

# Boreal forest disturbance, regrowth, & age across the satellite era

*3D structure, site index, & ecosystem  
carbon flux with changing climate*



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# Site index explains forest growth

The relationship between forest height and age explains forest growth rates, biomass accumulation, etc.

Models (eg, LPJ) can use this productivity info to understand the role that the structure of forests has on the boreal forest carbon sink, seasonal and annual CO<sub>2</sub> concentration trends.

*This project uses direct spaceborne measures of height and age across the boreal biome to produce new site index estimates for global carbon models.*

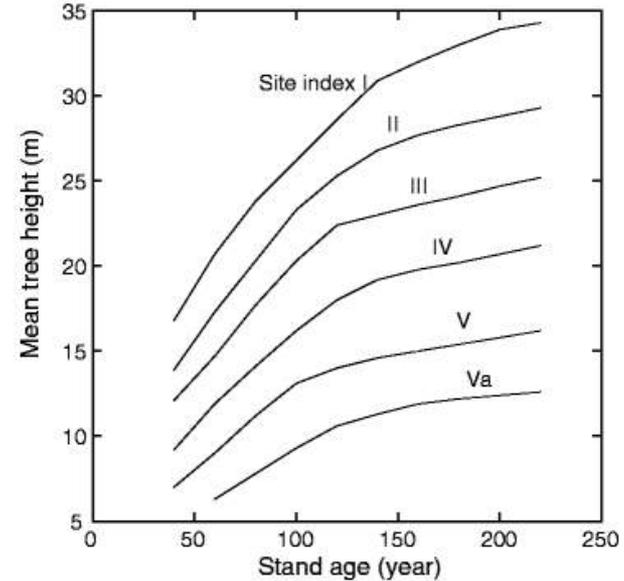
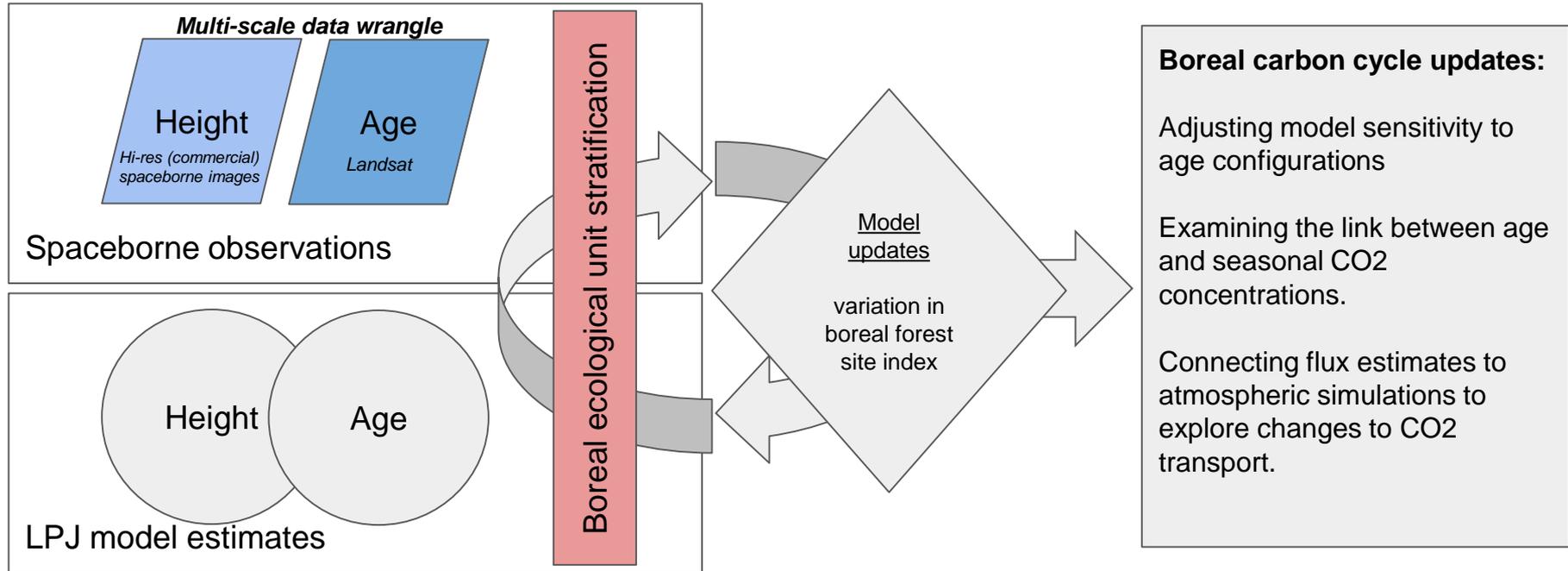


Fig. 7.1 Growth patterns of mean tree height in *Larix gmelinii*, defining site index of individual stands (data from Usoltsev 2002)

# This project: spaceborne estimates & model updates

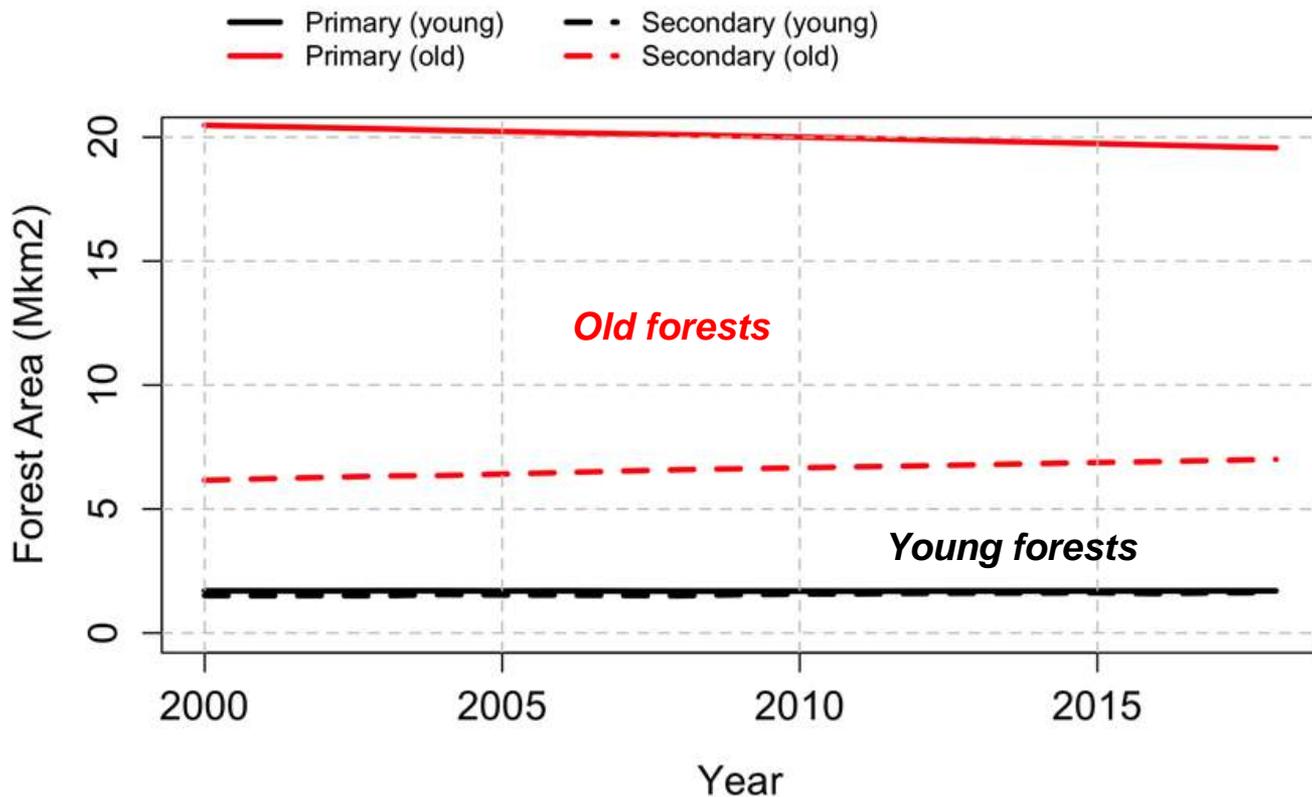


# In LPJ old forests dominate modeled forest area

LPJ modeled forest area for boreal forest >50°N

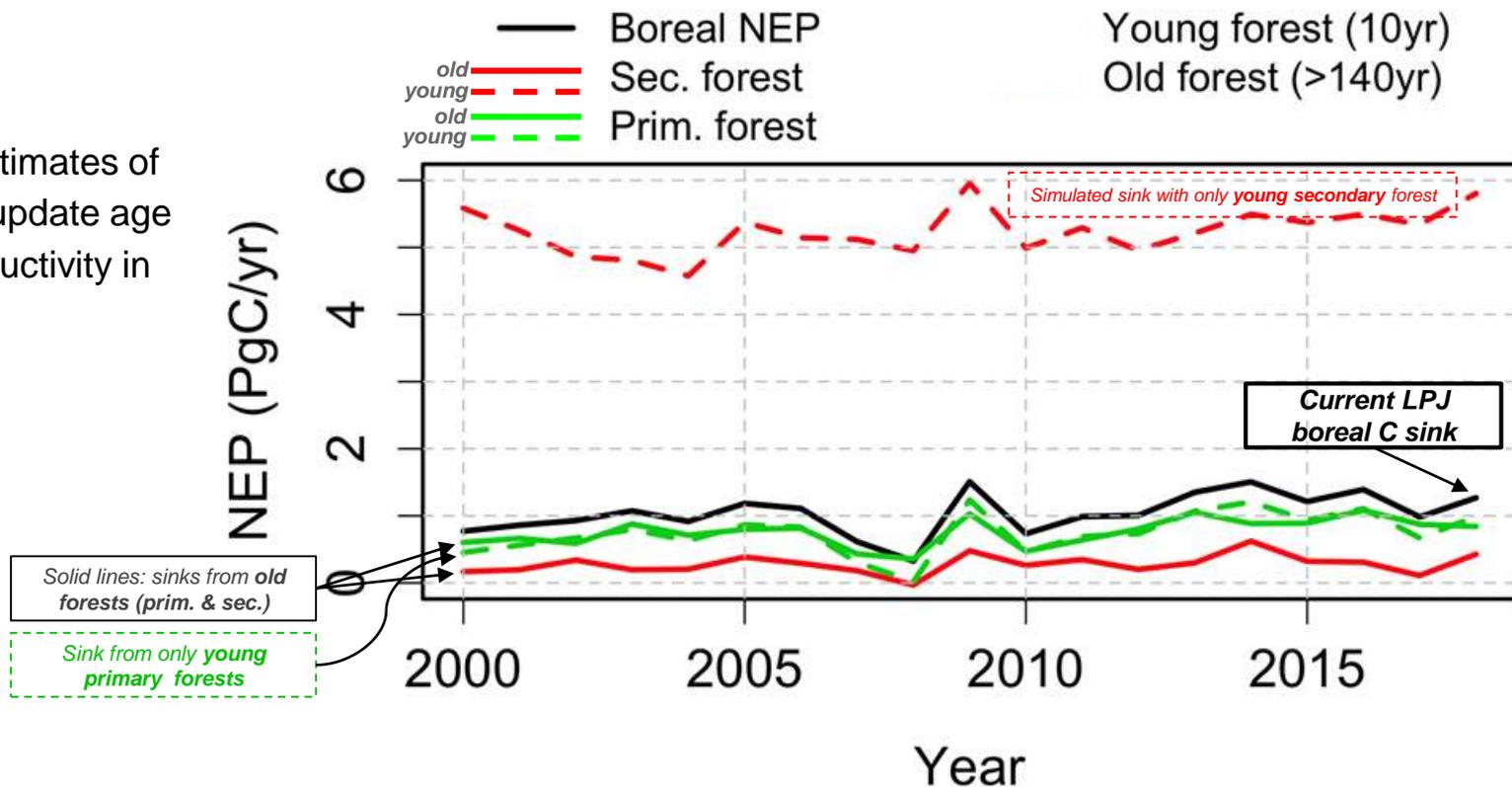
Mainly old primary and old secondary forests.

Secondary forests are ageing from earlier land cover changes.



# The LPJ boreal C sink is thus driven by old forests

Spaceborne estimates of site index can update age and forest productivity in LPJ.

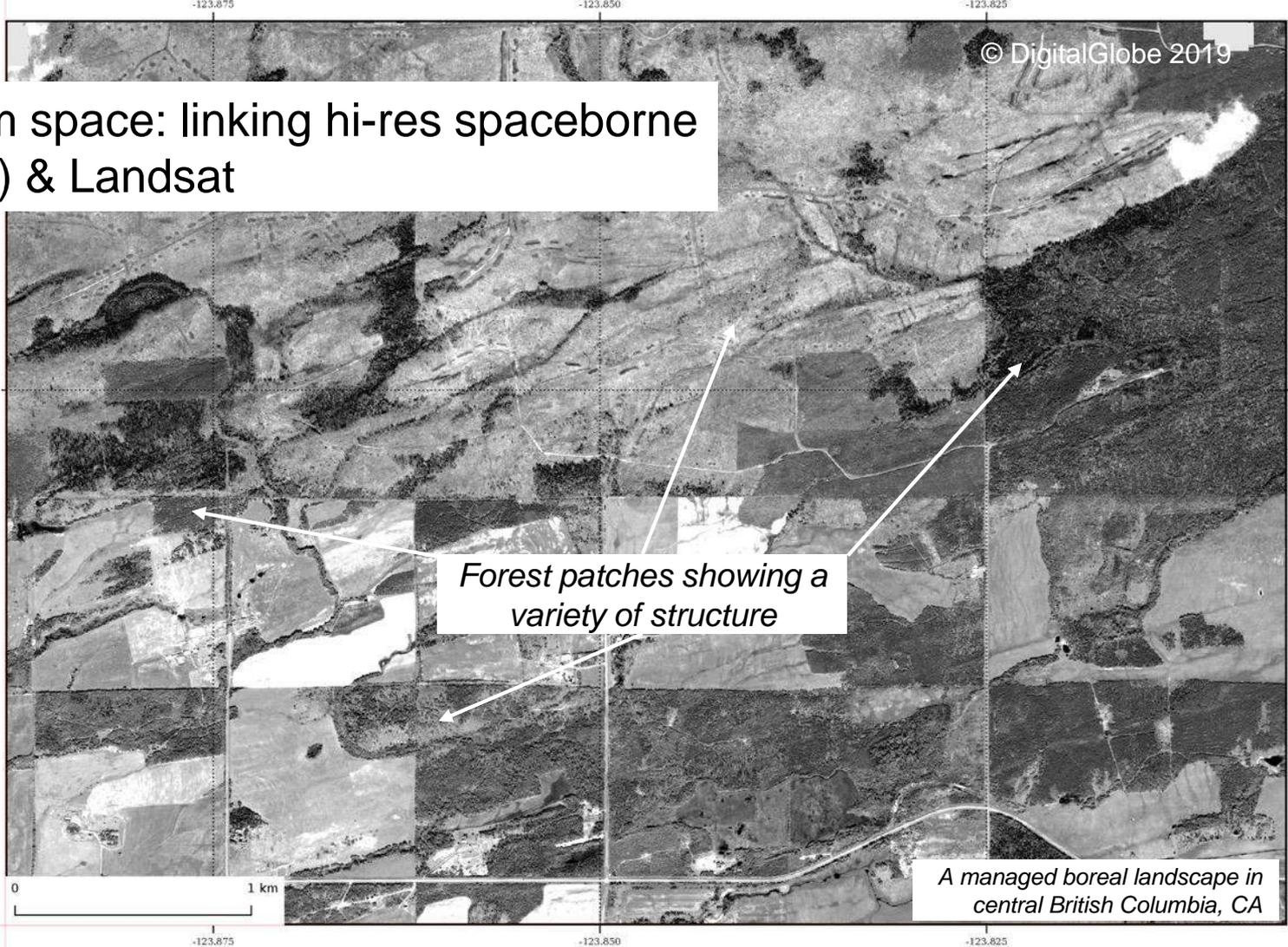


# Site index from space: linking hi-res spaceborne images (HRSI) & Landsat

The **spatial** detail from HRSI & **temporal** detail from Landsat provides insight into boreal forest structure and its variation.

**Stereogrammetry with HRSI** produces estimates of vertical forest structure (proxy for height).

For all HRSI structure estimates, we're building a **multi-decadal time series from Landsat**.



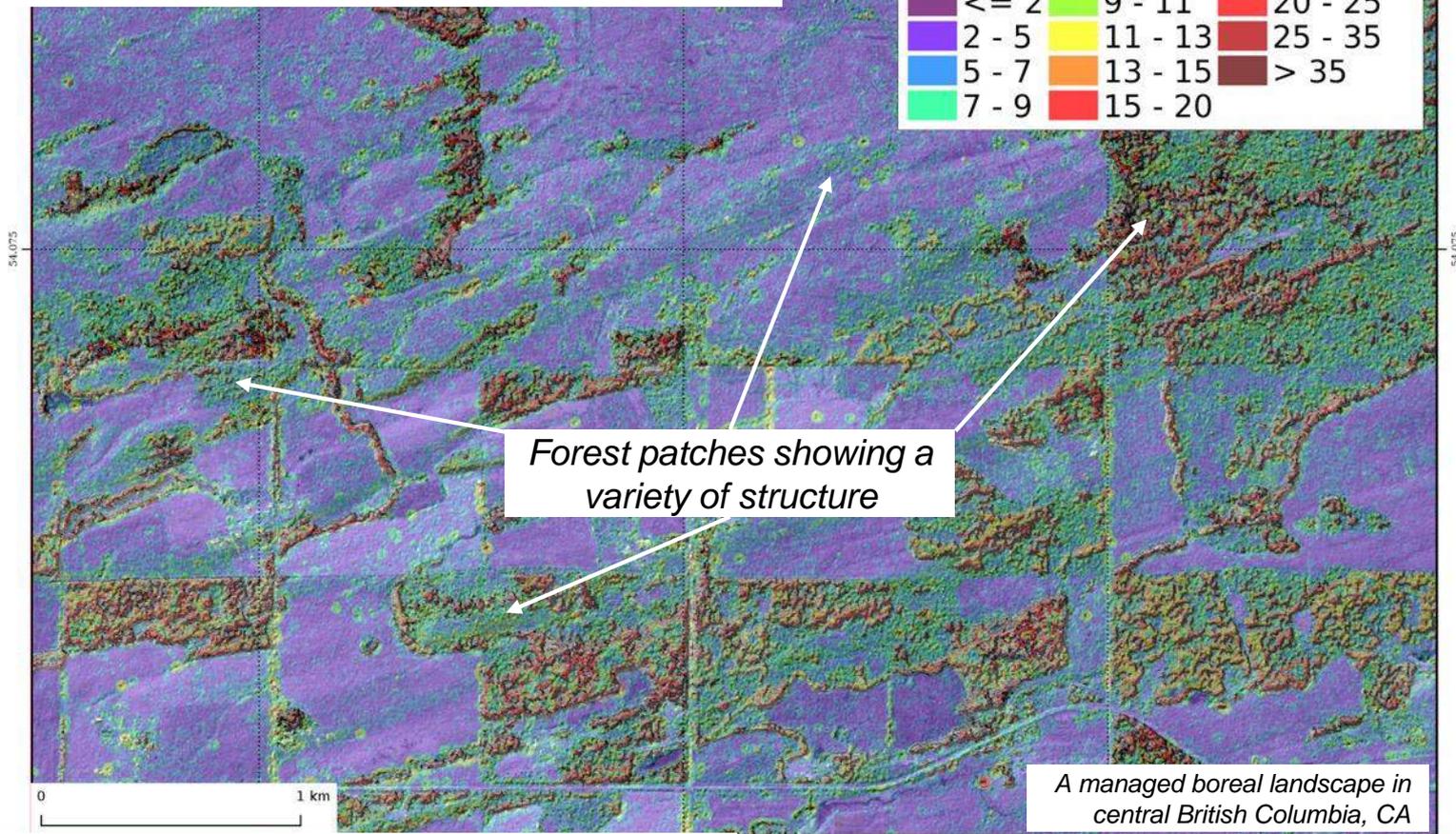
# HRSI DSMs estimate forest vertical structure

The **texture** of elevations of forest canopy surfaces from DSMs provides forest vertical structure.

Requires the presence of forest gaps, edges

Reveals forest structure patterns at **1 m resolution** across landscapes.

Forest vertical structure from DSM (m)



*Forest patches showing a variety of structure*

*A managed boreal landscape in central British Columbia, CA*

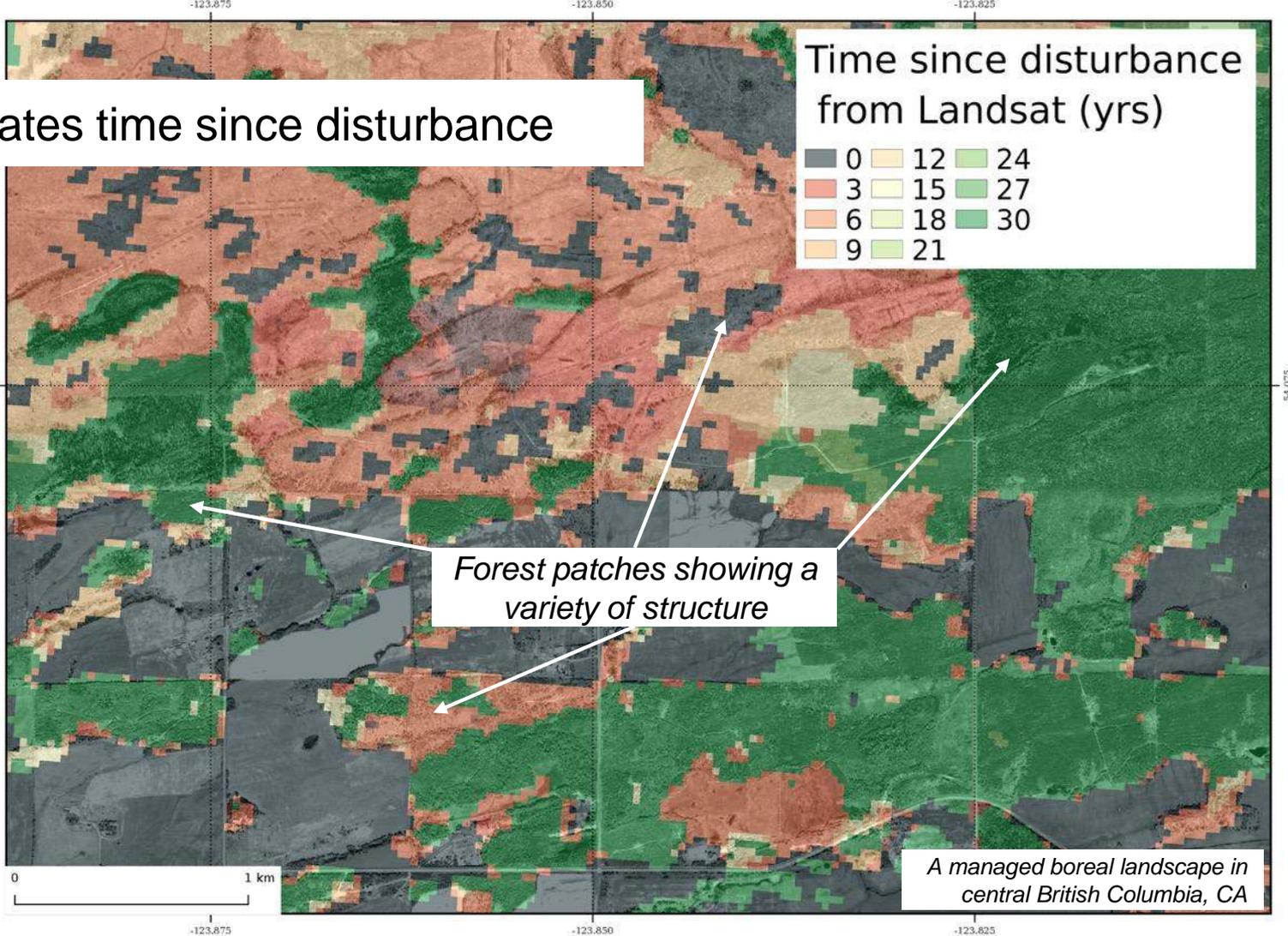
# Landsat estimates time since disturbance

Provides a proxy for forest age

Calc'd from forest change year

Based on yearly probabilistic estimates of forest cover.

Resolves yearly age-classes of forest patches.

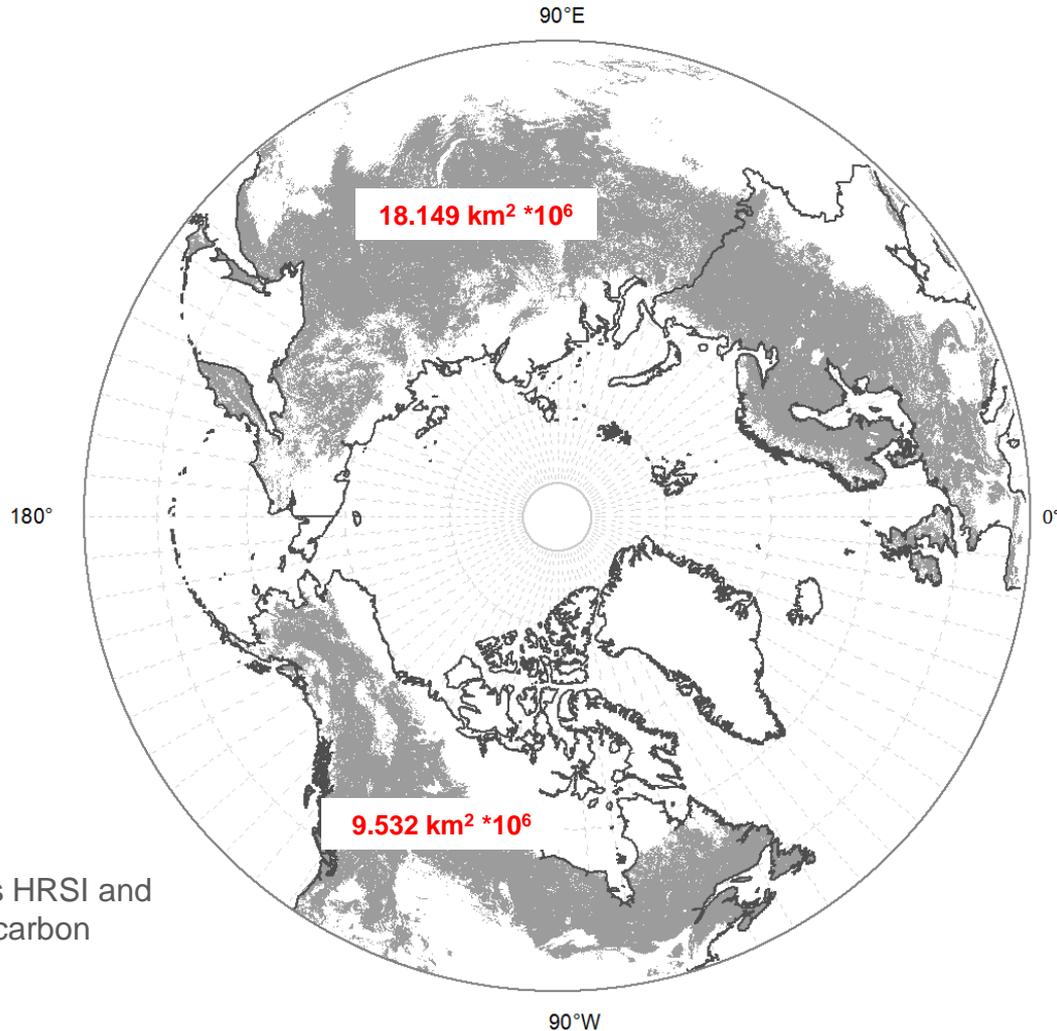


# Defining the boreal domain

We define the boreal domain using a variety of existing broad-scale data

- Climate envelope (WorldClim v2, Fick & Hijmans 2017)
- Tree canopy cover mask with tundra
  - N.A. (calibrated to boreal canopies > 2m; Montesano et al. 2016)
  - Eurasia (Hansen et al. 2013)
  - Taiga-tundra ecotone map (Montesano et al. in prep)
- Water extent (Pekel et al. 2016)

This limits the spatial extent in which to mass process HRSI and Landsat, examine forest structure, and model boreal carbon fluxes.



# Assessing forest age across the boreal

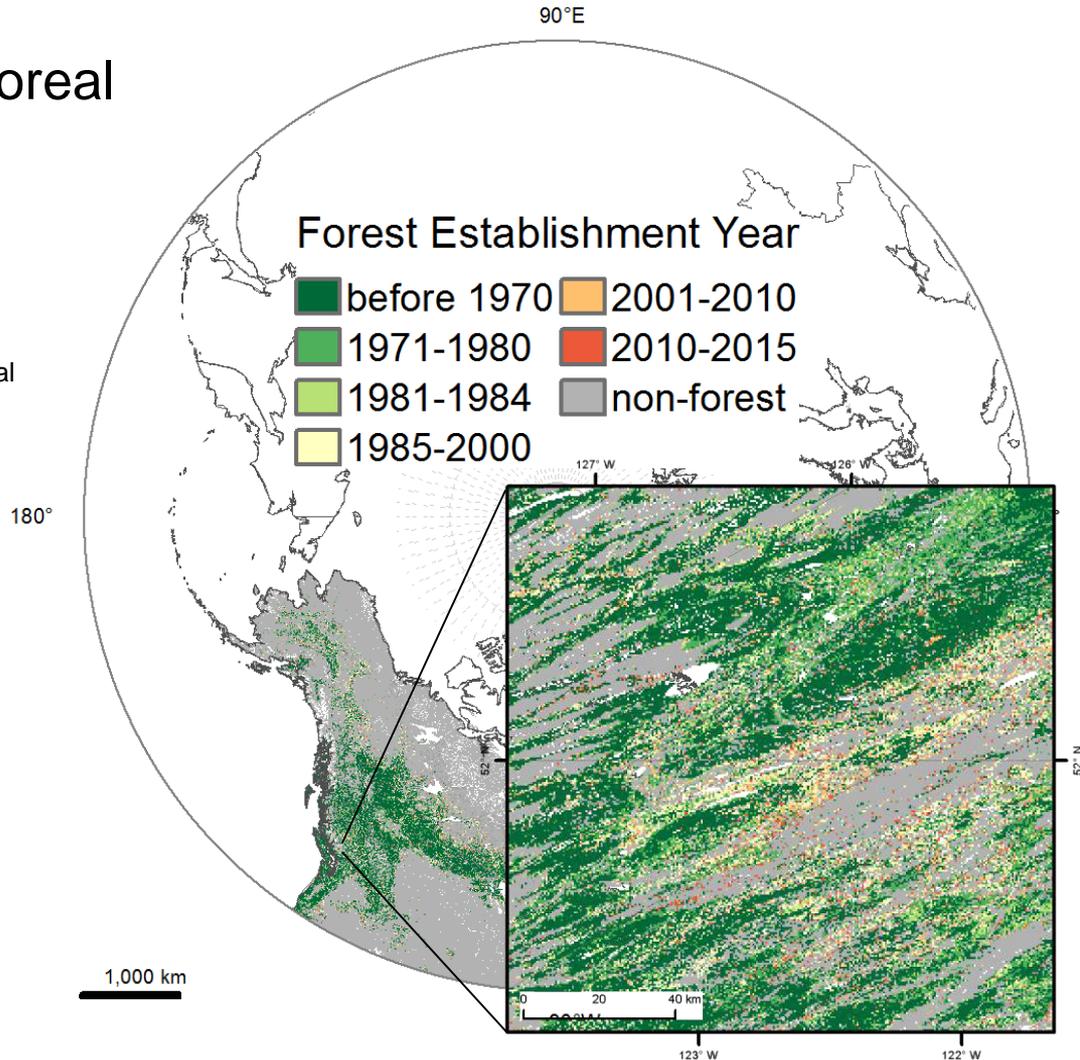
Age is assessed by first identifying a forest establishment year.

Derived from forest cover estimated yearly from the multi-decadal (since 1972) Landsat time-series

N. America has wall-to-wall coverage across the boreal domain.

Time-since-disturbance is computed from estimated establishment year.

Calibration and validation of these data in the boreal is on-going.

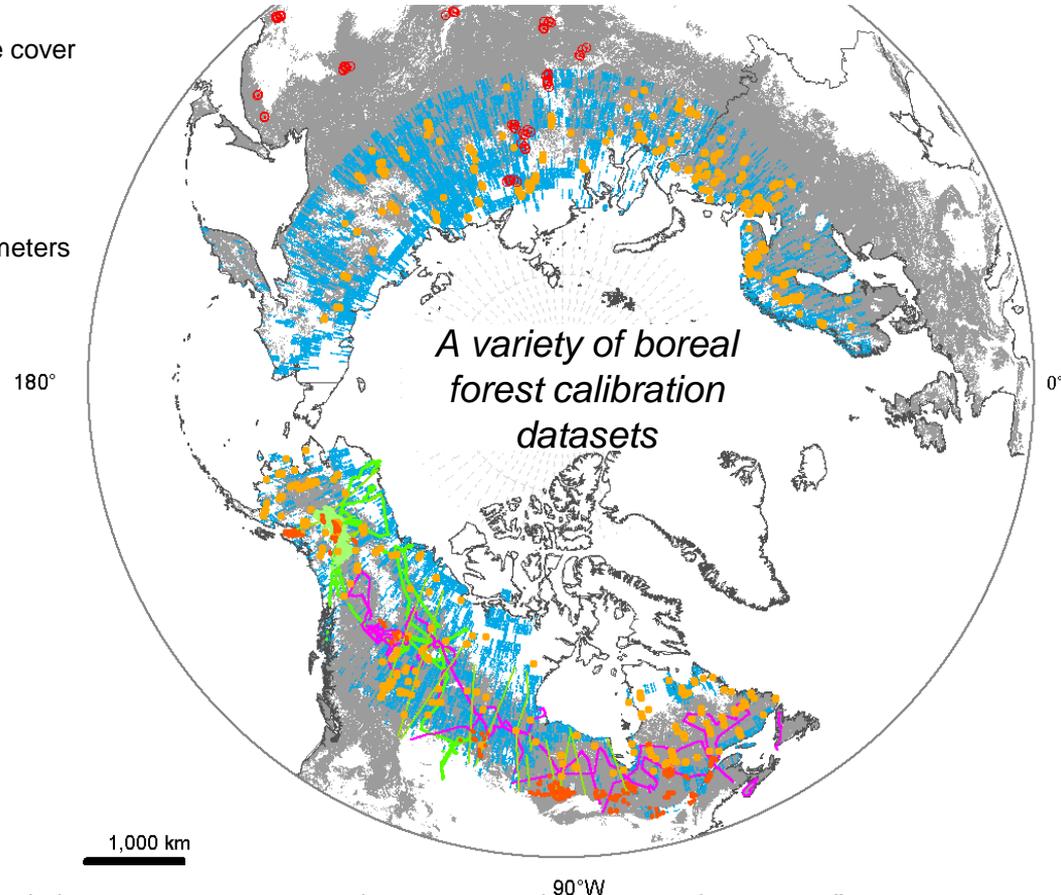
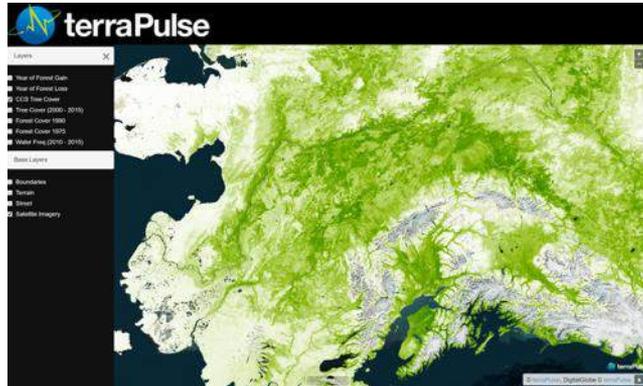


# Improving forest age from Landsat with calibration of tree canopy cover

Calibration will improve the forest classification and epochal tree cover estimates that are used in forest age estimates.

Improves forest loss and gain detection

Accounts for within-boreal structural variation by adjusting parameters by ecoregions.



See poster by Wang et al. "Ecoregional calibration of global, 30-m resolution tree-canopy cover estimates across the taiga-tundra ecotone"

# Mass processing of individual HRSI DSMs across the boreal domain

Forest height is approximated by estimating forest vertical structure signals in HRSI DSMs

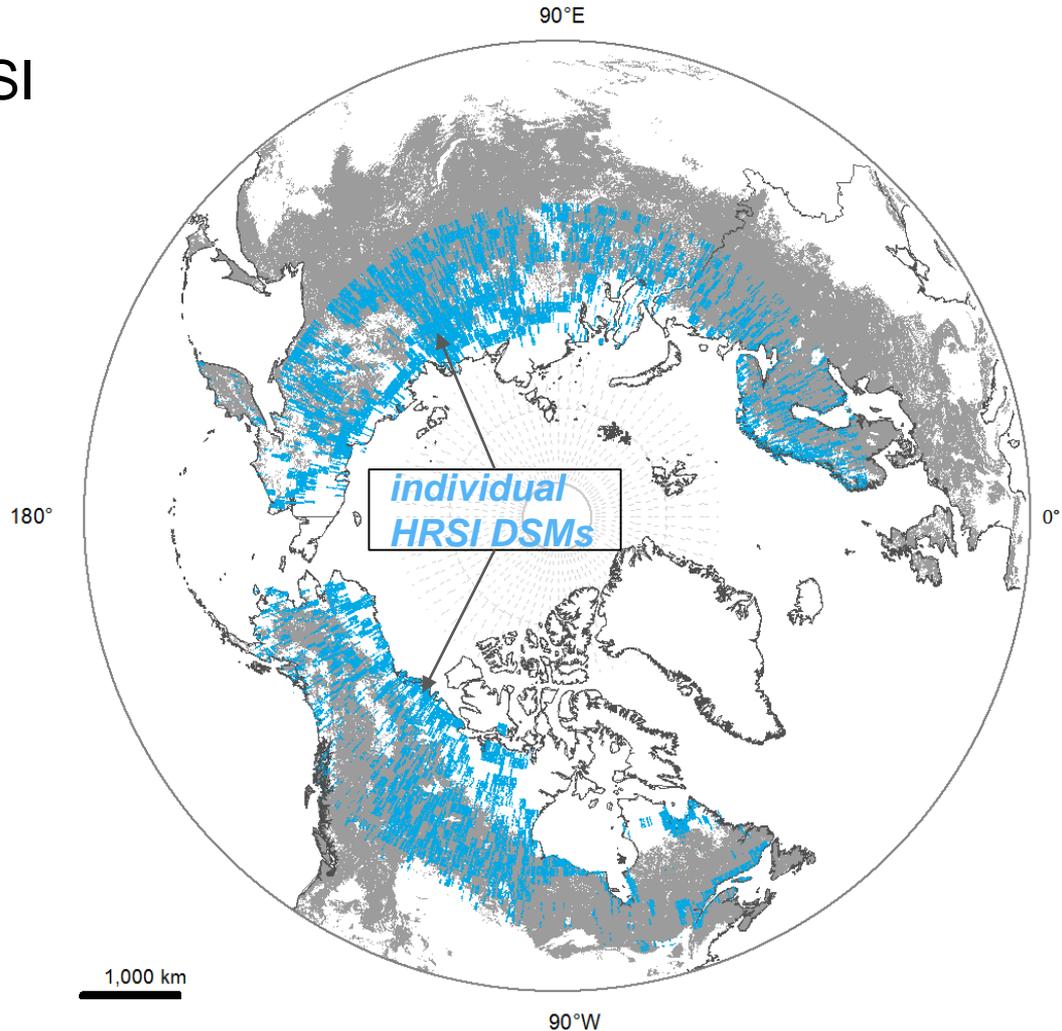
- from DigitalGlobe; primarily Worldview-1,2,3
- Each DSM covers ~2000 km<sup>2</sup> with 1m spatial resolution.

Using computing clusters (DISCOVER and ADAPT):

- Thousands of individual DSMs have been processed in the boreal.
- Billions of individual pixels.

Evaluations of DSM-derived forest structure

Montesano *et al.* 2019 RSE, Montesano *et al.* 2017 RSE, Neigh *et al.* 2014 RS



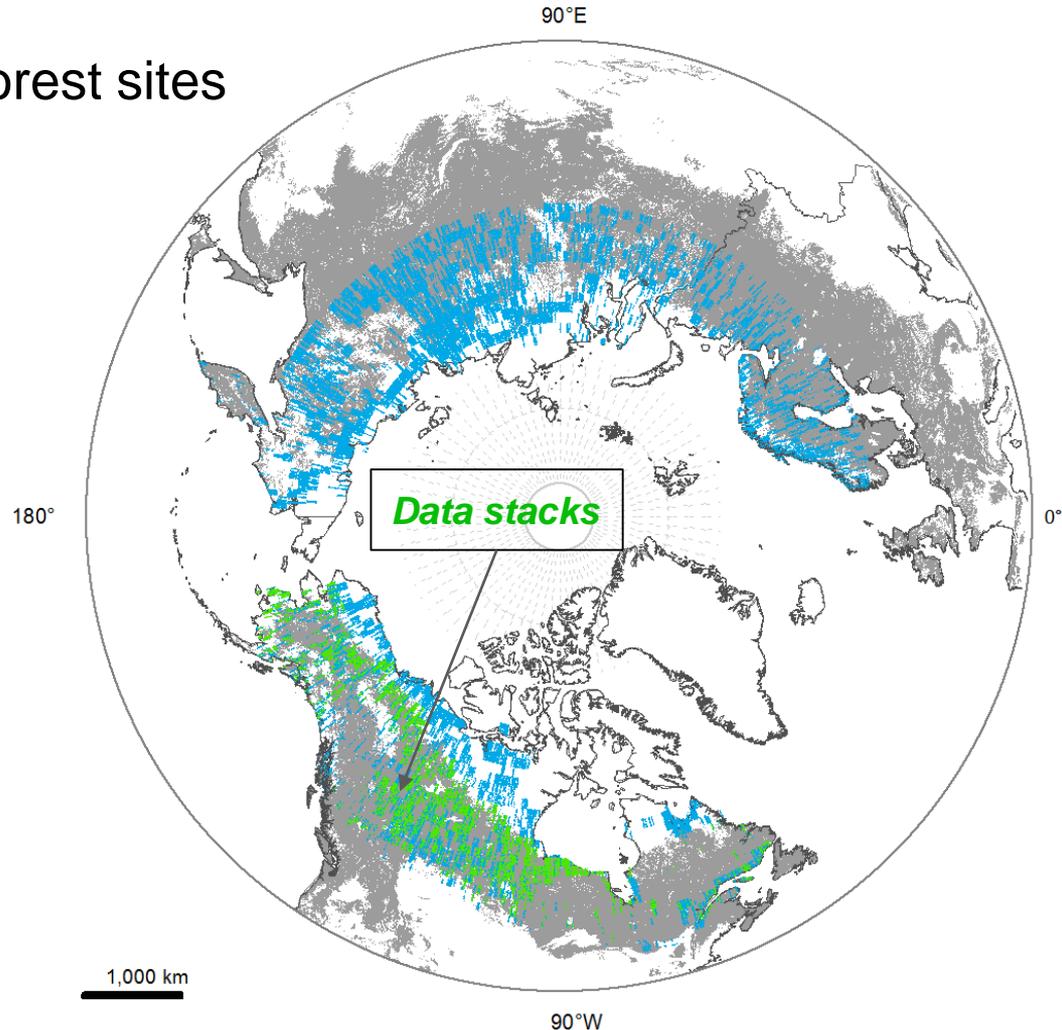
# Accumulating samples of boreal forest sites with multi-resolution data stacks

Data stacks aggregate a variety of data

- spatially link HRSI estimates of forest structure & Landsat age
- Incorporate landscape characteristics (site factors)

Each data stack (4 m resolution) features layers describing site factors:

- Vertical forest structure from DSM
- Topographic variables from DSM (1m; co-registered to ICESat-GLAS)
- Tree canopy cover (30m; calibrated to 2 m hts)
- Forest Age (time since disturbance)
- MODIS plant functional type (250m)
- statistical principal components of soil & climate data



# Stratifying boreal ecoregions to group spaceborne estimates

Boreal ecoregions are stratified into sub-units:

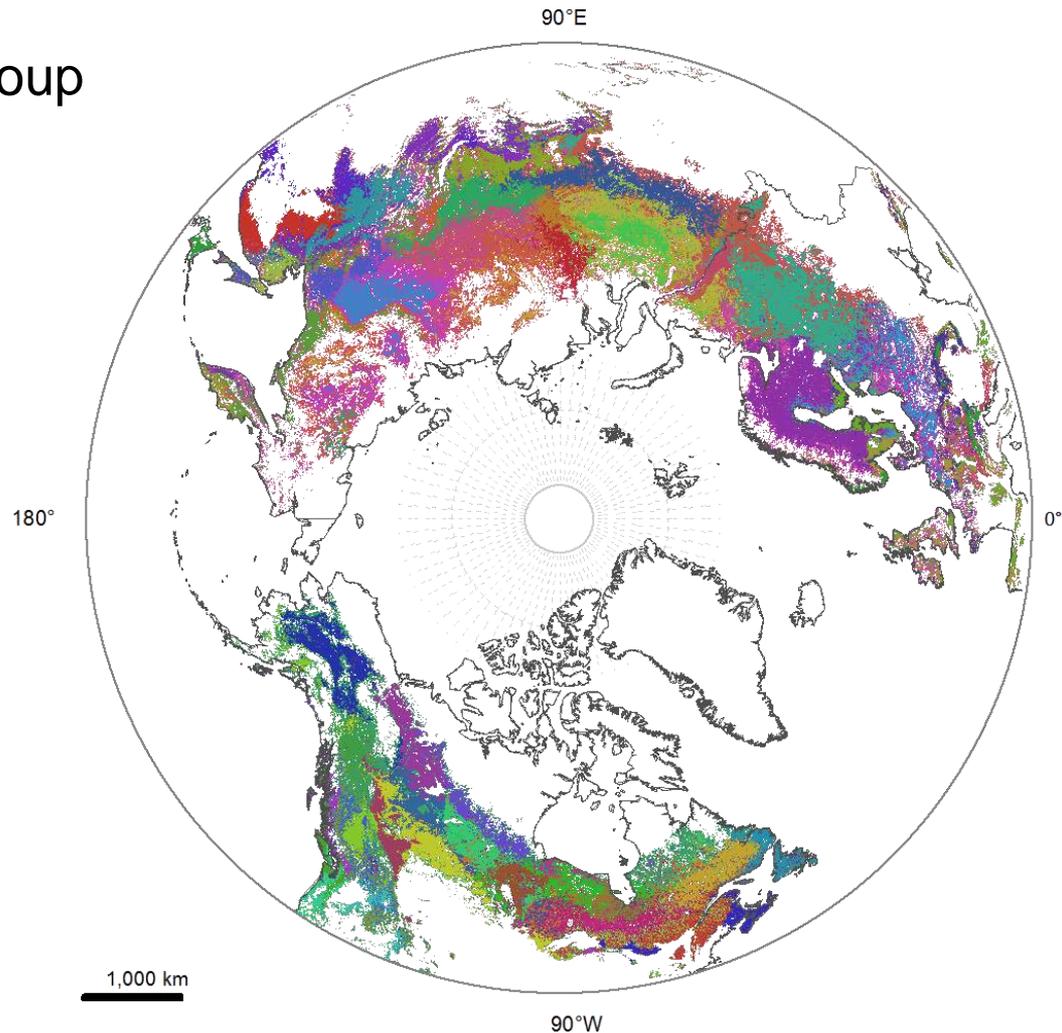
- statistical decomposition of ~60 environmental factors (temperature, precipitation, soil character, and permafrost)
- represent boreal sub-domains (distinct ecological functional units)
- may explain variations in forest growth.

The spatial detail of these sub-domains helps address issues of scale.

Soil grids (250 m) (Hengle et al. 2017)

Permafrost probability (1 km) (Obu et al. 2018)

WorldClim (v2) bioclimatic variables (1 km) (Fick & Hijmans 2017)

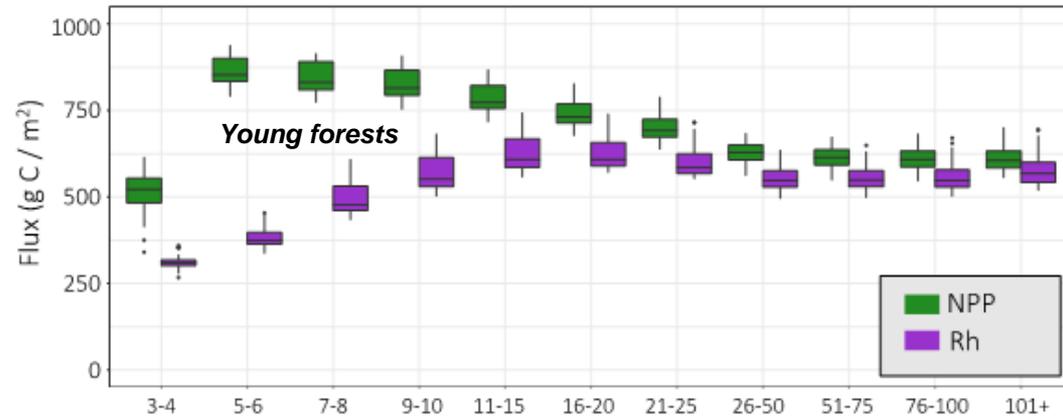


# Updating the representation of forest age in boreal carbon models

Age-class dynamics provide important insight to carbon dynamics.

Identifying young stands (regrowth) resolves differences in vegetation-atmosphere carbon fluxes.

Improves estimates of the strength of the carbon sink in young forests.



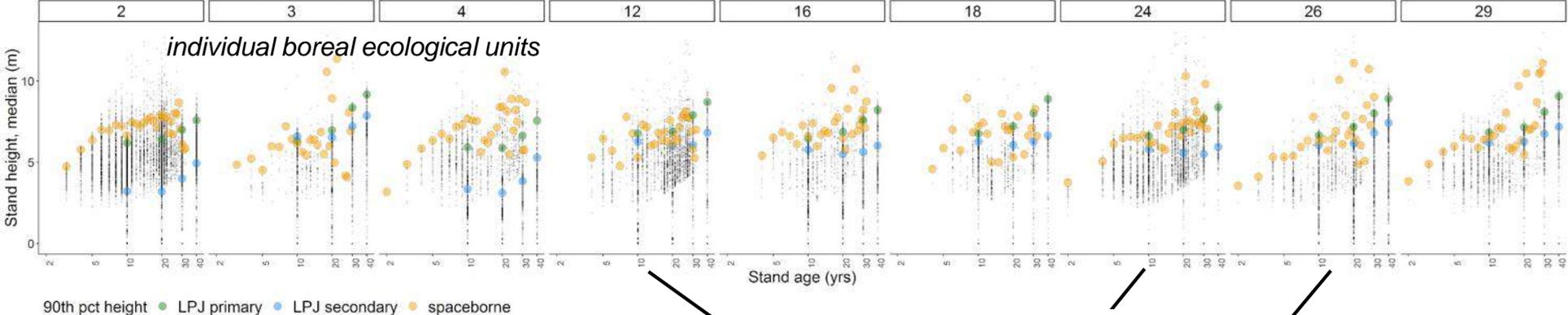
Boxplots of NPP and Rh by age-classes (x-axis, *in years*) from LPJ simulations for U.S. States MI, MN, WI. Small age-widths in the youngest age-classes towards progressively larger age-widths.

***Calle and Poulter, 2019 Biogeosciences under review***

# Estimating site index identifies young forests

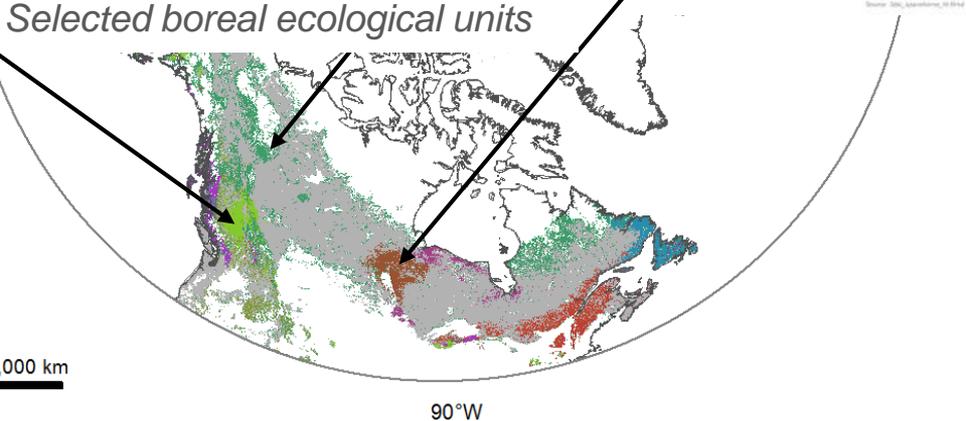
Site indices for N. American boreal ecological units

Age: years-since-disturbance (spaceborne), 10-year-age-class (LPJ); Obs: ICESat-GLAS footprint (spaceborne), 0.5° grid cell (LPJ)



Samples of forest structure show spaceborne and LPJ site index curves for various boreal regions.

Spatial variability of differences suggest where LPJ height, age can be updated/optimized.



# Summary: capturing boreal forest structural variation with spaceborne data

- We're linking a large subset of the commercial hi-res image archive with the Landsat record across the boreal domain.
- This is yielding large samples of coincident forest height and age estimates (site index).
- Site index is valuable input to global carbon models, for which improvements to the simulation of young forests helps resolve important variation in the boreal carbon cycle.



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