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Monthly Vegetation Essential Climate Variable Maps for the Hudson Bay Lowland using the LEAF-Toolbox Implementation of the SL2P Algorithm

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ABSTRACT

Leaf area index (LAI), fraction of canopy cover (fCOVER), and fraction of absorbed photosynthetically active radiation (FAPAR) are essential climate variables and widely used in monitoring, understanding, and modeling activities related to land surfaces. Landscape Evolution and Forecasting (LEAF) which includes the Simplified Level 2 Product Prototype Processor (SL2P) algorithm provides an efficient way to produce biophysical parameters in a regional level using Sentinel 2 or Landsat 8. This study applies LEAF to produce monthly LAI, fCOVER and FAPAR for supporting permafrost modeling in Hudson Bay Lowland. The limited field samples were used to assess the thematic performance of those products.

1. Introduction

Earth observation data can provide a timely and efficient way to estimate vegetation biophysical variables such as leaf area index (LAI), fraction of canopy cover (fCOVER), and fraction of absorbed photosynthetically active radiation (FAPAR). Those variables are widely used in monitoring, understanding, and modeling activities related to land surfaces and the Global Climate Observing System (GCOS) has included those vegetation biophysical variables in essential climate variables.

A variety of biophysical products at various spatiotemporal resolutions have become available, which include the MODIS (500m, 4-day), the CGLS (GEOV2, 1km and 300m, 10-day) Version 3, and the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT) Polar System Satellite Application Facility (SAF EPS, 1.1km, 10-day), and the Global Land Surface Satellite (GLASS) (500m, 8-day), Visible Infrared Radiometer Suite (VIIRS, 1km, 8-day) (Dugesar et al. 2023). However, the spatial resolution of those products does not satisfy the GCOS threshold 250m or goal 50m spatial resolution requirements. Landsat 8 and 9 satellites (hereafter Landsat) carries the Operational Land Imager (OLI) with 8 spectral bands at 30m spatial resolution covering the visible, the near infrared (NIR) and the shortwave-infrared (SWIR) spectral regions, and one 15m spatial resolution panchromatic band, with a 8 day revisit at the

Equator. The Copernicus SENTINEL-2 (S2) mission comprises a constellation of two polar-orbiting satellites (Sentinel-2A and Sentinel-2B), which cover the visible, NIR and SWIR spectral regions and different spatial resolution (10m, 20m, and 60m) with a 5day revisit at the Equator.

The Simplified Level 2 Product Prototype Processor (SL2P) algorithm was developed by Weiss et al. (2016) to derive vegetation biophysical variables from Sentinel-2/MSI and Landsat data. SL2P is a collection of backpropagation artificial neural networks (ANN) trained using a globally representative set of simulations from a canopy radiative transfer (RT) model (Najib et al. 2019). Landscape Evolution and Forecasting (LEAF) Toolbox includes SL2P for efficient global mapping of biophysical variables (Fernandes et al., 2021). The thematic performance of the LEAF implementation of SL2P estimates of FAPAR, fCOVER and LAI has been quantified at more than 1000 North American in-situ sites across different land cover classes (Brown et al., 2021; Fernandes et al., 2023). LEAF can also generate products corresponding to temporal composites based on selected available clear sky S2 or Landsat data covering a field site based on criteria (Sun and Fernandes, 2023).

This study applies LEAF to generate monthly fCOVER, FAPAR and LAI for the Hudson Bay Lowland (HBL) from 2019 to 2023 at 20m resolution using S2 from May to Sep. to support permafrost modelling in this area. Landsat products is also processed for the purpose of the comparison to identify any difference of two products. Validation is performed using available in-situ measurements in the HBL and bordering ecozones.

2. Study area

The study area is located in the Hudson Bay Lowland, mostly in far north of Ontario, partly located in Manitoba and Quebec. Land cover is mainly wetland and needleleaf forest (Figure 1). The percentages of each land cover class in this study area are included in Table 1.

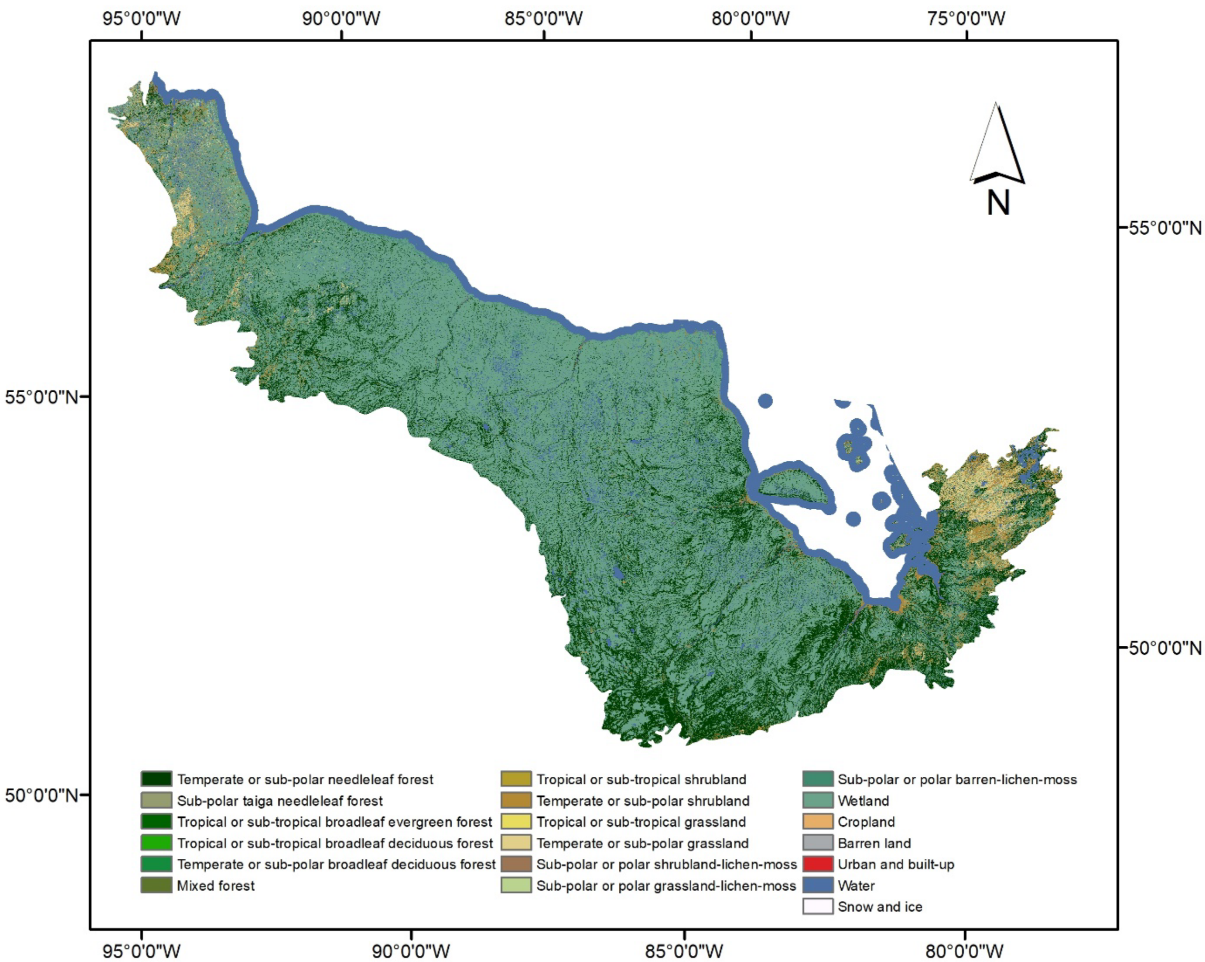


Figure 1. Study area.

Table 1. Summary of land cover classes in the study area.

Class	Percentage (%)
Temperate or sub-polar needleleaf forest	21.3
Sub-polar taiga needleleaf forest	1.3
Temperate or sub-polar broadleaf deciduous forest	0.0
Mixed forest	0.3
Temperate or sub-polar shrubland	3.5
Temperate or sub-polar grassland	2.0
Sub-polar or polar shrubland-lichen-moss	0.0
Sub-polar or polar grassland-lichen-moss	0.3
Sub-polar or polar barren-lichen-moss	0.6
Wetland	56.7
Barren land	0.0
Urban and built-up	0.0
Water	13.9

3. Data sets

3.1. Field data

There are six field sites in Peawanuck collected in late August of 2022 and 58 sites in Geraldton (600km south from the sites of Peawanuck) in the middle of July of 2020. Figure 2 shows the locations of those field sites. The camera used for Peawanuck was a NikonD850 fisheye and for Geraldton, NikonD850 fisheye for upward and NikonD300 fisheye for downward. NX studio was used to enhance the image before running CAN_EYE (V6.495), which was used for processing digital hemispherical photographs (DPH). DHP technique uses a digital camera with fisheye lens to measure canopy gap fraction over a wide range of viewing directions (Fernandes et al. 2023).

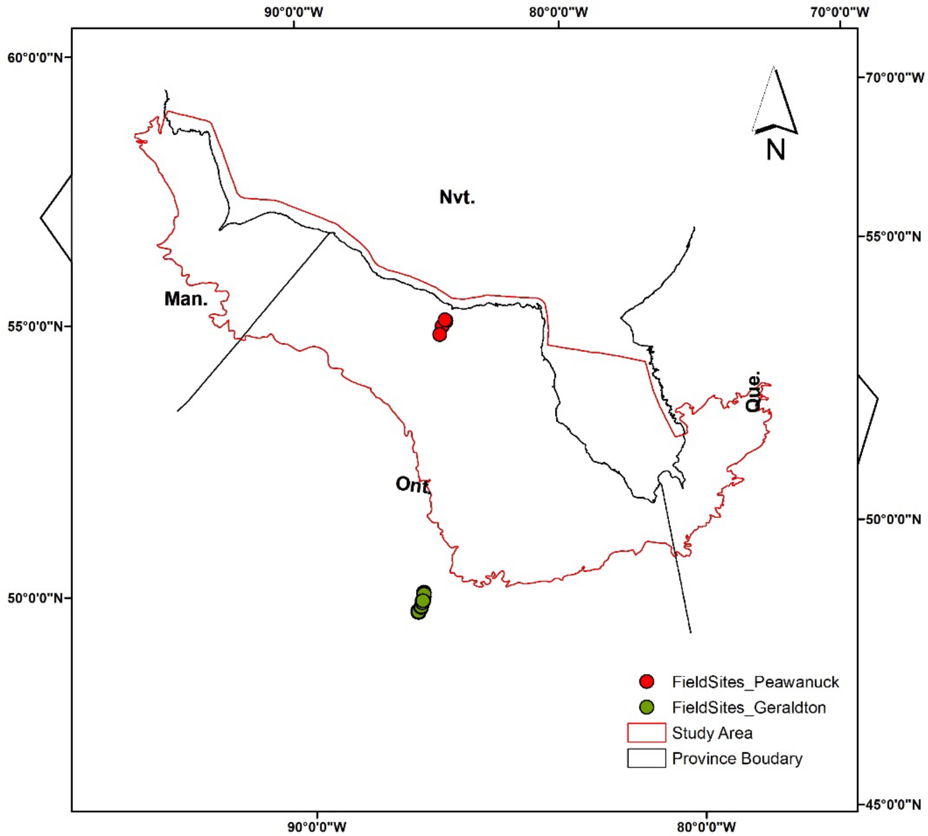


Figure 2. The location of field data

3.2. Optical data sets and products

The detailed band information of S2 is included in Table 2 and the bands used in SL2P is highlighted in bold and Table 3 for Landsat 8. The spectral information of Landsat 9 is similar to Landsat 8.

Table 2. S2 MSI spectral bands (bands indicated in bold are used by SL2P).

Band	Resolution (m)	Central Wavelength(um)	Description
B1	60	0.443	Coastal and Aerosol
B2	10	0.490	Blue
B3	**10**	**0.560**	**Green**

B4	**10**	**0.665**	**Red**
B5	**20**	**0.705**	**Visible and Near Infrared**
B6	**20**	**0.740**	**Visible and Near Infrared**
B7	**20**	**0.783**	**Visible and Near Infrared**
B8	10	0.842	Visible and Near Infrared
B8a	**20**	**0.865**	**Visible and Near Infrared**
B9	60	0.940	Short Wave Infrared
B10	60	1.375	Short Wave Infrared
B11	**20**	**1.610**	**Short Wave Infrared**
B12	**20**	**2.190**	**Short Wave Infrared**

Table 3. Landsat-8 OLI spectral bands (bands indicated in bold are used by SL2P).

Band	**Resolution (m)**	**Wavelength (μm)**	**Description**
B1	30	0.443	Coastal / Aerosol
B2	30	0.482	Visible blue
B3	**30**	**0.561**	**Visible green**
B4	**30**	**0.655**	**Visible red**
B5	**30**	**0.865**	**Near-infrared**
B6	**30**	**1.609**	**Short wavelength infrared**
B7	**30**	**2.201**	**Short wavelength infrared**
B8	15	0.590	Panchromatic
B9	30	1.373	Cirrus

The LEAF production tool (https://github.com/fqqlsun/LEAF_production/tree/main) generates the monthly biophysical mosaiced products of LAI, fCOVER, fAPAR. There is a QC (Quality Control) map and an acquisition date map corresponding to those products. The detailed definition of each product is included in Table 4.

Table 4. Product definition*

Variable Definition	**Variable Definition**
FAPAR	Fraction of absorbed photosynthetically active radiation by green vegetation for a given solar illumination condition.
fCOVER	Fraction of ground covered by green vegetation.
LAI	Half the total foliage area per unit horizontal ground area.

*(Richard et al. 2023)

4. Results

4.1. Examples of results

This study applies LEAF to produce monthly fCOVER, FAPAR and LAI for the Hudson Bay Lowland from 2019 to 2023 at 20m resolution using S2 and 30m for Landsat 8 from May to Sep. Some of results are listed in this section for performance assessment in a qualitive way.

Figure 3 shows LAI, fCOVER, FAPAR from S2 for August, 2022, it is easy to see the vegetation ground condition from those variables in August. Although S2 has a higher revisiting time (5 days), it is still not easy to have a full coverage cloud free results in this month. Figure 3 (d) corresponds to quality control layer; the meaning of the number can be found in LEAF_production github (https://github.com/fqqlsun/LEAF_production/tree/main).

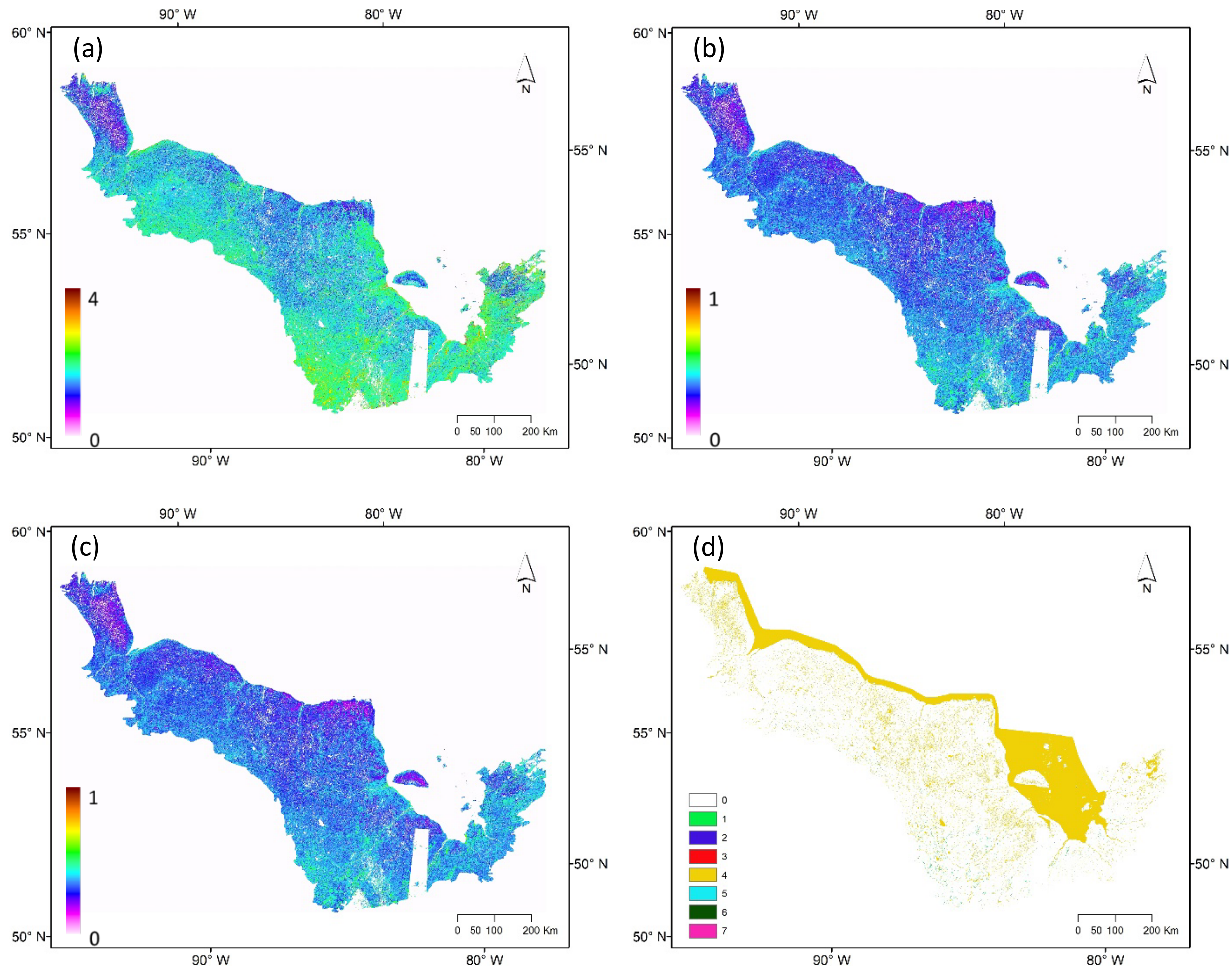


Figure 3. Biophysical parameters for 2022 using S2.

(a) LAI, (b) fCOVER, (c) FAPAR (d) Quality Control (QC)

Figures 4,5, 6 show LAI, fCOVER and FAPAR from June to September in 2022. The comparison of different months clearly shows the vegetation seasonal change.

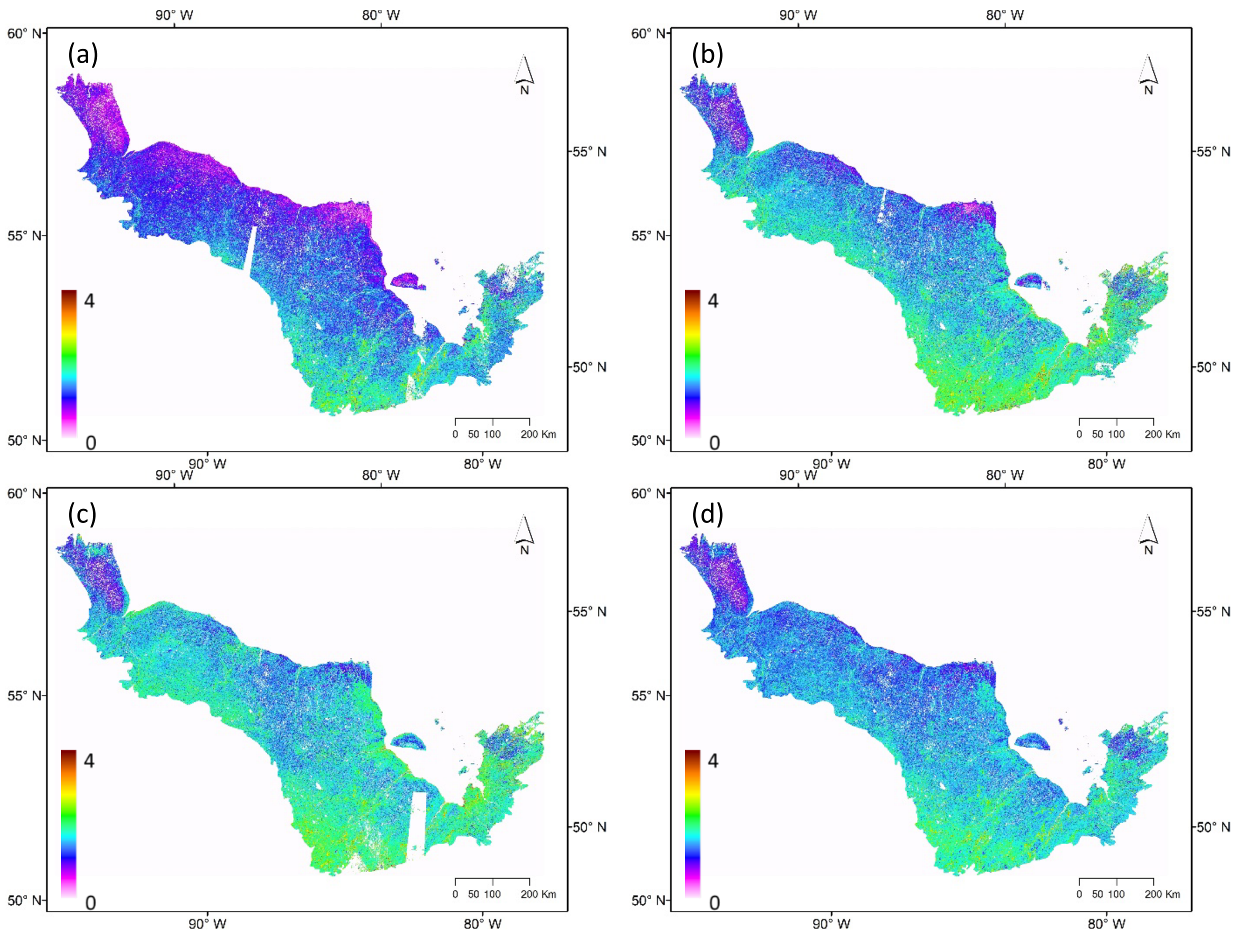


Figure 4. Monthly LAI for 2022.

(a) June, (b) July, (c) August (d) Sep.

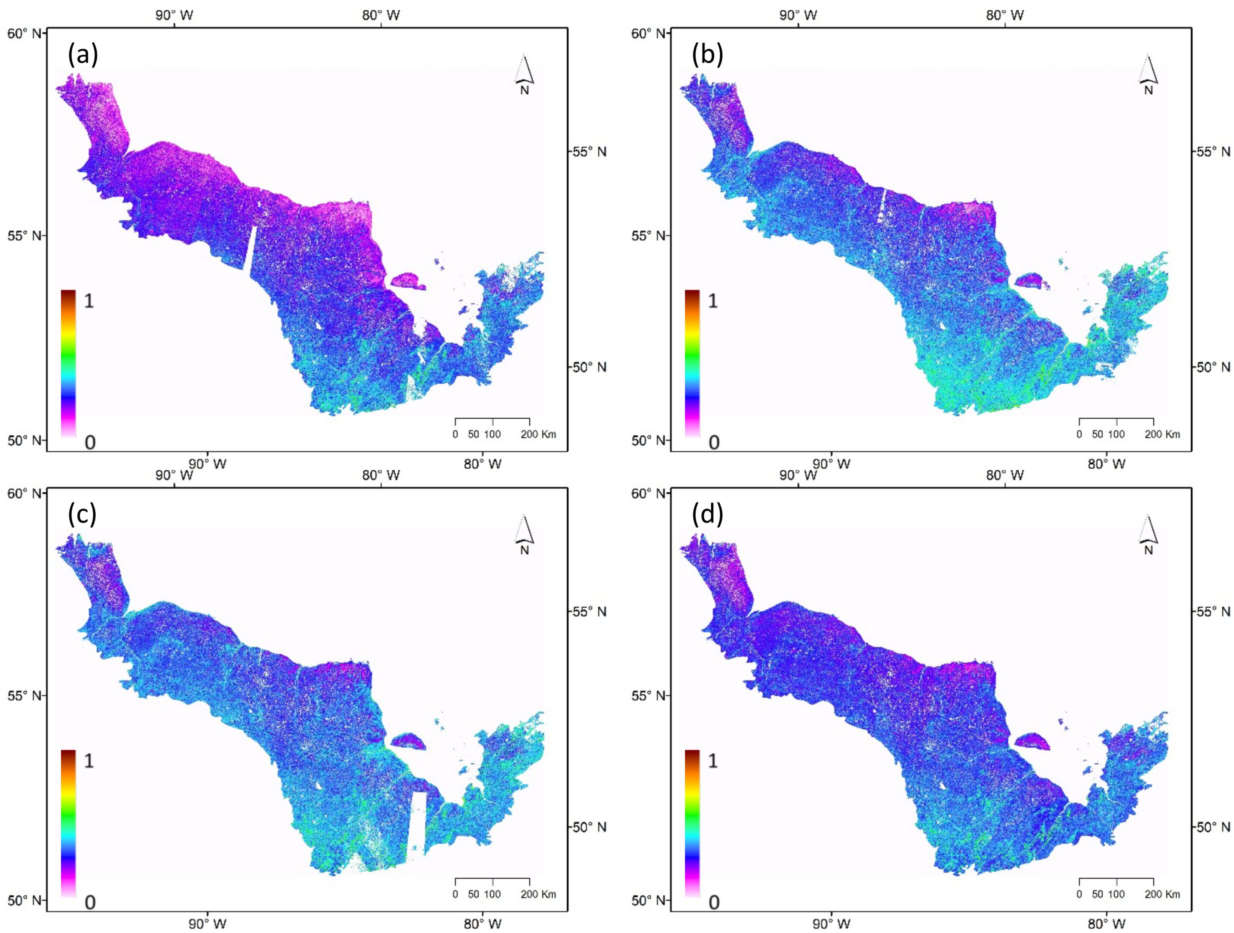
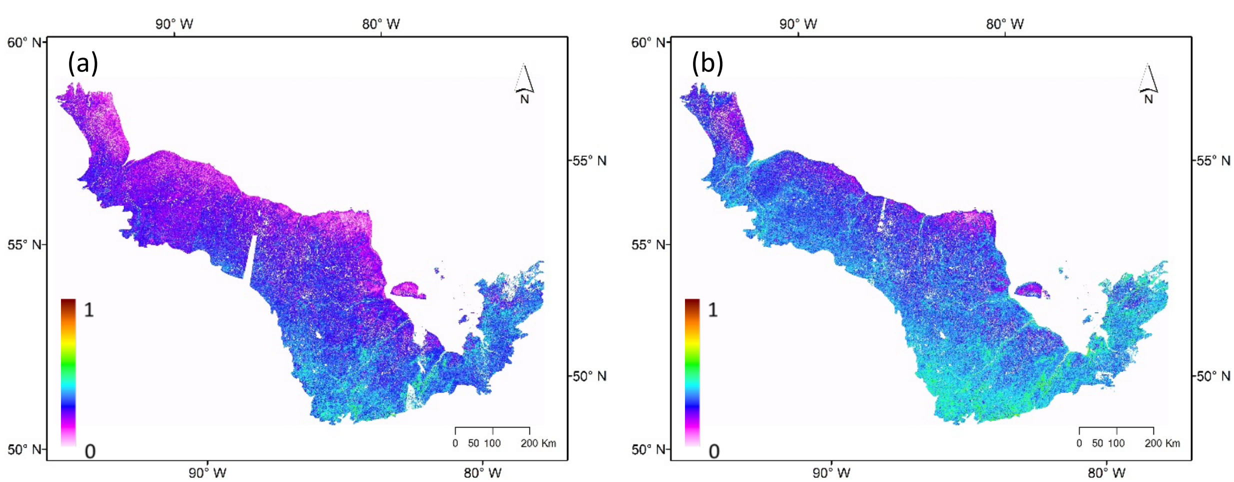


Figure 5. Monthly fCover for 2022.

(a) June, (b) July, (c) August, (d) Sep.



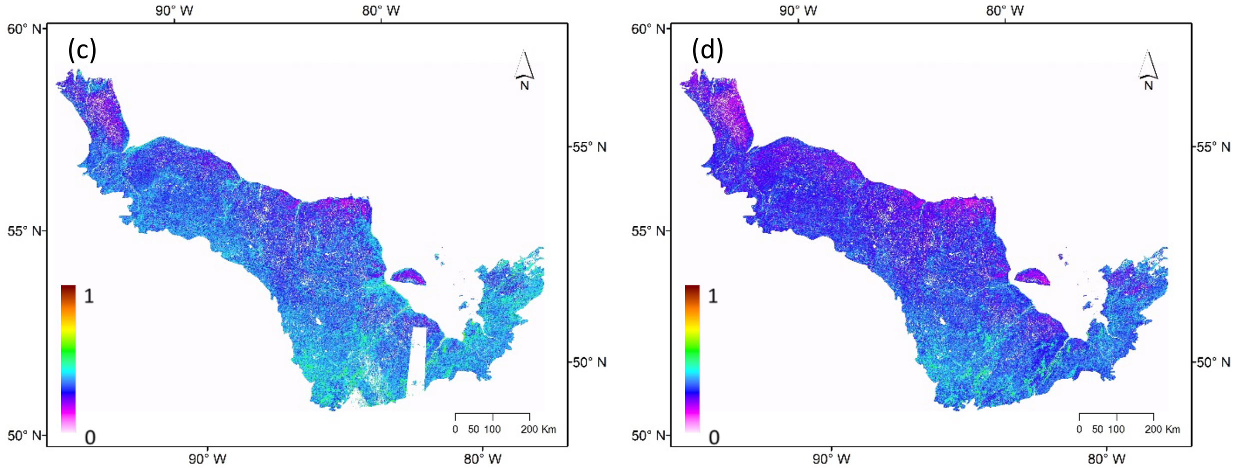
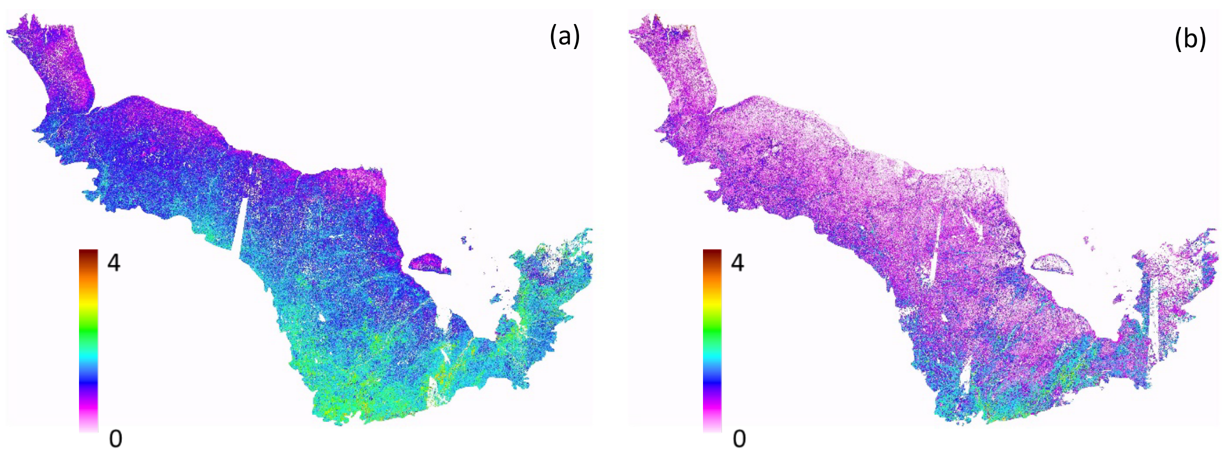


Figure 6. Monthly FAPAR for 2022.

(a) June, (b) July, (c) August, (d) Sep.

Figure 7 shows the LAI comparisons between S2 and Landsat 8/9 for each month, which indicate LAI from Landsat 8/9 is underestimated compared with S2.



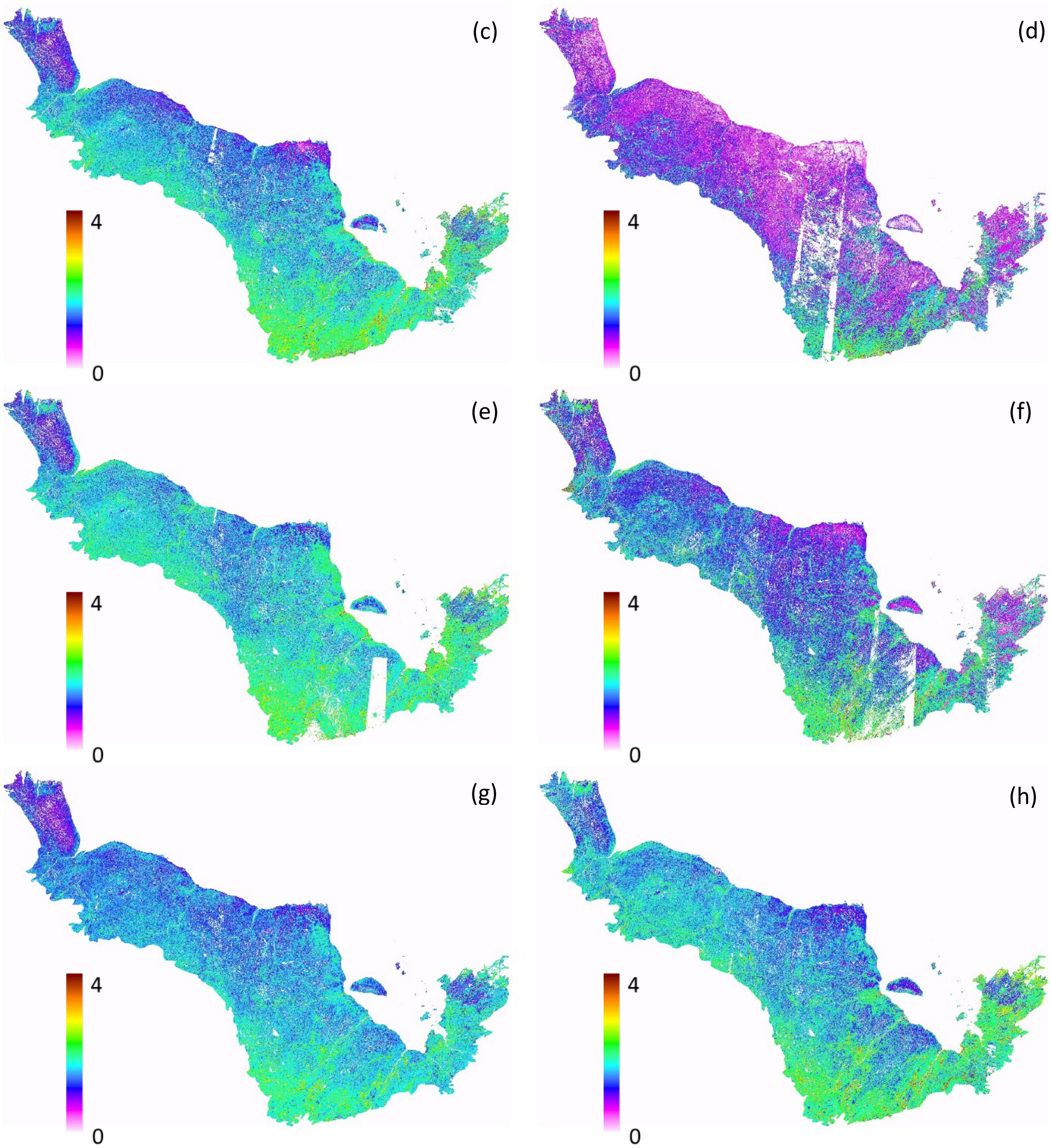


Figure 7. Monthly LAI for S2 and Landsat 8/9 in 2022.

(a) S2 (June), (b) Landsat8/9 (June), (c) S2 (July), (d) Landsat 8/9 (July), (e) S2 (August) (f) Landsat 8/9 (August), (g) S2 (Sep.), (h) Landsat8/9 (Sep.).

4.2. In-situ analysis

Thematic performance was assessed using LEAF using temporal windows +/- 10 days based on the date of field sample site to generate biophysical parameters and then cloud percentage was calculated for each site. A cloud thresholding of 10 is set to remove some sites with heave cloud. The results are compared to in-situ reference measurements (RM), the details of this procedure could be found in Fernandes et al. (2023). Table 5 lists the metrics used in the validation procedure. International Geosphere Biosphere Programme (IGBP) classes (Lambin and Geist, 2006) was used to label the RM sites, there are mainly mixed forest, deciduous broadleaf forest, evergreen needleleaf forest in this study. Clumping index is defined as a ratio of the effective leaf area index to the leaf area index.

Table 5. Thematic error metrics used for product validation*

Metric	Acronym	Definition
Uncertainty	U	Square root of the expected value of the squared difference of estimated and product values.
Accuracy	A	Expected value of the estimated value minus the product value.
Precision	P	Square root of the expected value of the square of the total of the estimated value minus both the product value and the accuracy metric.
Uncertainty agreement ratio	UAR	The fraction of validated samples that meet a given uncertainty requirement, in this case, GCOS.

**(Richard et al. 2023).*

Figure 8 shows the in-situ analysis result of S2. There are 64 field sites for both field trips. After cloud screening procedure for S2, there are 56 sites left (2 sites are from Peawanuck). Figure 8 shows that LAI processed by SL2P result fits very well with in-situ data. There are some sites with issues for fCOVER and FAPAR. Further checking the field data will be helpful to refine the in-situ analysis.

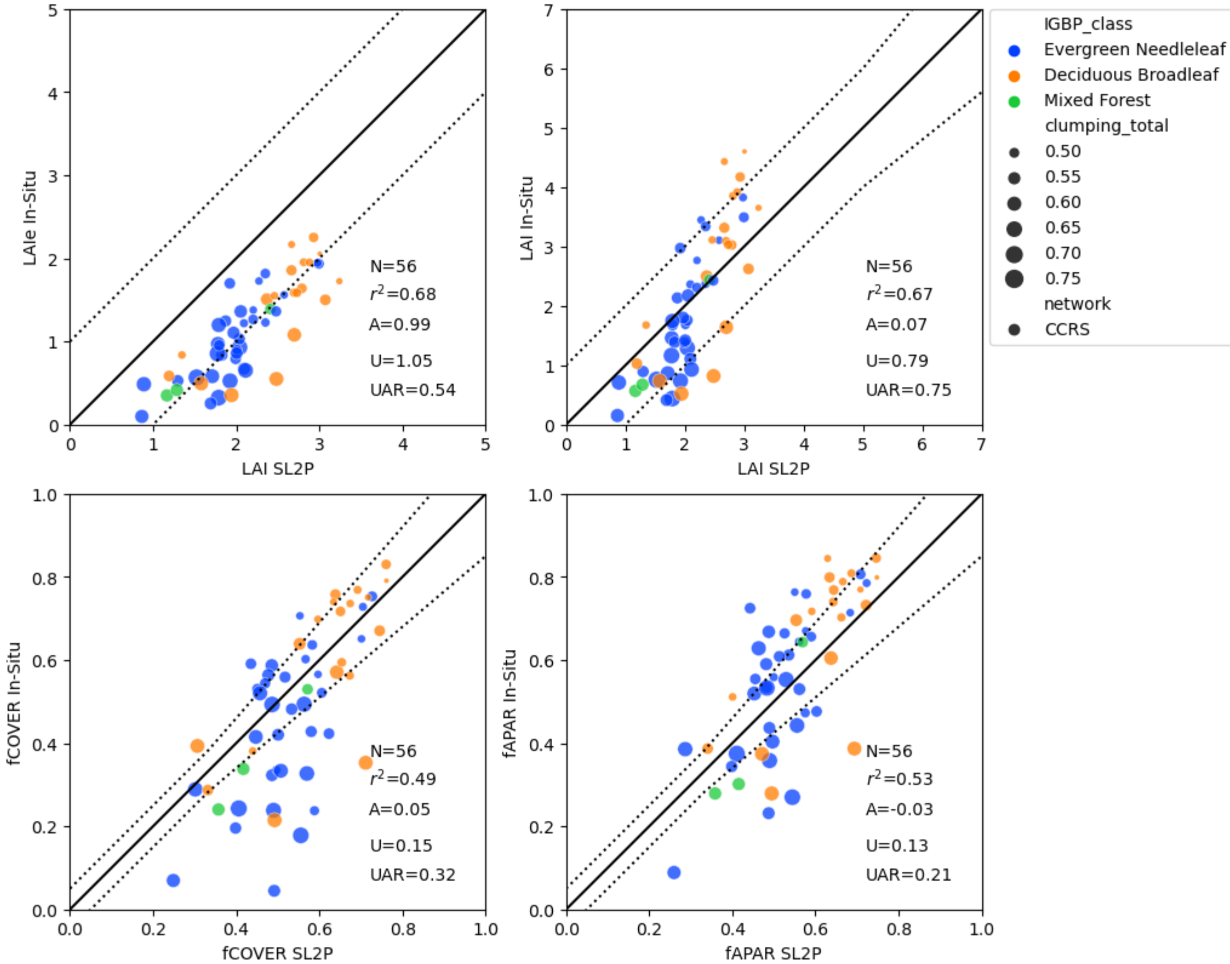


Figure 8. In-situ analysis results of S2

Figure 9 shows the in-situ analysis result of Landsat 8/9. There are 40 sites left (6 sites are from Peawanuck) for in-situ analysis after cloud screening. Figure 9 shows that LAI processed by SL2P result fits very well with in-situ data except some needle leaf forest sample sites falling close to bottom dash boundary. There are some sites with issues for fCOVER and FAPAR, like S2 case.

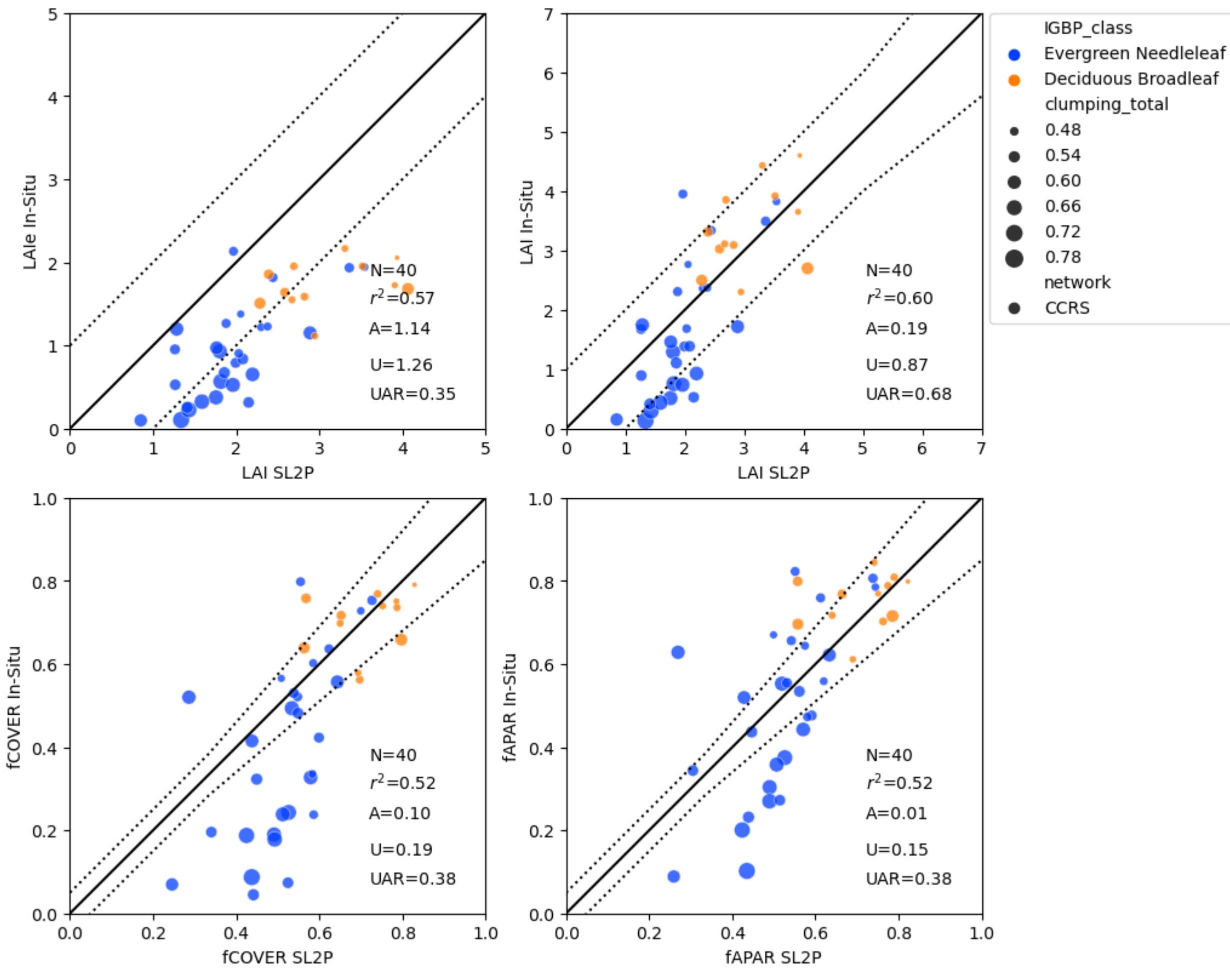


Figure 9. In-situ analysis results of Landsat 8/9

5. Discussion

Both S2 and Landsat provide qualitatively acceptable regional patterns of fCOVER, LAI and fAPAR. Gaps due to clouds suggest combined products may be required to ensure complete monthly coverage.

The S2 validation, while limited, agrees with Fernandes et al. (2023) that LEAF using the SL2P-CCRS algorithm provides relatively unbiased estimates over forests. Some of the LAI underestimation for LAI<2 may be due to using a fixed conversion factor for woody area. Local factors should be calibrated. fCOVER precision is lower than that of FAPAR. This may be due to lower precision of the in-situ fCOVER due to biased sampling towards gaps. Further in-situ measurements and quality control of these measurements is recommended. Landsat validation and intercomparison with S2 is required if the products are to be combined.

6. Conclusion

Maps with 20m and 30m resolution of monthly LAI, fCOVER and FAPAR were produced and validated using S2 and Landsat imagery over the HBL.SL2P algorithm provides an efficient way to produce biophysical parameters for S2 and Landsat 8/9. LEAF developed in CCRS provided an operational way to generate monthly products. In this study, we produced two products in Hudson Bay Lowland, the comparison shows that the results based on Landsat 8/9 is underestimated compared to S2 results. The other issue found that gap due to cloud still exist in monthly product of S2 although S2 revisiting period is 5 days. There are not enough field data near the study area of Hudon Bay Lowland, we used a close area about 600km far for in-situ analysis, the current in-situ analysis result might not reflect the study area completely.

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Products contains modified Copernicus Sentinel data 2019, 2020,2021,2022,2023. Dr. Marie Weiss and Dr. Fred Baret provided an initial version of the code used to produce the S2P regression algorithms later modified as described in Fernande et al., 2023. We acknowledge Dr. Wenjun Chen, Julie Lovitt, and Dr. Liming He for field data collection. This work was based on algorithms developed within the Natural Resources Canada Earth Observation of Cumulative Effects programme of the Government of Canada.

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