, and current monitoring systems have proven insufficient or prohibitively expensive. There is a clear need for improved and standardized national baseline datasets with related regionally application guidelines and tools. Federal investment into EO technologies and methodology provide an opportunity to address these needs.

Concurrent with open standardized national datasets being developed via EO technologies (Status and Trends Mapping Program (STMP)) is a need to support targeted regional environmental indicators associated with site monitoring. Understanding how sites in varying environments can draw upon the STMP promotes integration of this standardized database while concurrently directing development through demonstrated needs. This is accomplished by working with partners to develop HQP capacity able to compliment monitoring systems (*in situ* technologies and the STMP data layers).

David Chambers, director of the Center of Science in Public Participation, suggested in 2016 [1] that most catastrophic failures of remediation initiatives are the result of poorly-informed business and management decisions. Understanding cumulative impacts and remediation is dependent on design, maintenance, and monitoring. Recent failures to integrate these issues indicate current monitoring systems are lacking. There is a clear need for integrating standardized national baseline datasets to support regional monitoring systems in a regular and robust manner.

This Work Package reviews proposed STMP datasets with partners' needs, via technology demonstration to support regional cumulative effects monitoring. Guidance will be aimed to address the gaps of current practices including:

- Supporting integration of STMP baseline datasets with existing *in situ* methodologies,
- Monitoring remotely and continuously,
- Developing HQP capacity in key federal departments necessary for the operational integration of open national baseline EO datasets to cumulative disturbance and remediation monitoring.

Outcomes (FY 2019/20):

Site visits of various regional environmental cumulative effects initiatives have been pursued, with a focus on setting up partnerships, exploring opportunities, and acquiring field data and remote imagery. Field data campaigns have been pursued in partnership with other CE Work Packages, CANMET Mining, universities, and industrial stakeholders.

1. **The Myra Falls Mine, BC**. Over a half-century of mineral exploration and production has occurred at this site, located in Strathcona Park, Vancouver Island. The site has had numerous owners, leaving the present owners (NyrStar) with an inconsistent understanding of previous tailings management, yet accountable for pursuing responsible environmental management. Additionally, Myra Falls operates in wet mountainous terrain subject to landslides, and uses local (potable) water sources for energy production. A field campaign was pursued to survey tailings containment areas, the regional environment, and local lakes levels (figure 10b.1). A satellite image database is now being assembled.

Figure 10b.1 – Legacy tailings located on hill slope near Myra Falls.

2. **Mount Polley Mine, BC**. On 4 August 2014 a tailings pond breach released an estimated 25 billion litres of contaminated materials into Polley Lake, Hazeltine Creek and Quesnel Lake, the latter a source of drinking water for local comminutes and major spawning grounds for sockeye salmon. Mount Polley (Imperial Metals) mine records, filed with Environment

Canada in 2013, indicate that 326t nickel, 400t arsenic, 177t lead and 18,400t copper were held in the pond in 2012. The Univ. Northern British Columbia has maintained a research station at Quesnel Lake since 2002 (Quesnel River Research Centre - QRRC) and have monitored evolution of the breach. However, little effort has been directed to the use of EO, with most research focused on active sampling in known impacted areas [2]. A site visit was done, with aid from QRRC (Michael Allchin, Manager) and Imperial Metals (Gabriel Holmes, Environmental Technician). Data sharing has occurred with UNBC, and a RAP partnership with Univ. Ottawa created.

3. **Ekati Diamond Mine, NT**. Community concerns on a lack of understanding of the zone-of-influence (ZOI) from mining on caribou highlight the importance of development-vs-wildlife issues in Canada's north. In conjunction with WP 09, remote sensing-based methods are being evaluated to provide indicators to map ZOI. Archived data were used to examine the spectral detection of dust distributions due to mining activities at the Ekati Diamond Mine. Using CHRIS-Proba imagery combined with field data, dust distribution was mapped around site infrastructure that collaborated other studies [3] (figure 10b.2). This success led to invitations to evaluate these methods at other sites in NU (Jericho Diamond mine, closed; Mary River Mine, proposed expansion) and NS (abandoned mines). Participation is on-going, or is being evaluated.

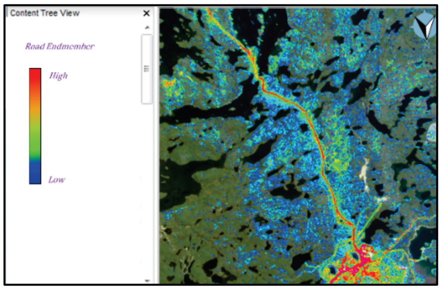


Figure 10b.2 – Dust distribution around Ekati Mine infrastructure, detected using spectral end-member extraction.

4. **Abandoned Mines, NS**. Abandoned mines across Nova Scotia are vulnerable to weather extremes from a changing climate. Increased risk from warming temperatures, extreme precipitation and overall reduction in rainfall allows tailings to be readily transported into nearby watersheds. The CANMET Mining *Enhancing Competitiveness in a Changing Climate* Project invited us to two sites where apparent aerial and water erosion were being investigated; Stirling Mine and Goldenville. Optical (spectral) EO imagery is to be evaluated as a complimentary method to detect and map dust (figure 10b.3). Highlighting the need for new innovative tools to better monitor these sites, the Provincial Government recently announced $48 million to remediate 2 of the 69 sites identified as needing intervention [4]. There are data sharing arrangements with CANMET Mining, collaboration with a CANMET RAP with Queen's Univ., co-op student support (University Waterloo) and a RAP partnership with Saint Mary's U. (to be pursued). Publications include [5].

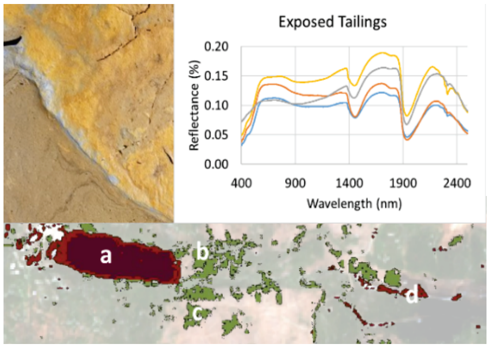


Figure 10b.3 – Spectral reflectance patterns at 4 sites in Stirling, NS: (a) tailings, (b) wetlands, (c) clear-cut, and (d) transported tailings.

Risks / Challenges:

Regional cumulative effects indicators are subject to their regional ecosystems and surrounding infrastructure development. Linking these indicators to a standardized set of data layers providing national scale coverage with regional scale detail (STMP) may require investigation extending past the scheduled completion of this program.

Additional References:

[1] D. M. Chambers, (2016) "Comments on the Code Review Changes to Part 10, Mine Health Safety and Reclamation Code," Center for Science in Public Participation, Bozeman, MT.

[2] E. L. Petticrew, S. J. Albers, S. A. Baldwin, E. C. Carmack, S. J. Déry, N. Gantner, K. E. Graves, B. Laval, J. Morrison, P. N. Owens, D. T. Selbie and S. Vagle, (2015) "The impact of a catastrophic mine tailings impoundment spill into one of North America's largest fjord lakes: Quesnel Lake, British Columbia, Canada," Geophysical Research Letters, **42**(9).

[3] H. P. White, W. Chen and S. G. Leblanc, (2018) "Satellite Observations for Detection of Dust from Mining Activities in a Caribou Habitat," as presented at, 17th North American Caribou Workshop (NACW).

[4] F. Willick, "CBC News," Canadian Broadcasting Corporation, (2019). [Online]. Available: https://www.cbc.ca/news/canada/nova-scotia/auditor-general-mine-remediation-nova-scotia-1.5339359. [Accessed 15 01 2020].

[5] P. Huntsman, H. P. White, A. Cleaver, H. E. Jamieson, J. Percival, N. Le, M. Orwin and C. J. Rickwood, (2019) "Use of biomonitoring and remote sensing to track mine dust in a changing climate," as presented, Society of Environmental Toxicology and Chemistry (SETAC) North America 40th Annual Meeting , Toronto.

WP 11: Regional Applications: Water Dynamics

Junhua Li, Sylvain Leblanc, Shusen Wang, Francis Canisius, Tom Rainville, Sarah Yoga

Overview:

Water links to every aspect of the lives of Canadians and is an essential part of our natural environment. However, available water resources, both above and below ground, are under increased pressure from a wide range of anthropogenic activities and subject to the effects of climate change, land use/land cover change in ways that are not yet fully understood.

The advances in remote sensing technologies provide efficient ways to retrieve water information from Earth Observation (EO) datasets in a timely fashion. The overall goal of this WP is to develop and demonstrate the utility of EO datasets and other forms of geospatial data, to gain knowledge about the state and dynamics of water resources at a regional scale. As such, we are developing and enhancing methodologies using optical data (Landsat, Sentinel-2), C-band SAR data (Radarsat-2, RCM, Sentinel-1), and Unmanned Aerial Vehicle (UAV) survey data to assess water dynamics, such as permafrost melting and erosion from river flooding. These datasets are also used to address the resolution limitations of GRACE and SMOS/SMAP satellites in measuring water storage changes and soil water content at a regional scale. A land surface model (EALCO) is being used to integrate the EO datasets including GRACE, SMOS/SMAP, Radarsat-2, RCM, Sentinel-1/2, MODIS, Landsat and UAV, and climate data for characterizing the environmental change induced cumulative effect on water resources at a regional scale, in which a multi-sensor UAV system is being used to map vegetation parameters for modelling calibrations and validations.

The work is undertaken in collaboration with other WPs, scientific partners from Canadian universities and targeted end-users representing organizations responsible for cumulative assessments. The transfer of developed techniques, guidelines and models for future operational use by end-user organizations will be planned.

Outcomes (FY 2019/20):

In this fiscal year, we mainly focused on setting up partnerships, preparing data including UAV surveys and Land Use and Land Cover Change (LULCC) maps, and developing/enhancing EO methods for water information (e.g. soil water content, water storage change, water quality) retrieval in our pilot study regions (southern Ontario, Sherbrooke, QC, and northern Canada areas that include the Dempster highway in the Yukon). The accomplishments include:

1. We set up a partnership with McMaster University for detecting LULCC over Southern Ontario during the past 30 years and the associated impacts on water resources.
2. We conducted UAV surveys at Turkey Point of Southern Ontario (Figure 11.1) and using the data to extract vegetation parameters for calibrating and validation water models.
3. We set up partnerships with the University of Ottawa by establishing two positions through the RAP (Research Affiliate Program). One in collaboration with WP 4 (PhD) that looks at permafrost melting in the Yukon and one on the detection of lakes affected by permafrost melting (Master's) by remote sensing techniques.

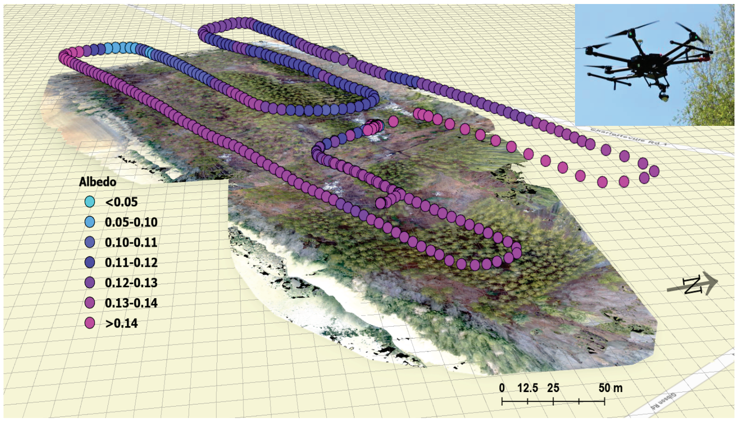


Figure 11.1 – Pyranometer sensor measured albedo (preliminary results) overlaid on a visible orthomosaic at Turkey Point in southern Ontario. Data from sensors mounted on a M600 UAV.

4. We started an ad-hoc partnership with the University of Sherbrooke on the use of remote sensing in river water management and mapping. This university group has a contract with local regional municipalities for these activities. UAV surveys were conducted for two small rivers that lead into the St-Francois, which had frequent flooding events in recent years. These were the Coaticook River which will be used for studying erosion and potential shallow water bathymetry (Figure 11.2a) and the Saumon River data which will be used for mapping debris after flooding (Figure 11.2b). A RAP (Master's) is expected to be awarded next FY as part of these activities.
5. We have started a shared activity with WP10 to study wetland (Mer Bleue) seasonal and annual dynamic changes using UAVs, airborne and satellite data.
6. We bought and tested a new UAV and a new camera for existing UAV equipment in support of WP 9, 10, and 11. These new systems have the usual RGB camera and red edge and NIR bands. Among interesting results, we developed software to combine all bands in single point clouds to ease future analysis and we developed a new normalization tool for UAV imagery.
7. We published a paper in *Journal of Hydrology: Regional Studies*. Li, J., Wang, S., Michel, C., Russell, H.A.J., 2020. Surface deformation observed by InSAR shows connections with water storage change in Southern Ontario, *Journal of Hydrology: Regional Studies*, 27, 100661. https://doi.org/10.1016/j.ejrh.2019.100661

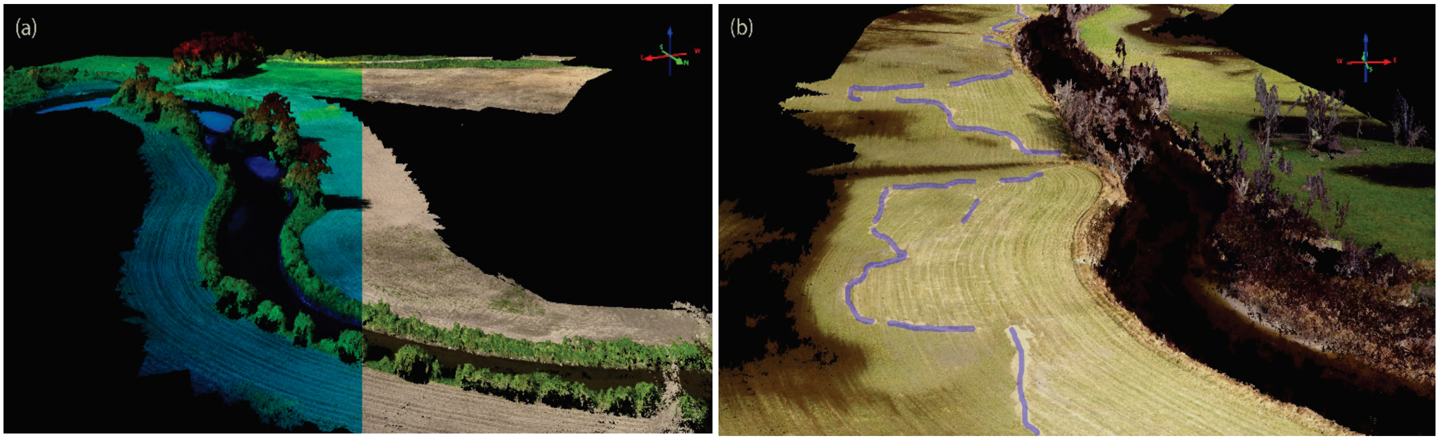


Figure 11.2 – (a) Point Cloud of Coaticook River, near Sherbrooke. Half image showing RGB and elevation values (left) and other half with just RGB values (right). (b) Saumon River, near Sheerbooke. RGB point cloud with debris remnants, manually marked in blue, after the 31 October 2019 flood. Both figures made with data from a small Mavic 2 Pro UAV.

Risks / Challenges:

1. It is a challenge to efficiently collect the required *in situ* data to support water variable characterization. One mitigation approach adopted in this activity is to partner with other organizations who will, in part, contribute to our *in situ* data collection requirements. This process will improve available data but also results in risk as data from other groups are not always adequate due to inexperience and limited understanding of the instruments.
2. Implementing research activities through University partnerships and the Research Affiliate Program does not guarantee that the PhD or MSc students will provide exactly what is expected. However, the risk is low as it is a very small investment for research activities that can yield innovative new methodologies.
3. Initial results/methods, such as the debris mapping, have been performed manually and there is a risk that automation may be difficult to achieve. Guidelines and frameworks can be developed to facilitate these approaches by regional practitioners and consultancies, but it may be challenging for those entities to carry them out without highly qualified personnel.

WP 12 (Supplemental): Canadian Wetland Inventory

Brian Brisco

Overview:

Wetlands are important ecosystems benefiting a number of important functions including providing key habitat to many plants and animals, maintaining water quality and quantity such as controlling floods, offering food and recreational opportunities for humans and acting as a carbon sink. They are also key components of both the water and carbon cycles. Thus, baseline information on the large-scale spatial distribution of wetlands is critical for monitoring these productive ecosystems, obtaining information on their historic status and trends, and acquiring accurate inputs for carbon budget, habitat, biodiversity, and resource management strategies. Production of nationally synoptic baseline information is of particular concern in countries such as Canada, which contains a quarter of the world's wetlands. Traditionally wetland classification is a time-consuming and expensive activity involving airborne photography and field visits to conduct wetland surveys. These considerable expense and time requirements means these type of classification efforts have only done periodically with different levels of quality and detail throughout Canada.

The Canadian Wetland Classification System has five classes: shallow water, marsh, bog, fen, and swamp. We produced a high-resolution 10-m wetland inventory map of Canada using these five classes, covering an approximate area of one billion hectares, using 2016-2018, multi-source (Sentinel-1 and Sentinel-2) EO data and a large volume of reference samples within an object-based random forest classification scheme on the Google Earth Engine (GEE) cloud-computing platform (figure 12.1). A total of 211,926 Sentinel-2 images from the summers of 2016, 2017, and 2018 were queried from the GEE data pool. The reference sample sources came from a number of federal, provincial, and NGO sources. The accuracies exceeded 80% in most regions with an overall accuracy of 78.88%. The resulting nationwide wetland inventory map illustrates that 19% of Canada's land area is covered by wetlands, most of which are peatlands which dominate in northern eco-zones. This represents a general increase of wetland extents in Canada (~6%) relative to past studies potentially reflecting recent climate change and/or better estimates due to the improved resolution of the Sentinel data. Importantly, the resulting ever-demanding wetland inventory map of Canada provides unprecedented details on the extent, status, and spatial distribution of wetlands, thus, is useful for many stakeholders, including federal and provincial governments, municipalities, NGOs, and environmental consultants. This approach can be reproduced annually, or even seasonally, using the developed framework and the associated consistent time-bound national coverage of imagery.

Version 2 with sentinel 1,2 and improved ground truth will be completed in March 2020 and will be assessed by CWS, DUC, and STATCAN for serving as a baseline for wetland status and trends in Canada. An invited talk at the CSRS 2020 in Yellowknife will present early results.

Outcomes (FY 2019/20):

Data Products:

Initial version with Landsat only created in spring 2019 (Amani et al (a)) with Version 1 of Sentinel-1, 2 was completed in the fall of 2019 (Figure 1, Mahdianpari et al,). Additional research on a supervised classification scheme (Amani et al. (b)) and deep versus shallow learning algorithms (Delancey et al) was also conducted.

Publications:

- Meisam Amani, Brian Brisco, Majid Afshar, S. Mohammad Mirmazloumi, Sahel Mahdavi, Sayyed Mohammad Javad Mirzadeh, Weimin Huang & Jean Granger (2019) A generalized supervised classification scheme to produce provincial wetland inventory maps: an application of Google Earth Engine for big geo data processing, Big Earth Data, 3:4, 378-394, DOI: 10.1080/20964471.2019.1690404: https://doi.org/10.1080/20964471.2019.1690404
- Masoud Mahdianpari, Eric Gill, Bahram Salehi, Laura Bourgeau-Chavez Fariba Mohammadimanesh, Brian Brisco, and Saeid Homayouni, "Big Data for a Big Country: The First Generation of Canadian Wetland Inventory Map at a Spatial Resolution of 10-m Using Sentinel-1 and Sentinel-2 Data on the Google Earth Engine Cloud Computing Platform,

Canadian Journal of Remote Sensing, DOI: 10.1080/07038992.2019.1711366. https://doi.org/10.1080/07038992.2019.1711366

- DeLancey, Evan, R. John Simms, Masoud Mahdianpari, Brian Brisco, Craig Mahoney, and Jahan Kariyeva, “Comparing deep learning and shallow learning for large-scale wetland classification in Alberta, Canada”, Remote Sens. 2019, 12, 2; DOI:10.3390/rs12010002.

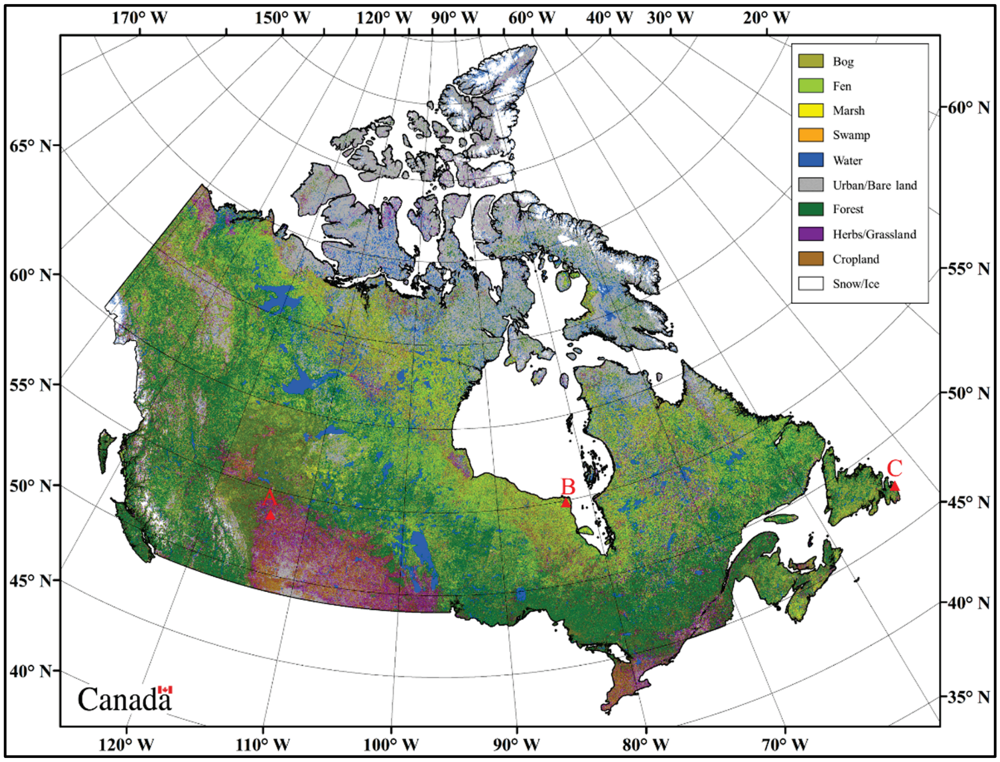


Figure 12.1 – The Canada-wide wetland inventory map with a spatial resolution of 10m obtained from an object-based random forest classification using multi-year optical/SAR data composite.

Symposium and Web Presentations

- Salehi, Bahram, Masoud Mahdianpari, Fariba Mohammadimanesh, Brian Brisco and Eric Gill, “A Wetland Inventory for Newfoundland: Toward Wetland Inventory of CANADA”, 40th Canadian Symposium on Remote Sensing & Geomatics Atlantic, June 3-7, 2019, Fredericton NB.
- Amani, Meisam Sahel Mahdavi, Majid Afshar, and Brian Brisco, “First Canadian Wetland Inventory Map”, 40th Canadian Symposium on Remote Sensing & Geomatics Atlantic, June 3-7, 2019, Fredericton NB.
- Brisco, Brian and Andrew Pratt, “Canadian Wetland Inventory now and into the future”, Wednesday, August 21, USFWS webinar.
- Bahram Salehi, Masoud Mahdianpari, Fariba Mohammadimanesh, and Brian Brisco, Wetland Inventory of Canada using Satellite Earth Observation Data and Google Earth Engine Cloud, AGU Fall Meeting 2019, December 9-13, San Francisco, California, USA.
- Brian Brisco, Bahram Saleh, Marcelle Grenier, Andrew Pratt, Masoud Mahdianpari, and Fariba Mohammadimanesh, “Wetlands Status and Trends in Canada: Development of a Baseline”
  To be presented at the 41st Canadian Symposium on Remote Sensing at Yellowknife NT, July 13-17, 2020.

Risks / Challenges:

Better ground-truthing data would continue to improve both the testing and training of the classification algorithm. Cost-efficient methods for improved ground-truthing are being explored. Also, adding ALOS and perhaps RCM would help improve the classification accuracy, especially for the wooded wetlands. We plan on addressing this in 2020/21.

WP 13 (Supplemental): Status and Trends Visualization

Nouri Sabo, Jean-Francois Bourgon, Catherine Vachon

Overview:

The Canada Centre for Mapping and Earth Observation (CCMEO) is currently deploying a data cube platform to simplify the management and exploitation of large temporal data sets. The objective is to lower both access and usability barriers to created datasets to facilitate their adoption into decision-making processes. The objective of the project is to **accelerate the integration of EO baseline data supporting Cumulative Effects assessment** inside the Data cube platform. This data integration will improve the accessibility of foundational geospatial layers derived from Earth Observation and the ability to exploit them in multiple applications. The availability of status and trends baseline data developed in the EO4CE project will help scientists and end-users focus their resources and efforts on their science and field of expertise.

The project will enhance the offering in terms of **Data visualization & Data analytics services** available for EO4CE data products by including the support of standardized visualisation web services and direct access to underlying data sets hosted through web accessible systems (see figures 13.1 and 13.2). These new capacities will allow users to efficiently display and dynamically process massive amount of data by levering existing open source big geospatial data technologies and elasticity available from Public Cloud IT environment.

This project will also ensure that the services and access points provided are compatible and integrated into the existing FGP tools and its web presence.

As high-level requirements, this activity will:

- Make data available to both public and internal end-users
- Deploy the solution in a sustainable IT environment
- Offer a generic solution that could be applied to future status and trends datasets

This project could eventually be expanded to be a full visualization, analysis, and dissemination application for data sets hosted on external Cloud IT Environment.

Outcomes (FY 2019/20):

Implementation of cloud-based Dev/Stage/Prod environments for the Data cube platform in close collaboration with the FGP GeoCommunity Cloud and Chief Information Office and Security Branch (CIOSB) teams.

Intake and release of the following EO4CE data products:

- Landsat Time Series over Canada (2009-2018)
- 2010/2015 Land Cover of Canada

Risks / Challenges:

The process to release the Data cube platform and the selected primary EO Baseline Data for Cumulative Effects on a production cloud-based IT environment is currently ongoing. The current target date is set for the first quarter (Q1) of FY 2020/21.

This project is responsible for providing web services to support the visualization and the access of temporal datasets. This project also supports the integration of temporal datasets with current FGP tools mainly through the development of FGP Viewer Extensions but additional development could be required on the FGP Catalog to offer complete support for such datasets in FGP tools, which are out of scope of this project.

Figure 13.1 – A Normalized Difference Vegetation Index (NDVI) map dynamically generated from the 2014 landsat-8 national mosaic at 30m spatial resolution hosted inside the Data Cube Platform.

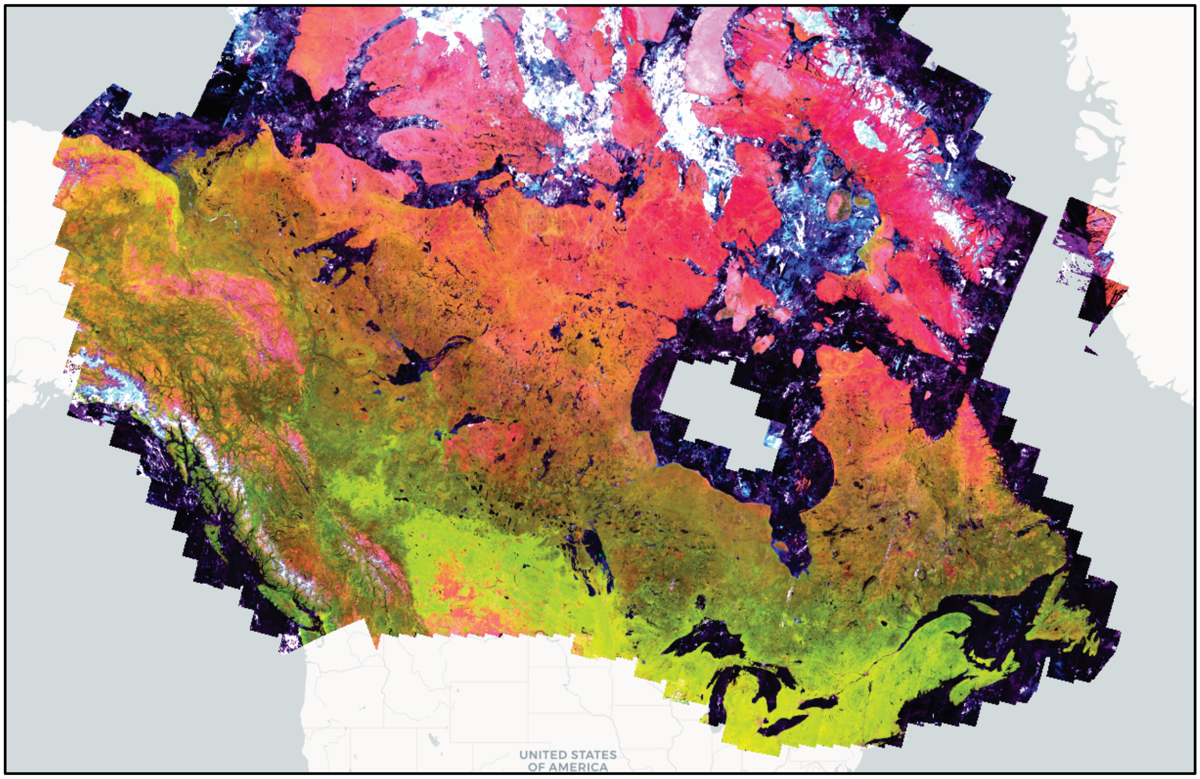
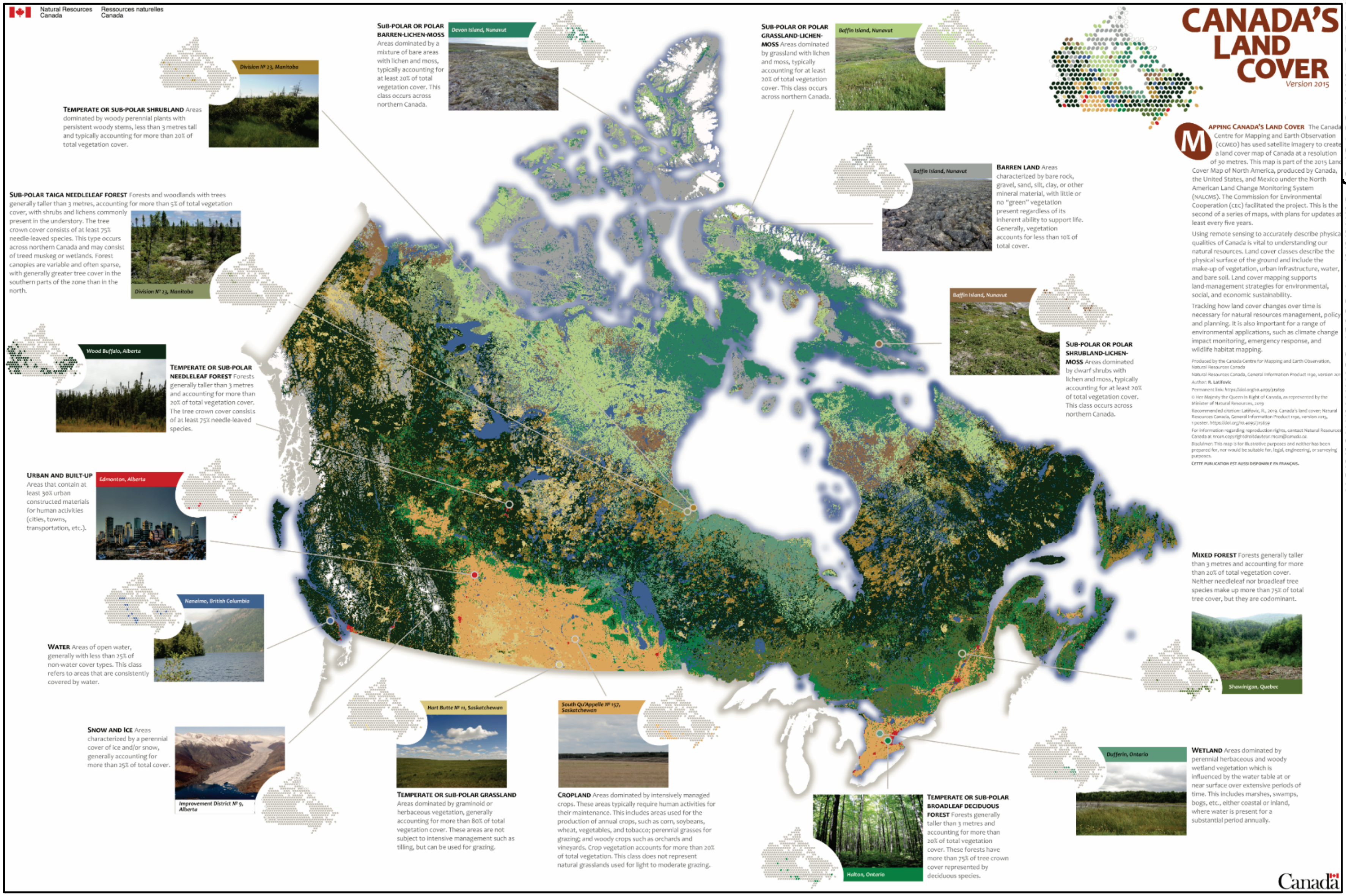


Figure 13.2 – A 6-5-4 band composite map dynamically generated from the 2015 landsat-8 national mosaic at 30m spatial resolution hosted inside the Data Cube Platform.

Appendix A: 2015 Land Cover of Canada – Poster Communication



CANADA'S LAND COVER

Version 2015

MAPPING CANADA'S LAND COVER The Canada Centre for Mapping and Earth Observation (CCMEO) has used satellite imagery to create a land cover map of Canada at a resolution of 30 metres. This map is part of the 2015 Land Cover Map of North America, produced by Canada, the United States, and Mexico under the North American Land Change Monitoring System (NALCMS). The Commission for Environmental Cooperation (CEC) facilitated the project. This is the second of a series of maps, with plans for updates at least every five years.

Using remote sensing to accurately describe physical qualities of Canada is vital to understanding our natural resources. Land cover classes describe the physical surface of the ground and include the make-up of vegetation, urban infrastructure, water, and bare soil. Land cover mapping supports land-management strategies for environmental, social, and economic sustainability.

Tracking how land cover changes over time is necessary for natural resources management, policy and planning. It is also important for a range of environmental applications, such as climate change impact monitoring, emergency response, and wildlife habitat mapping.

Produced by the Canada Centre for Mapping and Earth Observation, Natural Resources Canada

Natural Resources Canada, General Information Product 119e, version 2015

Author: **R. Latifovic**

Permanent link: https://doi.org/10.4095/315659

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CETTE PUBLICATION EST AUSSI DISPONIBLE EN FRANÇAIS.

TEMPERATE OR SUB-POLAR SHRUBLAND Areas dominated by woody perennial plants with persistent woody stems, less than 3 metres tall and typically accounting for more than 20% of total vegetation cover.

SUB-POLAR TAIGA NEEDLELEAF FOREST Forests and woodlands with trees generally taller than 3 metres, accounting for more than 5% of total vegetation cover, with shrubs and lichens commonly present in the understory. The tree crown cover consists of at least 75% needle-leaved species. This type occurs across northern Canada and may consist of treed muskeg or wetlands. Forest canopies are variable and often sparse, with generally greater tree cover in the southern parts of the zone than in the north.

TEMPERATE OR SUB-POLAR NEEDLELEAF FOREST Forests generally taller than 3 metres and accounting for more than 20% of total vegetation cover. The tree crown cover consists of at least 75% needle-leaved species.

URBAN AND BUILT-UP Areas that contain at least 30% urban constructed materials for human activities (cities, towns, transportation, etc.).

WATER Areas of open water, generally with less than 25% of non-water cover types. This class refers to areas that are consistently covered by water.

SNOW AND ICE Areas characterized by a perennial cover of ice and/or snow, generally accounting for more than 25% of total cover.

SUB-POLAR OR POLAR BARREN-LICHEN-MOSS Areas dominated by a mixture of bare areas with lichen and moss, typically accounting for at least 20% of total vegetation cover. This class occurs across northern Canada.

SUB-POLAR OR POLAR GRASSLAND-LICHEN-MOSS Areas dominated by grassland with lichen and moss, typically accounting for at least 20% of total vegetation cover. This class occurs across northern Canada.

BARREN LAND Areas characterized by bare rock, gravel, sand, silt, clay, or other mineral material, with little or no "green" vegetation present regardless of its inherent ability to support life. Generally, vegetation accounts for less than 10% of total cover.

SUB-POLAR OR POLAR SHRUBLAND-LICHEN-MOSS Areas dominated by dwarf shrubs with lichen and moss, typically accounting for at least 20% of total vegetation cover. This class occurs across northern Canada.

MIXED FOREST Forests generally taller than 3 metres and accounting for more than 20% of total vegetation cover. Neither needleleaf nor broadleaf tree species make up more than 75% of total tree cover, but they are codominant.

TEMPERATE OR SUB-POLAR GRASSLAND Areas dominated by graminoid or herbaceous vegetation, generally accounting for more than 80% of total vegetation cover. These areas are not subject to intensive management such as tilling, but can be used for grazing.

CROPLAND Areas dominated by intensively managed crops. These areas typically require human activities for their maintenance. This includes areas used for the production of annual crops, such as corn, soybeans, wheat, vegetables, and tobacco; perennial grasses for grazing; and woody crops such as orchards and vineyards. Crop vegetation accounts for more than 20% of total vegetation. This class does not represent natural grasslands used for light to moderate grazing.

TEMPERATE OR SUB-POLAR BROADLEAF DECIDUOUS FOREST Forests generally taller than 3 metres and accounting for more than 20% of total vegetation cover. These forests have more than 75% of tree crown cover represented by deciduous species.

WETLAND Areas dominated by perennial herbaceous and woody wetland vegetation which is influenced by the water table at or near surface over extensive periods of time. This includes marshes, swamps, bogs, etc., either coastal or inland, where water is present for a substantial period annually.

Full resolution poster available at https://doi.org/10.4095/315659