Mapping the distribution of circumpolar forest carbon with field measurements, airborne and spaceborne LiDAR

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CRSS 2014

1 2 3 4 5 6 7 8

Science Objectives

Primary:

- How much Boreal C is stored?
- What is the distribution?
- Provide a baseline estimate of Above Ground live dry Biomass density (AGB)

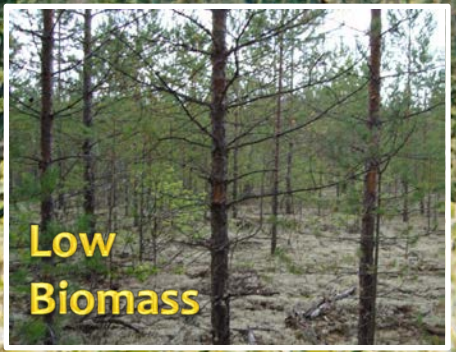
- Develop model equations that can be used to estimate AGB using a multi-phase sampling approach which integrates co-located field observations with airborne & space based ICESat GLAS LiDAR data.

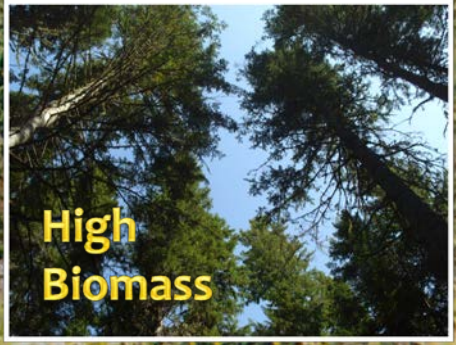
- Expand the spatial extent from prior investigations to cover the entire circumpolar boreal zone by scaling up methods from prior studies:
  - (Norway) Næsset 2011
  - (Siberia & Quebec) Nelson 2009
  - (Siberia) Ranson 2007

Secondary:

- Produce biomass variance estimates with different stratification strategies with uncertainties.

  (When do we have enough field data?)
  - 1) Is one model equation sufficient for multiple strata?
  - 2) Are different model equations needed for each laser acquisition?





Limitations and uncertainties associated to GLAS measurement approaches over large areas?

Stratify & Multiply (SM)

Assign avg val by stratum

Pros (+)

- Rigorous statistical variance estimate and error bound by stratum.
- Bias in regression model can be calculated.
- Appropriate where wall-to-wall field data is not available.
- Boreal LiDAR/Biomass r^2 significant <400 t/ha.

Cons (-)

- Limited spatial detail (paint by numbers).
- Sufficient field samples are needed for each stratum.
- Low Biomass = limited signal.

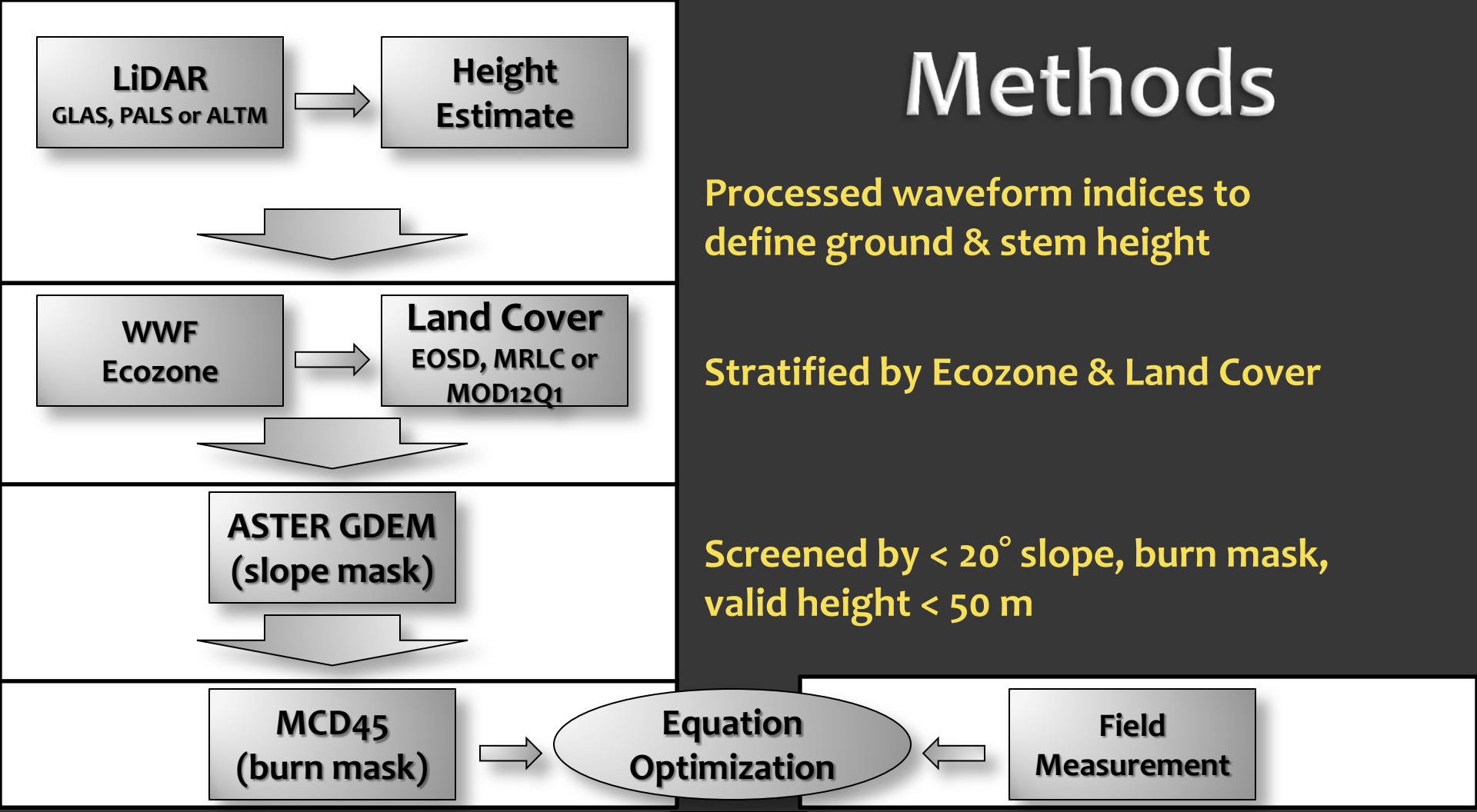
Refs: Nelson 2009
Boudreau 2008
Sun 2008
Ranson 2007

Direct Remote Sensing (DR)

- Calibrate RS to field measurement
- Pros (+)
  - High spatial detail (250 m+).
  - Global implementation with cost $ associated to number of field measurements.
  - Per-pixel model error can be calculated.
  - Boreal LiDAR/Biomass r^2 significant <400 t/ha.
- Cons (-)
  - Range of variance in measurement sacrificed.
    - Low biomass over predicted
    - High biomass under predicted
  - Omission/Commission error of forest extent.
  - Low Biomass = limited signal.

Refs: Blackard 2008
Satchi 2007
Baccini 2004, 2008

Methods



Processed waveform indices to define ground & stem height

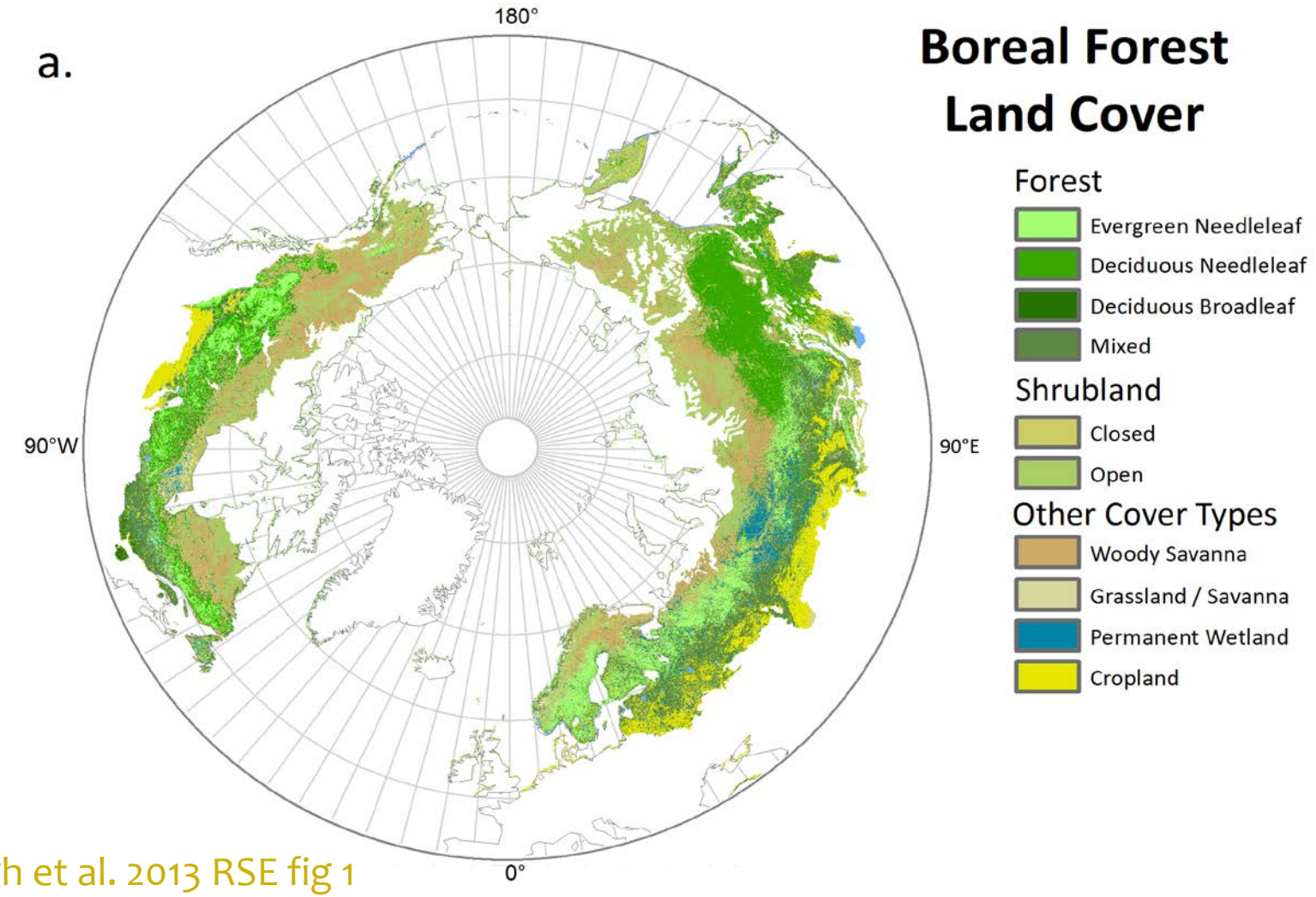
Stratified by Ecozone & Land Cover

Screened by < 20° slope, burn mask, valid height < 50 m

Biomass Map

Field measurements & local equations optimized in Field/GLAS sites to produce a stratified AGB map.

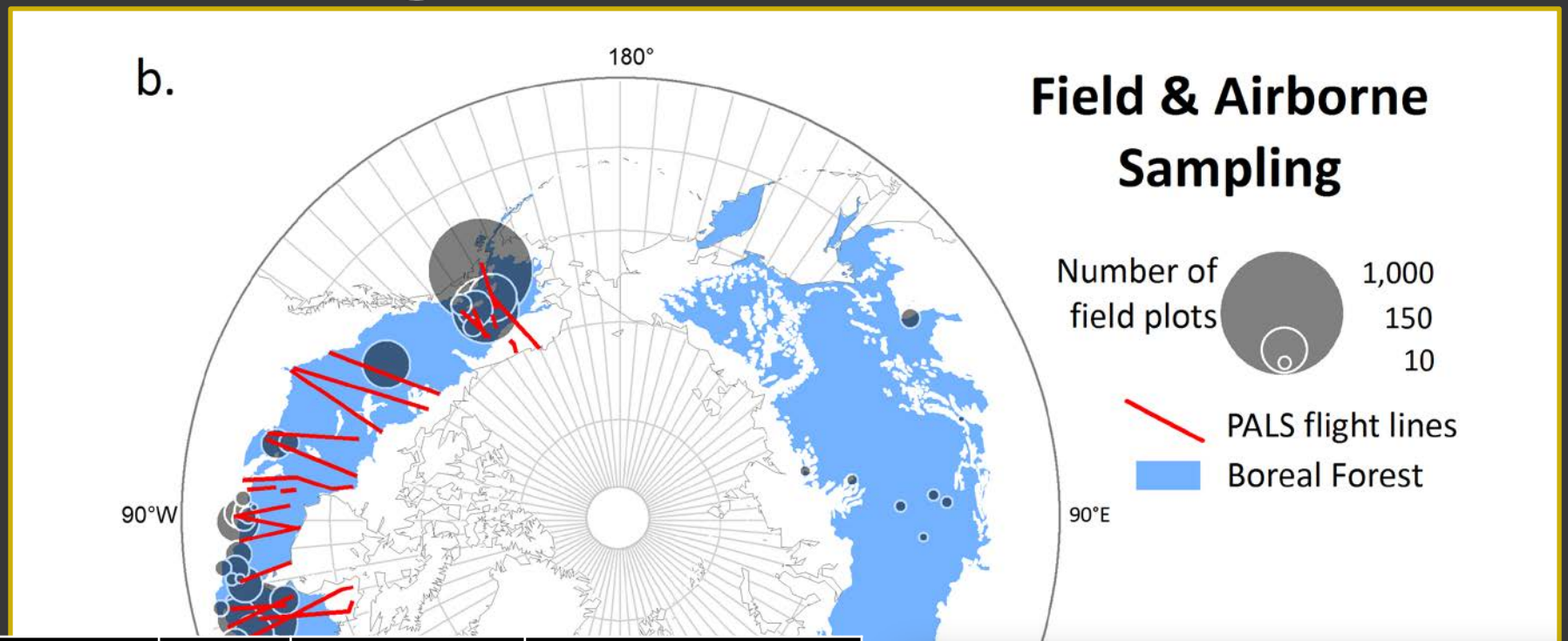
Study Region: Forested Area 47-72° N | 11.9 m km²



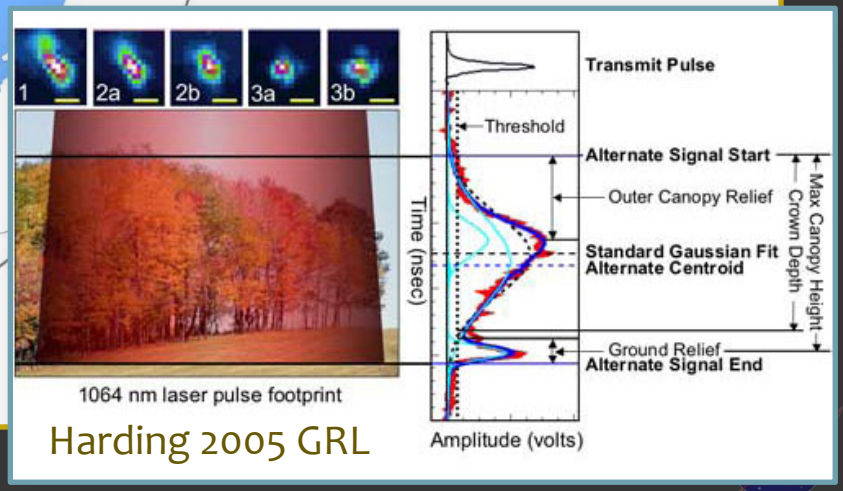
Neigh et al. 2013 RSE fig 1

MODIS MCD12Q1 IGBP 500m Land Cover

Study Region: Forested Area 47-72° N

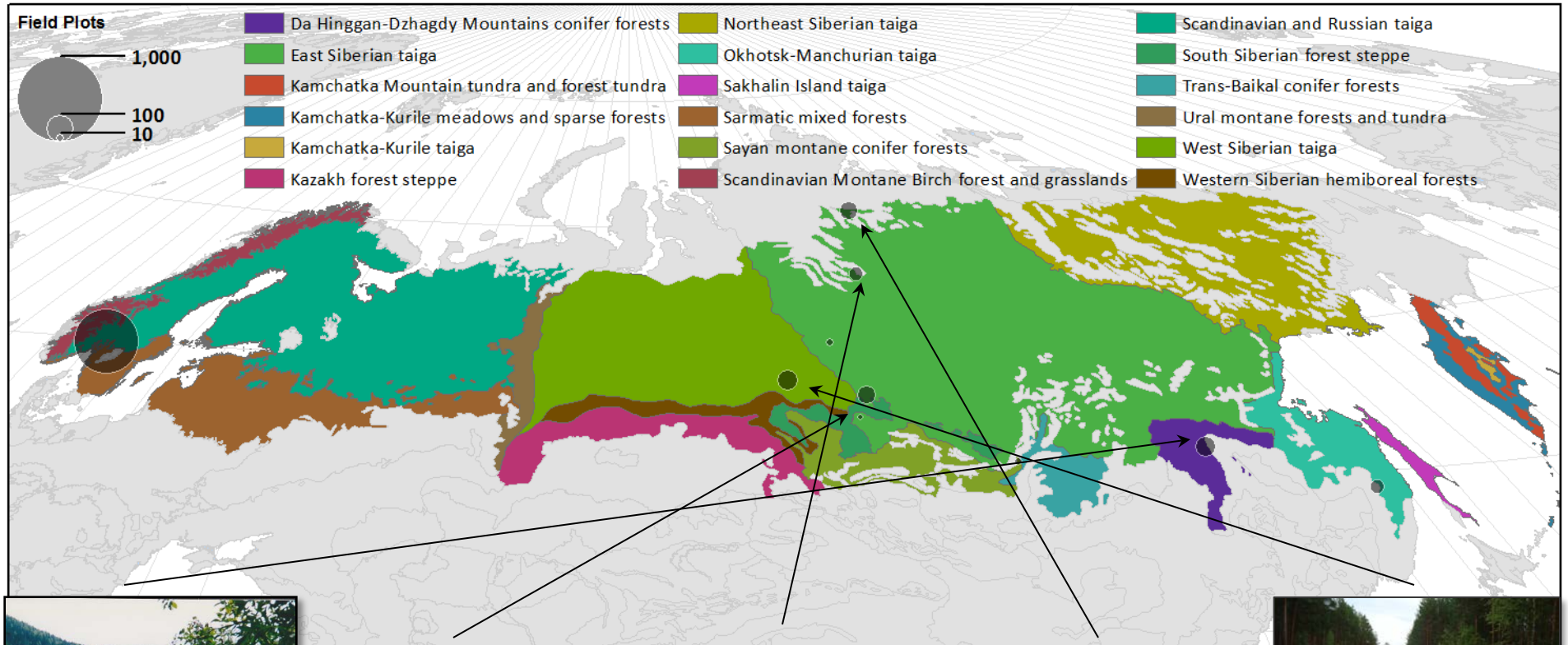


	GLAS Laser	# of GLAS Pulses	Acquisition Period
North America	L3c L3f	930,400	6/08/05->6/13/05 6/08/06>6/26/06
western Eurasia	L2a L3a	738,159	9/24/03->10/15/03 10/3/04->10/15/04
eastern Eurasia	L3c L3f	1,768,539	6/08/05->6/13/05 6/08/06>6/26/06



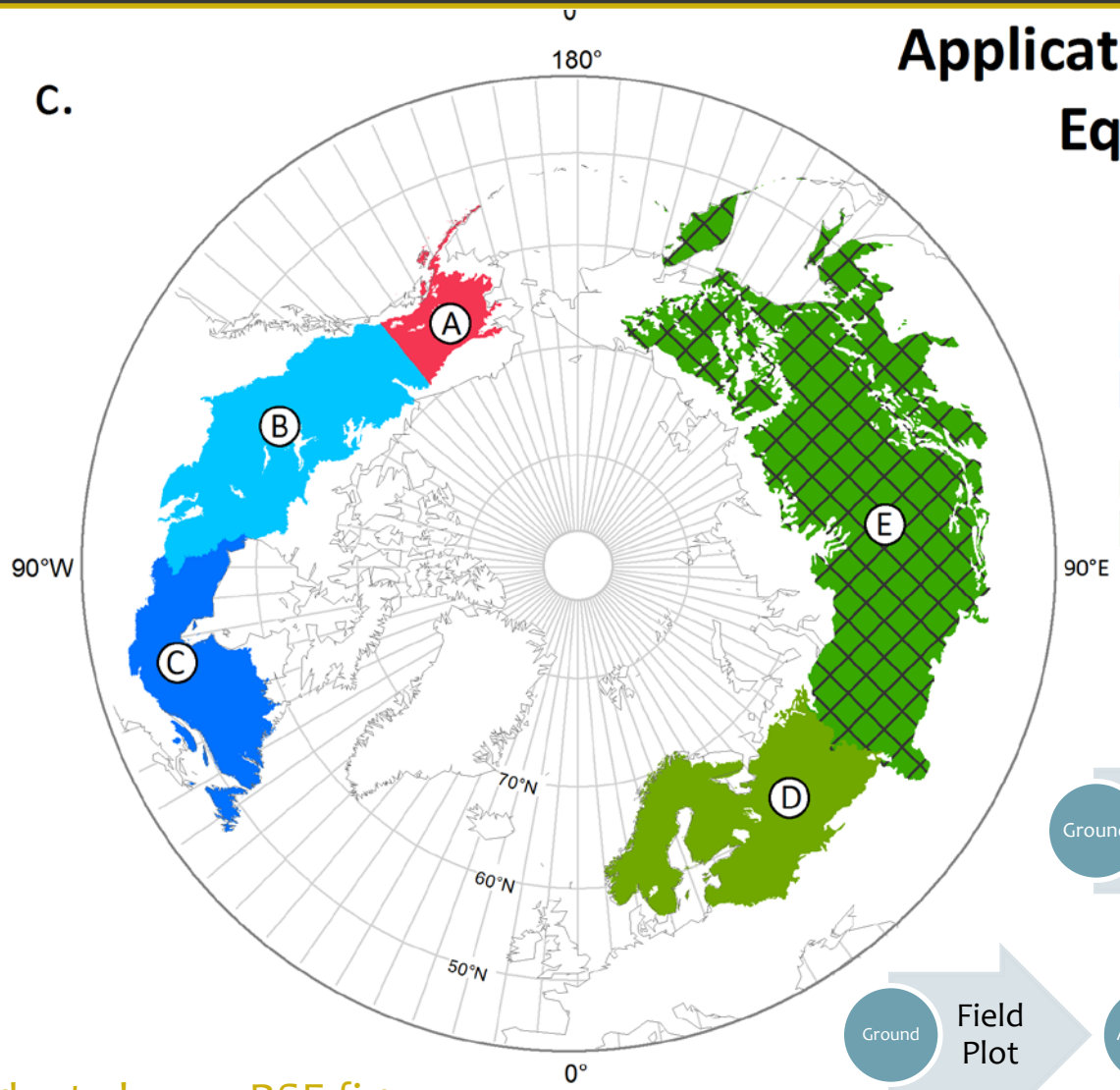
Harding 2005 GRL

Eurasia Field Data & Ecozones



Co-located Field Data for 2 phase model

2 and 3 Phase AGB models



Application of Carbon Equations

Ecoregion groups

North America

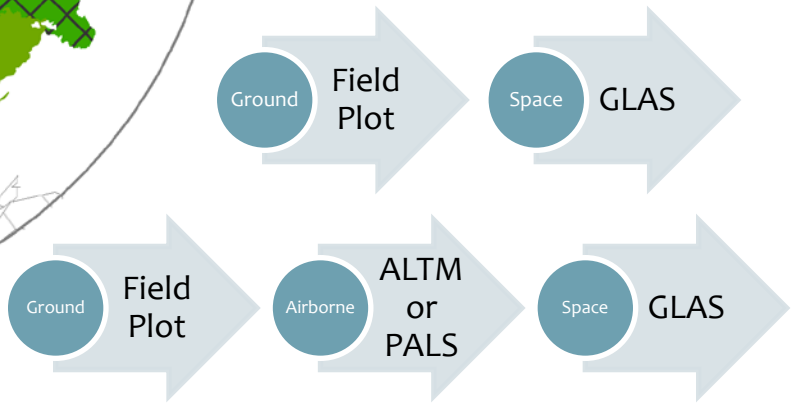
- A
- B
- C

See Table S4 for corresponding equations

Eurasia

- D
- E

2-Phase AGB model (Ground-GLAS)

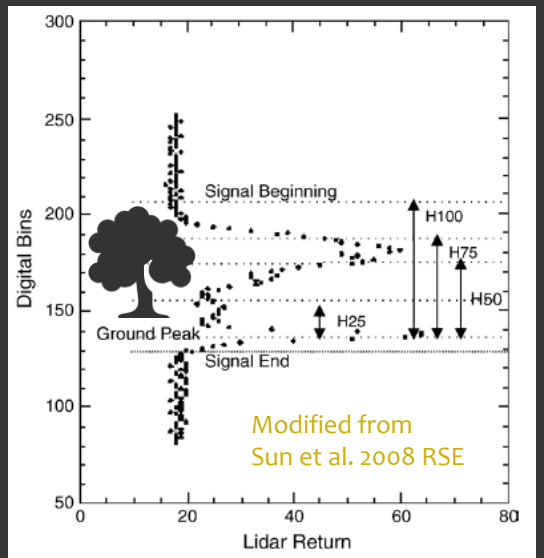


Neigh et al. 2013 RSE fig 1

Results: Regression Analysis

STATISTICAL COUPLING OF KEY GLAS HEIGHT METRICS
(REMOMOVING COLLINEARITY)

- G. Sun height vs. energy indices
  - ht1->ht4 vs. h90->h100 = r^2 >0.97
- Within energy indices step of 20 e.g.
  - H30->H60 vs. h60->h80 = r^2 >0.97
- H14 vs. wfl0
  - r^2 = 0.98
- Metrics removed from analysis:
  - h20, h40, h75, h80, ht1, ht2, ht3, meanh



KEY LIDAR METRICS OUTPUT FROM MODEL EQUATIONS

GLAS: h14, h30, h50, h70, h90

PALS: d80, ha

ALTM: hf90, hf25, hl50

Metrics input into SAS software using:
All possible subsets

Goal = a regression model with good fit between co-located field biomass data, airborne & GLAS height metrics

Results: Regression Models

- **All Possible Subsets (SAS)**
  - **Results 2 to 4 GLAS metrics = r^2 0.46-> 0.84, VIF < 10**
  - **29 Ground to Airborne**
  - **17 Airborne to GLAS**
  - **1 Ground to GLAS**

- **Examples of Models in High Biomass Areas**
  - Eastern Canada

    Quebec and Maritimes Conifer

    Ground to PALS

    - Biomass = 4.90(h90) + 6.30(h10) – 0.19

      R^2 = 0.69, RMSE = 27.90 Mg ha^{-1}, VIF = 1.74, n = 66

    PALS to GLAS Conifer

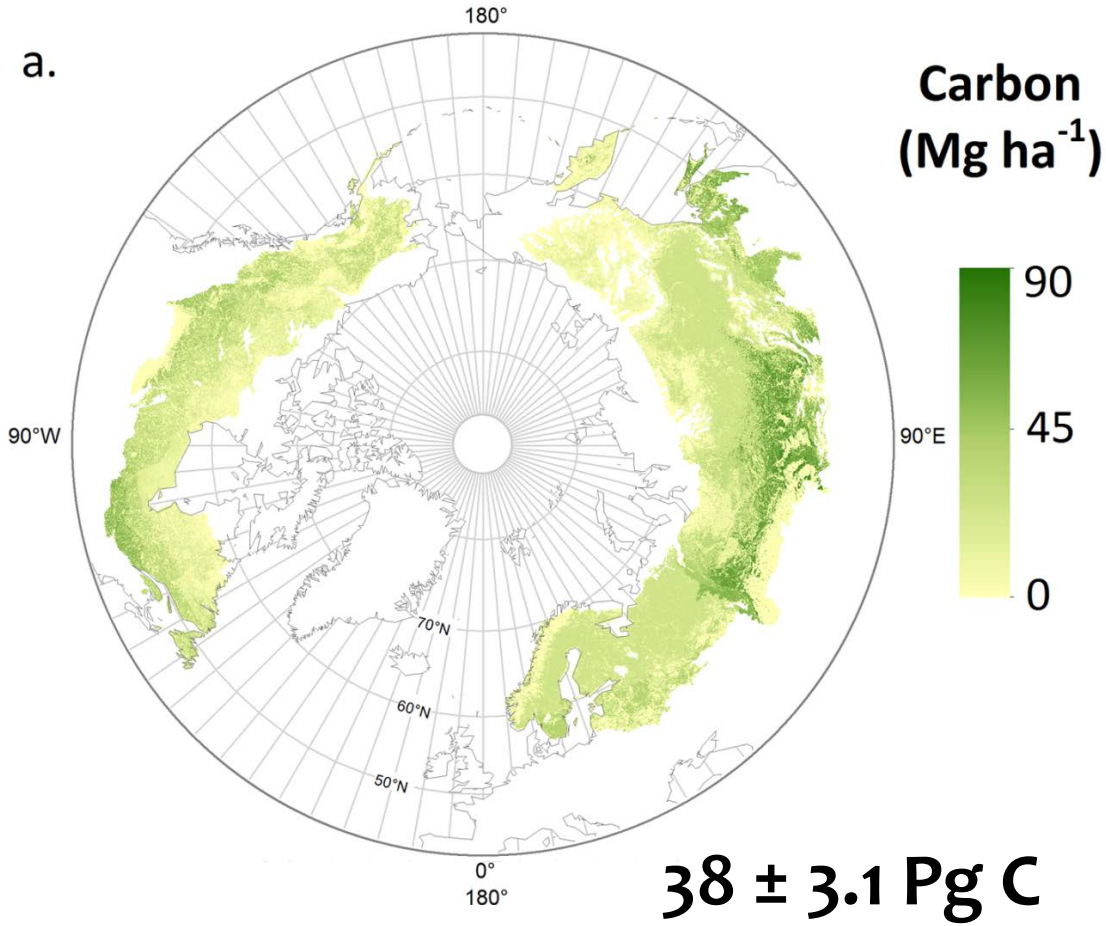
    Biomass = 2.27(h14) + 5.54(h90) – 9.13(h25) + 2.40

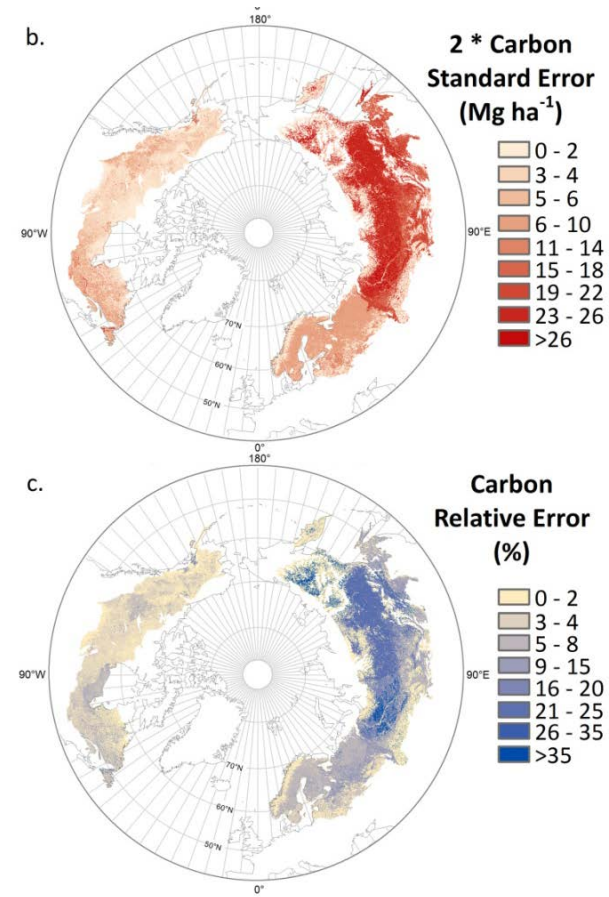
    R^2 = 0.62, RMSE = 23.56 Mg ha^{-1}, VIF = 4.66, n = 850
  - Eastern Eurasia (Ground to GLAS)

    Biomass = 13.60(h75) – 14.30(h25) – 3.49

    R^2 = 0.60, RMSE = 58.47 Mg ha^{-1}, VIF = 1.8, n = 55

Results: C Estimates with Uncertainties



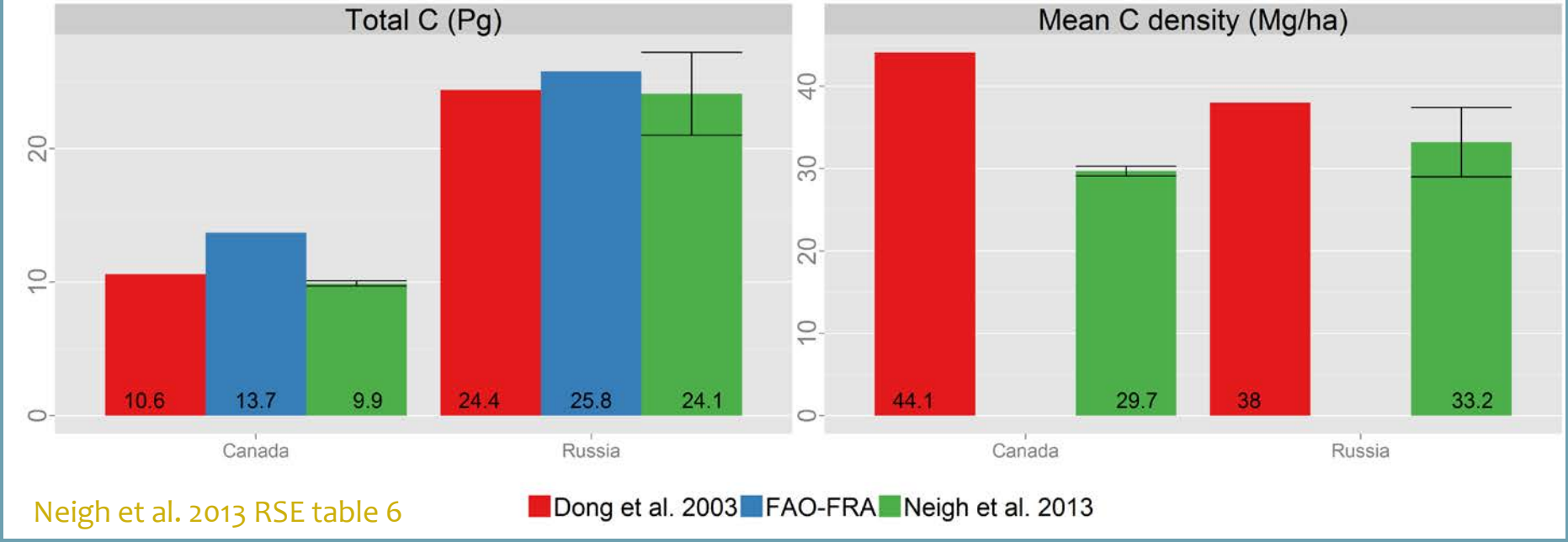


38 ± 3.1 Pg C

Neigh et al. 2013 RSE fig 2

Results: C Estimates with Uncertainties

C Estimates Compared to Other Studies



Neigh et al. 2013 RSE table 6

38 ± 3.1 Pg C

Neigh et al. 2013 RSE fig 2

Conclusions

SUMMARY

1) Estimates of variance in carbon comparable to independent studies.
2) To stratify models by cover type additional co-located field data is required. Highest error in locations with sparse field data.
3) Maps produced could be a baseline for future studies and a boundary of variance for terrestrial C-cycle models.

FUTURE CONSIDERATIONS

Error Mitigation

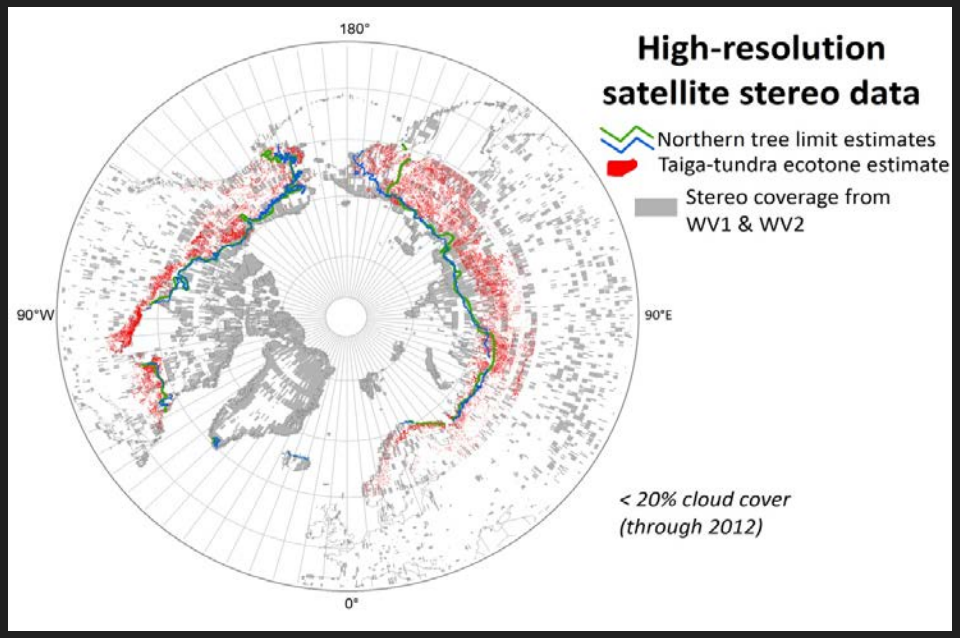
1) Temporal error associated to non-coincident ground, airborne and GLAS measurements (small)
2) Allometric error (small)
3) Geolocation error between ground plots and LiDARs (large if geolocation error > 10 m)
4) Land cover mapping and geolocation error (unknown)
5) DTM slope error (unknown)

Airborne measurements in Siberia

Future Work

TAIGA-TUNDRA ECOTONE

1) Use recently available Landsat based percent tree cover maps, circa 2005, with estimates of uncertainty to improve our prior circumpolar arctic-boreal transition assessment.
2) Use high-resolution data in intensive study sites along the forest-tundra transition zone and characterize the spatial patterns of the tree-tundra mosaic across the boundaries. These data include commercial sub-meter panchromatic and stereo imagery from WorldView-1, WorldView-2, and Quickbird-2.
3) Estimate forest cover and biomass change in intensive study site transects using high-resolution stereo satellite data, field observations, and allometry.



Thank You!

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Aboveground Carbon Stocks in the Circumpolar Boreal Forest

Publications:

2013 Neigh CSR, Nelson RF, Ranson KJ, Margolis H, Montesano P, Sun G, Kharuk V, Næsset E , Wulder MA, and Andersen HE Taking stock of circumboreal forest carbon with ground measurements, airborne and spaceborne LiDAR. *Remote Sensing of Environment*, **137** 274-287.

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