Methods to research status and changes of Russia's northern forests using multiscale remote sensing

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Lectures of the young scientists' school-conference on *Remote sensing of vegetation at high latitudes in response to climate change and other disturbances, IKI RAS, Moscow, Russia 16-17 November 2020*

Project goal

to develop a technology for assessing the dynamics of phytomass of northern forests of Russia since 2000 due to climate change, to provide such an assessment with validation at key sites, based on processing of multiplatform space and aerial imagery, ground surveys

Expected results

Technologies to assess tree stand characteristics using very high resolution UAV imagery

Technologies to map tree stand structure and forest-tundra ecotone using Sentinel 2 MSI high resolution satellite imagery

Technologies to map the dynamics of the forest biophysical parameters (LAI – Leaf Area Index, GSV – Growing Stock Volume) for the whole of northern Russia, using multitemporal MODIS image series, and statistically analyse their relationship with regional climate variability

Methodology and software for remote monitoring of the dynamics of Russia’s northern forests

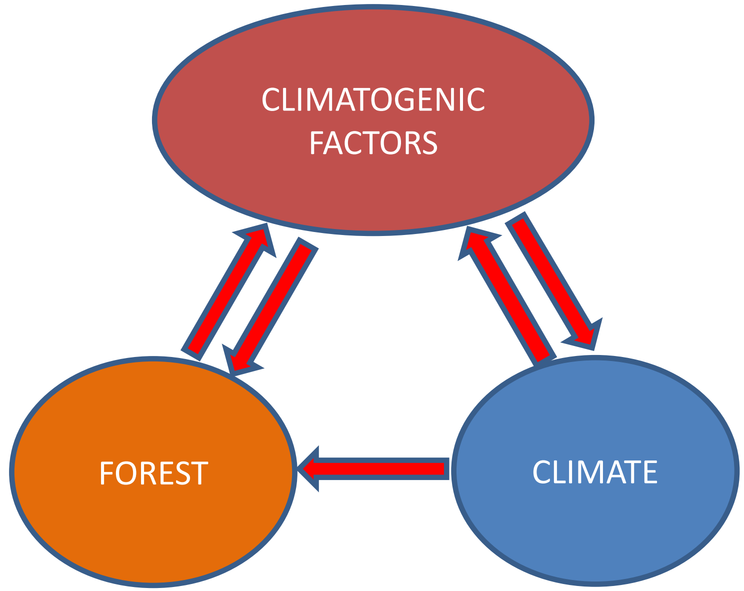
Research design

MONITORED PHENOMENA

- **F1 Forest fires**
- F2 Pests
- **F3 Permafrost**

FOREST PARAMETERS FOR REMOTE AND GROUND MONITORING

- **P1 YEAR Seasonal dynamics**
- **P2 10-20 YEARS Production**
- P3 20-50 (100) YEARS Tree stand structure (vertical, horizontal, by species)
- P4 CENTURIES Ecosystem change



Strong anthropogenic influences (forest cuts, airborne pollution) have to be separated or masked

CLIMATE AND WEATHER DATA

- **C1 Temperature**
- C2 Precipitation
- C3 Solar radiation
- **C4 Snow (depth, fraction, events)**
- C5 Winds

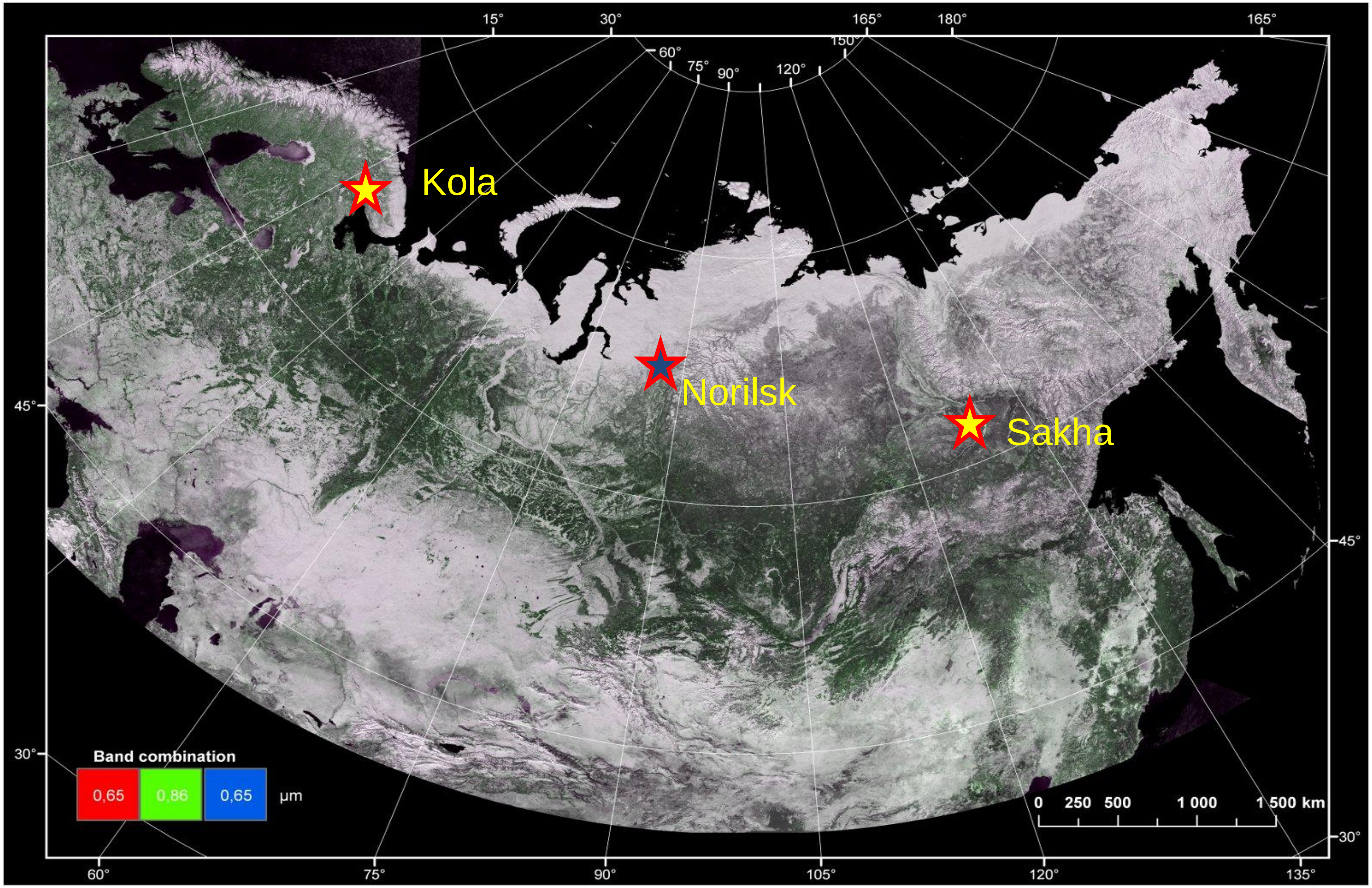
The multiscale concept

Analysis of MODIS LAI and GSV data series since 2000 г., comparison with climate dynamics for the whole of northern Russia. Determining the role of climate and other factors within model territories

Scaling up LAI and GSV data from the ground and UAV surveys to MODIS (through intermediate imagery from Sentinel 1/2), to validate MODIS LAI and GSV

Assessing tree stand parameters (including LAI, GSV) within model territories using unmanned aerial vehicle (UAV) survey (from 50 and 100 m), field measurements and descriptions

Key field regions



Tree stand measurements

Tree height and Diameter at Breast Height (DBH) measurements, geobotanic descriptions

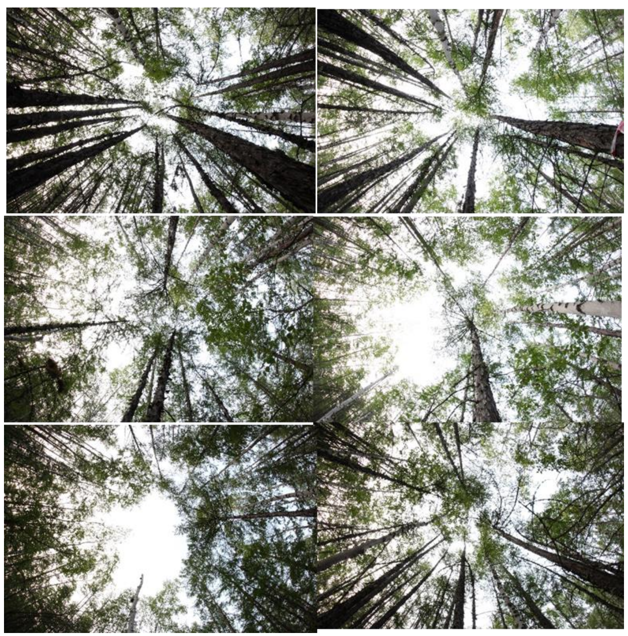
Kola2018: 28 sites
Kola 2019: 6 sites
Sakha 2019: 11 sites

PLOTLESS SAMPLING
To assess basal area fraction
5 points per plot
We find method is accurate to ~ 5%

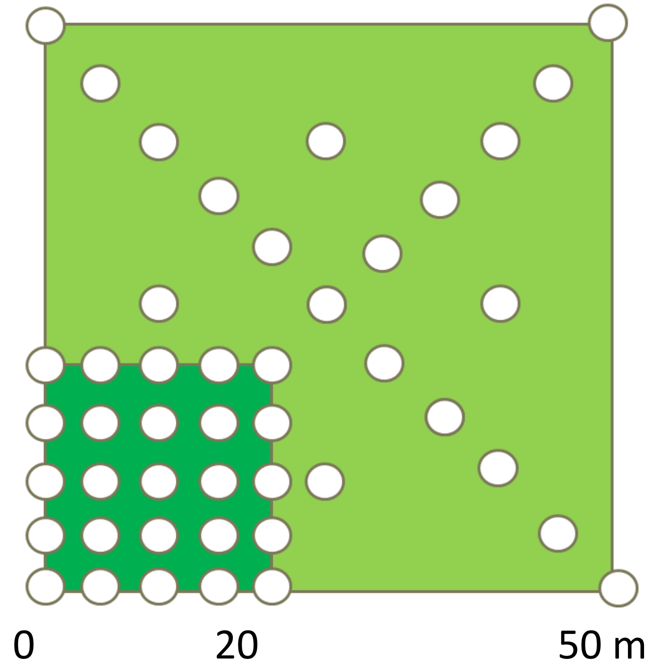
DENDROCHRONOLOGY

SAMPLING to establish climate/growth relationships

Measurements to estimate Leaf Area Index (LAI)



Hemispherical photography

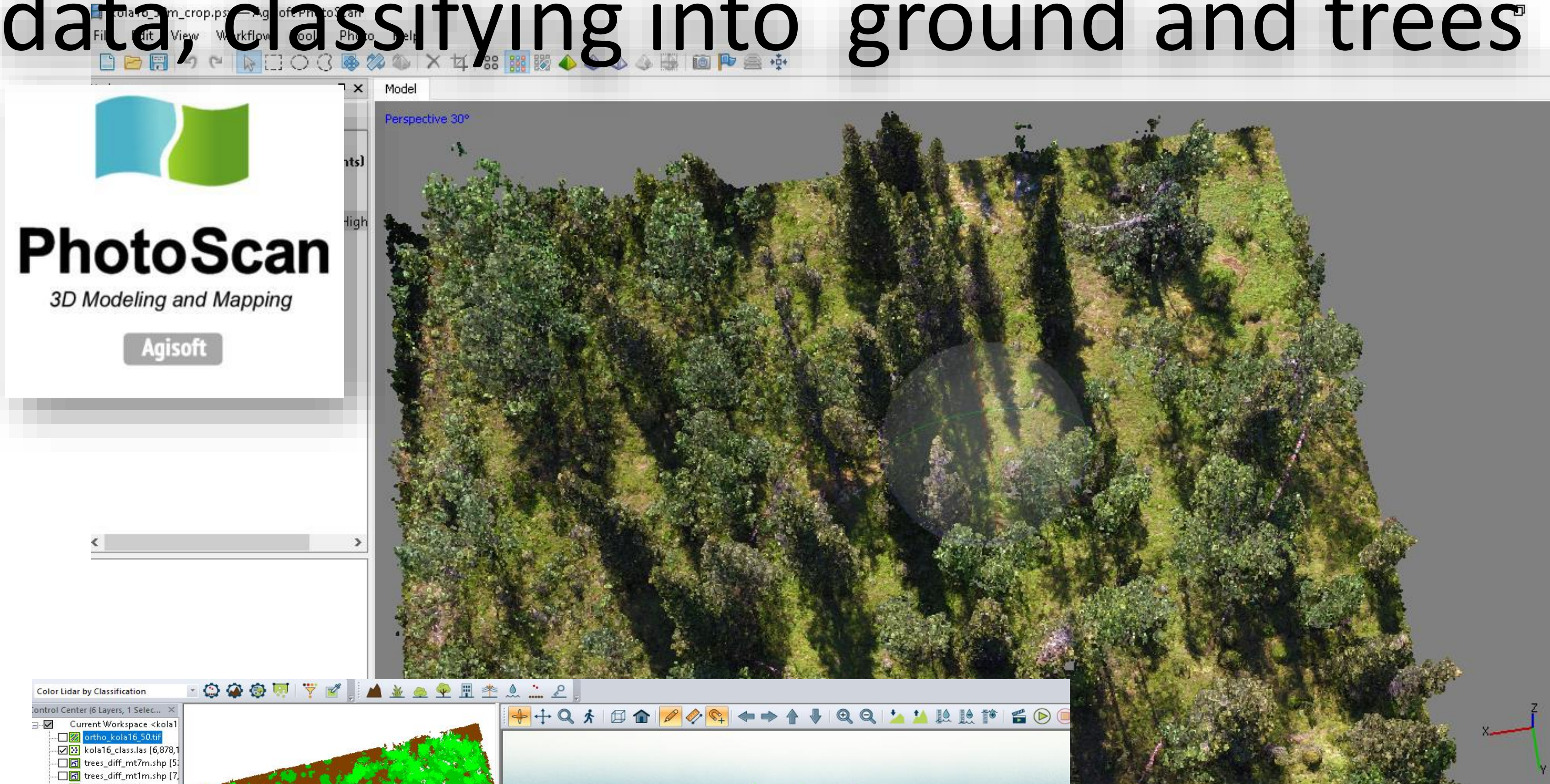


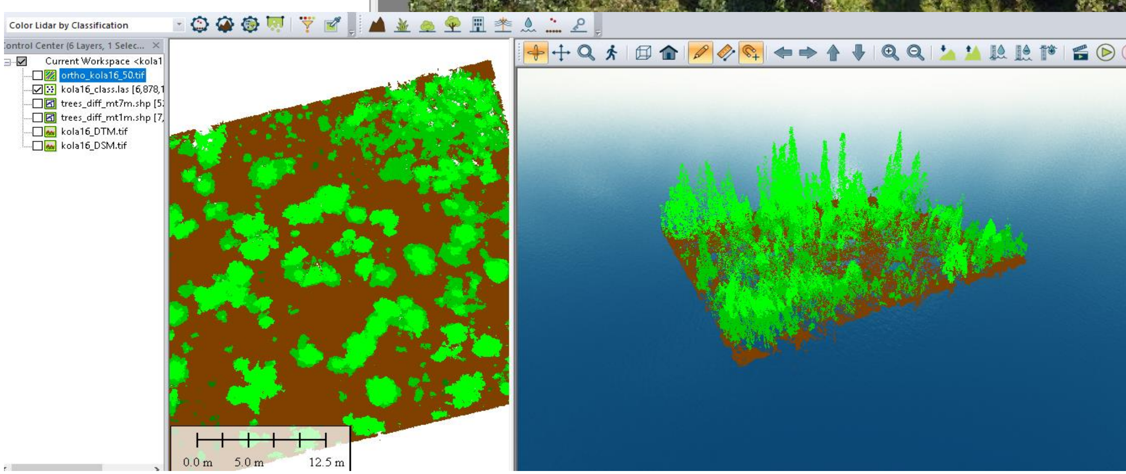
LAI and spectral reflectance: AccuPar LP-80 ceptometer and SpectroSense2+ 4-band radiometer

UAV surveys

- DJI Phantom 4 Pro
- Field plots – from 50 m (then height of top trees derived with accuracy better than the ground measurements)
- Larger homogeneous areas – from 100 m (useful to upscale growing stock volume to Sentinel 2 MSI data)
- 80-90% overlap
- In remote locations, coverage limited by number of batteries…

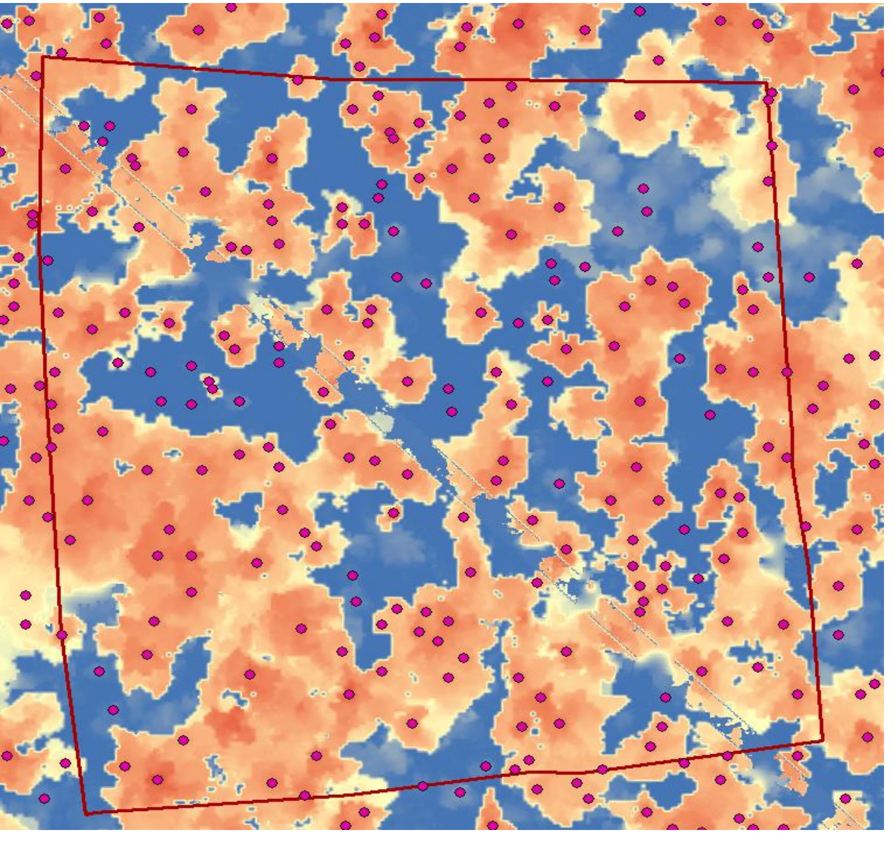
Building dense point clouds from UAV data, classifying into ground and trees





GlobalMapper LiDAR Module

Further UAV data processing



Canopy height model
CHM =DTM-DEM
Pit-free CHM
(by post-processing in LAStools)

Canopy peaks with height
+allometric formulae -> GSV

UAV vs. field measurements (for 11 sites in Sakha)

- Average height, m – UAV is accurate for top-level trees, but average 40% difference with ground measurements in average height of multi-level stand (from -27 to +45%)

- Stand density, trees/ha –average 40% error (from -18 to +59%)

- GSV m3/ha – average 30% error (from -149 to +16%)

- Canopy cover – average 20% difference with visual estimates (from -28 to +38%)

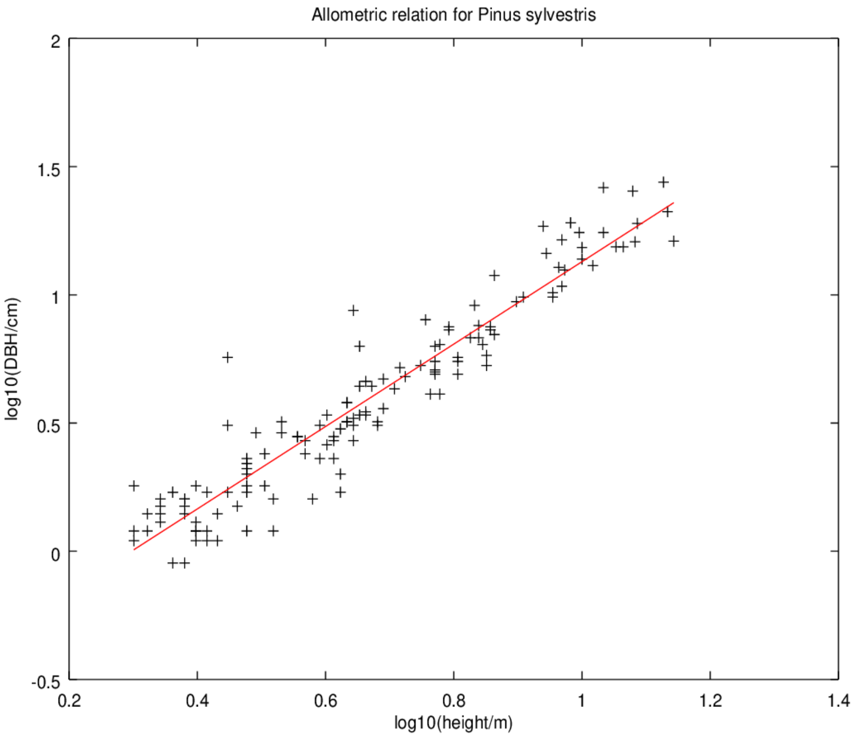
Field/UAV research: conclusions

- **20x20 and 50x50 m** plots for field measurements + **UAV surveys** covering plots in detail **from 50 m** and large areas **from 100 m** are a good combination for subsequent upscaling of GSV (feasible and useful).
- Multiseason UAV survey + ground lidar/photogrammetry are highly recommended to add, to characterise lower tree levels
- LAI measurements of tree layer need to be complemented by LAI measurements of ground layer (represents 40-60% of northern forest area) to improve validation of satellite-derived LAI
- Also need to account for diurnal light variation when measuring LAI with optical methods

Application of comprehensive DBH and tree height measurements by plot

Field survey → N(species, DBH, height) per hectare → biomass variables (e.g. GSV) per hectare

From airborne and spaceborne measurements, DBH is much more difficult to measure than tree height



Allometric relations calculated from Spasskaya Pad station data (Sakha) allow DBH (→ GSV etc) to be estimated from height alone

$$ln(d/cm) = -0.48 + 1.61 ln(h/m)$$

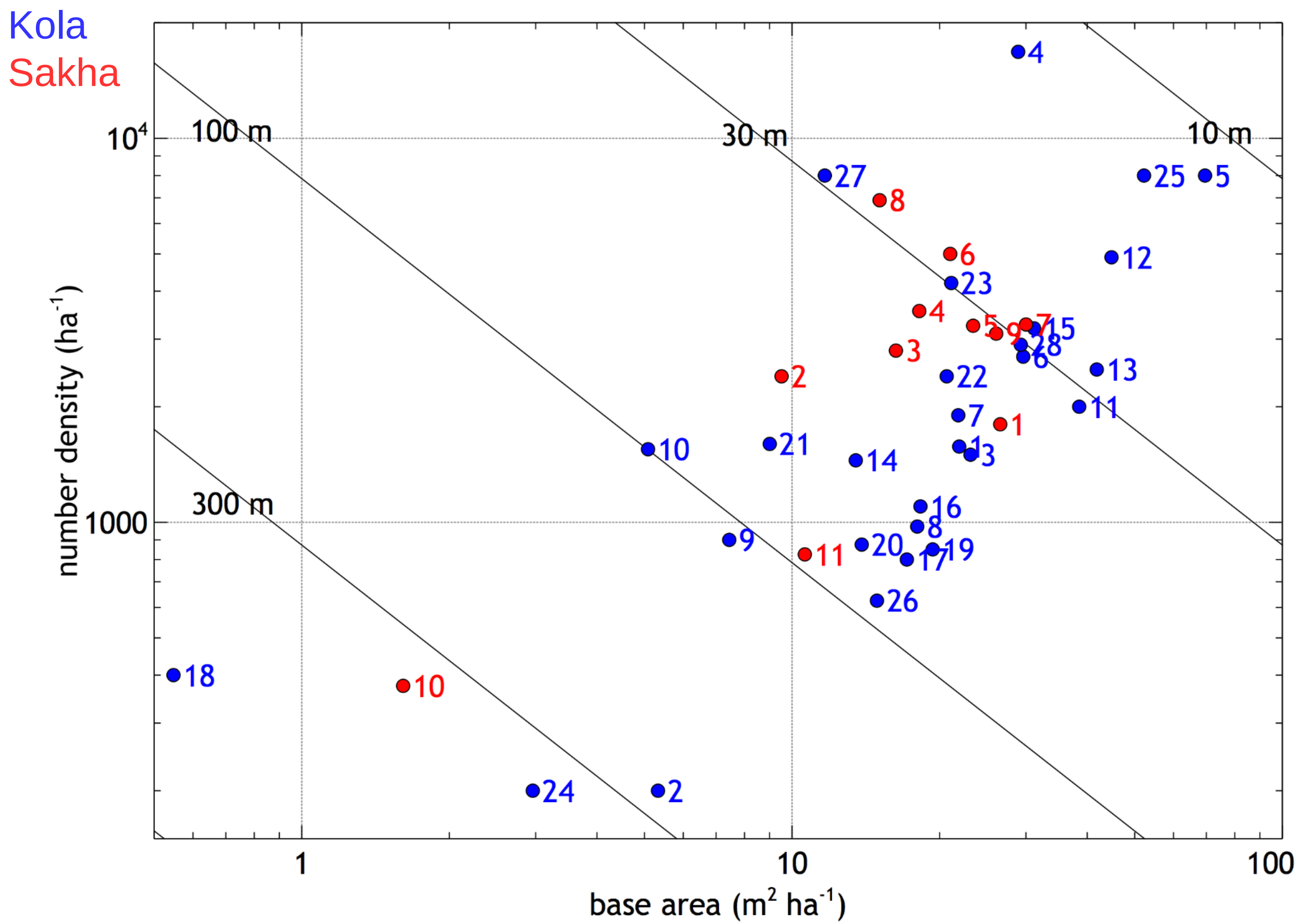
Example for Scots Pine

Estimating Growing Stock Volume (GSV) from tree geometry

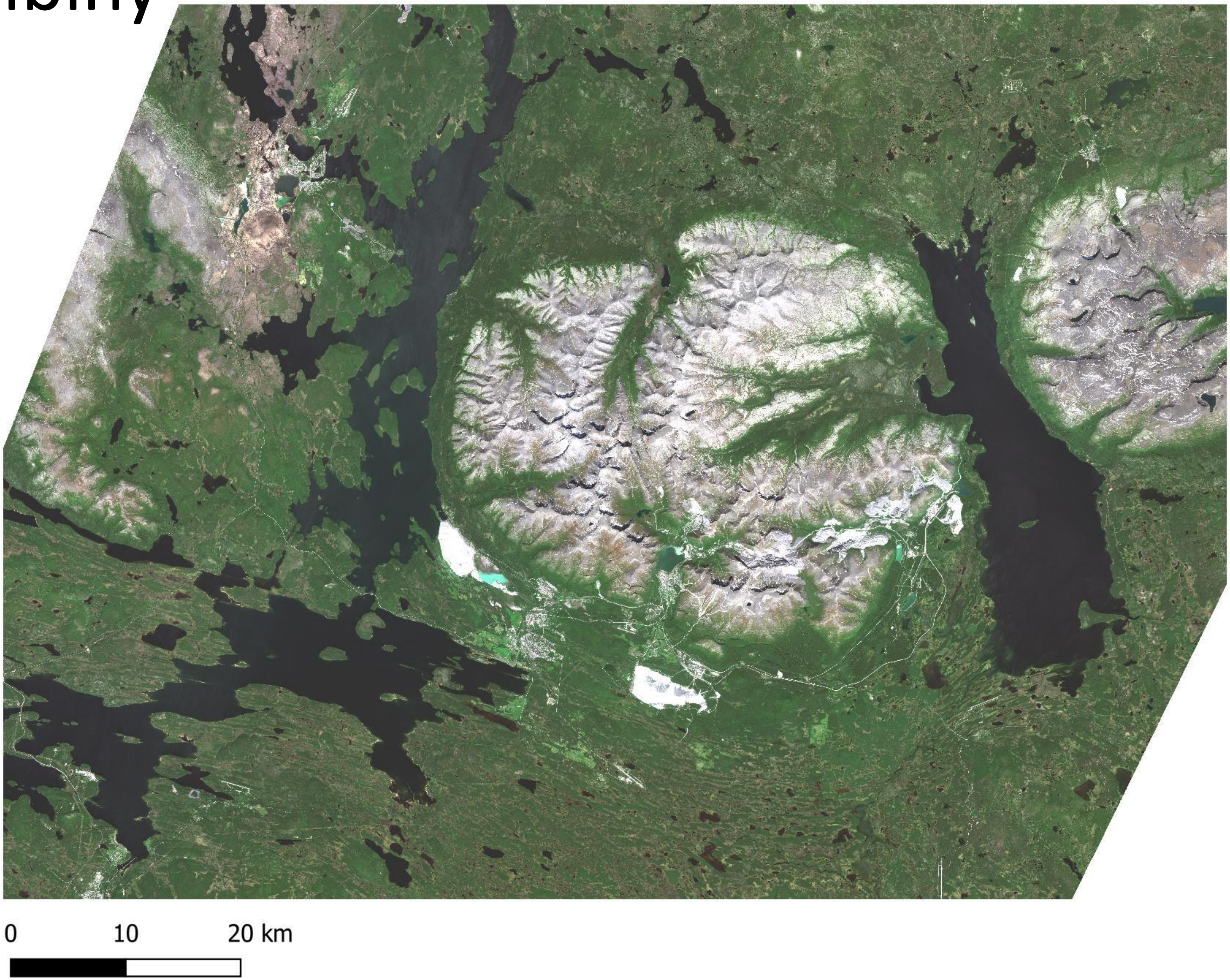
- measured ~ 2000 trees (pine, spruce, birch, larch, ++)
- calculate GSV from published allometric relations, hence deduce accuracy with limited information:

- 20% from genus, D, H
- 50% from genus, H
- factor 2.5 from H

Summary of field measurement sites

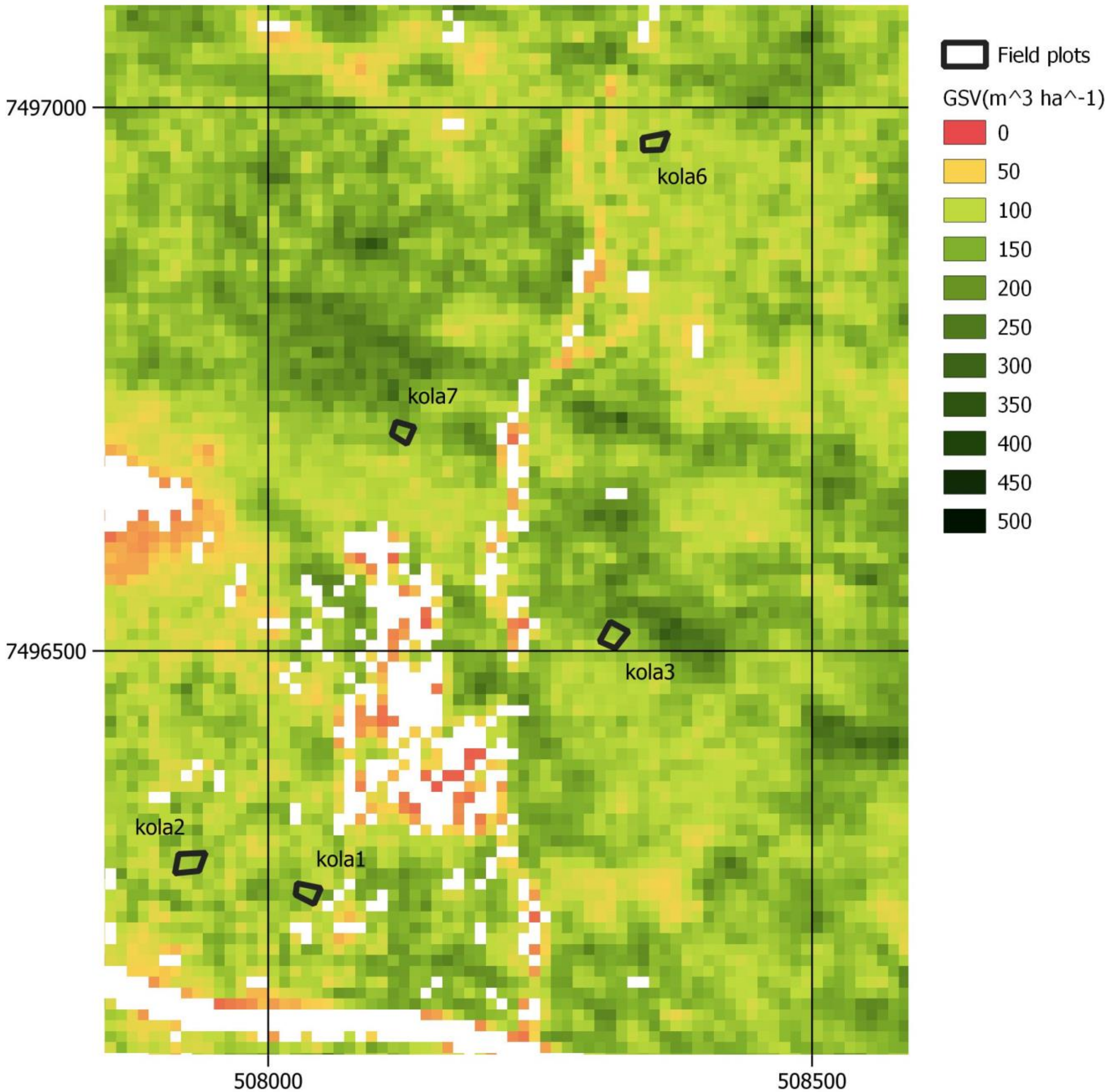


Khibiny



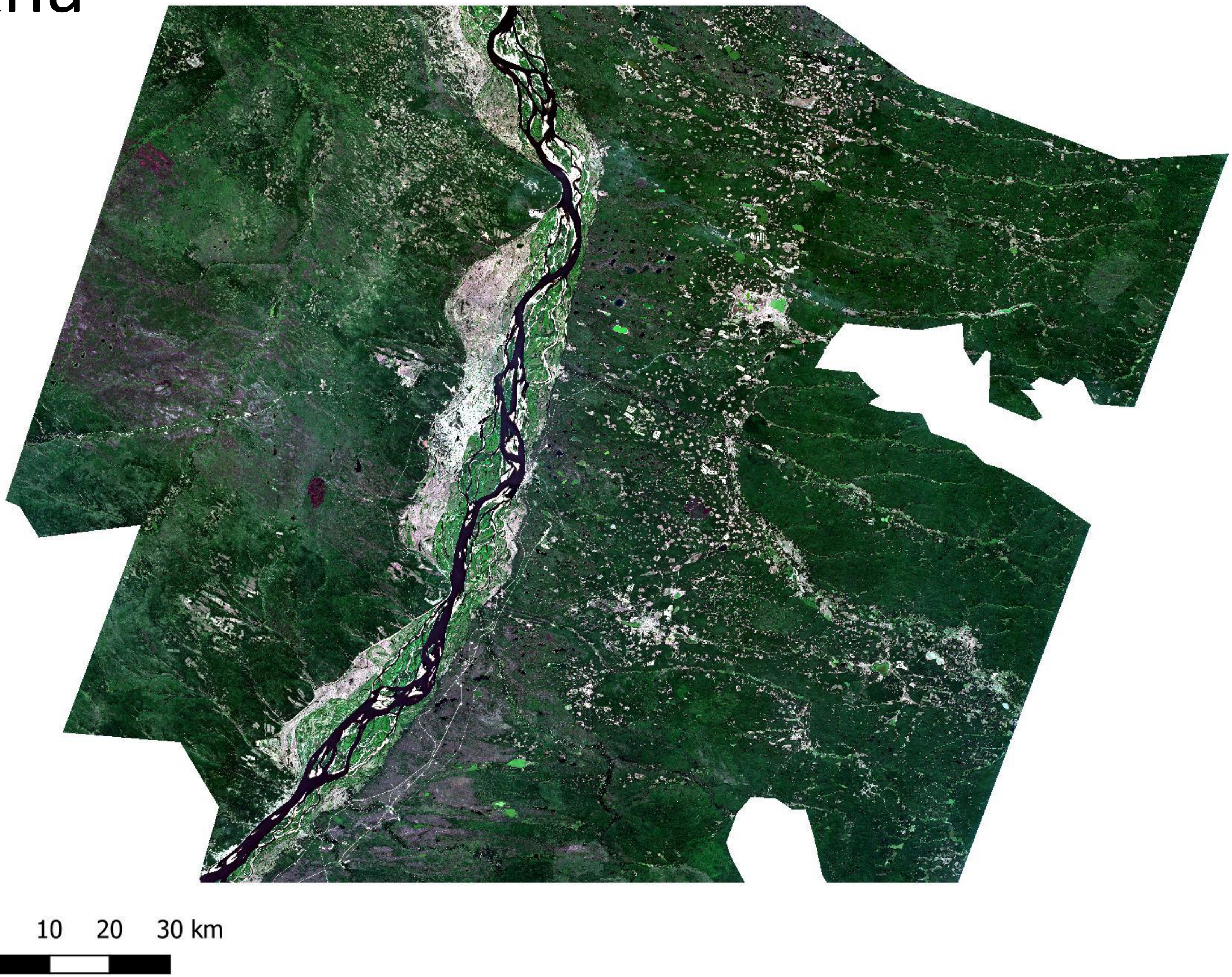
Methodology to derive GSV from Sentinel 2 MSI data

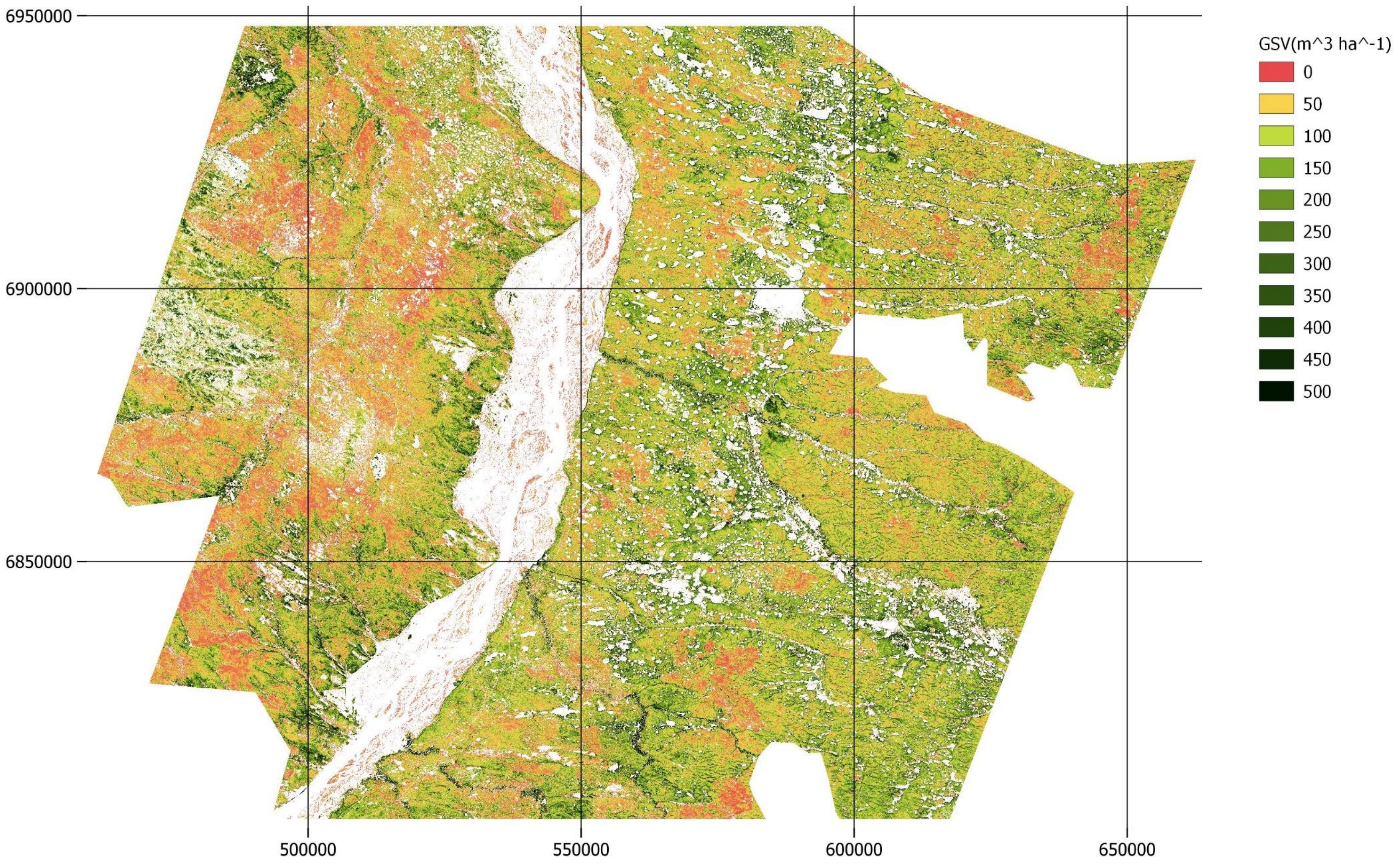
- Upscaling from field measurements of GSV to landscape scale using Sentinel-2 MSI data
- Empirical model using MSI data and land cover types as explanatory variables
- Parameters tuned for each main field site (Khibiny, Sakha)

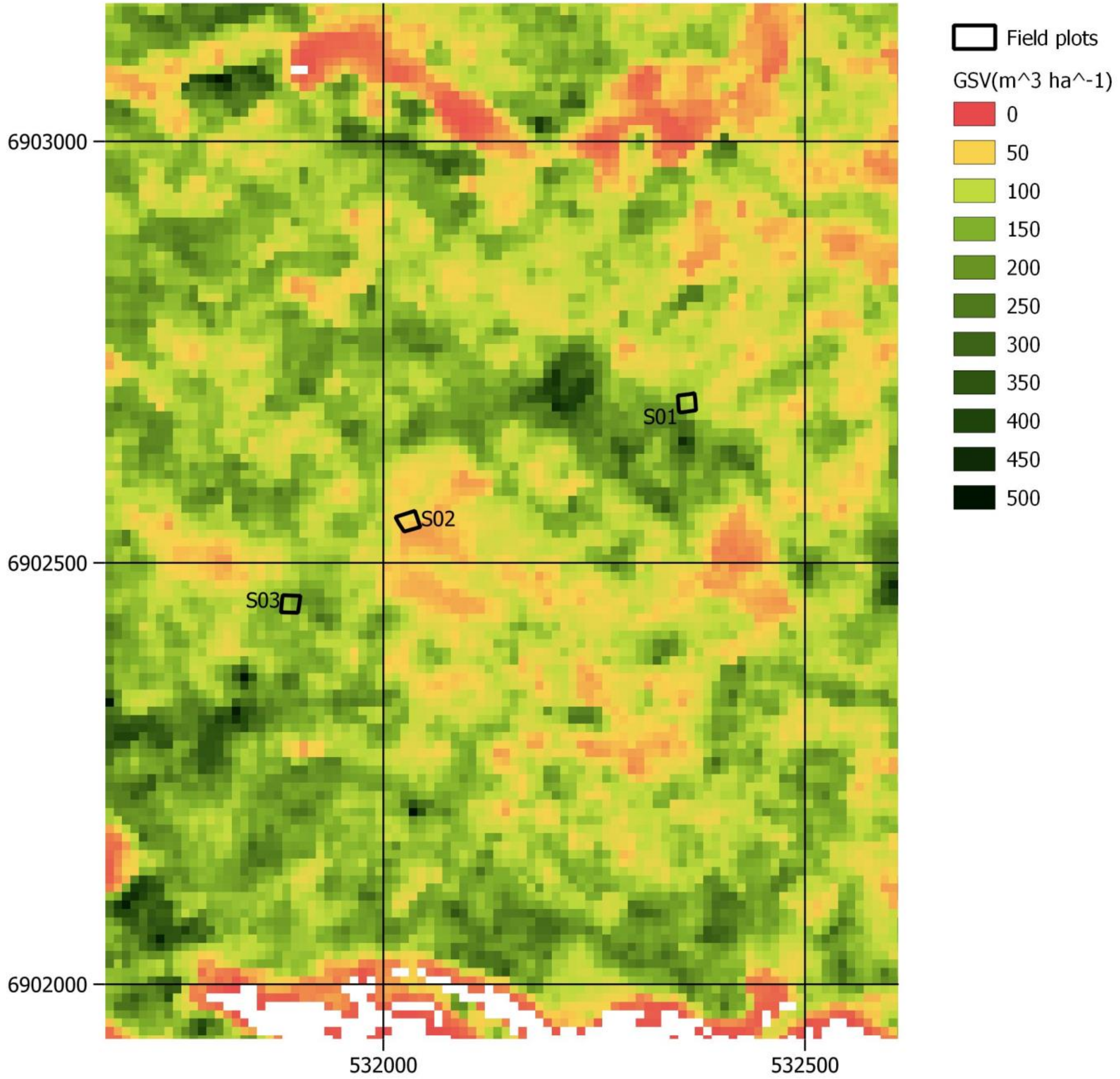


Field plots
GSV(m^3 ha^-1)
0
50
100
150
200
250
300
350
400
450
500
7497000
7496500
508000
508500
kola6
kola7
kola3
kola2
kola1

Sakha

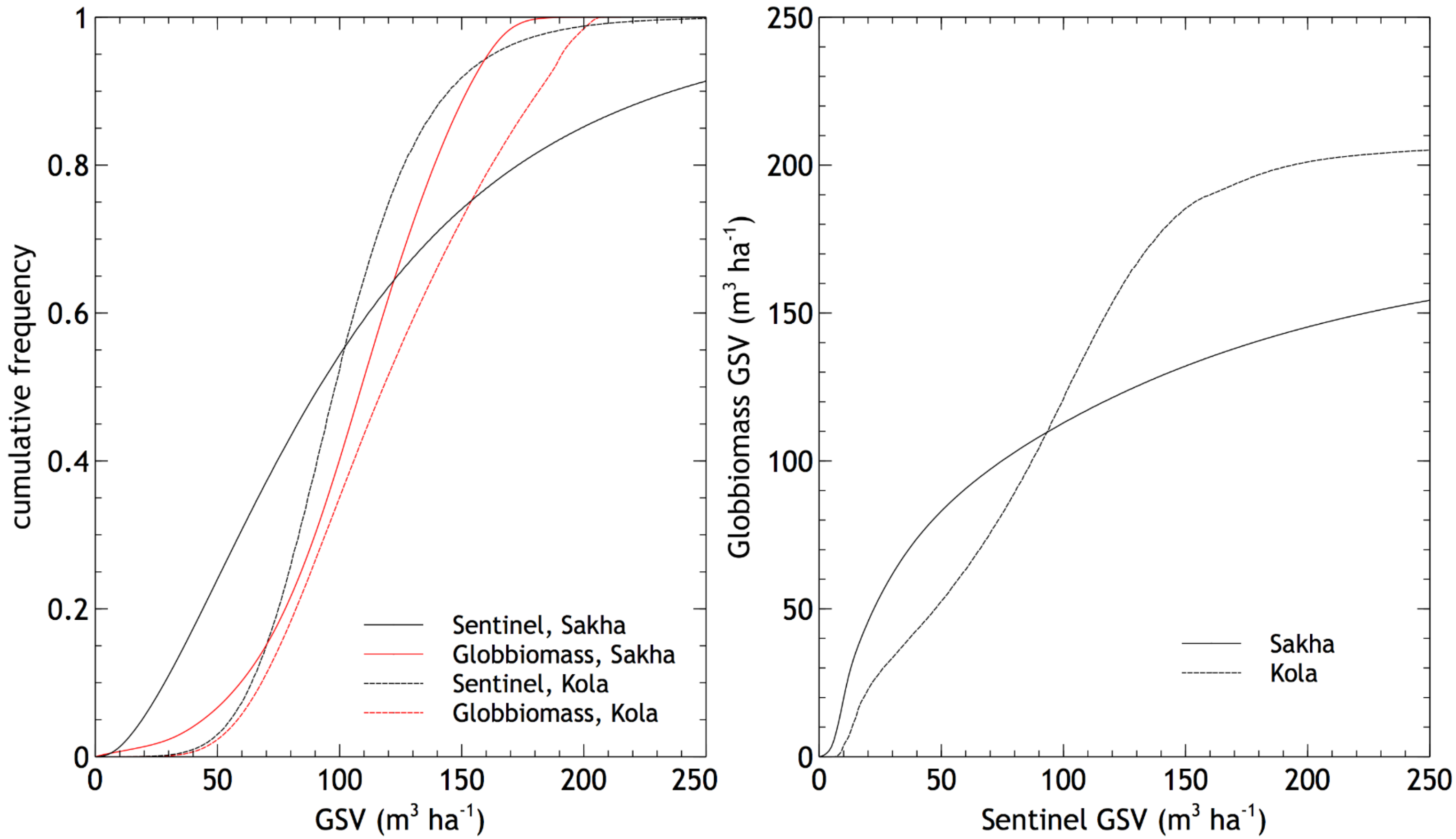



6950000
6900000
6850000
500000
550000
600000
650000
GSV(m^3 ha^-1)
0
50
100
150
200
250
300
350
400
450
500

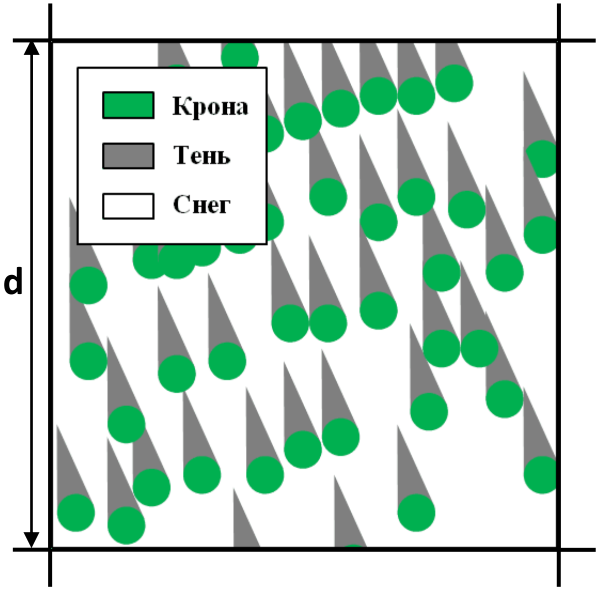


Field plots
GSV(m^3 ha^-1)
0
50
100
150
200
250
300
350
400
450
500
S01
S02
S03
6903000
6902500
6902000
532000
532500

How do our calculated GSVs compare with GLOBBIOMASS estimates?



GSV-winter reflectance relationship



Sc – snow area

Sk – crown area

St – shadow area

Pixel VNIR band reflectance:

$$R = f\left(S_c, S_k, S_t\right);$$

$$S_c = d^2 - S_k - S_t,$$

$$S_k = f_1(n), S_t = f_2(n,h),$$

$$R = f_3(n,h);$$

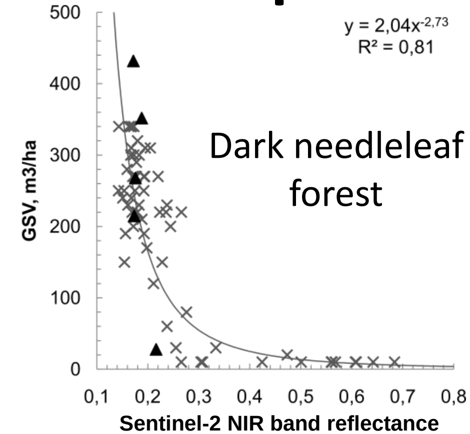
h – tree height; n – number of trees

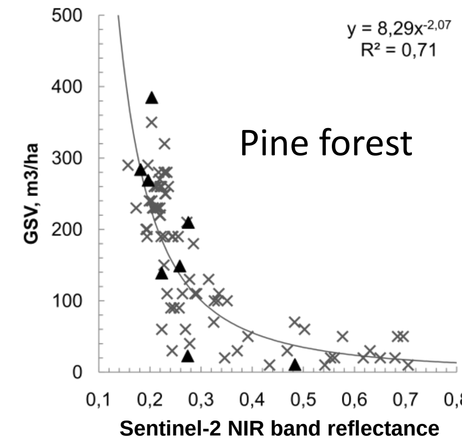
Pixel GSV:

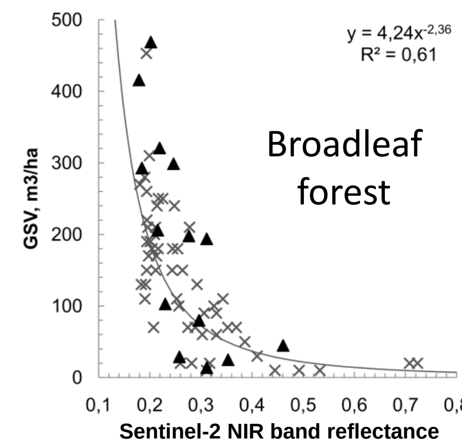
$$GSV\left[m^3/ha\right] = f_4(n,h)$$

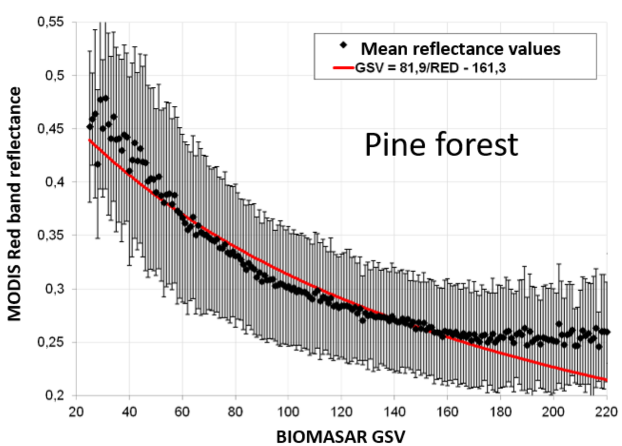
Model:

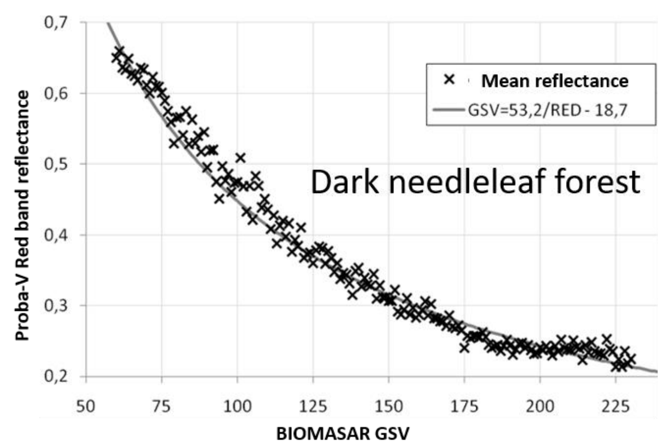
$$GSV\left[m^3/ha\right] = f_5(R,h)$$





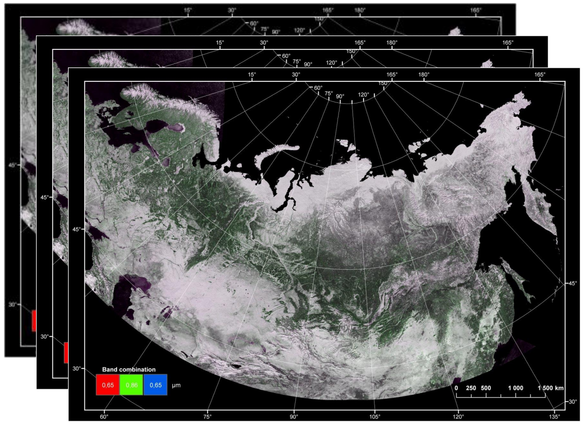






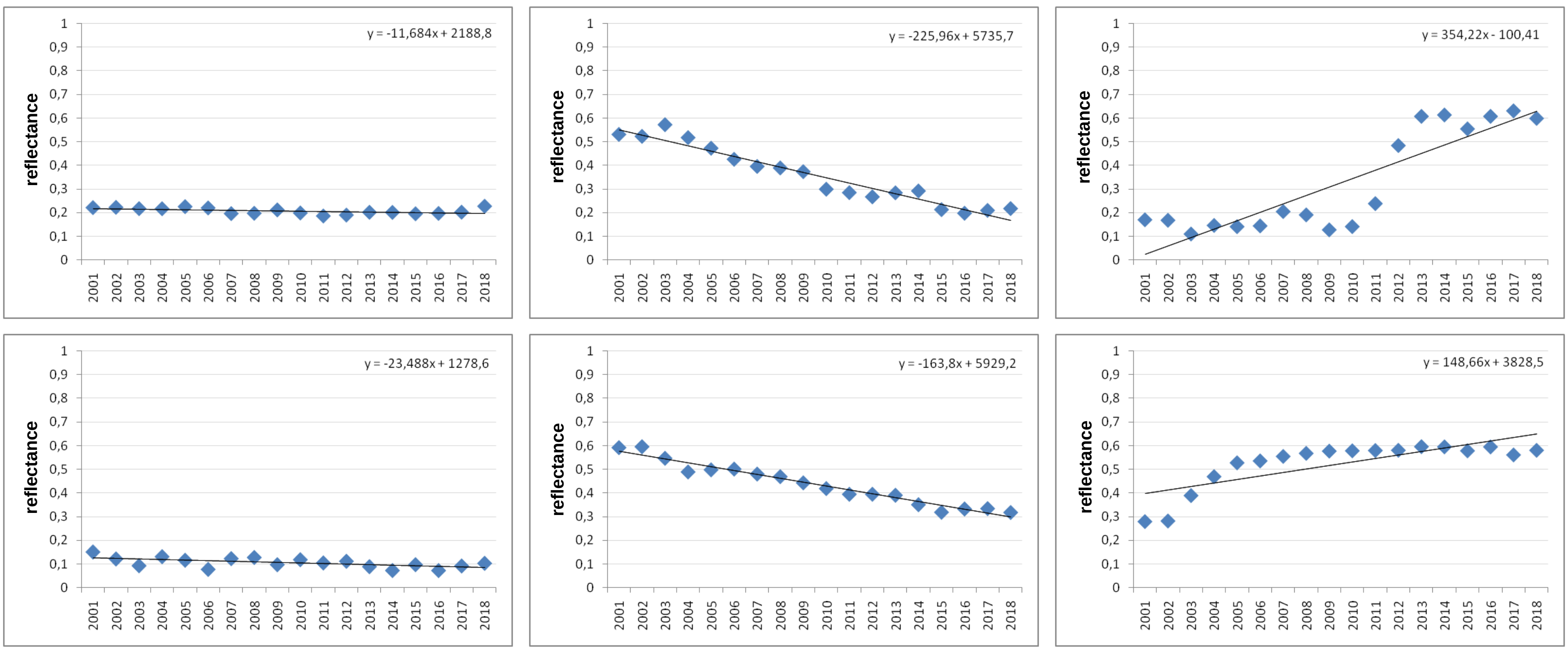
More detail: poster by Vasily Zharko et al.

Multi-year snow-covered surface reflectance dynamics



Analysis of MODIS winter composite images time series to evaluate multi-year dynamics of forest growing stock volume over Northern Russia

More detail: lecture by Sergey Bartalev tomorrow



Stable forest cover

Regenerating forest

Disturbance

Validation of MODIS LAI product using UAV data

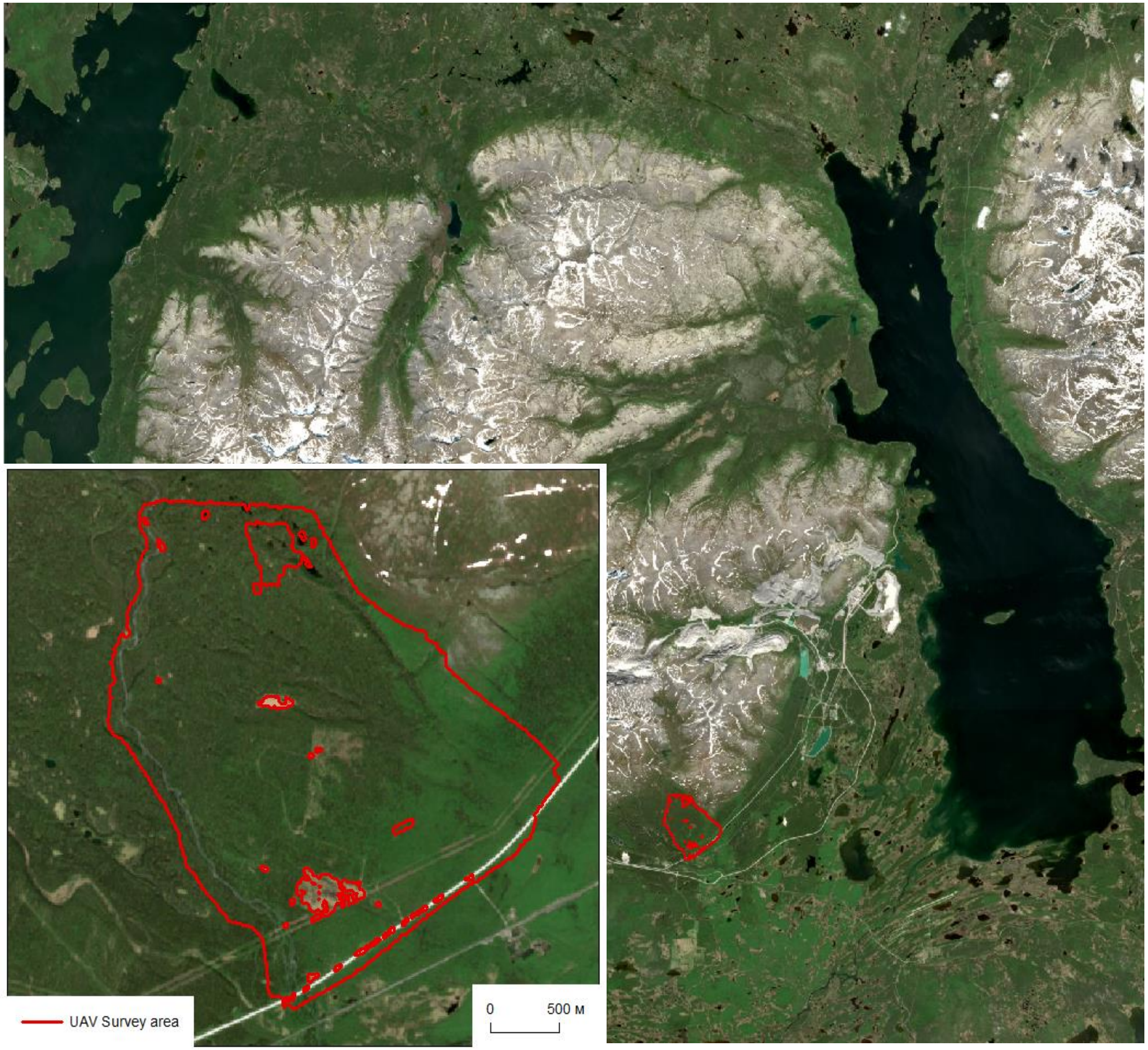
Study area: Kola peninsula, south of Khibiny

{67.573223-67.540376 с.ш. 33.947955-34.022029 в.д.}

Mixed forest of two types:

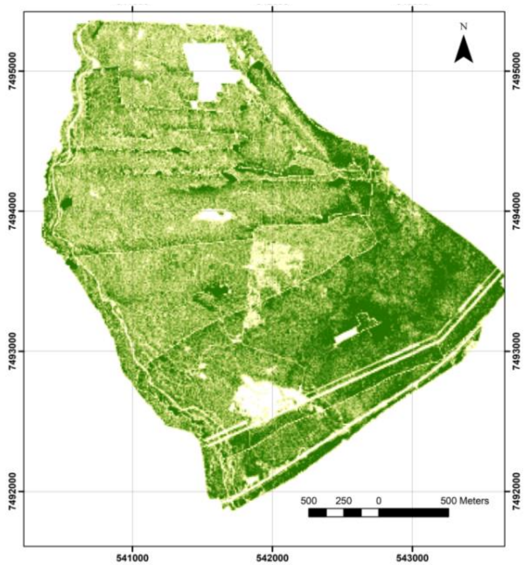
1) with prevalence of birch
2) with prevalence of spruce

UAV survey: 18-20 June 2019

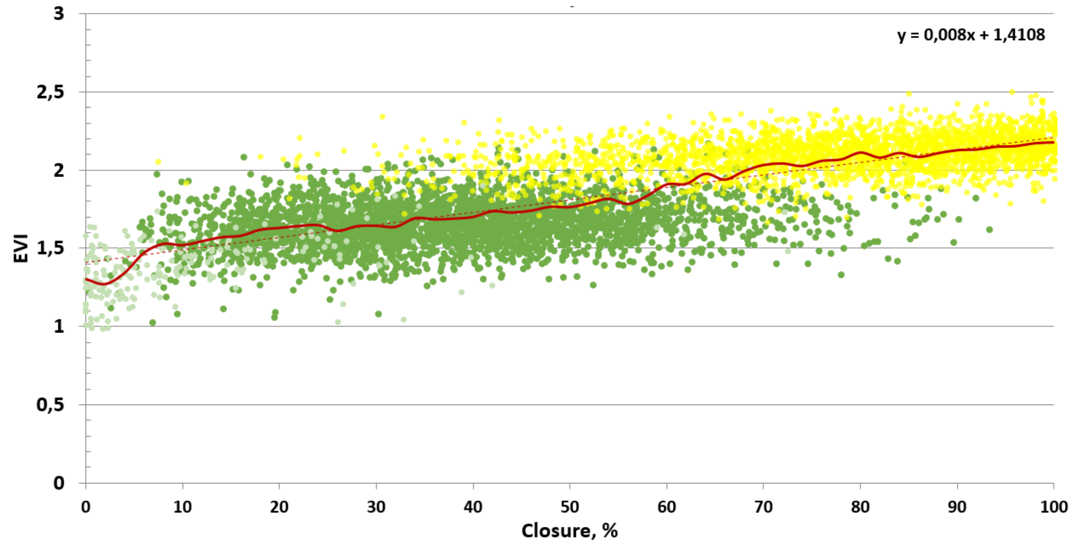


Validation of MODIS LAI product using UAV data

1) UAV canopy closure

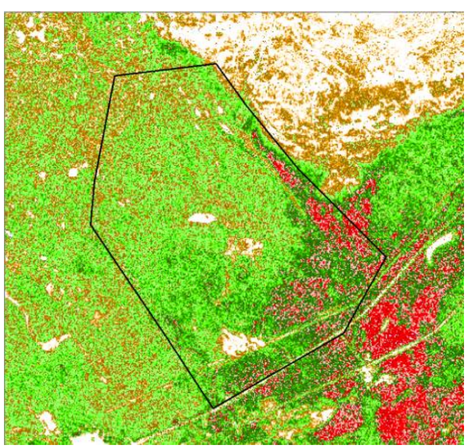


2) Smoothing and upscaling closure using SENTINEL EVI



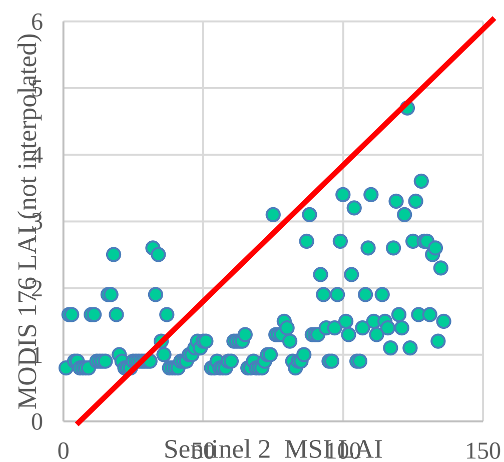
3) LAI estimate: closure = 1-exp (-0.5*LAI)

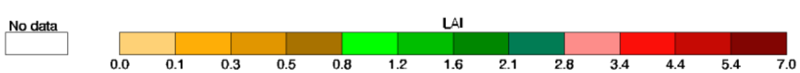
4) SENTINEL LAI (10 m)



5) MODIS LAI (230 m)

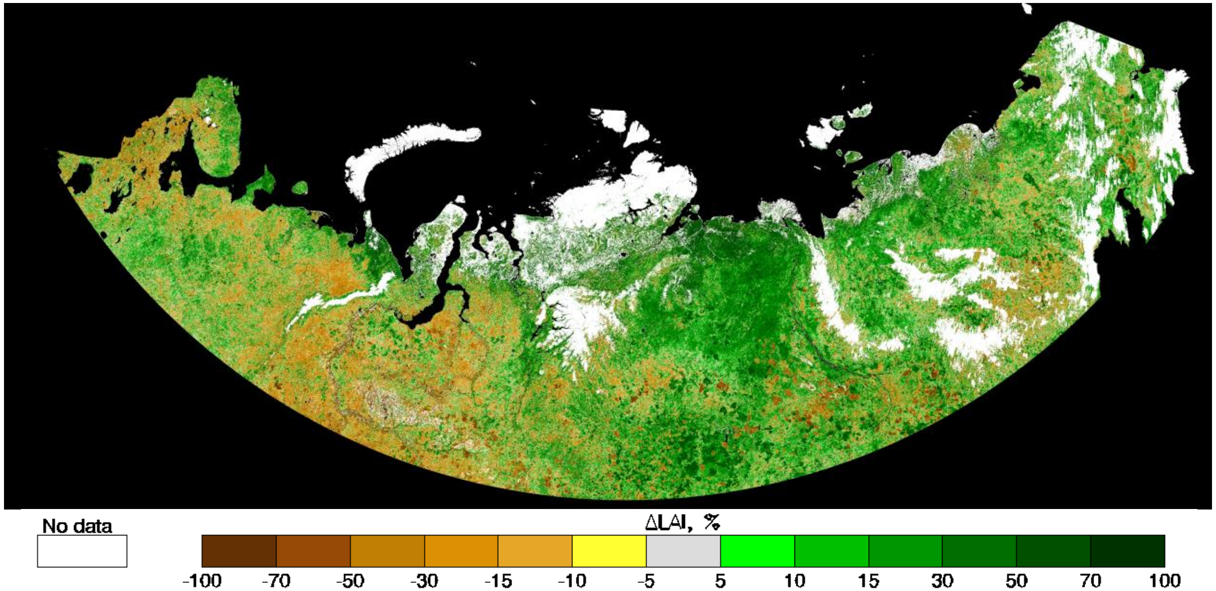
6) comparison



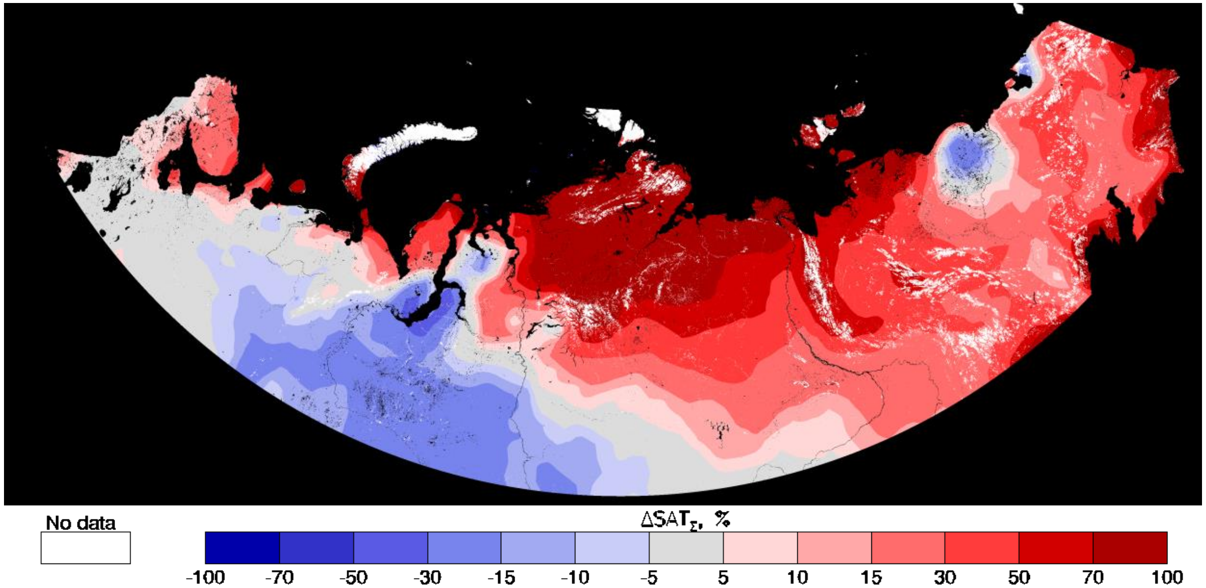


MODIS LAI trends and cumulative temperature SAT_{Σ} for 17 June 2019

LAI trends were assessed thoughout all seasonal profile with a 7-day interval. A linear regression was performed for each interval for the 20 years of MODIS observations (2000-2019 гг). Results are shown as relav=tive change in LAI (ΔLAI, %).



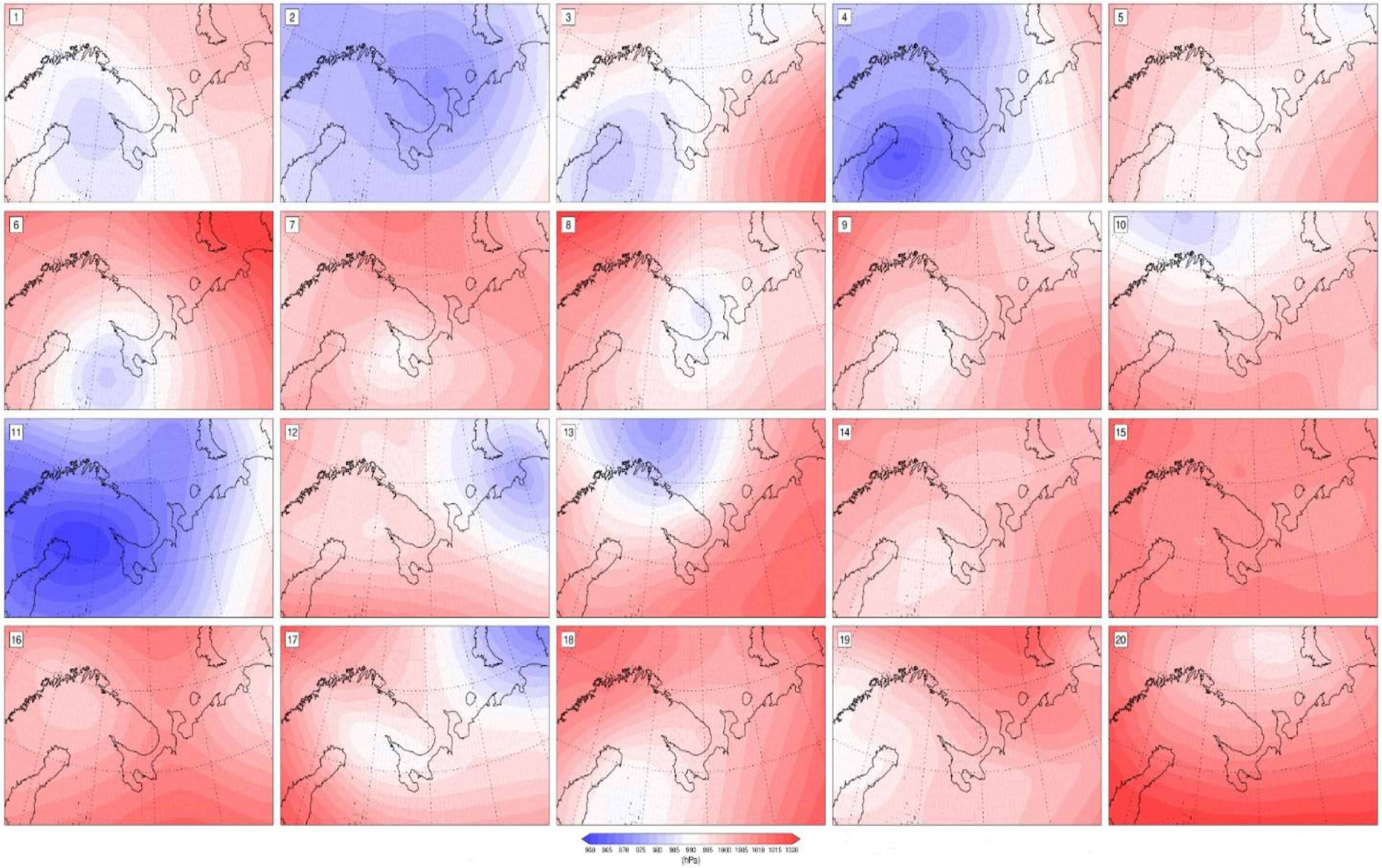
Cumulative temperature is calculate since 1 March and only for average day temperatures above +5C. Then Linear trends ΔSAT_{Σ}.are calcultated Time intervals correspond to the LAI product. ERA Interim data.



More detail: talk by Nikolay Shabanov, Wednesday Session D

In spring the green leaf biomass is conditioned by cumulative temperature. The same is true for trends. Therefore the spatial distribution of LAI trends is very well explained by the SAT trends.

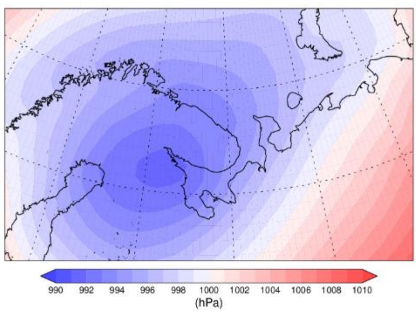
Analysis of atmospheric circulation at times of extreme snowfall in the Kola Peninsula (1979-2017) Sea Level Pressure patterns associated with top 20 regional extreme snowfall events



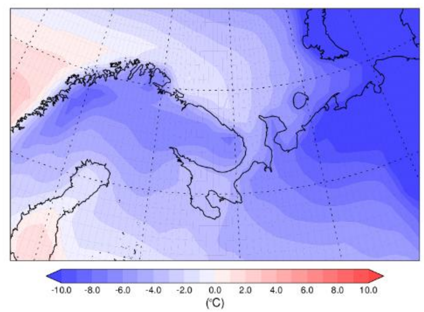
- daily snow-depth measurements from 11 stations
- top 20 ‘events’ :when at least 3 stations have an increase in snow depth in top 2% of values
- events can last more than one day
- circulation data from ERA-Interim reanalysis

Sea Level Pressure (SLP) and Surface Air Temperature (SAT) patterns associated with top 20 regional extreme snowfall events

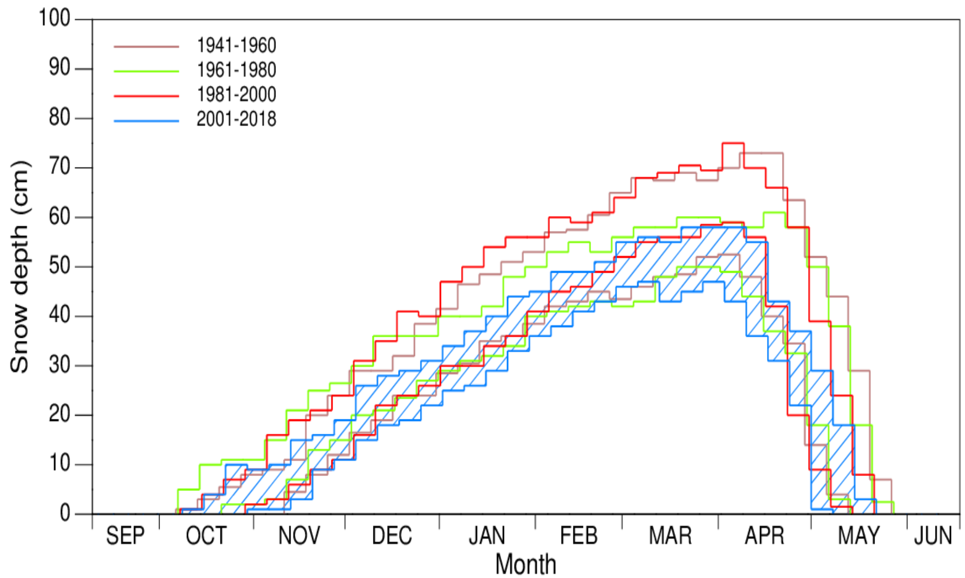
Mean SLP



mean SAT



Extreme snowfall events are associated with low pressure centred south of Kola so moisture coming from east.
SAT values show that the White Sea/Barents Sea north of Kola are not frozen, so providing a local moisture source to feed extreme snowfall events.



Weekly snow depth at Krasnoscel’e binned in two decade periods: data shows marked decadal variability, more in terms of snow depth rather than duration

Conclusions

- Field measurements of 20/50 m plots +
UAV survey from 50 and 100 m give valuable data
- Published allometric relationships
give 20% uncertainty if tree genus, D, H are known,
50% uncertainty if genus and H are known
- Single-season UAV surveys not sufficient, need multi-season
or ground photogrammetry/lidar for accurate GSV measurements
- Upscaling GSV from ground measurements to Sentinel 2 MSI
imagery gives promising results, but need to continue validation
- Validation and scaling-up techniques for Leaf Area Index
(ground data to MODIS) work, but need further ground data
- LAI growth trends over Russian forest
are clearly linked to growth of seasonal cumulative temperatures
(sum of > +5C daily average)

Thank you for your attention!

We also heartily thank all colleagues and students who contributed to this project

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