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Impact of land cover characterization and properties on simulated winter albedo in CMIP5 models and in CLASS

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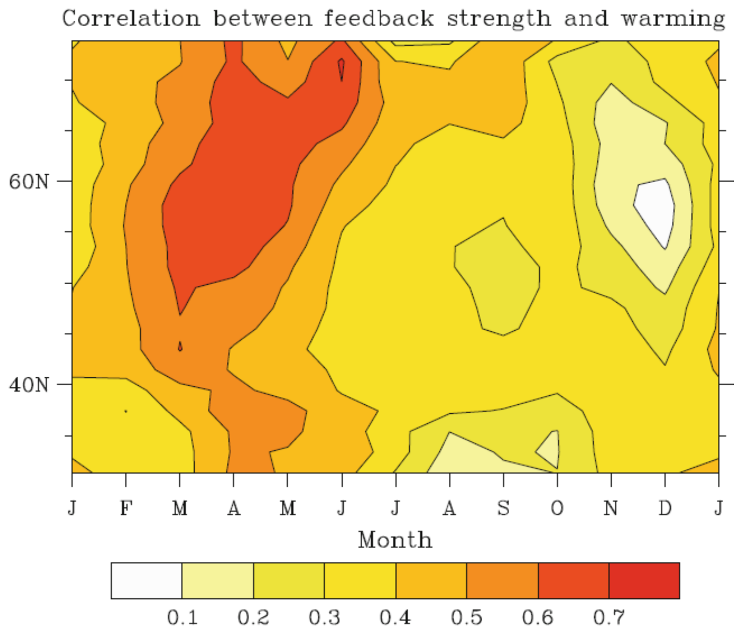
outline

- Part I: what cause the spread in surface albedo for snow-covered forests in the CMIP5 models?
  - Methods for calculating albedo in climate models
  - Relationship between surface albedo and LAI
  - Spread of Winter LAI and Surface Albedo in CMIP5 models
  - Summary

- Part II: global land cover datasets used in climate models and ongoing CLASS experiments
  - Land cover datasets used in climate models
  - PFTs in CLASS
  - Preliminary results from some CLASS test runs
  - Summary

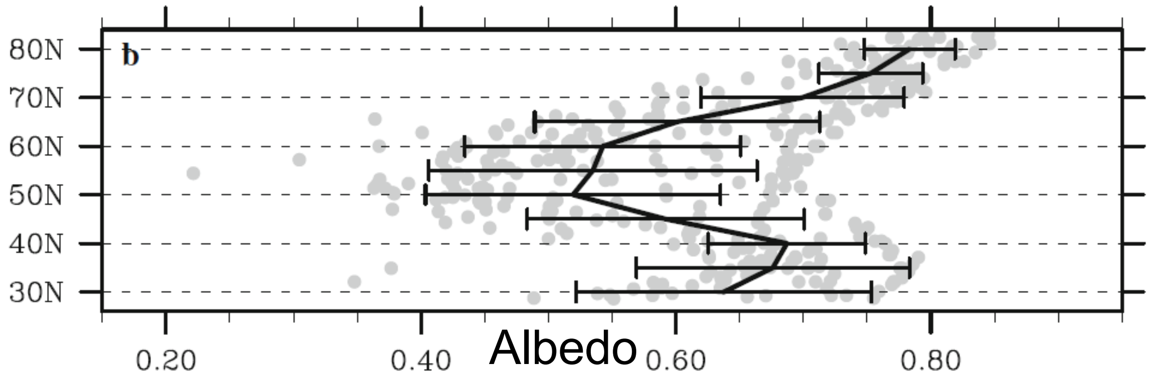
A large spread in snow albedo persists in CMIP3 & CMIP5 climate models

- Roesch (2006) found large winter/spring albedo biases in the Third Coupled Model Intercomparison Project (CMIP3) climate simulations.
- Although new developments have occurred to several of the land surface schemes since then, a large snow albedo spread persists in the CMIP5 simulations (Qu and Hall, 2013; Fletcher et al., 2015).

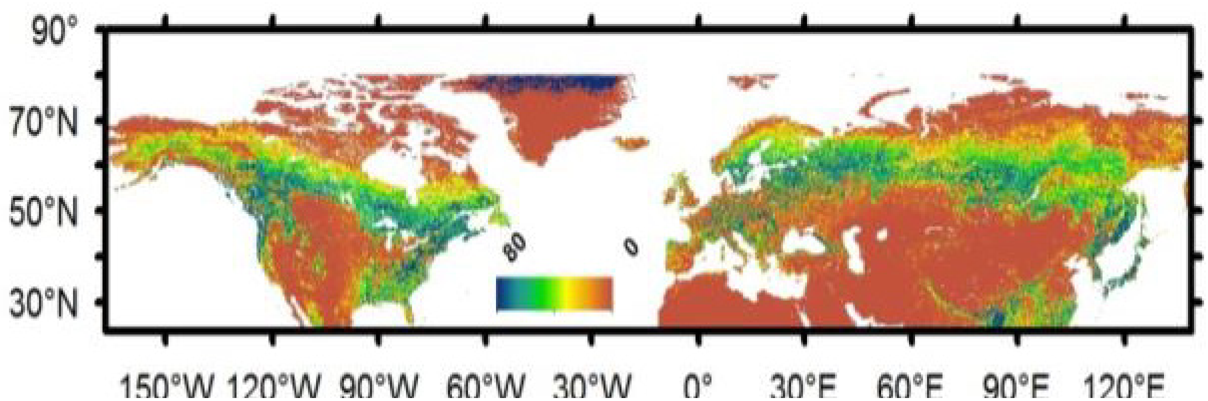


This spread is largely responsible for uncertainties in simulated snow-albedo feedback strength, which is closely correlated with projected 21st century warming at the northern high latitudes [Qu and Hall, 2013].

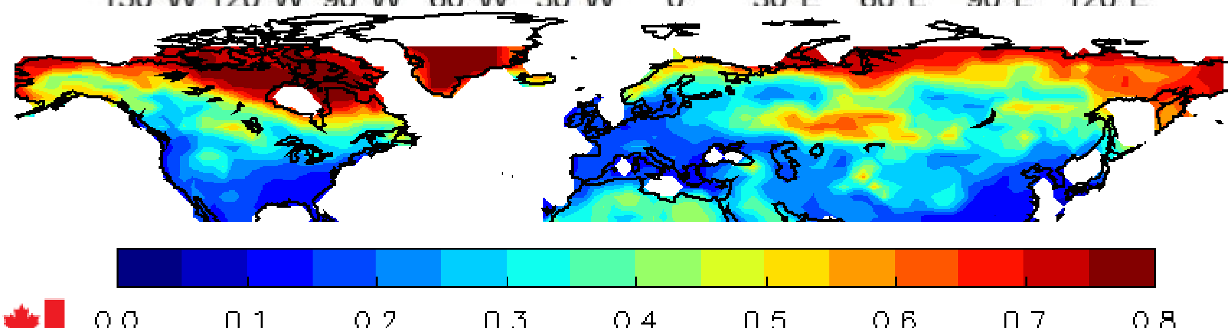
The spread in snow albedo is most pronounced in the boreal regions



Zonal-mean value of surface albedo (SCF>90%) in 14 CMIP5 models (Qu & Hall, 2013)



Tree cover fraction from MODIS



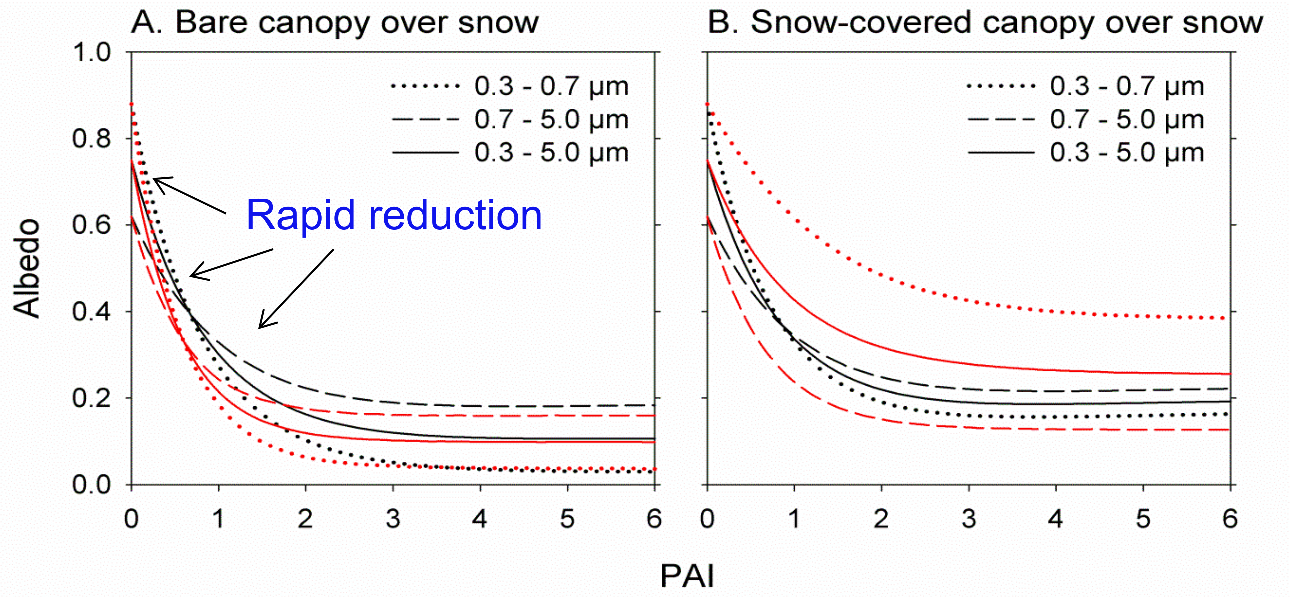
Surface albedo from MODIS in March

Three common methods for calculating the albedo of snow covered forests in climate models (Essery, 2013; Qu and Hall 2007)

- **Type 1:** uses two-stream approximations for canopy radiative transfer – NCAR CLM4
- **Type 2**: distinguishes between snow intercepted in forest canopies and snow on the ground – CLASS
- **Type 3**: calculates albedo as a weighted average of snow-free and snow covered albedos depending on vegetation type – LSM in INMCM4

- Forest structural attributes such as leaf area index (LAI) and canopy cover fraction are important parameters that control snow interception and radiation transfer in canopies [Pomeroy et al., 2002].
- LAI is used in calculating canopy albedo in both type 1 & type 2 models, which are the most common models in the CMIP simulations.

Surface albedo decreases exponentially with increasing LAI in CLASS (black) and CLM4 (red)



Based on canopy snow formulations in CLASS and CLM - similar relationship – albedo decreases exponentially with LAI, most of the albedo reduction occurs when LAI increases from 0 to 1.0, suggesting the albedo for even a sparse forest should be notably lower than areas with short vegetation or bare ground.

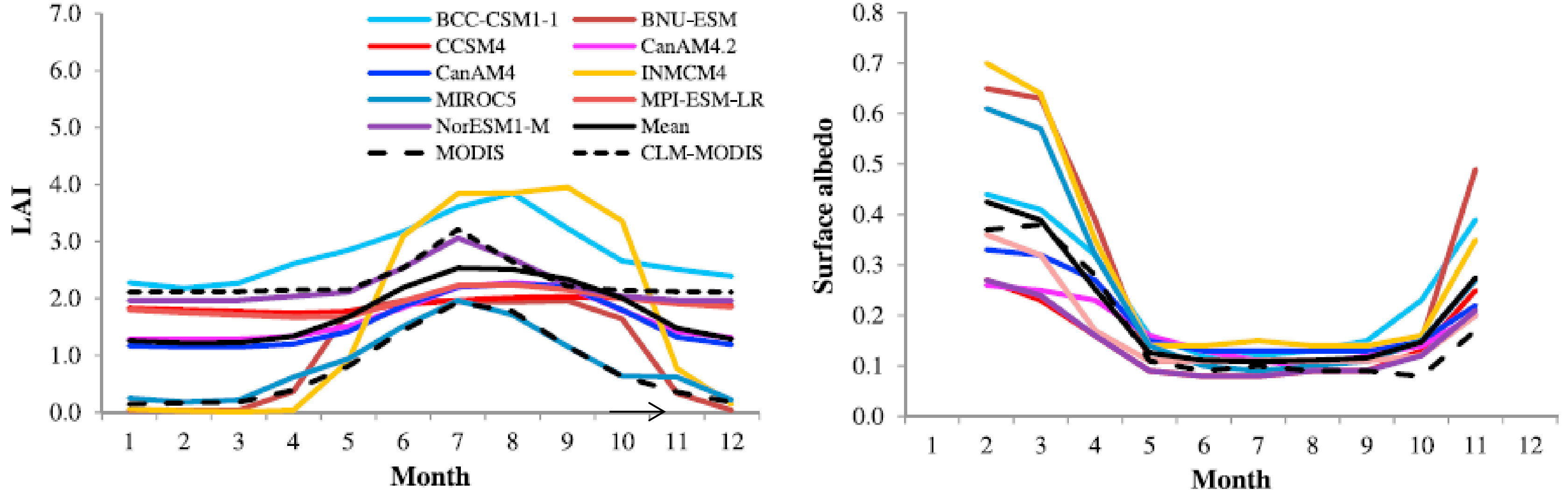
CMIP5 model data

only models with LAI and snow cover outputs from the AMIP runs, plus a simulation by CanAM4.2+CLASS 3.6

Models	Land models	Albedo scheme	Resolution Lat x Lon	Reference
BCC-CSM1-1	AVIM1	Type1	2.81 x 2.81	Wu et al. (2010)
BNU-ESM	CoLM	Type1	2.81 x 2.81	Ji et al. (2014)
CCSM4	CLM4	Type1	0.94 x 1.25	Gent et al. (2011)
CanAM4	CLASS2.7	Type2	2.81 x 2.81	Von Salzen et al. (2013)
CanAM4.2	CLASS3.6	Type2	2.81 x 2.81	N/A
MIROC5	MATSIRO	Type1	1.40 x 1.40	Watanabe et al. (2010)
MPI-ESM-LR	JSBACH	Type2	1.88 x 1.88	Brovkin et al. (2013)
INMCM4	simple	Type3	1.50 x 2.00	Volodin et al. (2010)
NorESM1-M	CLM4	Type1	1.88 x 2.50	Bentsen et al. (2012)

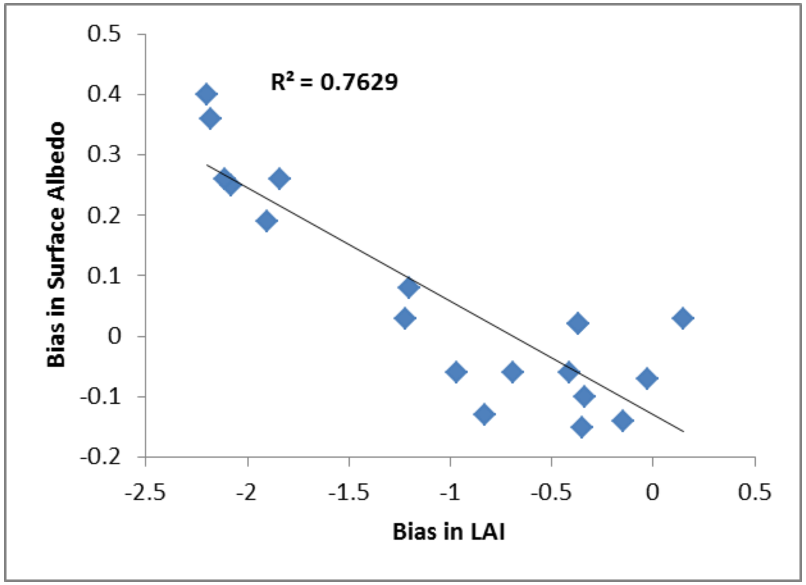
The monthly clear sky surface albedo was computed as the ratio of upwelling and downwelling clear sky solar radiation from the models.

CMIP5 models with low winter LAI had highest albedo bias in the boreal regions (Wang et al, 2016)



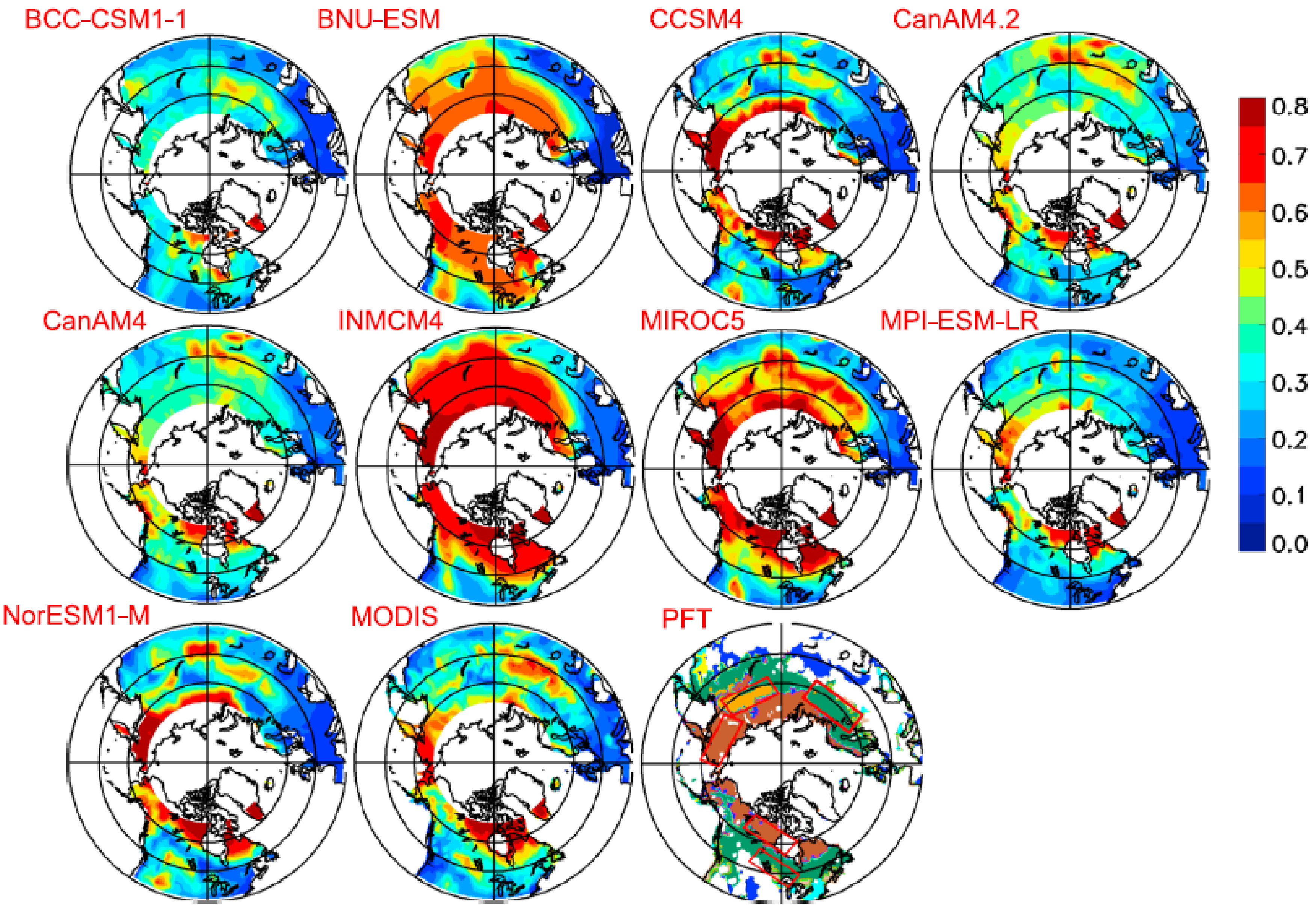
- MODIS winter LAI underestimated in boreal forest (unreasonable seasonal cycle)
- CLM-MODIS (Lawrence and Chase, 2007) is more reasonable
- The three models with the smallest winter LAI show the largest albedo bias
- The Canadian models shows LAI values near the mean but albedo is biased low

Correlation between bias in winter albedo and bias in LAI for ENF in CMIP5 models

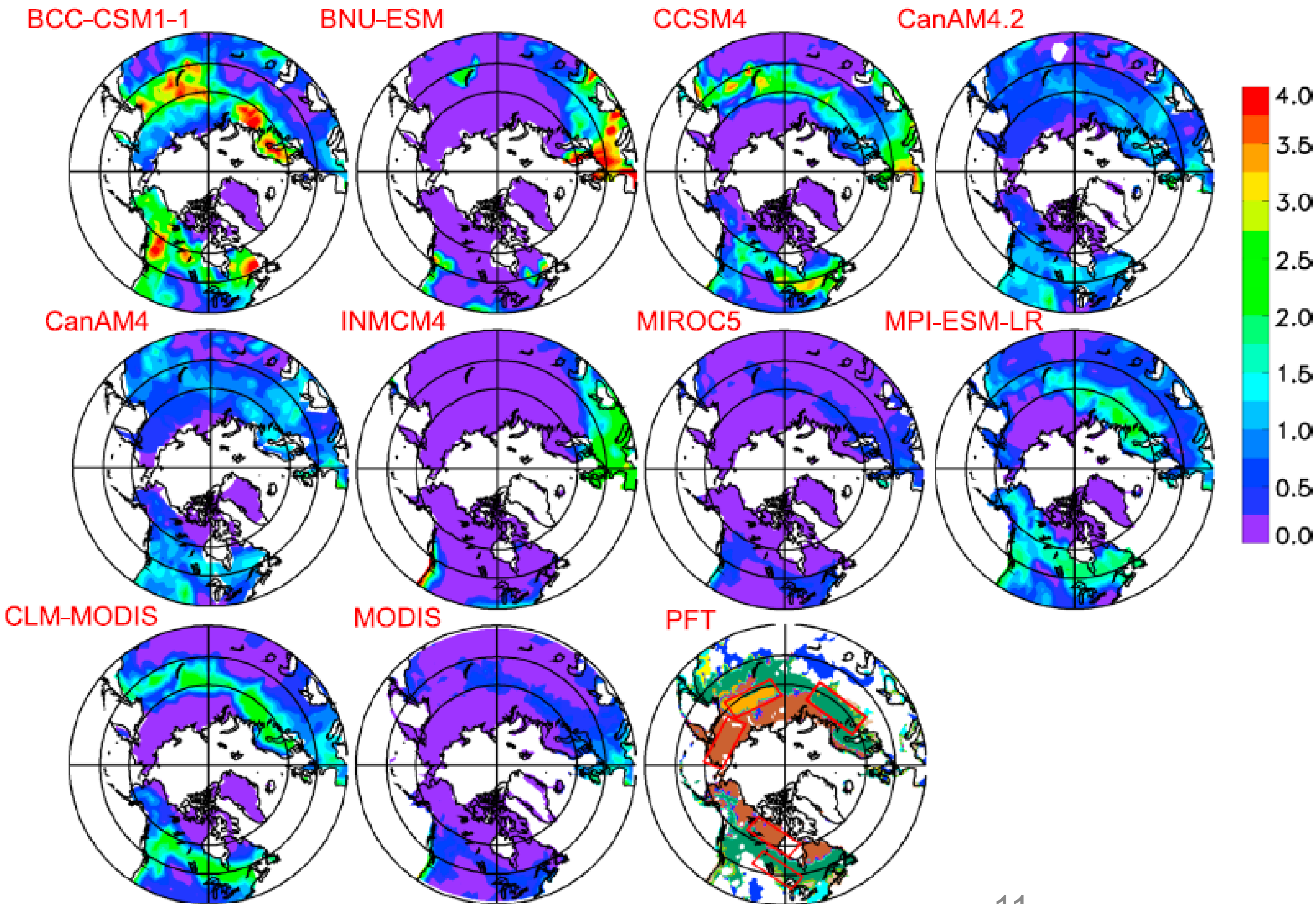


There are significant correlations between bias in surface albedo and bias in LAI from the models in both EUR1 (r = -0.79) and NA1 (r = -0.84) during March, consistent with the sensitivity analysis results.

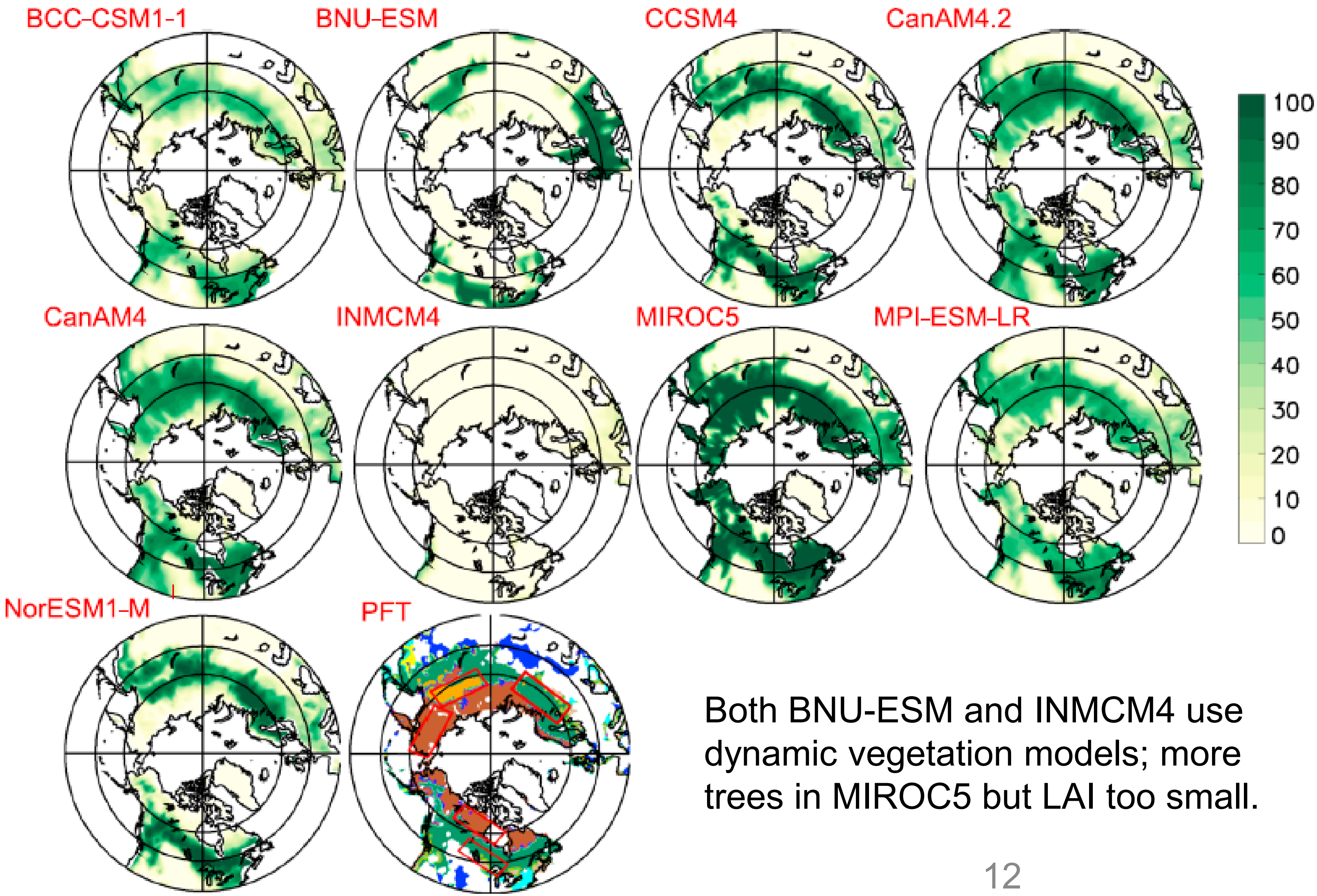
March surface albedo in CMIP5 models and OBS



March Leaf Area Index in CMIP5 models and OBS



Distribution of March tree cover fraction in CMIP5 models



Both BNU-ESM and INMCM4 use dynamic vegetation models; more trees in MIROC5 but LAI too small.

Summary of Part I

- The results show that albedo biases are very sensitive to negative LAI biases, especially in association with smaller LAI values.
- The evaluation of CMIP5 models suggest that inaccurate tree cover fraction or poor LAI parameterization in some models explains, in part, an observed positive bias in winter albedo over boreal regions of the Northern Hemisphere.
- Errors are largest (+20-40%) in models with large underestimation of LAI but are typically within ±15% when simulated LAI is within the observed range.
- These results underscore the importance of accurate representation of vegetation distribution and parameters in realistic simulation of surface albedo.

Part II: global land cover datasets used in climate models and ongoing CLASS experiments

- Vegetation distributions for use in climate models have been obtained from field surveys, remote sensing, and dynamic vegetation models.

- Three satellite-derived land cover datasets with 1km resolution are commonly used to derive PFTs (Plant functional types) for use in the CMIP5 models: IGBP DISCover (Loveland et al., 2000), GLC2000 (Latifovic and Olthof, 2004), and the MODIS based land cover data set (Lawrence and Chase, 2007).

- Two new datasets GlobCover and CCI-LC (ESA) are now available in higher spatial resolution (~300 m), https://www.esa-landcover-cci.org/.

- It is a challenge to compare the different datasets. They are produced from different satellite data using different methods, and especially they have different legends. Intercomparison studies usually need to remap each of the datasets into a common legend and grid, then compare.

- Some comparison studies show large disagreement among the datasets, especially in heterogeneous landscapes characterized by a mosaic of trees, shrubs, and herbaceous vegetation (Herold et al., 2008; Fritz et al, 2011).

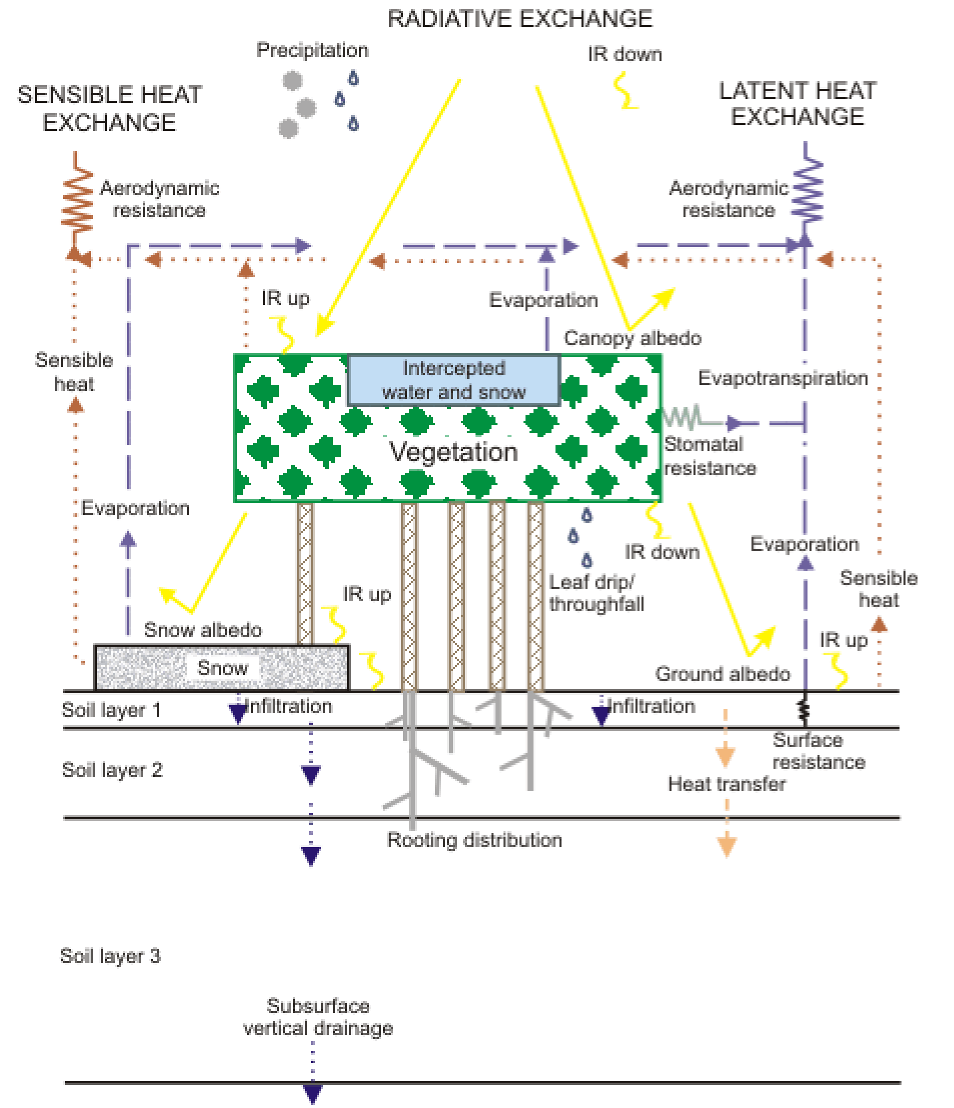
The Canadian Land Surface Scheme

CLASS is a physically based land surface scheme with complete thermal and hydrological budgets [Verseghy, 1991].

It includes three soil layers, a single snow layer.

Four broad vegetation classes are considered: needleleaf trees, broadleaf trees, crops, and grass.

Canopy snow processes such as interception/unloading, sublimation, and melt are included.



CLASS includes 4 Veg PFTs: needleleaf trees, broadleaf trees, crops, and grass.

Table for mapping 22 land classes from GLC2000 to CLASS PFTs

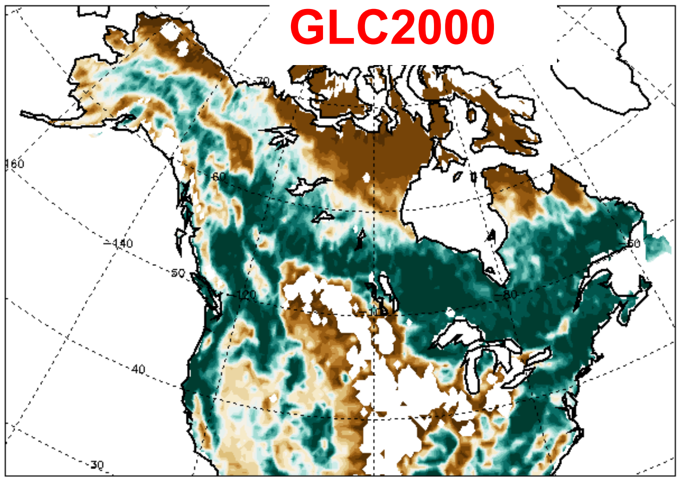
Class	FCAN1	FCAN2	FCAN3	FCAN4	FCAN5	Lake	Ocean	(Bare)
1 – Tree cover, broadleaved, evergreen		1.0						
2 – Tree cover, broadleaved, deciduous, closed		1.0						
3 – Tree cover, broadleaved, deciduous, open		0.6		0.2		0.1		0.1
4 – Tree cover, needle-leaved, evergreen	1.0							
5 – Tree cover, needle-leaved, deciduous	0.8			0.1				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					0.5	
9 – Mosaic: tree cover / other natural vegetation		0.6		0.2				0.2
10 – Tree cover, burnt	0.2	0.2		0.3				0.3
11 – Shrub cover, closed-open, evergreen		0.6		0.2		0.1		0.1
12 – Shrub cover, closed-open, deciduous		0.4		0.3				0.3
13 – Herbaceous cover, closed-open				0.7				0.3
14 – Sparse herbaceous or sparse shrub cover		0.1		0.1				0.8
15 – Regularly flooded shrub and/or herbaceous cover		0.5		0.3		0.1		0.1
16 – Cultivated and managed areas			0.5	0.4				0.1
17 – Mosaic: cropland / tree cover / other natural veg.		0.2	0.5	0.2				0.1
18 – Mosaic: cropland / shrub and/or grass cover		0.1	0.5	0.3				0.1
19 – Bare areas								1.0
20 – Water bodies						1.0		
21 – Snow and ice								1.0
22 – Artificial surfaces and associated areas					1.0			

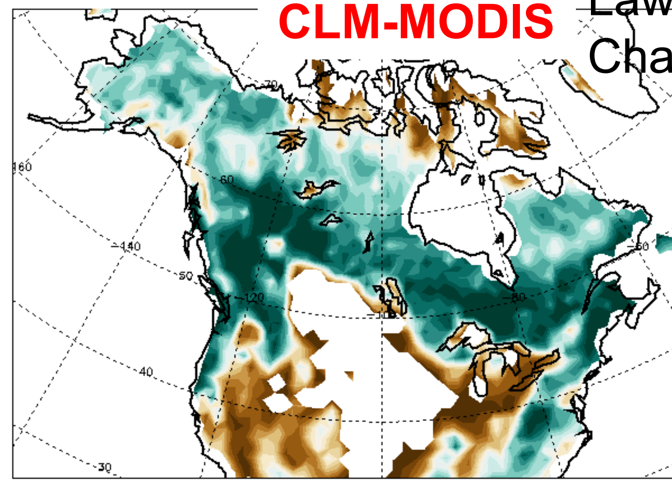
Weights are based on type description and knowledge of global biomes (Wang et al., 2006)

Table for mapping 37 land classes from CCI-LC to CLASS PFTs

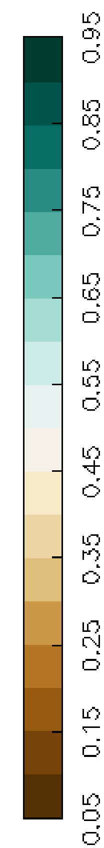
ID	Globcover map description	FCAN1	FCAN2	FCAN3	FCAN4	FCAN5	Lake	Ocean	(Bare)
10	Cropland			1.0					
11	Herbaceous cover			1.0					
12	Tree or shrub cover		0.5	0.5					
20	Cropland			1.0					
30	Mosaic cropland (>50%) / natural vegetation (tree	0.05	0.2	0.6	0.15				
40	Mosaic natural vegetation (tree	0.075	0.275	0.4	0.25				
50	Tree cover		1.0						
60	Tree cover		0.85		0.15				
61	Tree cover		0.85		0.15				
62	Tree cover		0.55		0.35				0.1
70	Tree cover	0.75	0.1		0.15				
71	Tree cover	0.75	0.1		0.15				
72	Tree cover	0.35	0.05		0.3				0.3
80	Tree cover	0.75	0.1		0.15				
81	Tree cover	0.75	0.1		0.15				
82	Tree cover	0.35	0.05		0.3				0.3
90	Tree cover	0.35	0.4		0.15				0.1
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				0.2
121	Shrubland evergreen	0.3	0.3		0.2				0.2
122	Shrubland deciduous		0.6		0.2				0.2
130	Grassland				0.6				0.4
140	Lichens and mosses				0.6				0.4
150	Sparse vegetation (tree	0.02	0.08		0.05				0.85
151	Sparse tree (<15%)	0.02	0.08		0.05				0.85
152	Sparse shrub (<15%)	0.02	0.08		0.05				0.85
153	Sparse herbaceous cover (<15%)				0.15				0.85
160	Tree cover		0.6		0.2		0.2		
170	Tree cover		0.8					0.2	

Tree cover fraction (PFT1+PFT2) based on different land cover datasets in CLASS

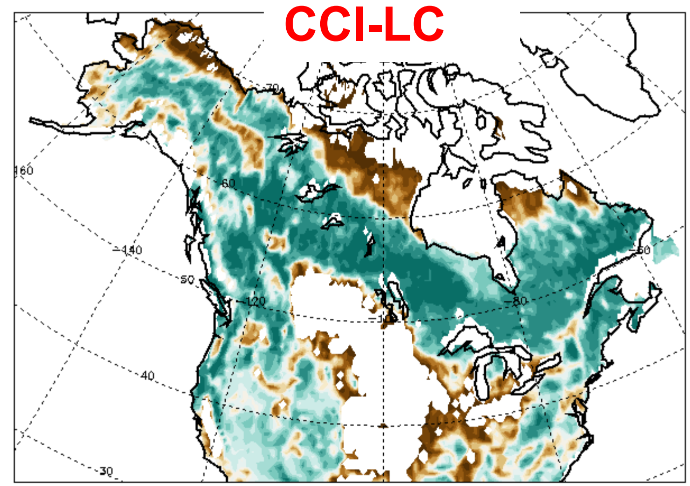




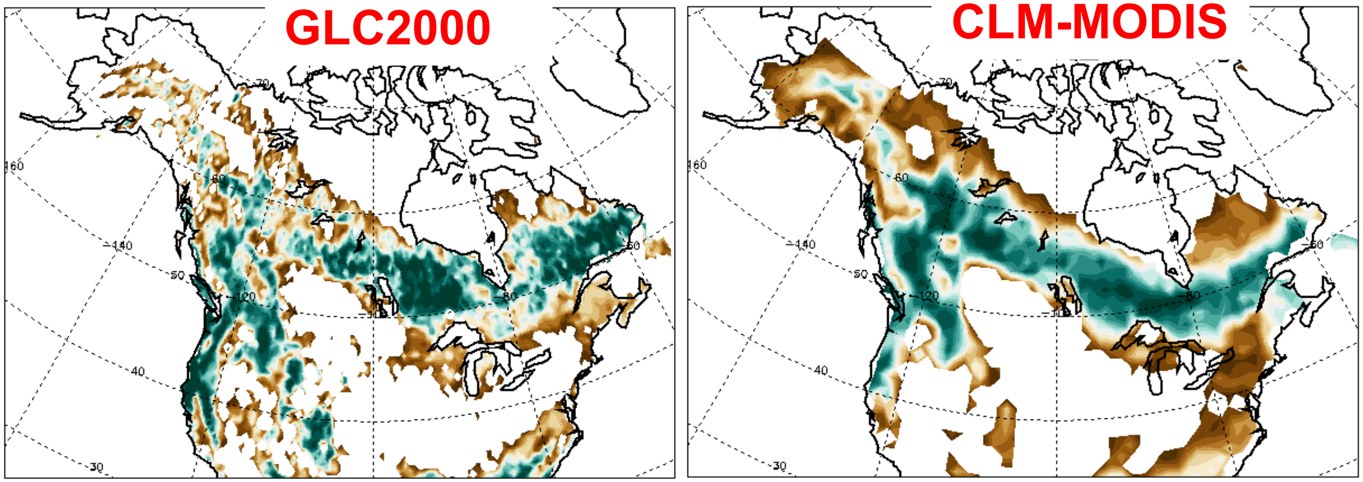
Lawrence and Chase, 2007

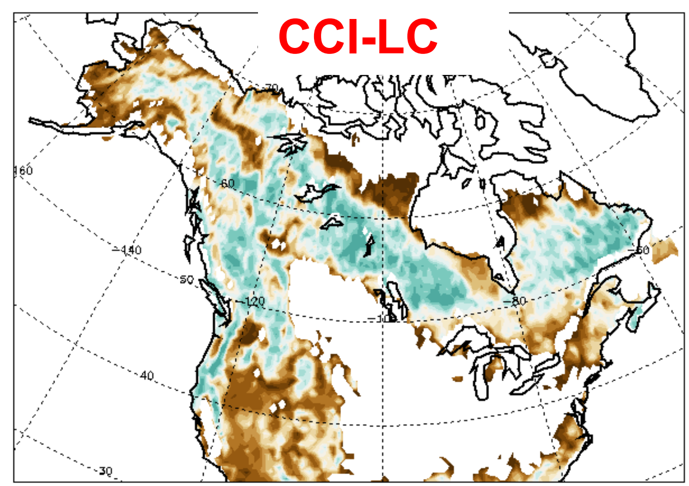


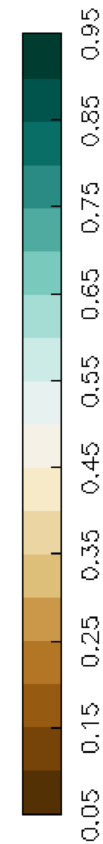
CLASS doesn't have a PFT for shrubs, woody shrubs are included in PFT2. CLM-MODIS has a larger fraction of shrubs, contributing to the much large tree coverage than the other datasets.



CLASS PFT1 – needleleaf trees





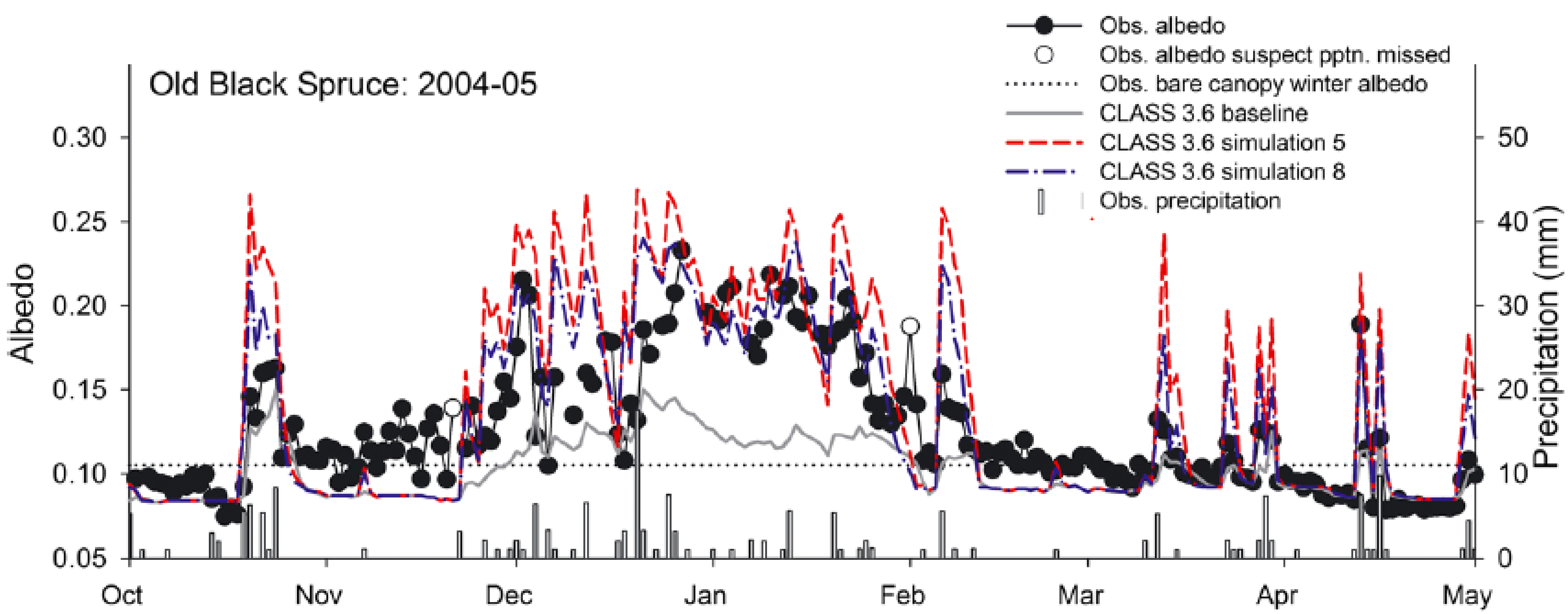


Possible causes to the low fraction in CCI-LC: classification methods? converting weights? Resolution? needs to be studied further

Recent developments in CLASS

Bartlett and Verseghy, 2015, Hydrological Processes

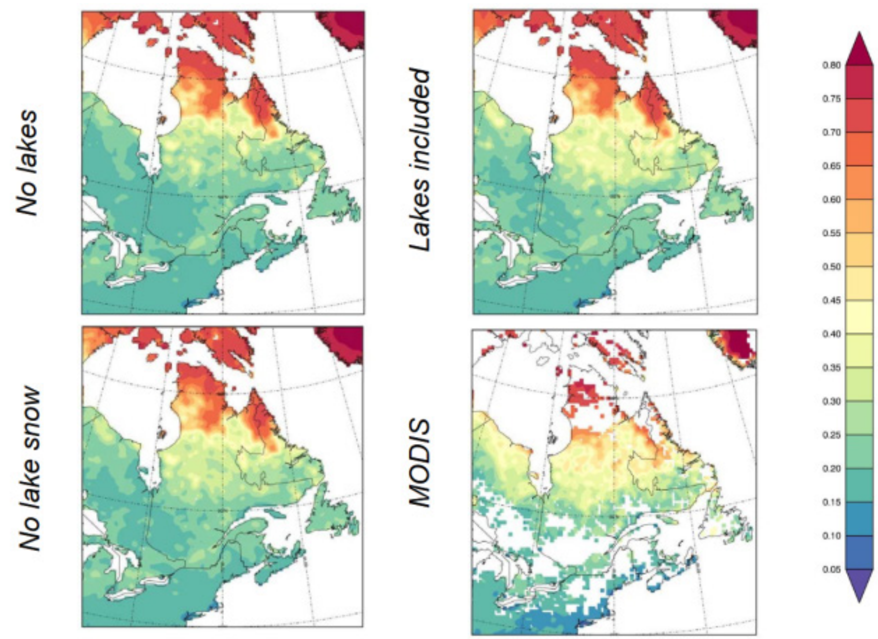
Increased values for the albedo of snow-covered canopy ($\alpha_{VIS,cs}$ = 0.27 and $\alpha_{NIR,cs}$ = 0.38) and more rapid refreshment of fractional canopy coverage by snow resulted in improved simulated winter albedo values for snow-covered canopy.



Recent developments in CLASS

The Canadian small lake model (Mackay 2012; Verseghy and MacKay 2017)

- Previously, vegetation cover was normalized to fill in unresolved lakes (top left) and forest albedo was substantially underestimated.
- Including lakes without a snowpack produced a small improvement in simulated albedo (bottom left).
- Allowing a snowpack to form on frozen lakes further improved the simulated albedo (top right) eliminating about half the albedo bias.

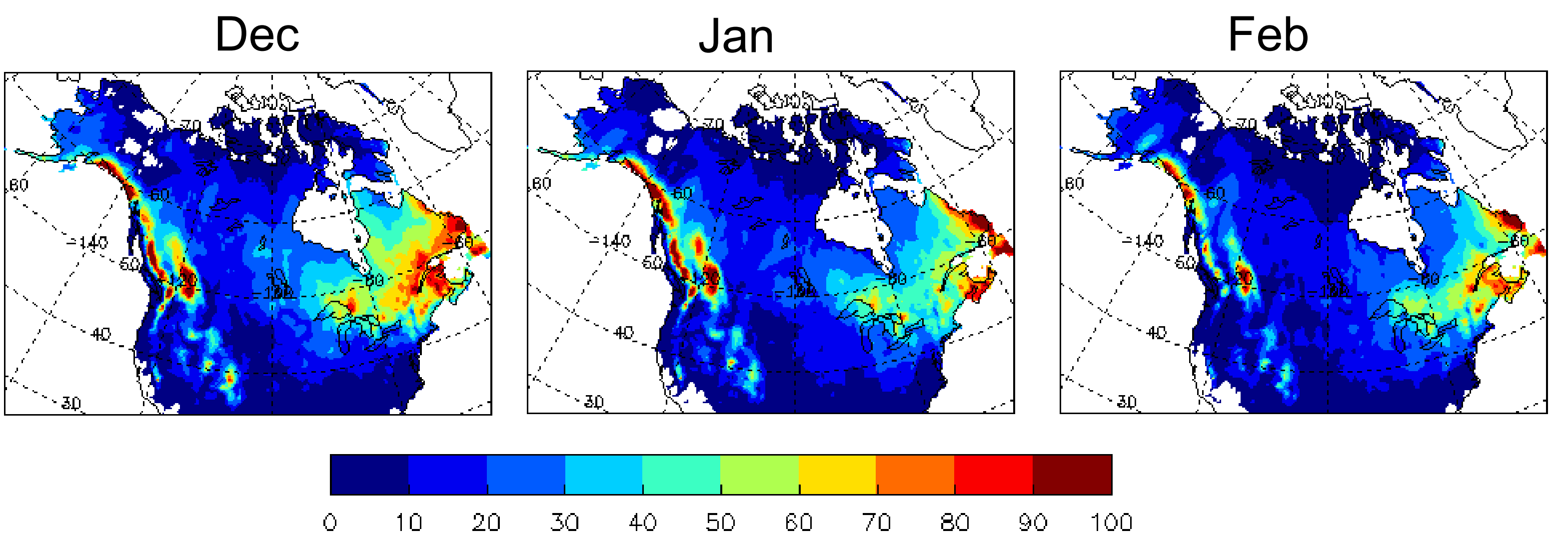


Courtesy Diana Verseghy

CLASS 3.6.1 experiment setup

Objective: best vegetation data for use in CLASS

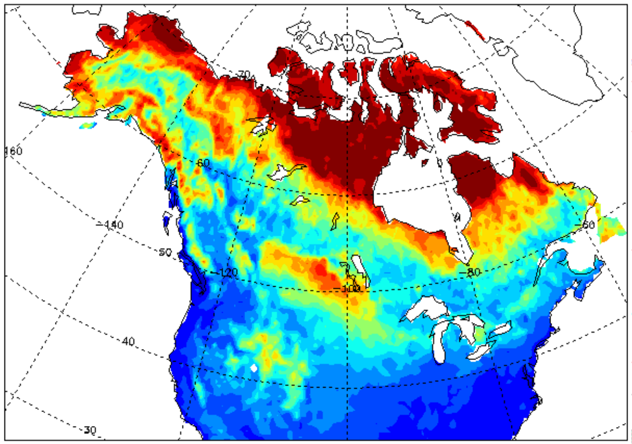
- Domain: North America north of 30º latitude
- Resolution: 0.5 x 0.5 lat/lon degree
- Land cover: GLC2000
- Period: June 1999 – December 2011
- Forcing: CRUNCEP + WATCH precip. for Alaska



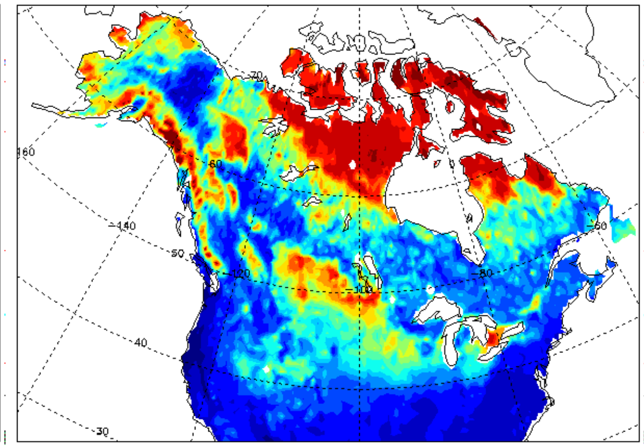
Monthly precipitation from CRUNCEP: holes in Alaska during the snow cover season

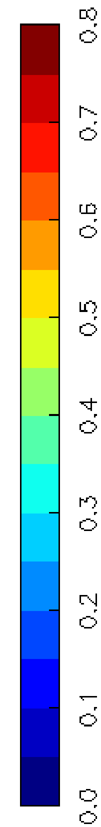
March surface albedo from MODIS and CLASS during 2001-2011

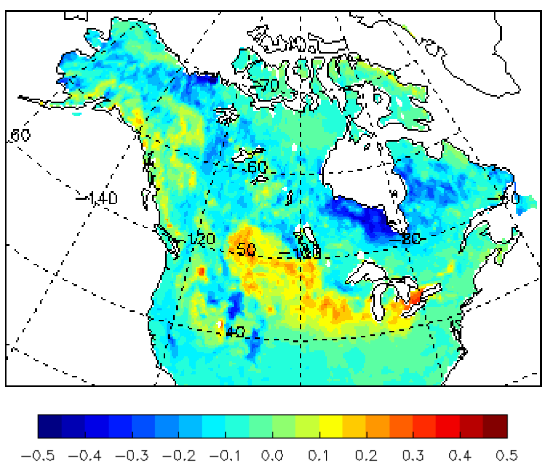
MODIS



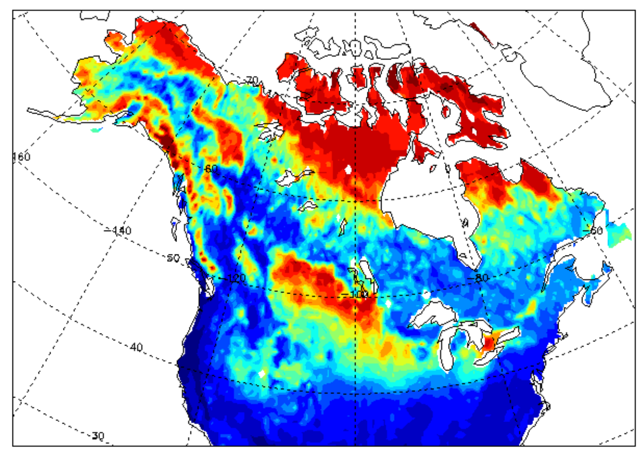
CRUNCEP Forcing





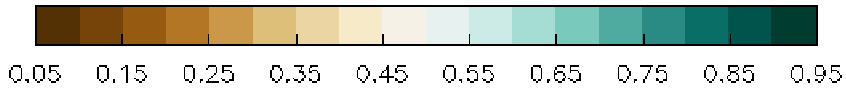


Diff: CLASS-MODIS

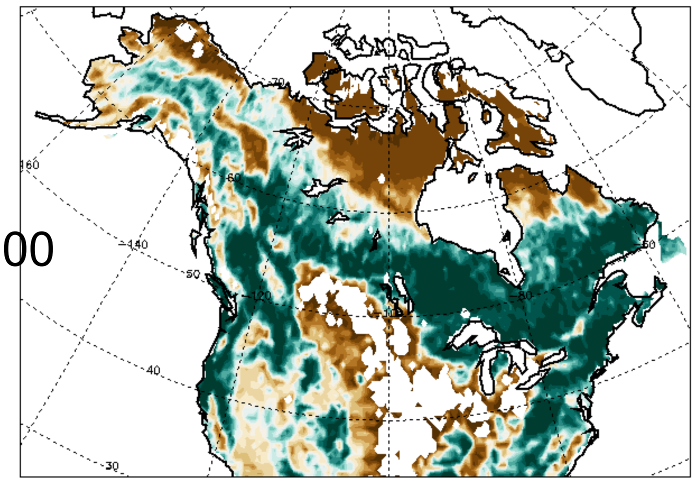


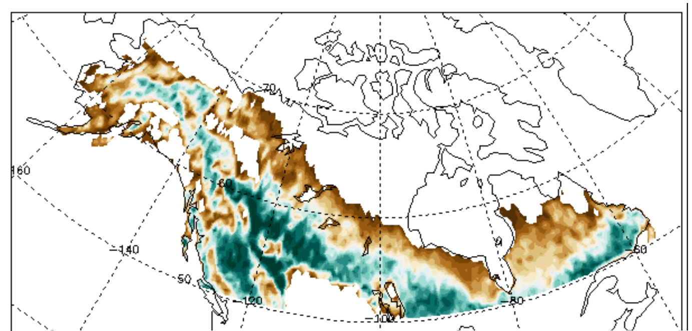
CRUNCEP + WATCH
Precip for Alaska

GLC2000 overestimates tree cover fraction in the tundra-taiga transition zone

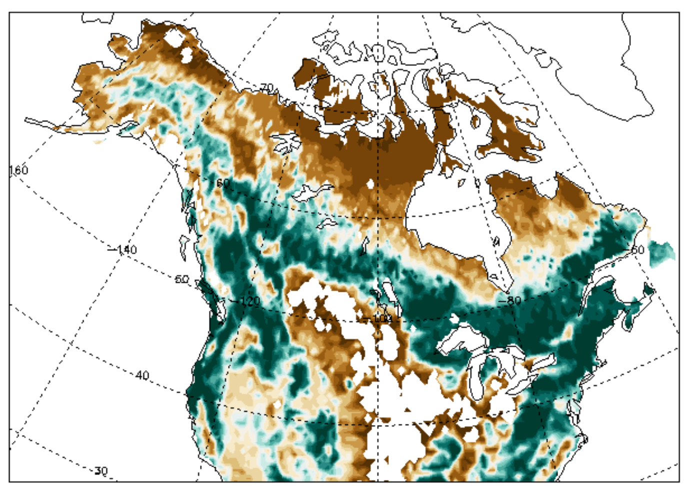


GLC2000





Quickbird adjusted MODIS Tree cover (Montesano et al., 2009)



Adjusted GLC2000

Quick and dirty way:
PFT1/(PFT1+PFT2)
PFT2/(PFT1+PFT2)

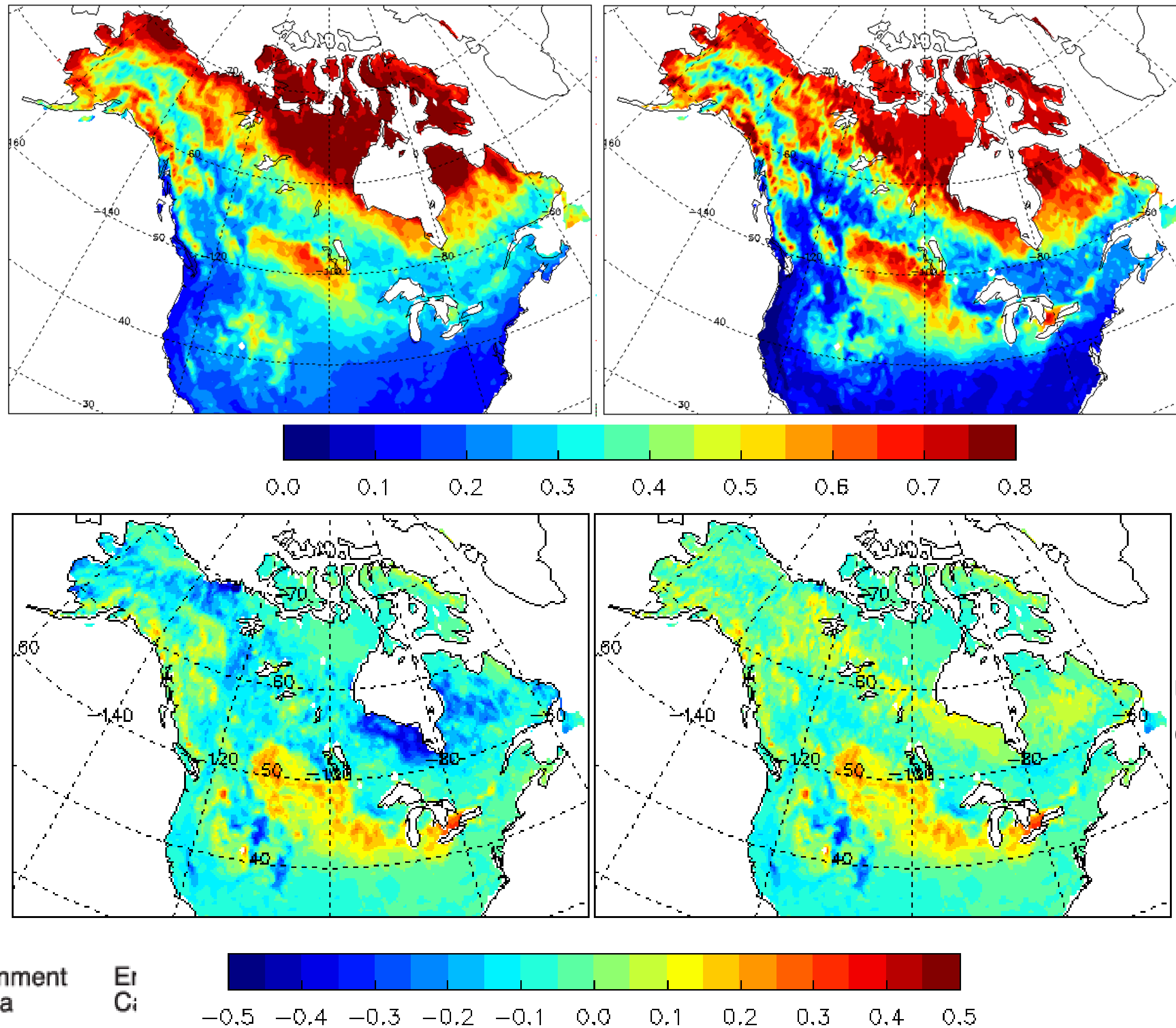
March surface albedo from MODIS and CLASS with adjusted GLC2000

MODIS

CLASS using adjusted GLC2000

Difference Using GLC2000

Difference using adjusted GLC2000

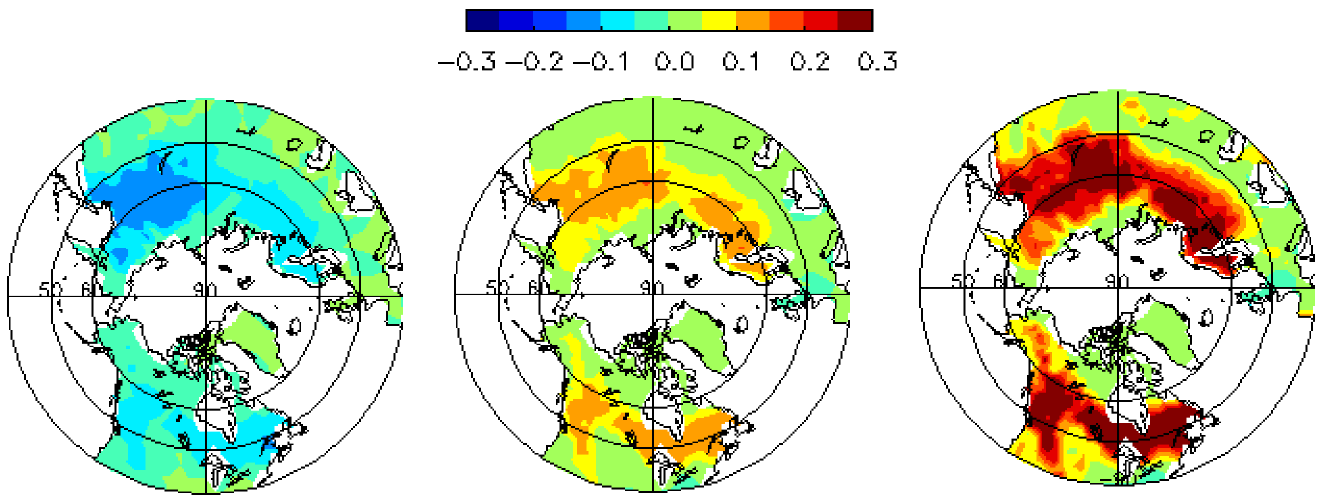


Summary of Part II

- Vegetation distribution and parameters (e.g. LAI) have significant impacts on surface albedo for snow-covered forests.
- There are large disagreements in PFTs derived from different land cover datasets.
- In CLASS, large negative winter albedo biases along the taiga-tundra transition zone appear to be linked to overestimation of tree coverage (~40 – 50%) in the GLC2000 land cover dataset.
- Some high resolution (~30m or less) satellite-derived tree cover fraction data are useful in validating and improving tree coverage based on mid-resolution (300m ~1km) land cover datasets.
- Question: which is the best land cover dataset for use in climate models?


Thank you!

Results from tests with CanAM4.2 – albedo difference (test-control)



(a) Doubling PAI

(b) Halving PAI

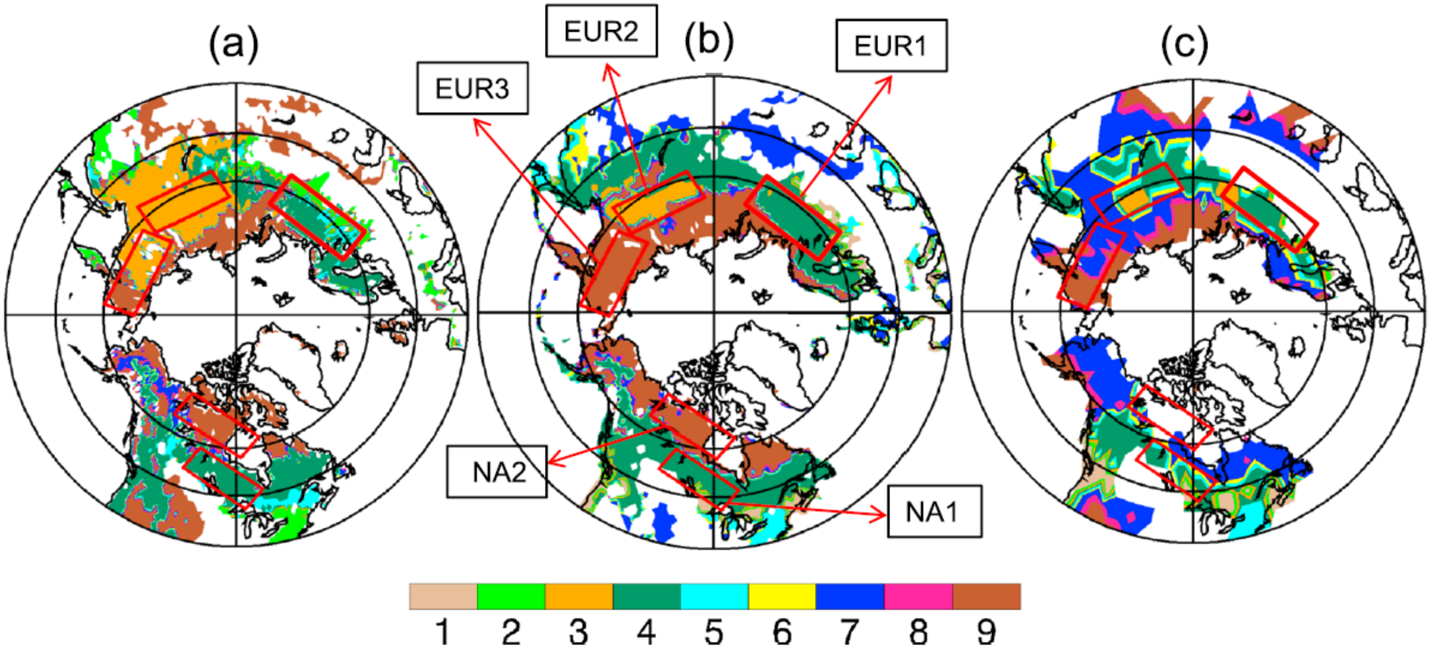
(c) 1/10 of the default mini PAI in CLASS

Doubling PAI causes a limited decrease in albedo (max 15%); Halving PAI results in a notable increase in albedo across the boreal forest belt; When PAI is reduced to one tenth of the default minimum PAI set in CLASS, a large increase in surface albedo of 20-40% was observed in all the boreal forest areas

Satellite data

- Monthly surface albedo was computed from MODIS CMG product (MCD43C3), using good quality data (QC<=2) with solar zenith angle less than 70°. MODIS albedo is for clear sky only.
- We use Leaf area index (LAI), plant functional type (PFT), and tree cover fraction (TCF) from the land surface dataset of NCAR CLM4, which is consistent with the MODIS land surface products developed by Lawrence and Chase [2007].
- At high latitudes, snow cover and low sun angles prevent realistic LAI estimation for evergreen forest from satellite [Heiskanen et al., 2012]. Winter LAI values from CLM4-MODIS were adjusted by c*Lmax, c=0.7 for ENF [Zeng et al., 2002; Tian et al., 2004].
- The period from 2000 to 2008 is used due to overlapping availability of satellite and CMIP5 model data. Both model and satellite data were interpolated into a common 2^ox2^o latitude/longitude grid.

Distribution of dominant PFTs from (a) GLC2000, (b) MODIS, and (c) IGBP



3 deciduous needleleaf tree ; 4 evergreen needleleaf tree; 5 broadleaf deciduous temperate tree; 6 broadleaf deciduous boreal tree; 7 C3 grass; 8 C4 grass; and 9 shrub

Only grid cells with ENF/DNF >60% were used to compute regional averages in LAI and albedo for the 3 forest regions