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ASSESSMENT OF THE CCI LAND COVER PRODUCT FOR USE IN THE CANADIAN LAND SURFACE SCHEME

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Background & Introduction

- The simulation of winter albedo in boreal and northern environments has been a particular challenge for land surface modelers.

- Assessments of output from the CMIP3 and CMIP5 climate models have revealed a large spread in simulated winter albedo and snow-albedo feedback strength in the boreal forest.

- Recent studies suggest that inaccurate representation of vegetation distribution, improper simulation of leaf area index, and poor treatment of canopy-snow processes are the primary causes of albedo errors (Bartlett and Verseghy, 2015; Thackery et al., 2014; Wang et al., 2016).

- Most land surface models (LSM) represent global vegetation from a set of plant functional types (PFTs), which are commonly based on LC products. The LC information is usually converted to PFTs through a cross-walking (CW) procedure that assigns PFT fractions for each LC class.

- Different LC products have been used by different model groups, potentially leading to inconsistencies between models.

Background & Intro --- cont…

- CLASS is a physically based land surface scheme with complete thermal and hydrological budgets [Verseghy, 1991]. It has four broad PFTs: needleleaf forest (NF), broadleaf forest (BF), crops, and grass.

- GLC2000 has been used to obtain PFTs and initial surface conditions for CLASS when employed as the land surface component in the climate and Earth system models of ECCC.

- The Climate Change Initiative (CCI) LC product recently produced by ESA was developed specifically to address the needs of the climate modelling community (ESA, 2017). It has 300m resolution, available annually for 1992-2017.

- The finer spatial resolution makes it inherently superior for LC mapping in heterogeneous landscapes than coarser resolution products, such as the GLC2000 dataset (1km resolution).

- The objective of this study is to compare and assess the accuracy of the CCI and GLC2000 datasets through comparison with high resolution LC datasets over Canada, and to determine the applicability of the CCI dataset for use in CLASS.

Background & Intro --- cont…

- We modify the default CW table from the CCI LC user guide (ESA, 2017) to generate four PFTs for CLASS, and compare them with those derived from GLC2000.

- We conduct offline simulations with CLASS 3.6.1 using PFTs and initial surface conditions from CCI and GLC2000 respectively, and compare the simulated winter albedo with satellite observations.

- The GSWP3 (Global Soil Wetness Project Phase 3) dataset with CanGRD adjusted Precp. are used to drive the model at 0.5x0.5 degree lat/lon grid.

- CLASS is setup to run from June 1999 to Dec. 2010; analyses are done for 2001-2010 with June 1999 to Dec. 2000 treated as spin up period.

outline

- Background and Introduction
- Part I: comparison of land cover datasets
- Part II: comparison of PFTs and winter albedo from offline simulations with CLASS
- Summary and work ongoing

Part I -- LC datasets comparisons

- **Two global datasets**:

(1) *GLC2000*, 1km, 22 classes, based on the United Nations Land Cover Classification System (LCCS) from SPOT/VEGETATION data, for 2000 only (Bartholomé and Belward, 2005).
(2) *CCI* (Climate Change Initiative), 300m, 22 level 1 and 15 level2 classes, based on LCCS mainly using ENVISAT/MERIS data, available annually for 1992-2017 (ESA, 2017).

- **Three regional datasets over Canada**:

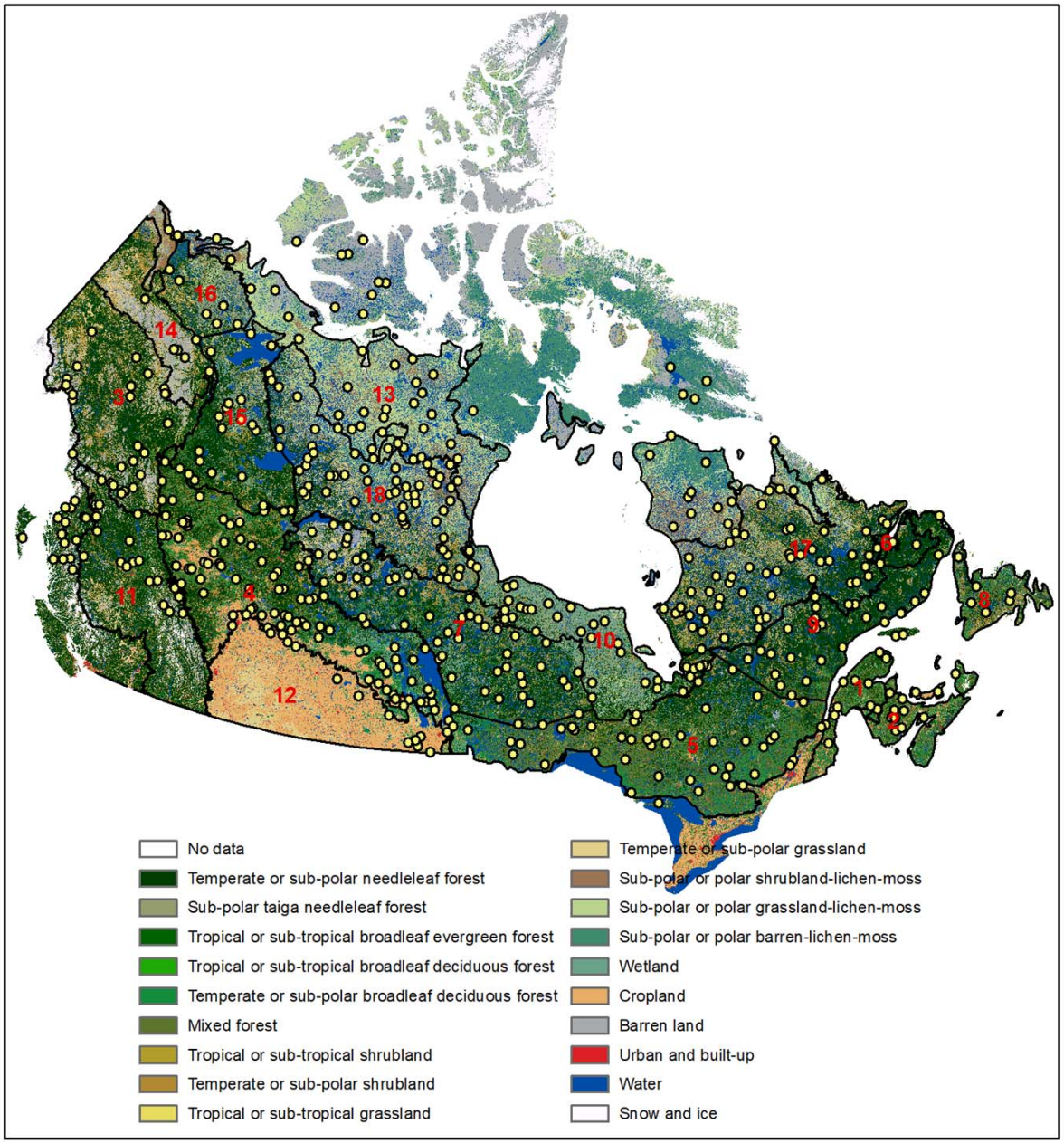
(1) *NALCMS* (North America Land Cover Monitoring System program), 30m, 19 classes, based on LCCS, 2010 (Latifovic et al., 2017)
(2) *EOSD* (Earth Observation for Sustainable Development of Forests), 25m, 23 classes, based on the National Forest Inventory hierarchical classification system, for 2000 (Wulder et al., 2008).
(3) *MODIS* (Moderate Resolution Imaging Spectroradiometer), 250m, using the same legend as the NALCMS dataset, available for 2000-2011 (Pouliot et al., 2013).

- **Tree cover fraction and forest loss/gain**

Hansen data, 30m, a vegetation continuous field product based on Landsat images, instead of cover type it provides fractional tree cover at each pixel, may better represent heterogeneous areas than is possible by discrete LC classification, TCF available for 2000 and forest loss/gain during 2000-2012 (Hansen et al., 2013).

- NALCMS was used as the reference dataset in our comparisons, which is not ideal.
- 567 randomly selected samples to assess the uncertainties in NALCMS.
- The results show that the wetland class in NALCMS exerts the largest uncertainty in forest cover mapping because treed-wetland was not separated from herbaceous wetland in the legend.
- An approximation of wetland-treed pixels in NALCMS is derived based on the ratio of wetland-treed pixels and total wetland pixels in EOSD.

NALCMS: 30m LC map of Canada

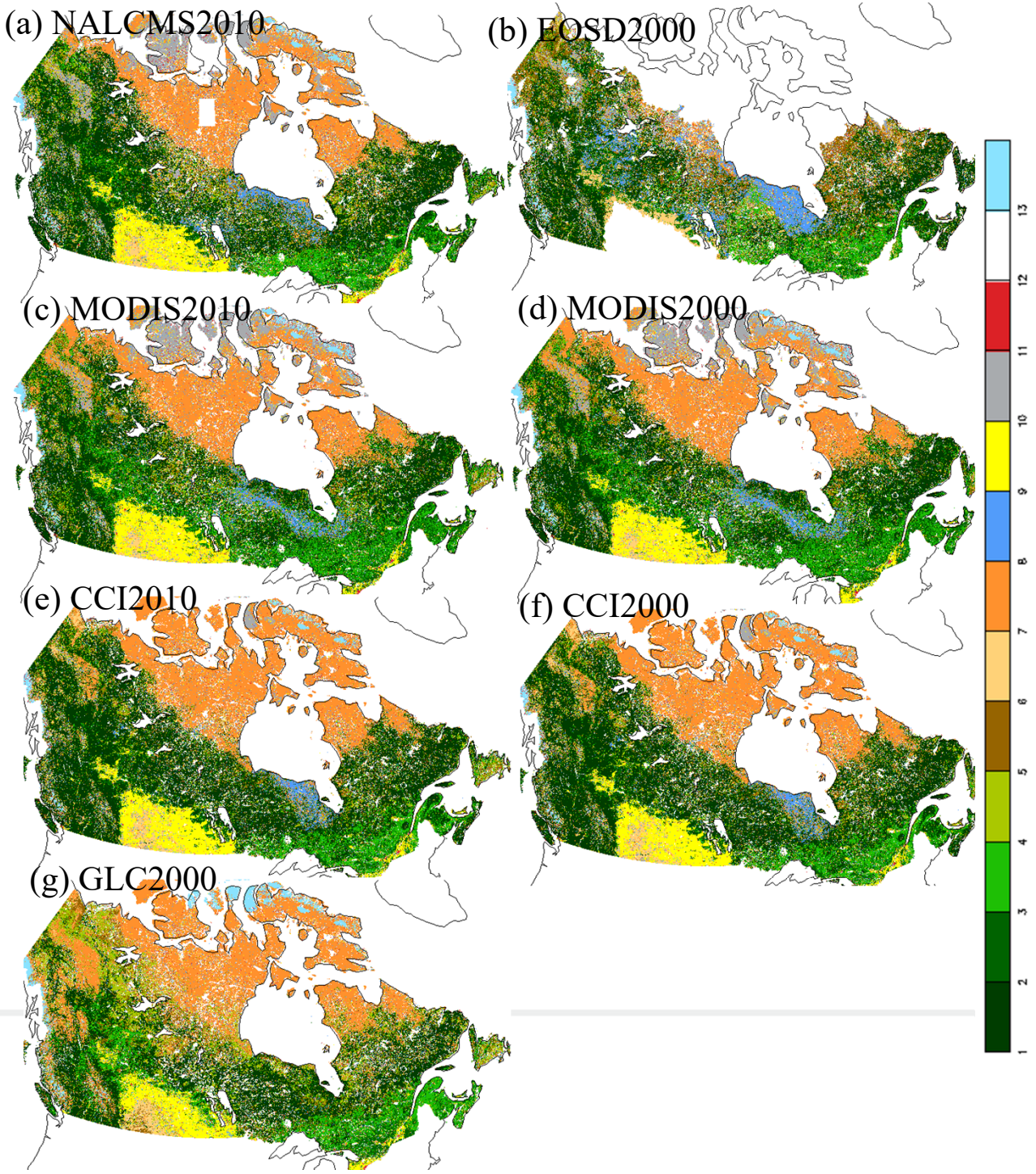


NALCMS/MODIS	EOSD	CCI	GLC2000
[1] Temperate or sub-polar needleleaf forest [2] Sub-polar taiga needleleaf forest [3] Tropical or sub-tropical broadleaf evergreen forest [4] Tropical or sub-tropical broadleaf deciduous forest [5] Temperate or sub-polar broadleaf deciduous forest [6] Mixed forest [7] Tropical or sub-tropical shrubland [8] Temperate or sub-polar shrubland [9] Tropical or sub-tropical grassland [10] Temperate or sub-polar grassland [11] Sub-polar or polar shrubland-lichen-moss [12] Sub-polar or polar grassland-lichen-moss [13] Sub-polar or polar barren-lichen-moss [14] Wetland [15] Cropland [16] Barren lands [17] Urban [18] Water [19] Snow and Ice	[11] Cloud [12] Shadow [20] Water [31] Snow/Ice [32] Rock/Rubble [33] Exposed/Barren Land [40] Bryoids [51] Shrub Tall [52] Shrub Low [81] Wetland-treed [82] Wetland-shrub [83] Wetland-herb [100] Herbs [110] Grassland [211] Coniferous-dense [212] Coniferous-open [213] Coniferous-sparse [221] Broadleaf-dense [222] Broadleaf-open [223] Broadleaf-sparse [231] Mixedwood-dense [232] Mixedwood-open [233] Mixedwood-sparse	[10] Cropland rainfed (11) Herbaceous cover (12) Tree or shrub cover [20] Cropland irrigated or post-flooding [30] Mosaic cropland (>50%) / natural vegetation (tree shrub herbaceous cover) (<50%) [40] Mosaic natural vegetation (tree shrub herbaceous cover) (>50%) / cropland (<50%) [50] Tree cover broadleaved evergreen closed to open (>15%) [60] Tree cover broadleaved deciduous closed to open (>15%) (61) Tree cover broadleaved deciduous closed (>40%) (62) Tree cover broadleaved deciduous open (15-40%) [70] Tree cover needleleaved evergreen closed to open (>15%) (71) Tree cover needleleaved evergreen closed (>40%) (72) Tree cover needleleaved evergreen open (15-40%) [80] Tree cover needleleaved deciduous closed to open (>15%) (81) Tree cover needleleaved deciduous closed (>40%) (82) Tree cover needleleaved deciduous open (15-40%) [90] Tree cover mixed leaf type (broadleaved and needleleaved) [100] Mosaic tree and shrub (>50%) / herbaceous cover (<50%) [110] Mosaic herbaceous cover (>50%) / tree and shrub (<50%) [120] Shrubland (121) Shrubland evergreen (122) Shrubland deciduous [130] Grassland [140] Lichens and mosses [150] Sparse vegetation (tree shrub herbaceous cover) (<15%) (151) Sparse tree (<15%) (152) Sparse shrub (<15%)	[1] Tree cover, broadleaved, evergreen [2] Tree cover, broadleaved, deciduous, closed [3] Tree cover, broadleaved, deciduous, open [4] Tree cover, needle-leaved, evergreen [5] Tree cover, needle-leaved, deciduous [6] Tree cover, mixed leaf type [7] Tree cover, regularly flooded, fresh water [8] Tree cover, regularly flooded, saline water [9] Mosaic: tree cover / other natural vegetation [10] Tree cover, burnt [11] Shrub cover, closed-open, evergreen [12] Shrub cover, closed-open, deciduous [13] Herbaceous cover, closed-open [14] Sparse herbaceous or sparse shrub cover [15] Regularly flooded shrub and/or herbaceous cover [16] Cultivated and managed areas [17] Mosaic:

Common legend based on LCCS and the merging rules for each LC datasets

Common legend	NALCMS/MODIS	EOSD	CCI	GLC2000
1. Needleleaf forest	1,2	211,212,213	70,71,72,80,81,82	4,5
2. Broadleaf forest	5	221,222,223	50,60,61,62	1,2,3
3. Mixed forest	6	231,232,233	90	6
4. mosaic forest/other			100,110	9
5. Shrubs	8	51,52	120,121,122	11,12,10
6. Grassland	10	100,110	130	13
7. Sparse Veg	11,12,13	40	140,150,151,152,153	14
8. Wetland	14	81,82,83	160,170,180	7,8,15
9. Cropland	15	N/A	10,11,12,20,30,40	16, 17, 18
10. Barren land	16	32,33	200,201,202	19
11. Urban and buildup	17	34	190	22
12. Water	18	20	210	20
13. Snow and ice	19	31	220	21

LC maps under the common legend at 1km grid



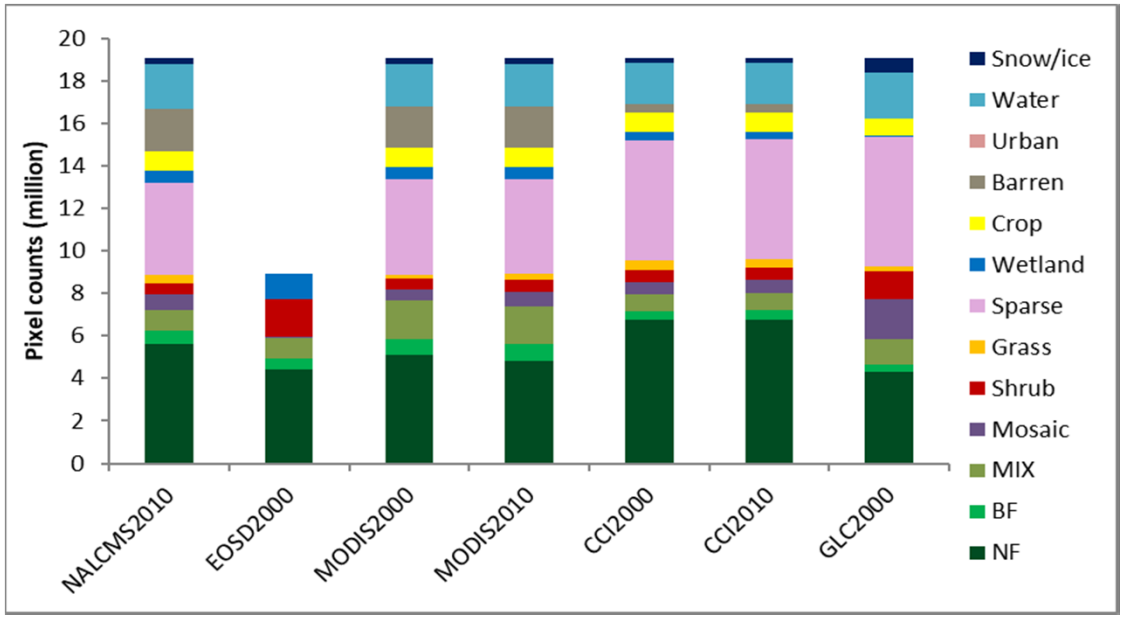
1 NF, 2 BF, 3 MF, 4 mosaic, 5 Shrub, 6 Grass, 7 Sparse, 8 Wetland, 9 Crop, 10 Barren, 11 Urban, 12 Water, 13 Snow/Ice

Pixel counts (million) for different LC classes from each dataset at 1km under the common legend

LC class	NF	BF	MF	Mosaic	Shrub	Grass	Sparse	Wland	Crop	Barren	Urban	Water	Snow
NALCMS2010	**5.63**	0.60	0.99	0.74	0.50	0.40	4.33	0.59	0.91	1.96	0.03	2.11	0.25
EOSD2000	4.44	0.51	0.95	0.08	1.74			1.22					
MODIS2000	5.12	0.71	1.86	0.50	0.50	0.20	4.46	0.60	0.90	1.96	0.01	1.96	0.28
MODIS2010	4.82	0.77	1.81	0.64	0.60	0.25	4.46	0.58	0.90	1.96	0.01	1.97	0.28
CCI2000	6.73	0.42	0.80	0.58	0.58	0.43	5.67	0.39	0.92	0.37	0.01	1.96	0.20
CCI2010	**6.78**	0.42	0.81	0.62	0.58	0.43	5.62	0.35	0.92	0.37	0.02	1.95	0.20
GLC2000	**4.31**	0.35	1.16	**1.87**	1.33	0.23	6.09	0.06	0.78	0.00	0.01	2.18	**0.68**

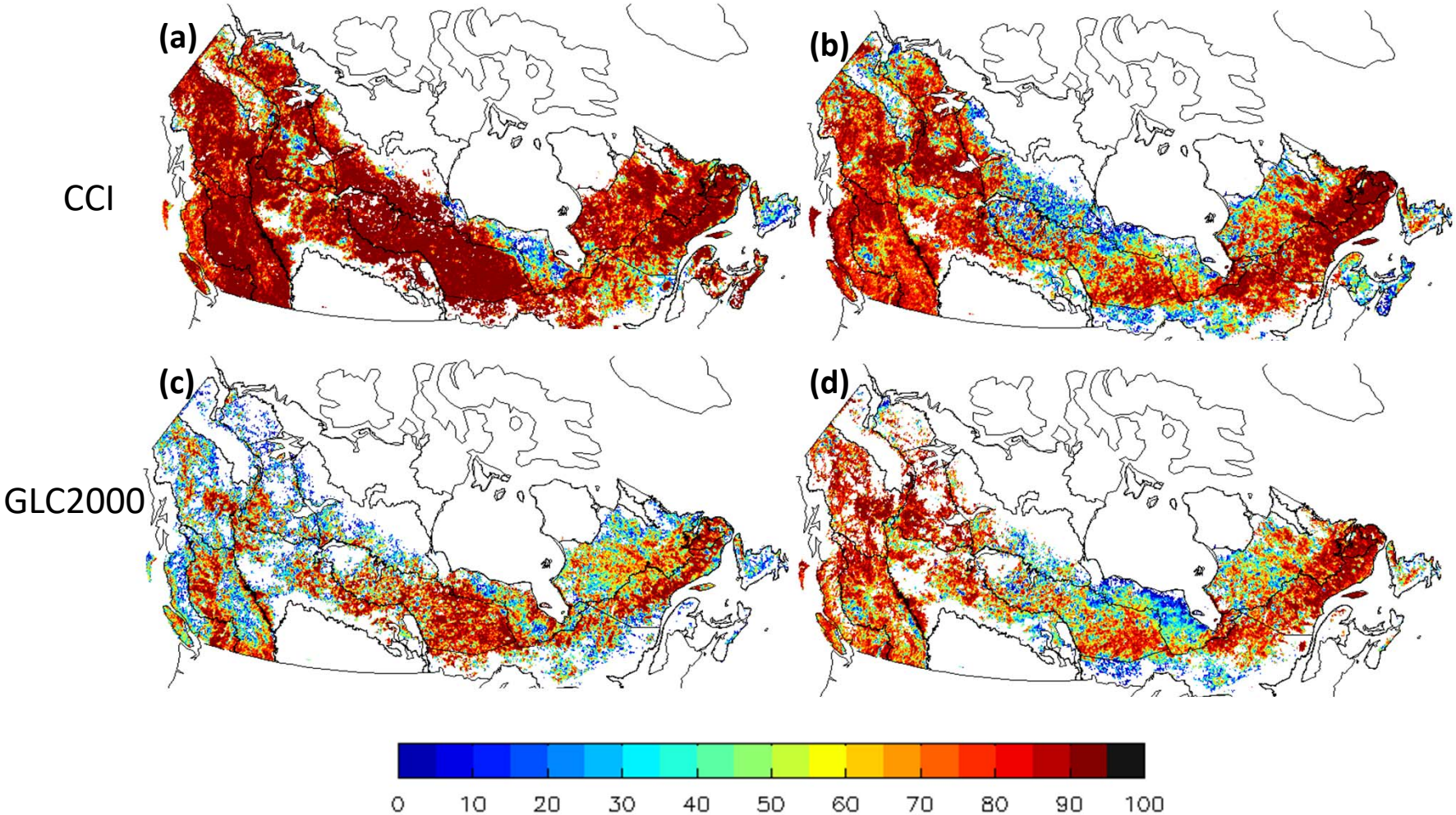
CCI mapped over 1 million more pixels of NF than all the other maps, while it mapped a bit less of all the other tree classes relative to NALCMS; in contrast, GLC2000 mapped over 1 million less pixels of NF but more mosaic, MF and shrub, and 50% more snow and ice pixels.

Pixel counts (million) for different LC classes from each dataset at 1km under the common legend



Note that the EOSD dataset is for forested areas only.

The producer (left) and user (right) accuracies for NF in the CCI (top) and GLC2000 (bottom) datasets relative to NALCMS

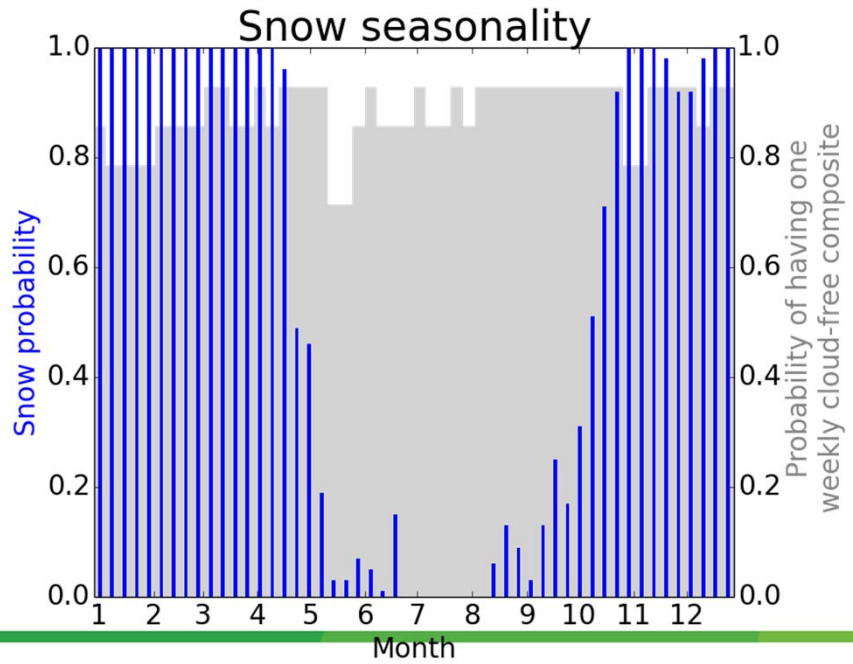


Possible causes of NF overestimate in CCI:

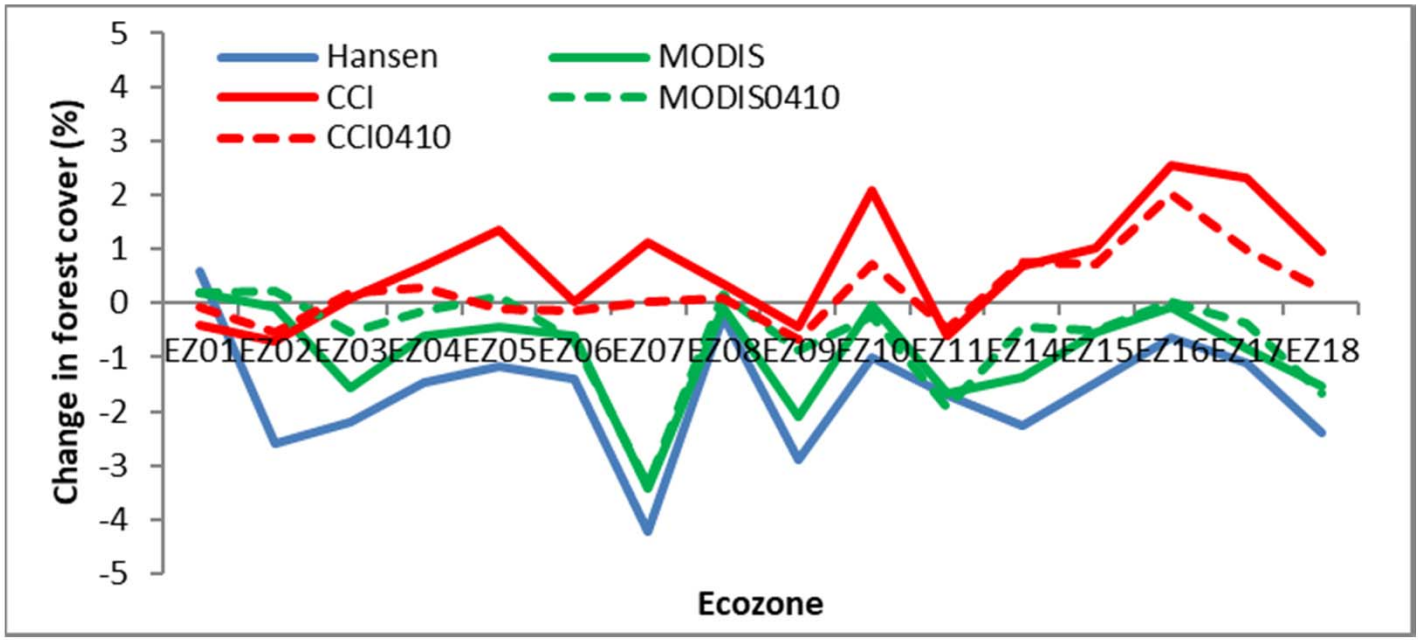
(1) The classification algorithm was based on seasonal composites;

(2) Due to long snow cover season at high latitude regions (including Canada), only the summer seasonal composite of MERIS data at FR (300m) were available, and reduced resolution (1200m) MERIS data were also used in the classification, thus some BF, MF, and wetland maybe misclassified as NF.

These may explain part of the overestimation, but this needs to be investigated further.



Change in forest cover from the Hansen, MODIS, and CCI datasets between 2000 and 2010 (solid lines).



Hansen and the MODIS datasets show a decrease (negative value) of forest cover from 2000 to 2010, with the largest decrease in EZ7, while CCI shows the opposite sign of change (forest gain) in most regions during the same period.

Part II: PFT comparison and CLASS tests

PFTs based on GLC2000:

- CLASS requires grid-scale parameters for LC related variables, such as surface albedo, leaf area index, surface roughness and rooting depth, etc., which have been computed by a weighted average of LC fractions from GLC2000.

- Based on expert knowledge of global biomes, Wang et al. (2006) generated a CW table to convert the GLC2000 classes to nine PFTs for use in the Canadian Terrestrial Ecosystem Model (Arora, 2003; Arora and Boer, 2006).

- It was later modified to produce four PFTs for use in CLASS.

Cross-walking table for GLC2000 LC classes to CLASS PFTs – modified from CW table in Wang et al. (2006).

GLC2000 legend description	NF	BF	Crop	Grass	Urban	Lake
1 – Tree cover, broadleaved, evergreen		1.0				
2 – Tree cover, broadleaved, deciduous, closed		1.0				
3 – Tree cover, broadleaved, deciduous, open		0.6		0.2		0.1
4 – Tree cover, needle-leaved, evergreen	1.0					
5 – Tree cover, needle-leaved, deciduous	0.8			0.1		
6 – Tree cover, mixed leaf type	0.4	0.5		0.1		
7 – Tree cover, regularly flooded, fresh water		0.5				0.5
8 – Tree cover, regularly flooded, saline water		0.5				
9 – Mosaic: tree cover / other natural vegetation		**0.6**		**0.2**		
10 – Tree cover, burnt	0.2	0.2		0.3		
11 – Shrub cover, closed-open, evergreen		0.6		0.2		0.1
12 – Shrub cover, closed-open, deciduous		0.4		0.3		
13 – Herbaceous cover, closed-open				0.7		
14 – Sparse herbaceous or sparse shrub cover		0.1		0.1		
15 – Regularly flooded shrub and/or herbaceous cover		0.5		0.3		0.1
16 – Cultivated and managed areas			**0.5**	0.4		
17 – Mosaic: cropland / tree cover / other natural veg		0.2	**0.5**	0.2		
18 – Mosaic: cropland / shrub and/or grass cover		0.1	**0.5**	0.3		
19 – Bare areas						
20 – Water bodies						1.0
21 – Snow and ice						
22 – Artificial surfaces and associated areas					1.0	

Mosaic class is assigned to BF, none to NF, in contrast with other LC datasets.

PFTs based on CCI

- The ESA LC product user guide (ESA, 2017) provides a CW table for converting the CCI classes into 10 PFTs. It was originally developed by Poulter et al. (2015) based on recommendations from experts in the remote sensing and climate modelling communities.

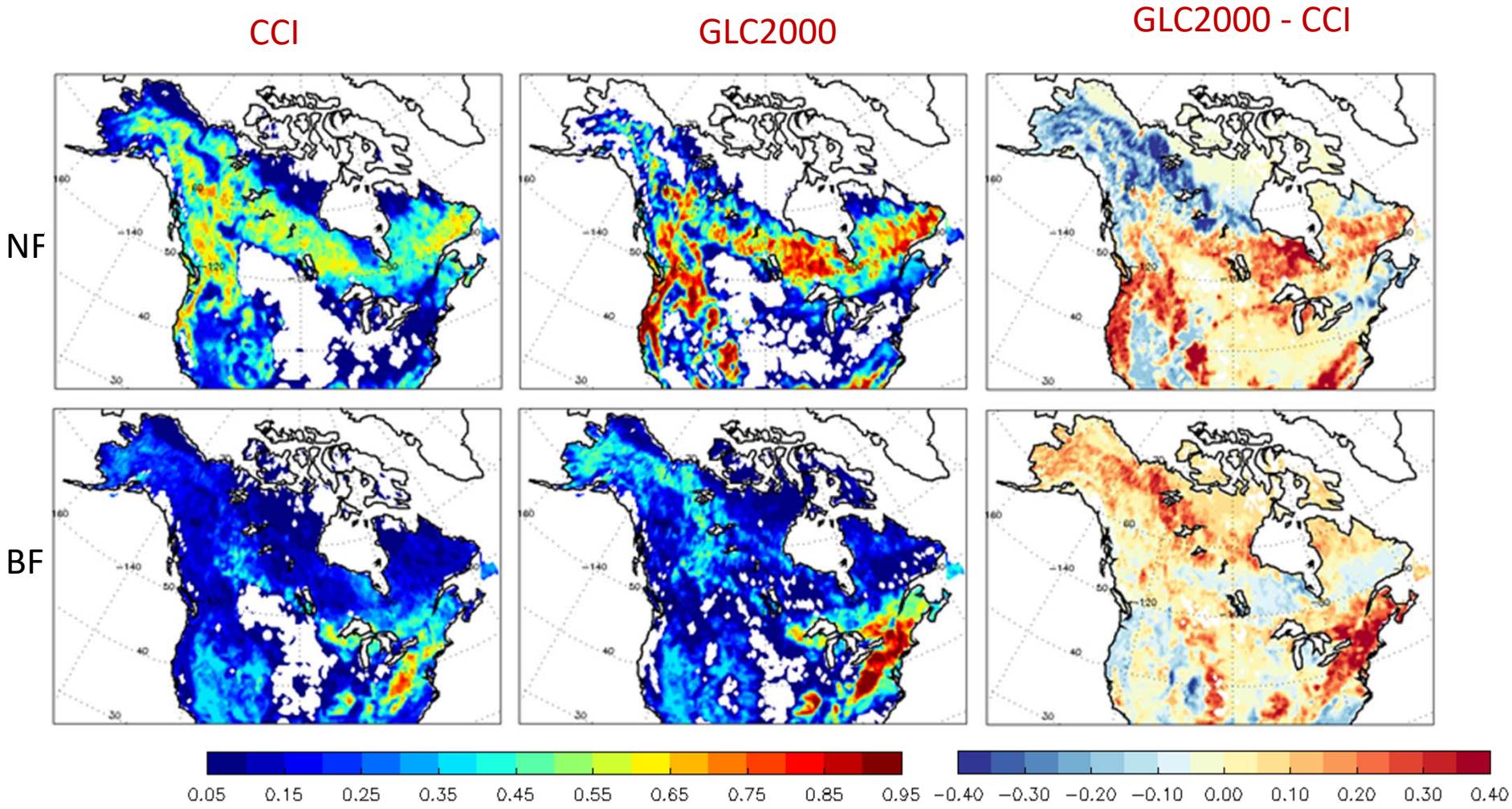
- It includes four tree PFTs, four shrub PFTs and two grass PFTs (managed and natural grass).

- CLASS doesn't have explicit shrub PFTs (research on including shrubs as a separate PFT is ongoing), so the four shrub PFTs were merged into either the NF or BF PFTs as was done in creating the GLC2000 table.

Cross-walking table for CCI LC classes to CLASS PFTs – modified from CW table in ESA documentation.

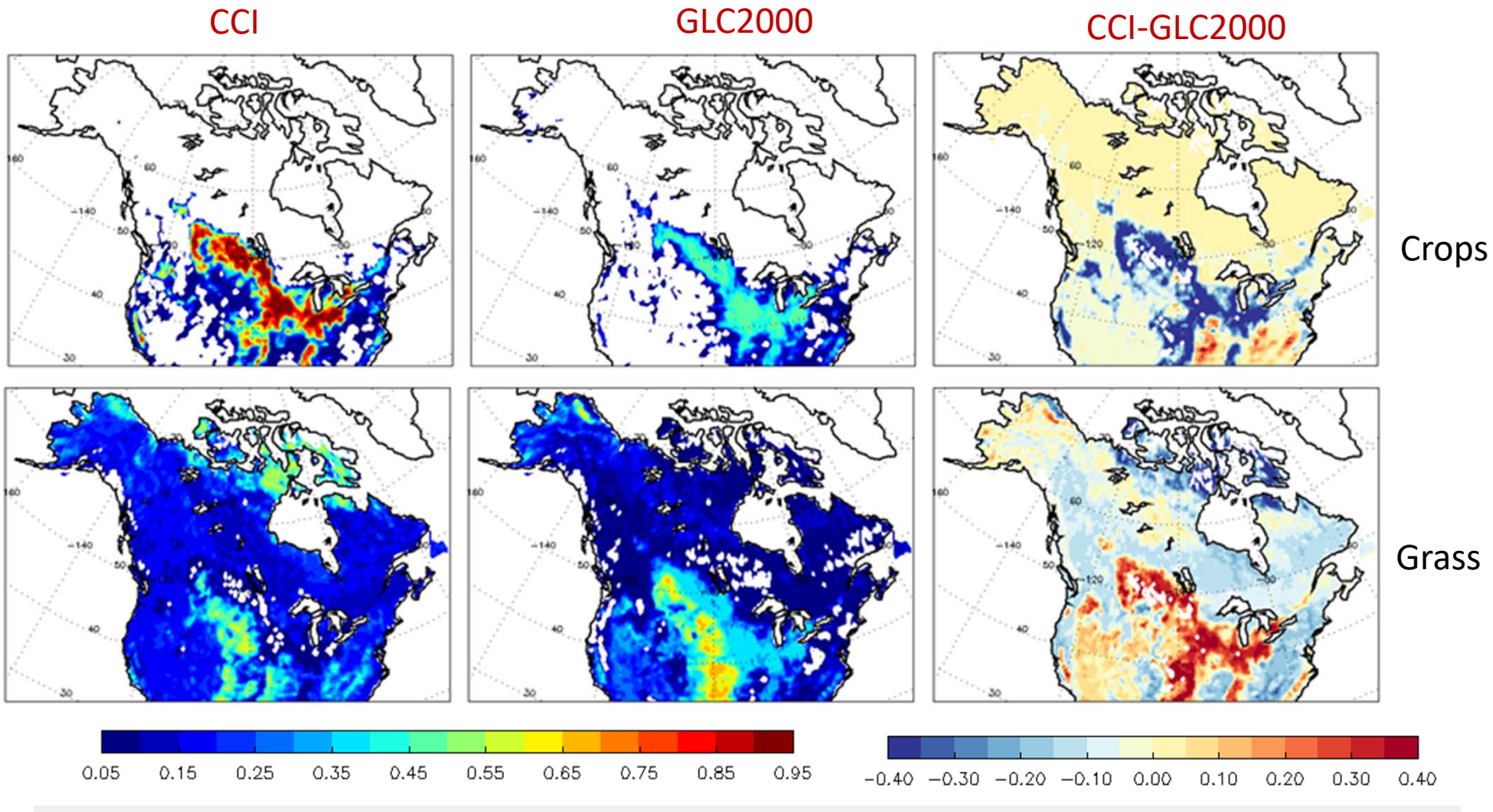
ESA-CCI legend description	NF	BF	Crop	Grass
10 - Cropland, rainfed (CR)			**1.0**	
11 - CR Herbaceous cover			**1.0**	
12 - CR Tree or shrub cover		0.5	**0.5**	
20 - Cropland, irrigated or post-flood			**1.0**	
30 - Mosaic cropland (>50%) / natural vegetation (tree, shrub, herb)	0.05	0.2	0.6	0.15
40 - Mosaic natural vegetation (tree, shrub, herb) >50% / crop	0.075	0.275	0.4	0.25
50 - Tree cover broadleaved evergreen closed to open		1.0		
60 - Tree cover broadleaved deciduous closed to open		0.85		0.15
61 - Tree cover broadleaved deciduous closed		0.85		0.15
62 - Tree cover broadleaved deciduous open		0.55		0.35
70 - Tree cover needleleaf evergreen closed to open	**0.75**	0.1		0.15
71 - Tree cover needleleaf evergreen, closed	**0.75**	0.1		0.15
72 - Tree cover needleleaf evergreen open	**0.35**	0.05		0.3
80 - Tree cover needleleaf deciduous closed to open	0.75	0.1		0.15
81 - Tree cover needleleaf deciduous closed	0.75	0.1		0.15
82 - Tree cover needleleaf deciduous open	0.35	0.05		0.3
90 - Tree cover Mixed	0.35	0.4		0.15
100 - Mosaic tree and shrub (>50%) / herbaceous cover (<50%)	0.15	0.45		0.4
110 - Mosaic herbaceous cover (>50%) / tree and shrub (<50%)	0.1	0.3		0.6
120 - Shrubland	0.2	0.4		0.2
121 - Shrubland evergreen	0.3	0.3		0.2
122 - Shrubland deciduous		0.6		0.2
130 - Grassland				0.6

Fractional coverage of CLASS PFTs from CCI (left), GLC2000 (mid), and the difference (right, GLC2000 – CCI)



CCI has more NF than GLC2000 in the Taiga shield EZs and west coast but less in Hudson Plains, consistent with LC comparison results.

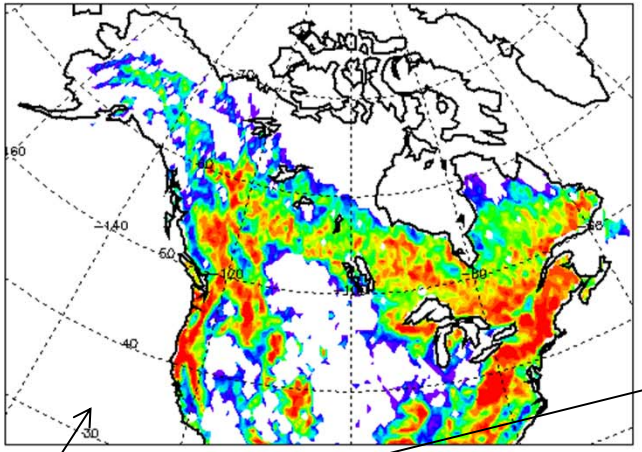
Fractional coverage of CLASS PFTs from CCI (left), GLC2000 (mid), and the difference (right, GLC2000 – CCI)



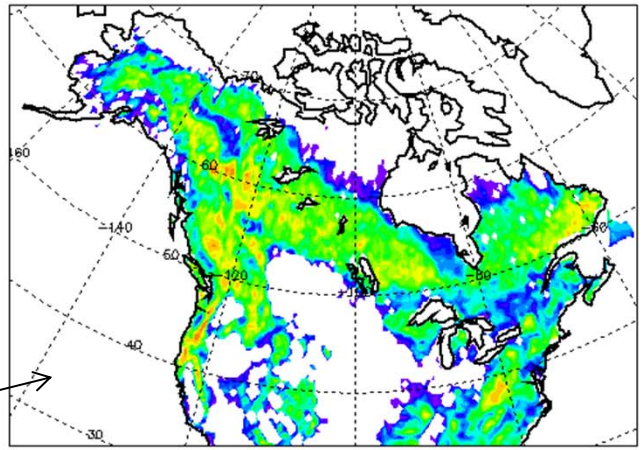
Larger fractions of crops in CCI are mainly due to larger fractions in CW table.

The distribution of tree cover fraction based on GLC2000, CCI, and Hansen datasets

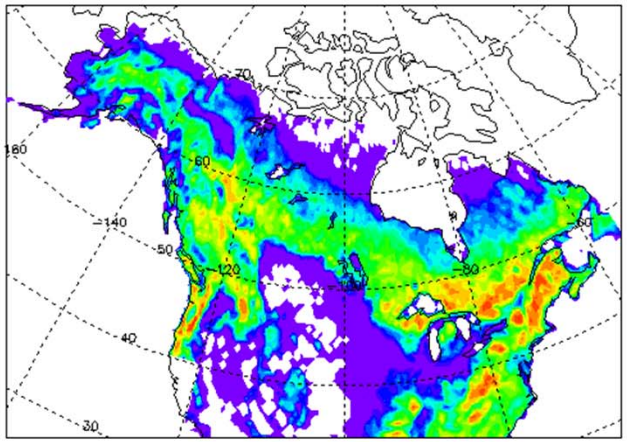
GLC2000



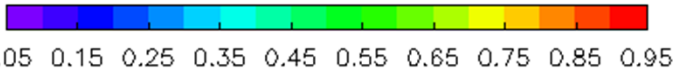
CCI



(PFT1+PFT2,
excluding shrubs)

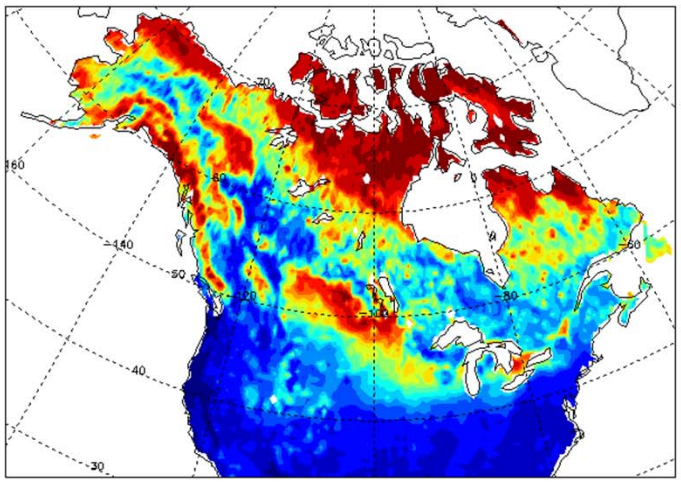


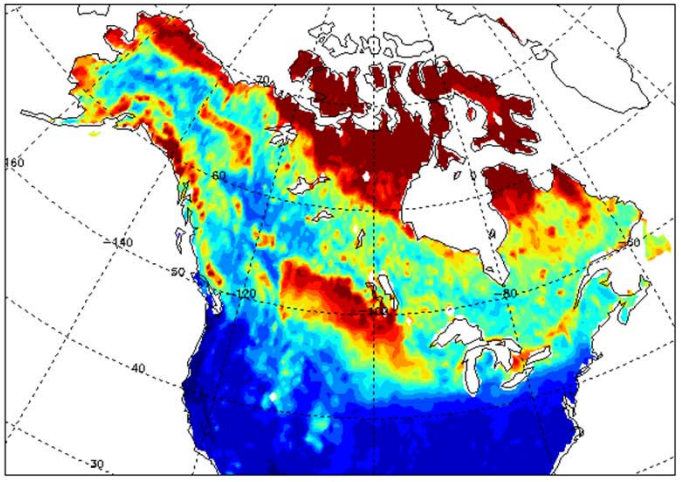
Hansen



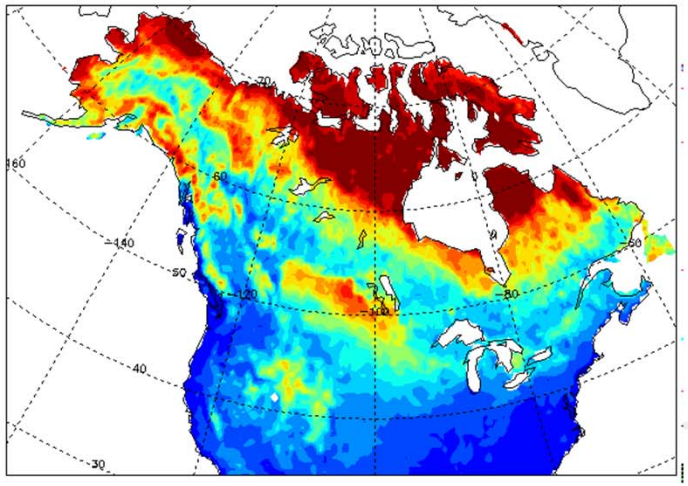
March surface albedo from CLASS with initial surface conditions based on GLC2000 (left) and CCI (right)

GLC2000

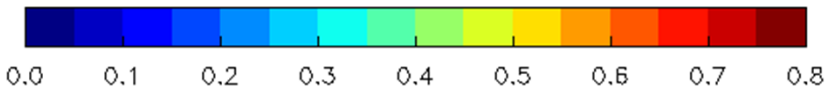




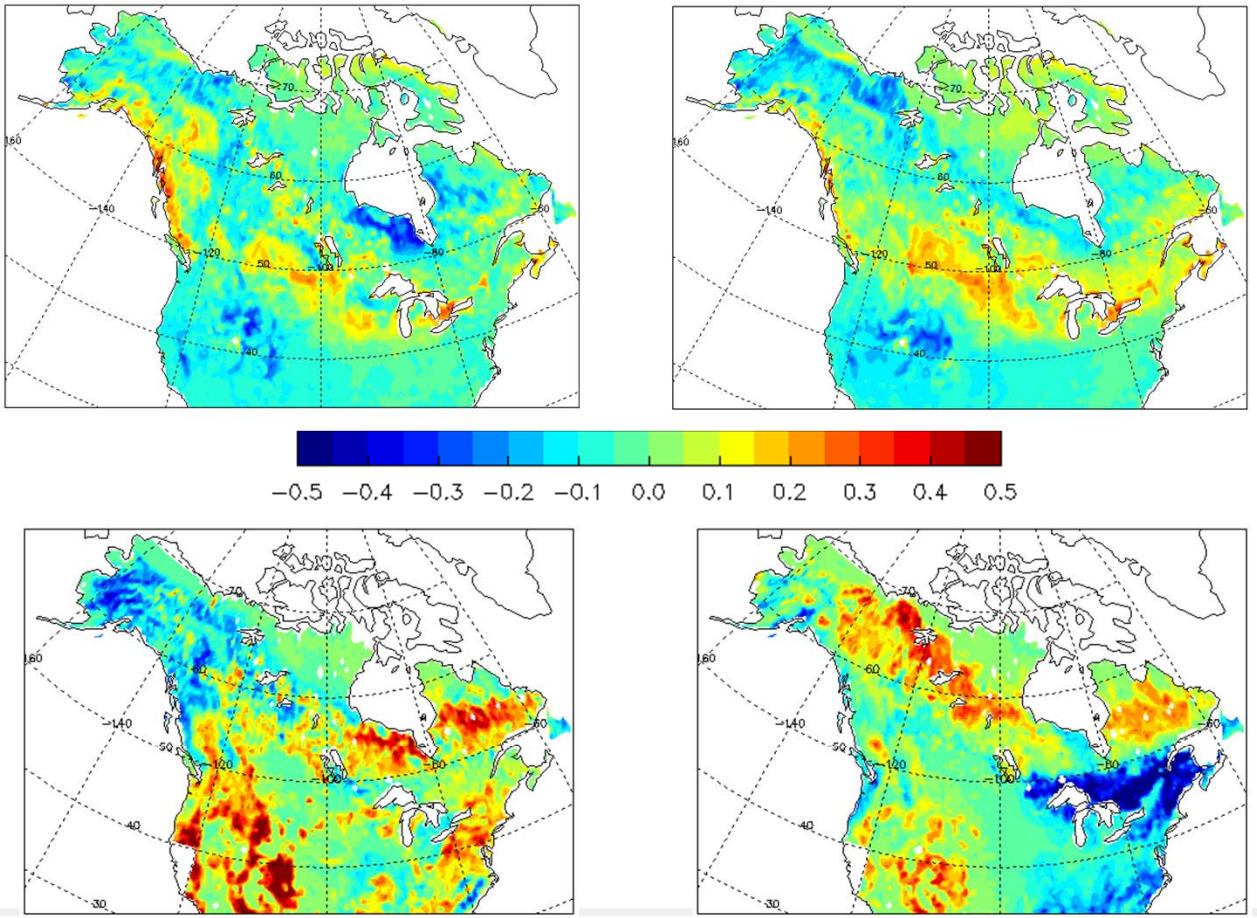
CCI



MODIS



Bias (model-obs) in simulated Mar albedo (top) using PFTs from GLC2000 (left) and CCI (right)



Difference in tree cover fraction
relative to Hansen data

Summary

- GLC2000 mapped too little NF in northwestern Canada, but too much in the Hudson Plains and some areas in northern Quebec. These appear to explain the simulated albedo biases in those areas well.

- GLC2000 mapped a large area as mosaic category, which exerts large uncertainties for PFT mapping (i.e. unknown tree type).

- The CW table for GLC2000 assigns 60% of the mosaic class to BF, none to NF. This is in contrast with the fact that NF dominates in those areas according to the other LC maps.

- These results suggest that in comparison with the high resolution maps over Canada, the CCI product shows much improved land cover distribution over that from the GLC2000 dataset.

Summary

- However, the CCI product appears to overestimate tree cover fraction in northwestern Canada, which consequently results in a negative bias in the simulated winter albedo in that region.

- Preliminary investigations suggest that the lack of full resolution MERIS clear sky data due to the long snow cover season in Canada may have resulted some BF, MF, and wetland being misclassified as NF. This at least explains part of NF overestimation in CCI.

- There are large differences in the PFTs derived from GLC2000 and CCI using the existing cross-walking tables, which are often in contrast with those in LC classes, suggesting large uncertainties in the CW tables.

- The CCI maps indicate a forest gain while both the MODIS and Hansen datasets indicate a forest loss in most ecozones across Canada between 2000 and 2010. Therefore caution should be exercised when using the annual CCI maps to identify forest change.

Work ongoing – how to reduce uncertainties in the LC dataset and CW table

LC dataset:

- We hope an improved version of the CCI LC datasets will be produced in the near future.
- At present, an integrated LC dataset by combining different LC datasets is being generated over Canada, and will be tested in offline simulations of CLASS-CTEM.

CW table

- Conduct sub-pixel error analyses following method in Latifovic and Olthof (2004). It's produced by assigning LC classes from all fine-resolution pixels from the reference data to the corresponding single coarse-resolution pixel.
- This allows a quantitative assessment of the fractional composition of each class in the coarse resolution map, which will be useful to inform the partitioning of the coarse-resolution dataset into PFTs.
- Use canopy cover from Lidar plots (Wulder et al., 2012) and high-res Google Earth Engine images to evaluate/calibrate LC class fractions in the CW table.

Acknowledgements

We thank all data providers:

Rasim Latifovic (NRCan) for NALCMS data,
ESA for CCI data,
Kim Hyungjun for GSWP3 data.

The Hansen tree cover fraction data is downloaded from https://earthenginepartners.appspot.com/science-2013-global-forest/download_v1.2.html.

The mean sub-fractional error matrix for homogenous CCI pixels (rows) relative to NALCMS (columns) based on the 13-class common legend across 18 ecozones over Canada.

CLASS	1	2	3	4	5	6	7	8	9	10	11	12	13
1	**0.71**	0.03	0.08		0.03	0.03	0.03	0.05	0.00	0.01	0.00	0.04	
2	0.07	**0.47**	0.15		0.10	0.04	0.13	0.01	0.01	0.00	0.00	0.01	
3	0.17	0.29	**0.35**		0.12	0.01	0.03	0.01	0.00	0.00	0.01	0.01	
4	0.21	0.14	0.06		0.32	0.05	0.08	0.10	0.01	0.00	0.00	0.02	0.00
5	0.14	0.07	0.03		**0.39**	0.09	0.15	0.06	0.03	0.03	0.00	0.01	0.00
6	0.15	0.04	0.01		0.14	**0.18**	0.23	0.08	0.06	0.08	0.01	0.01	0.00
7	0.14	0.00	0.00		0.08	0.13	**0.26**	0.07	0.01	0.22	0.02	0.07	0.01
8	0.26	0.05	0.05		0.10	0.05	0.11	**0.29**	0.00	0.00	0.00	0.07	
9	0.03	0.14	0.03		0.07	0.05	0.00	0.01	**0.57**	0.06	0.04	0.01	0.00
10	0.06	0.04	0.01		0.07	0.14	0.15	0.03	0.00	**0.35**	0.04	0.05	0.02
11	0.00	0.01	0.00		0.01	0.00	0.00	0.02	0.01	0.01	**0.92**	0.01	
12	0.01	0.00	0.00		0.00	0.00	0.00	0.00		0.00	0.00	**0.80**	
13	0.00		0.00		0.00	0.02	0.00	0.00		0.23		0.00	**0.74**
Frac	0.55	0.29	0.28		0.1	0.31	0.54	0.21	0.79	0.24	0.23	0.43	0.41

LC classes: 1 NF, 2 BF, 3 MF, 4 mosaic, 5 Shrub, 6 Grass, 7 Sparse, 8 Wetland, 9 Crop, 10 Barren, 11 Urban, 12 Water, 13 Snow/Ice

The proportion of Needleleaf forest (a), Mixed forest (b) and Mosaic of tree and other vegetation (c) in ecozones with greater than 10% cover (at least one dataset) from each datasets.