

North State – Forest Carbon Balance Estimation with the Help of of Optical Satellite Data and Modeling

Juhan Ross Legacy Symposium

August 24-25, 2017

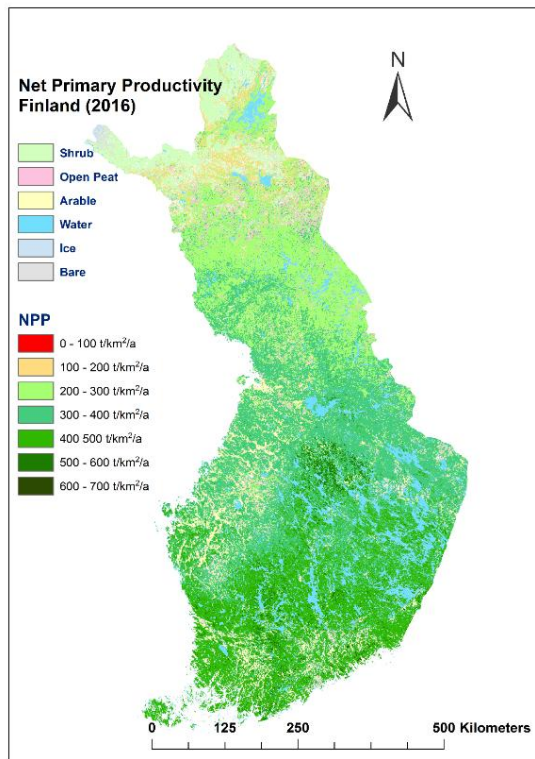
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<http://www.northstatefp7.eu/index.html>

<https://forestry-tep.eo.esa.int/>

www.vtt.fi



Motivation

- Boreal forest, with an area of 11.35 Mkm², is the largest terrestrial biome, and stores
- about 270 Pg C (32% of the world's forest C stock)
- Baltic land area belongs to boreal and partly temperate area
- Forest carbon and carbon balance is of great interest because of its influence to climate
- Hypothesis: It is possible to estimate carbon balance in a form of digital maps by combining forest variable prediction from satellite images, climatic data and modeling

- FP7 project North State
<http://www.northstatefp7.eu/>

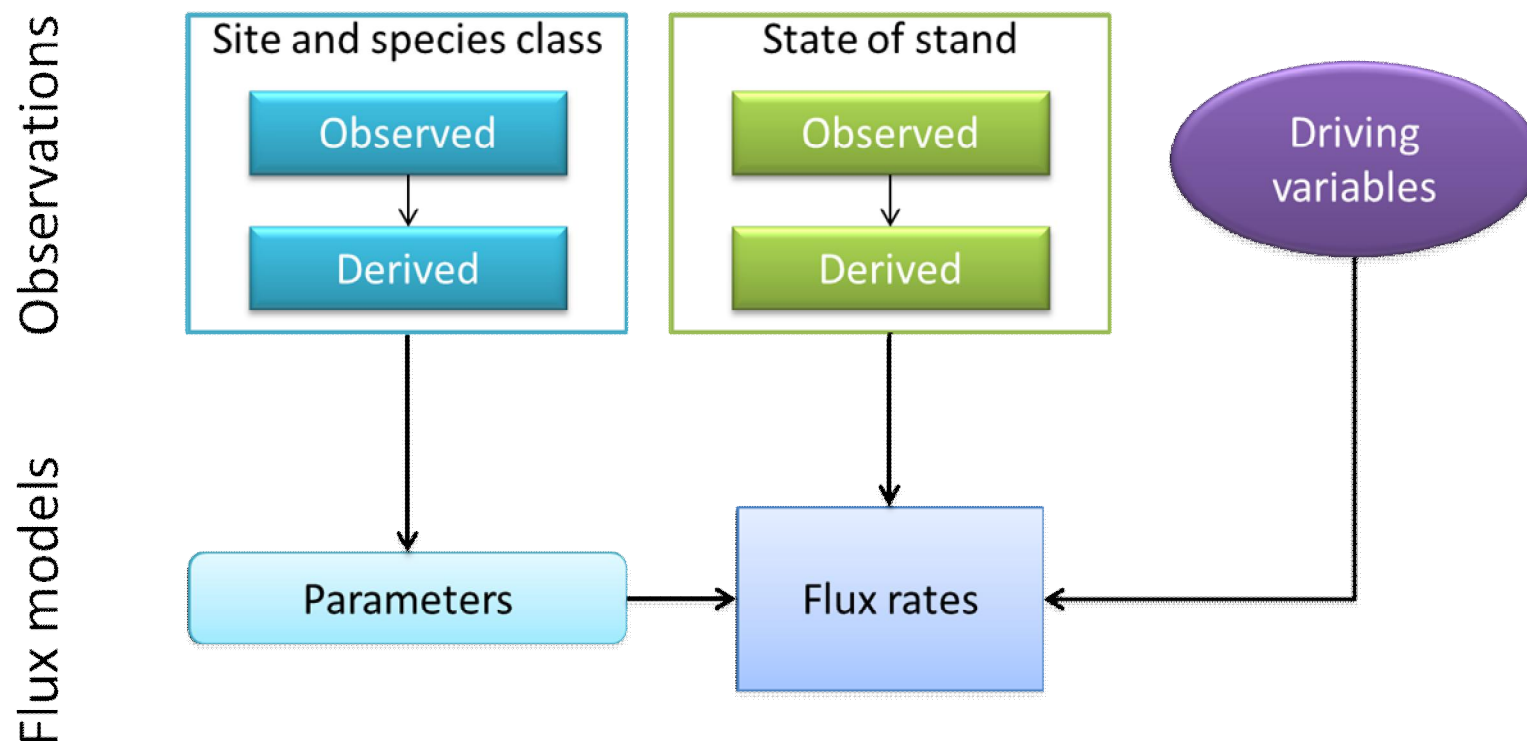


North State

- EU FP7 project 2014 – 2016, total budget about 3 million
- Coordinated by VTT
- VTT Technical Research Centre of Finland Ltd.
 - optical and radar satellite image analysis and preprocessing
- Norut, Norway
 - radar and UAV based hyperspectral image interpretation
- Institute of Biology of Komi
 - optical satellite data analysis
- University of Iceland
 - advanced image analysis approaches for optical mono- and multi-temporal data
- University of Sheffield
 - dynamic vegetation models
- University of Helsinki
 - semi-empirical models.

Forest models and dynamic vegetation models

- Forest models driven by forest area, forest structural variables and climate
- Dynamic vegetation models driven by climate variables



Forest variables predicted and reference data

Predicted

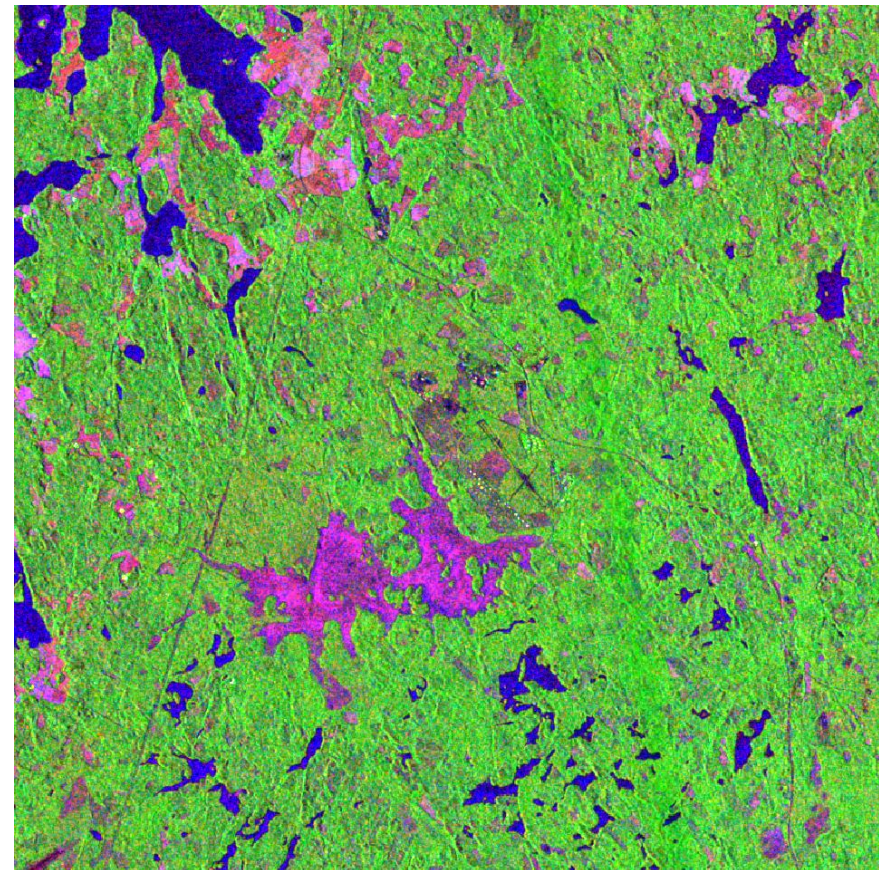
- Forest area (land cover type)
- Plant functional type (main tree species)
- Site fertility type
- Height
- Diameter
- Stem basal area (alternatively growing stock volume)
- Logging operations

Reference

- Luke (Natural Resources Institute of Finland) raster maps from national forest inventory data
- Stand maps with of State Forest Enterprise Metsähallitus
- Visually interpreted plots of VHR sample of 40 randomly sampled images
- Flux tower measurement data

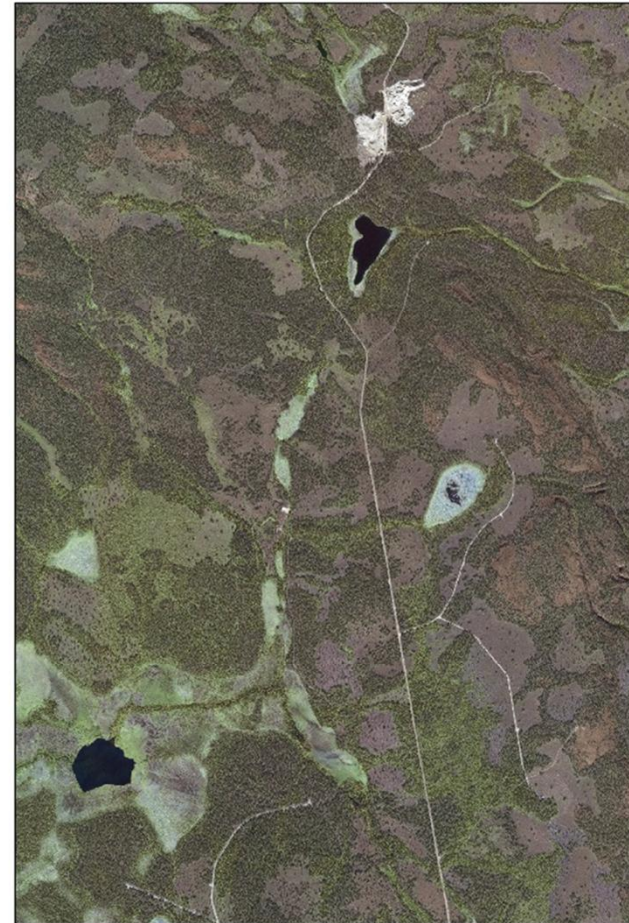
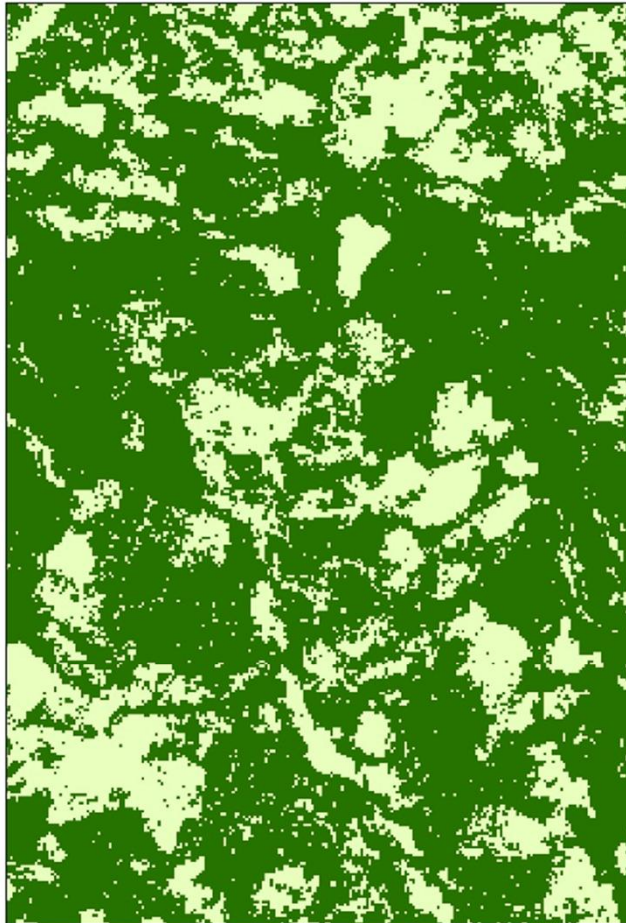
Satellite data

- 79 Sentinel-2A full images of which 11 from Finland
- 3521 Sentinel-1A images from Finland
- Landsat-8
- Suomi NPP 238
- Proba-V
- EO-1 Hyperion
- Rikola hyper-spectral UAV imagery
- 43 VHR images by simple random sampling



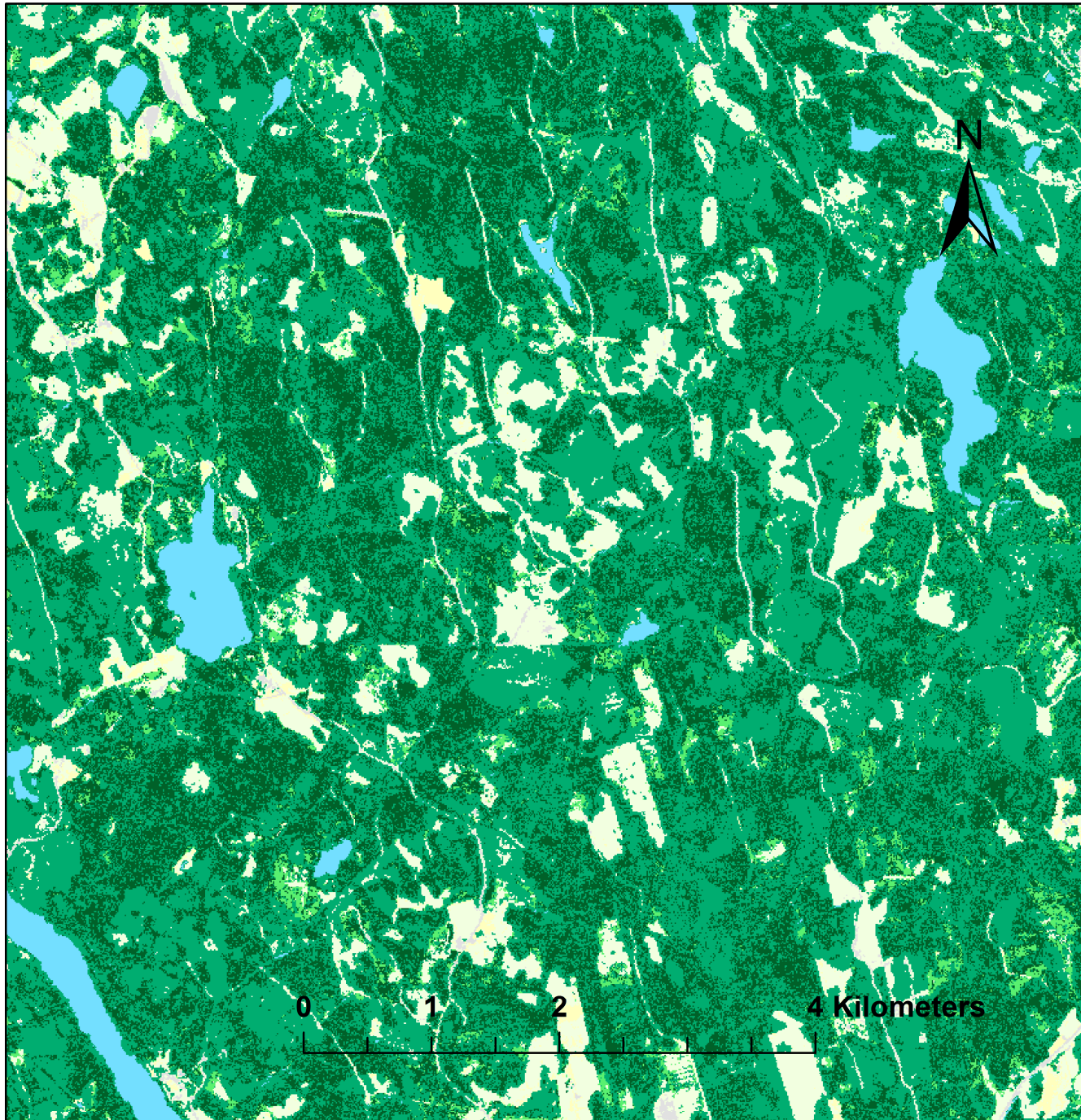
Sample of Sentinel-1 data variation in a stack of 12 images over the Hyytiälä area. Red = temporal variation in VH polarisation, green = average of VH polarisation, and blue = temporal variation in VV polarisation.

Sentinel-1 based forest area and detail of Pleiades image



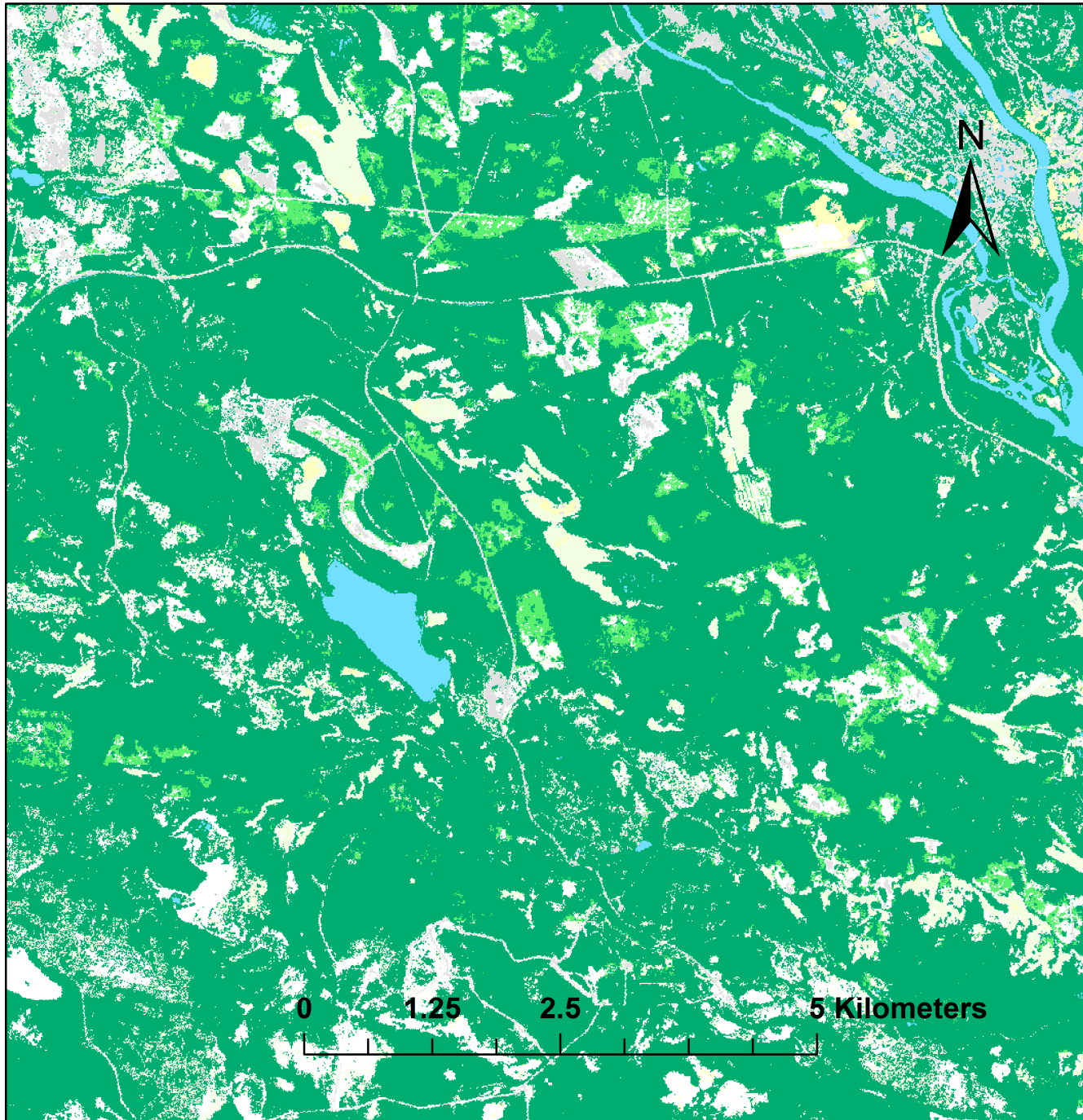
Sodankylä site, Finland

**Tree Species Classification
Hyytiälä - Finland (2016)
Data: Sentinel-2
Map area: 10 km x 10 km**



-  Pine
-  Spruce
-  Broadleaved
-  Open
-  Arable
-  Water
-  Artificial
-  No data

**Tree Species Classification
Sodankylä - Finland (2016)
Data: Sentinel-2
Map area: 10 km x 10 km**



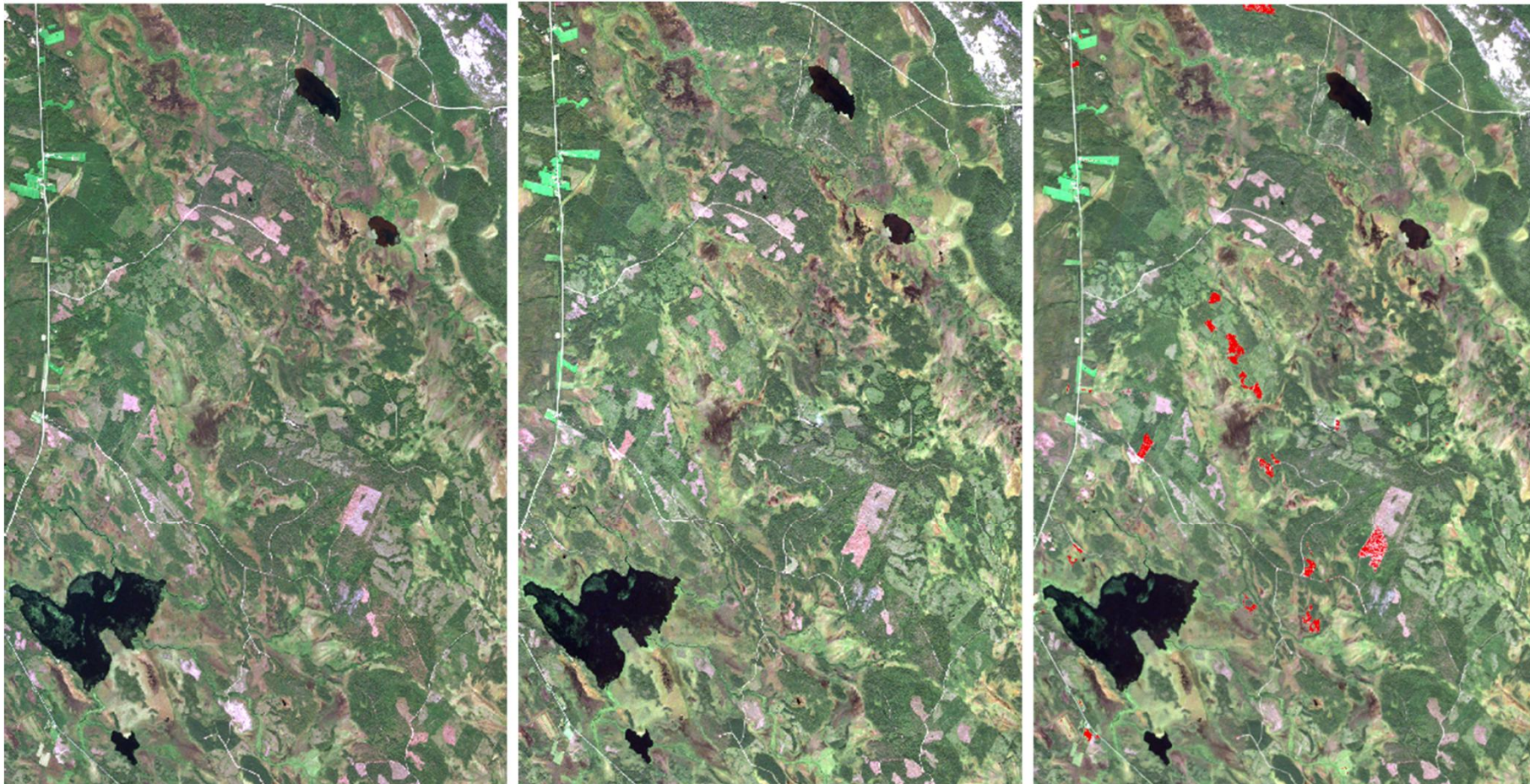
-  Pine
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Examples of satellite image analysis accuracies

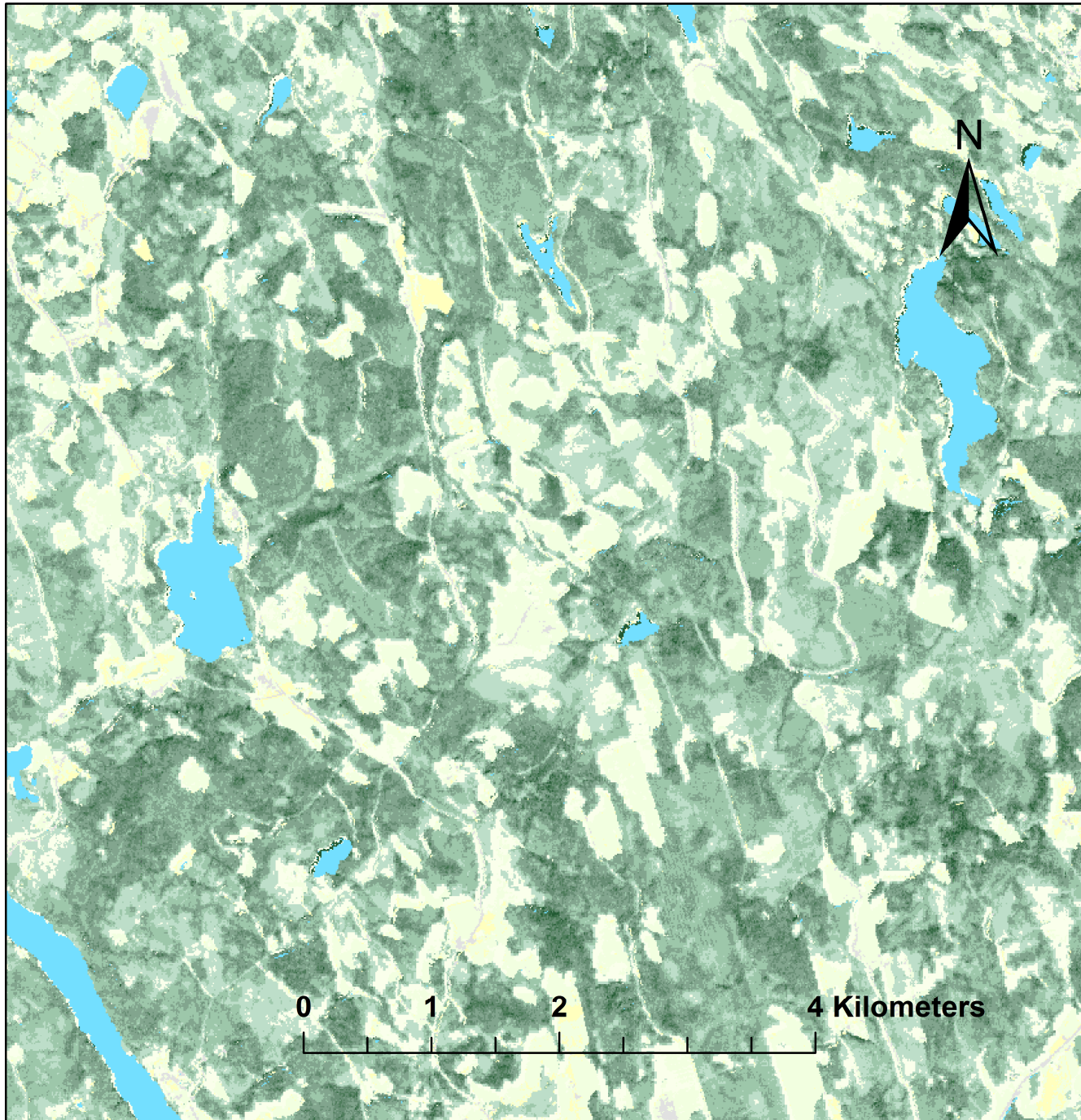
Table 18. Accuracies of forest variables that were predicted using Sentinel-2 data for Hyytiälä using operational stand map data as test reference.

Variable	Learning			Test		
	Bias	RMSE	RMSE %	Bias	RMSE	RMSE %
Vol/5-point m ³ /ha	2.7	50.1	36.1	-15.3	64.8	44.2
G/5-point m ² /ha	0.1	5.4	30.1	-2.1	6.2	31.8
H/5-point m	0.2 m	3.0	25.6	-0.2	3.8	32.1
Vol/All m ³ /ha	-3.1	82.2	58.6	-13.4	75.3	48.7
G/All m ² /ha	0.0	8.4	46.7	-1.4	7.8	39.8
H/All m	-1.3	7.0	54.2	-1.3	5.8	44.2

Change mapping from Sodankylä using Sentinel-2

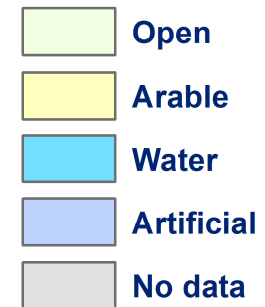
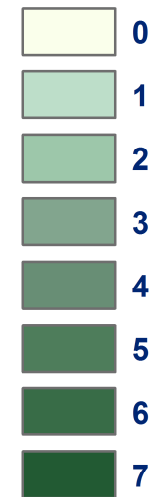


Sample of Sentinel-2 image of August 20, 2015 (left), Sentinel-2 image of August 24, 2016 (centre), and clear cut map where new clear cut areas are in red (right). Sodankylä area in Northern Finland.

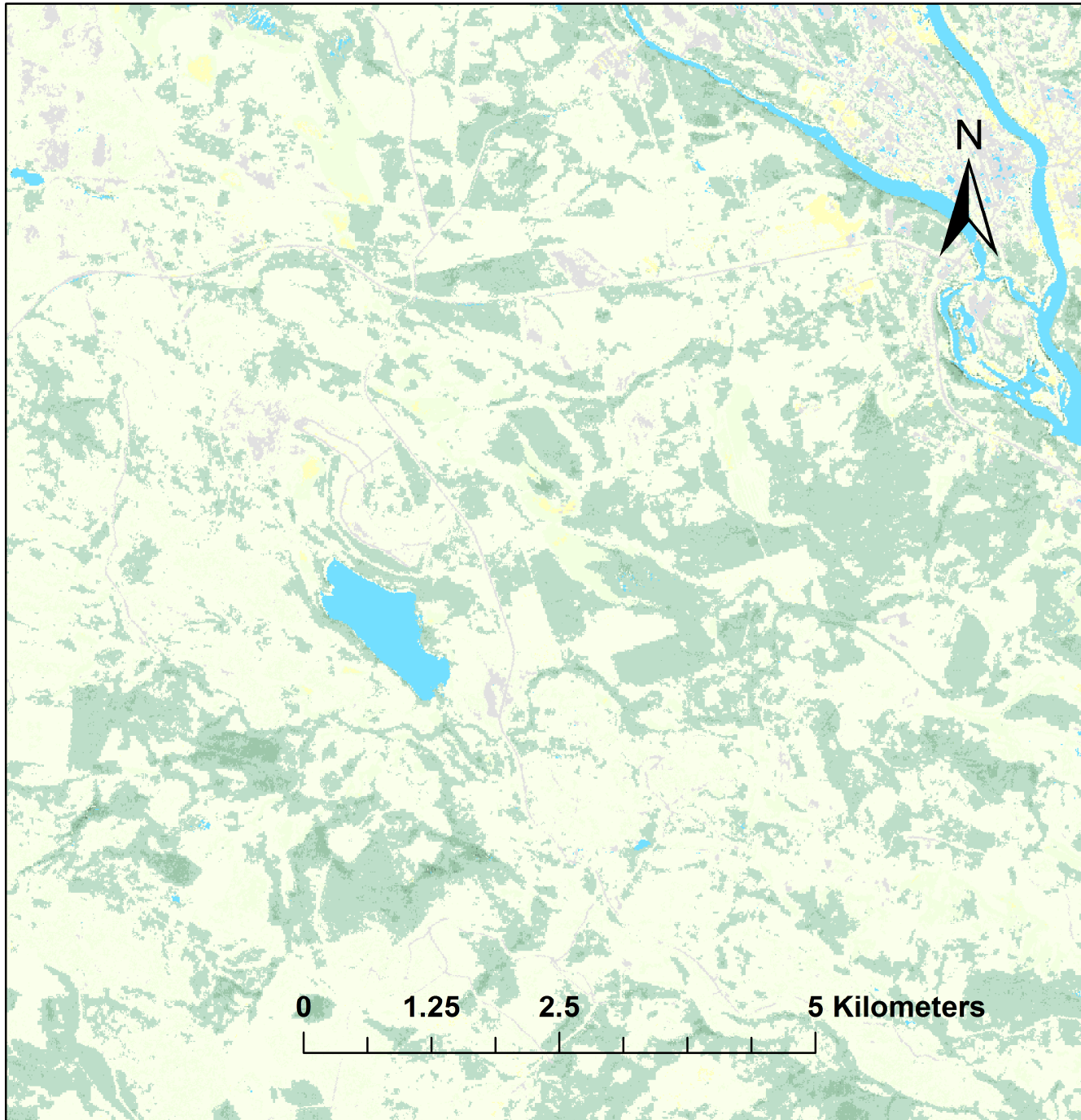


Leaf Area Index (LAI)
Hyytiälä - Finland (2016)
Data: Sentinel-2
Map area: 10 km x 10 km

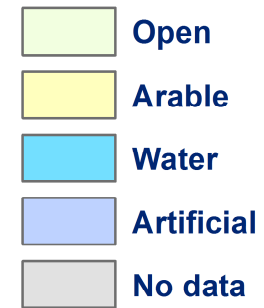
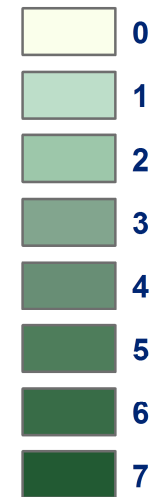
Value



**Leaf Area Index (LAI)
Sodankylä - Finland (2016)
Data: Sentinel-2
Map area: 10 km x 10 km**



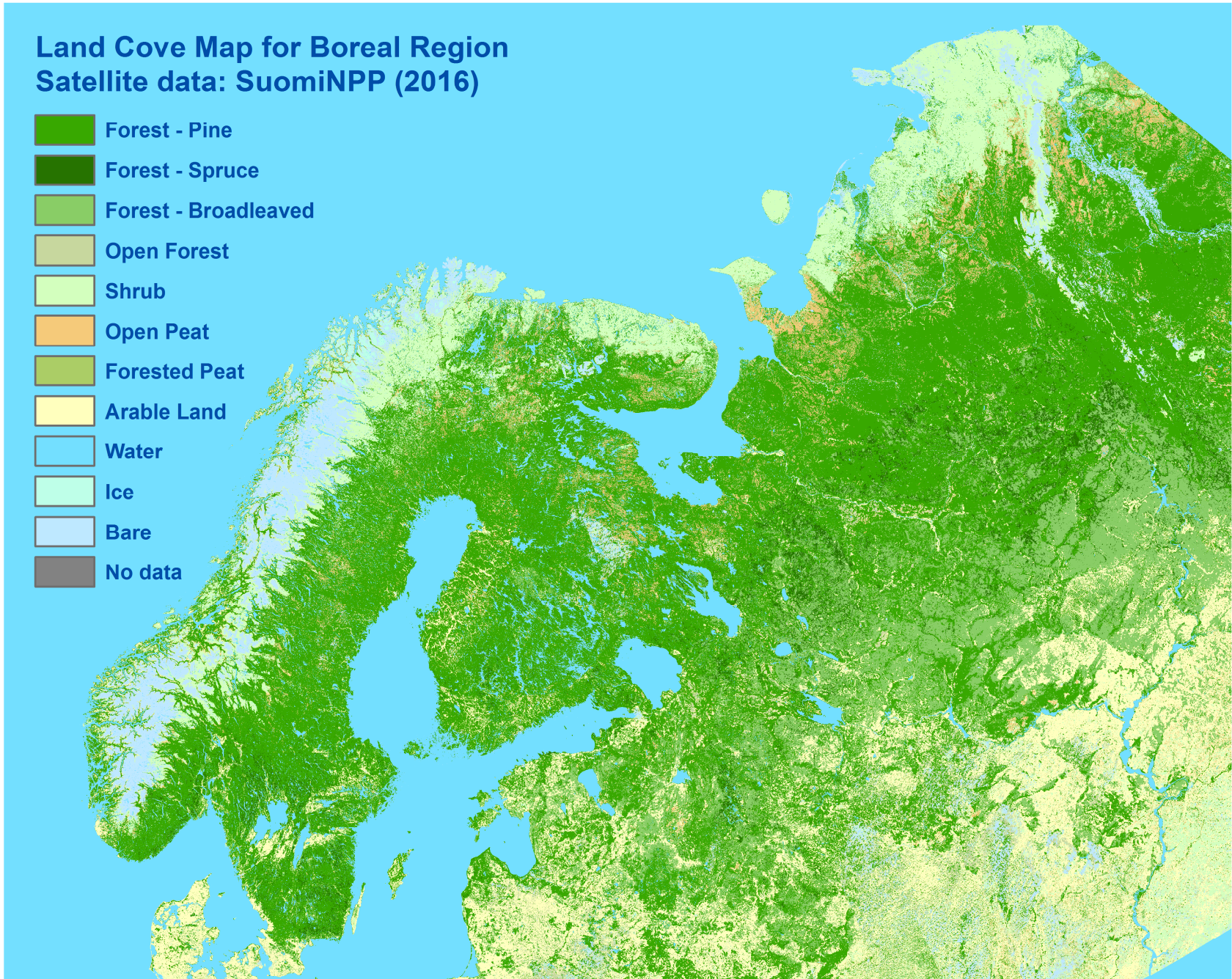
LAI



Land Cover Map for Boreal Region

Satellite data: SuomiNPP (2016)

- Forest - Pine
- Forest - Spruce
- Forest - Broadleaved
- Open Forest
- Shrub
- Open Peat
- Forested Peat
- Arable Land
- Water
- Ice
- Bare
- No data



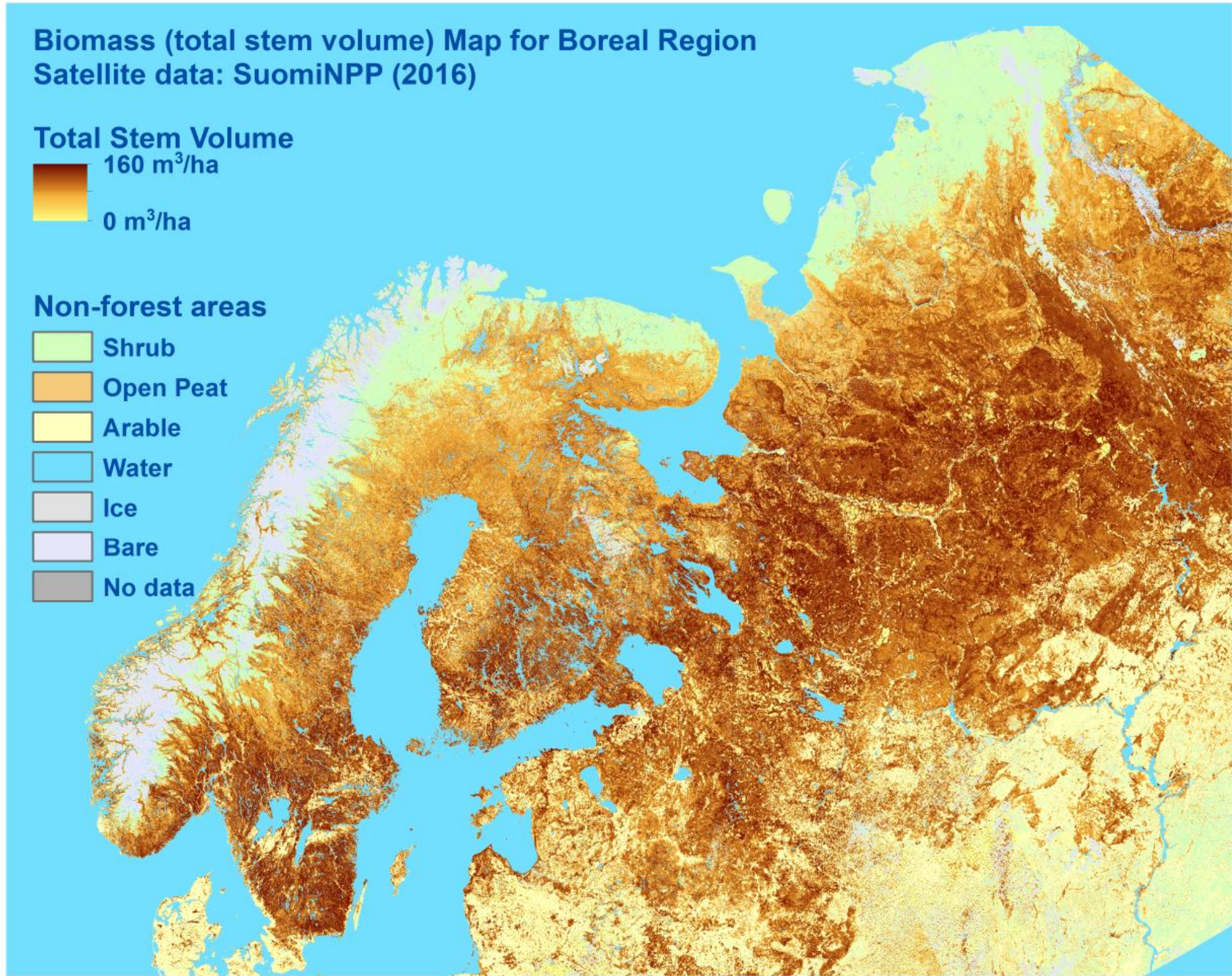
Biomass (total stem volume) Map for Boreal Region

Satellite data: SuomiNPP (2016)

Total Stem Volume



Non-forest areas

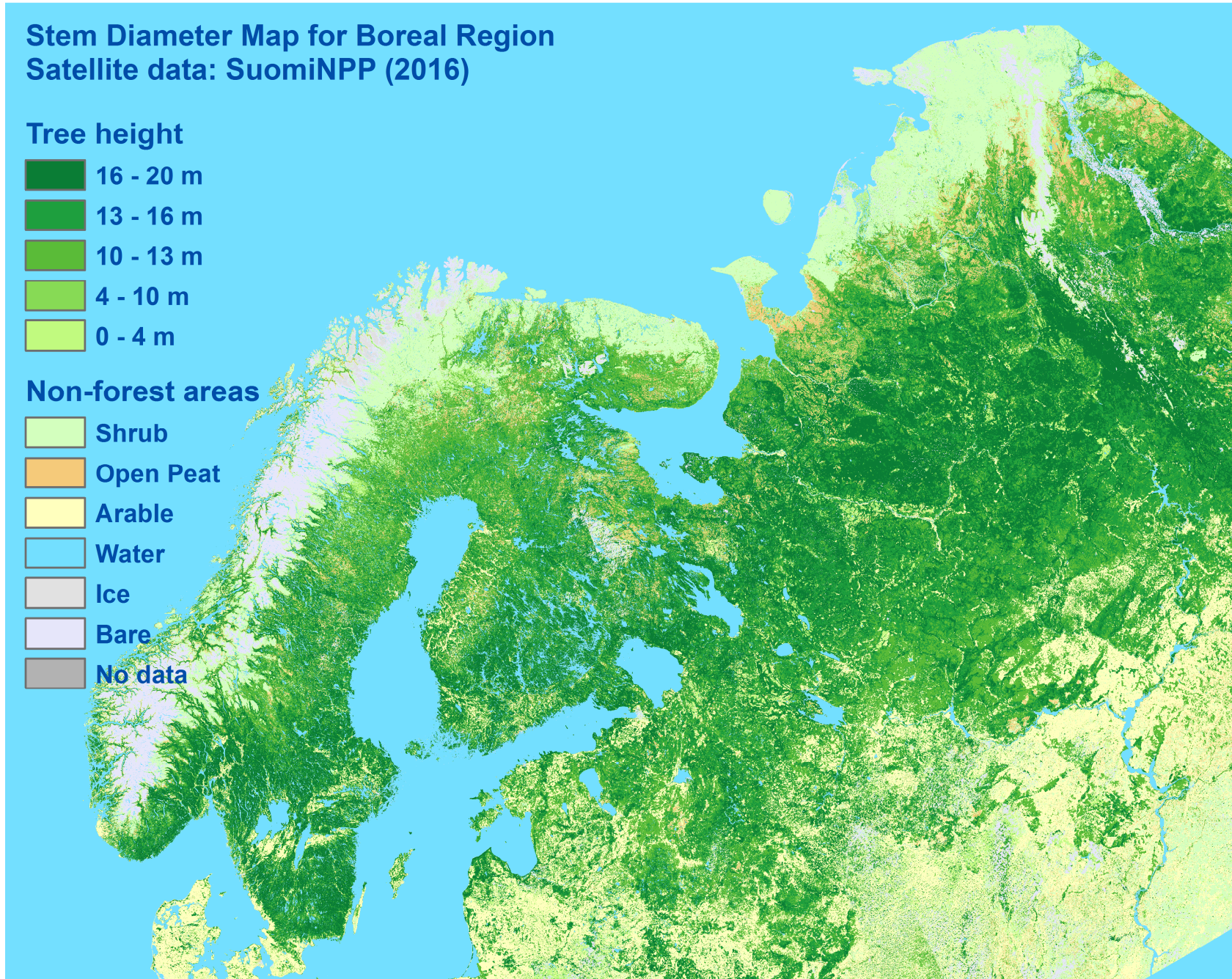


Stem Diameter Map for Boreal Region Satellite data: SuomiNPP (2016)

Tree height



Non-forest areas



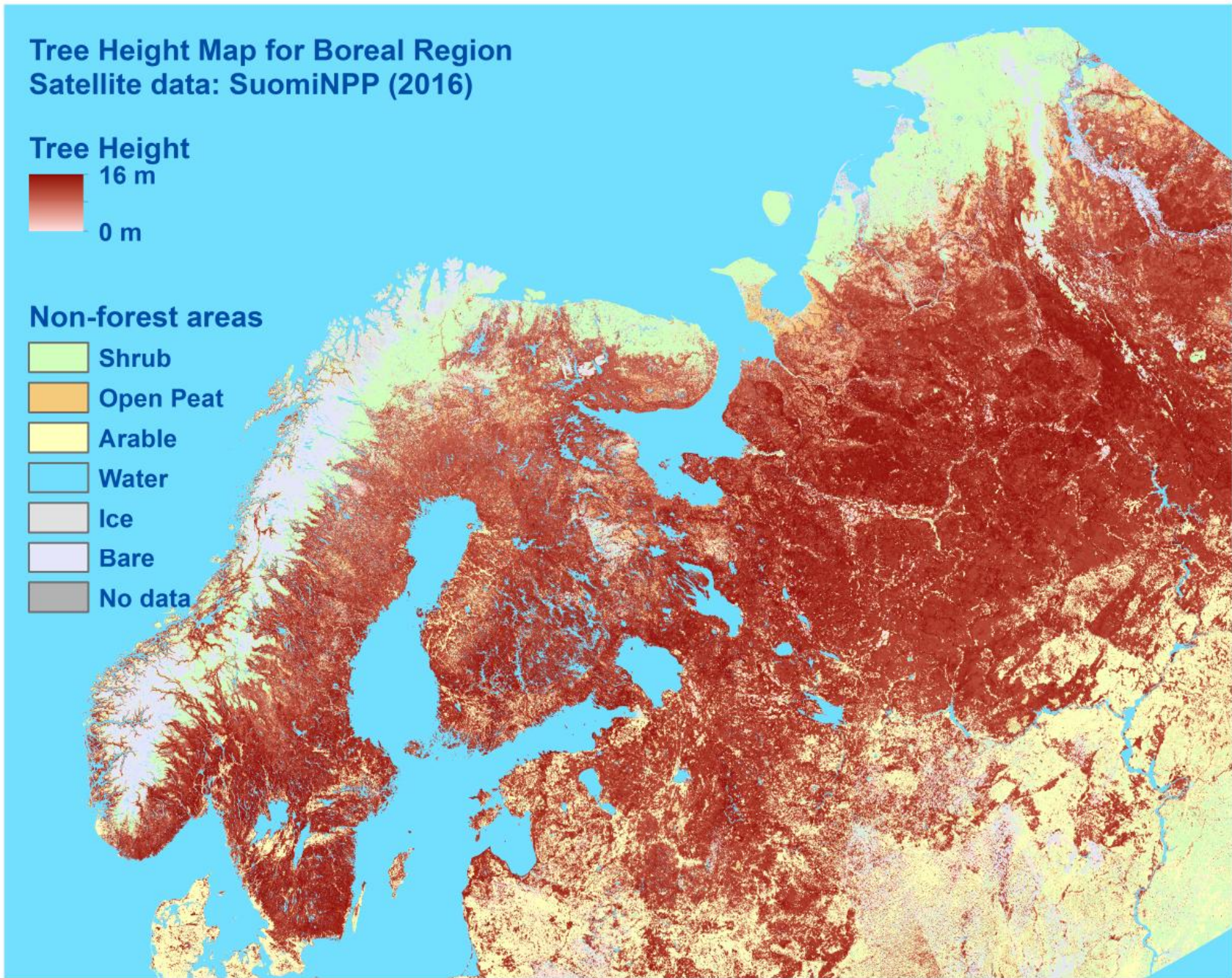
Tree Height Map for Boreal Region

Satellite data: SuomiNPP (2016)

Tree Height



Non-forest areas



Forest area from Suomi NPP for the boreal region

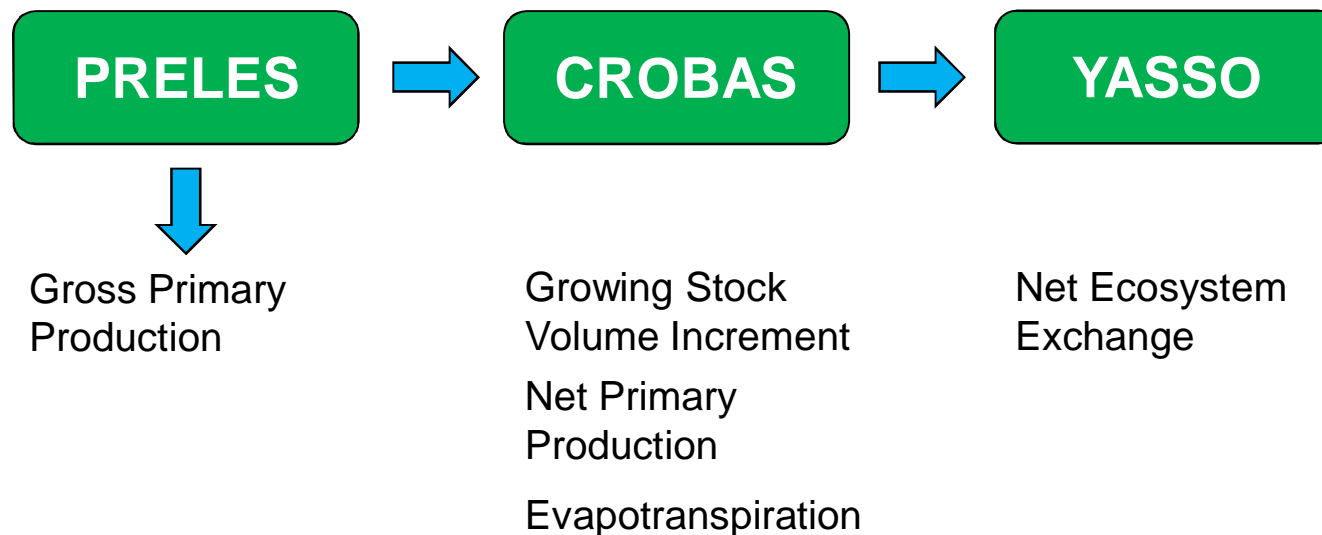
- VHR plots the proportion of forest was 70.7% (95% CI 61.5%, 79.9%) or 2 090 766 km²
- Suomi NPP map 70.4% or 2 080 034.5 km²
- -> VHR – Suomi NPP only 0.3 % or 10 731 km²

Forest growing stock volume from Suomi NPP for the boreal region

- VHR plots: Total predicted growing stock volume for the whole area of interest was $2\,080\,034.5 \text{ km}^2 \times 143.8 \text{ m}^3/\text{ha} = 29.9 \text{ billion m}^3$ ($\times 10^9 \text{ m}^3$) (95% CI 25.7, 34.1).
- In Suomi NPP prediction: the average growing stock volume was $100.8 \text{ m}^3/\text{ha}$ -> predicted total growing stock volume $2\,080\,034.5 \text{ km}^2 \times 100.8 \text{ m}^3/\text{ha} = 21.0 \text{ billion m}^3$ ($\times 10^9 \text{ m}^3$).
- -> Suomi NPP - VHR plot based total growing stock volume prediction was -8.9 billion m^3 or 29.9%. The difference to the lower limit of the 95 % confidence interval was -4.7 billion m^3 .
- For Finnish territory only: total volume prediction was the same as from national forest inventory statistics. The larger forest area in Suomi NPP prediction compensated the lower average growing stock volume.

Models for carbon balance estimation

PRELES	PREdict Light-use efficiency, Evapotranspiration and Soil water	Univ. Helsinki (Mäkelä et al.)
CROBAS	Tree growth and CROwn BASE from carbon balance	Univ. Helsinki (Mäkelä et al.)
YASSO	Yet Another Simulator of Soil Organic matter	Liski



The PRELES model

$$P_k = \beta f_S(S_k) \times f_\Phi(\Phi_k) \times \min\{f_D(D_k), f_\theta(\theta_k)\} \times f_{\text{APAR}}$$

Peltoniemi et al. 2015 Boreal Environ. Res. 20, 151–171.

where

P_k is canopy GPP on day k

β is potential daily LUE

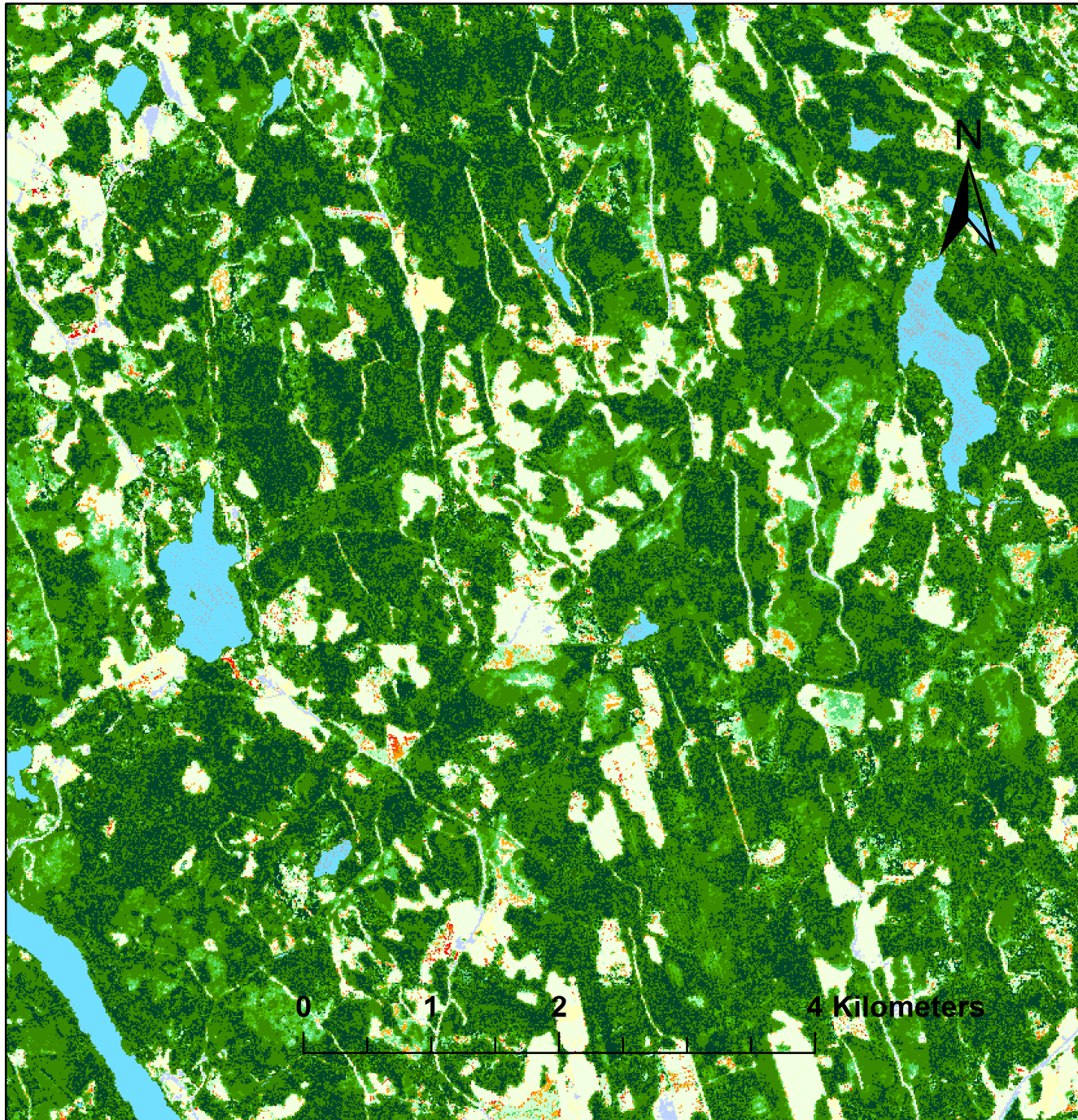
APAR is Absorbed Photosynthetically Active Radiation

S_k is the state of acclimation temperature

D_k is vapour pressure deficit and

W_k is the relative extractable water.

Net Primary Productivity Hyytiälä - Finland (2016) Map area: 10 km x 10 km

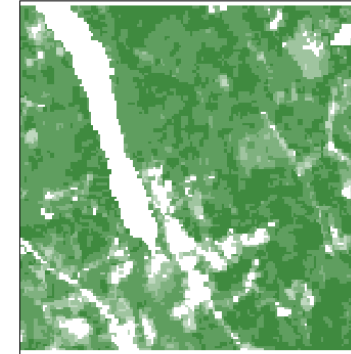
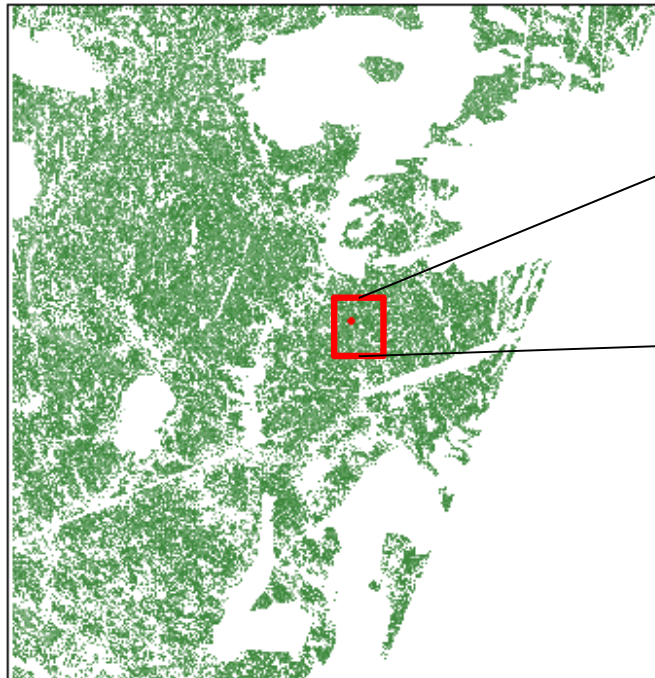


- Open
- Arable
- Water
- Artificial
- No data

NPP

- 50 - 100 t/km²/a
- 100 - 150 t/km²/a
- 150 - 200 t/km²/a
- 200 - 250 t/km²/a
- 250 - 300 t/km²/a
- 300 - 350 t/km²/a
- 350 - 400 t/km²/a
- 400 - 450 t/km²/a
- 450 - 500 t/km²/a
- > 500 t/km²/a

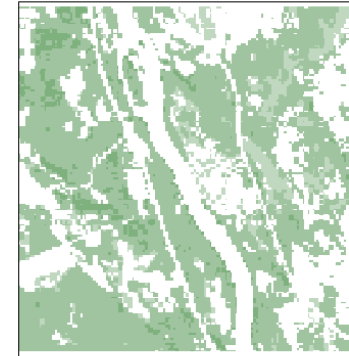
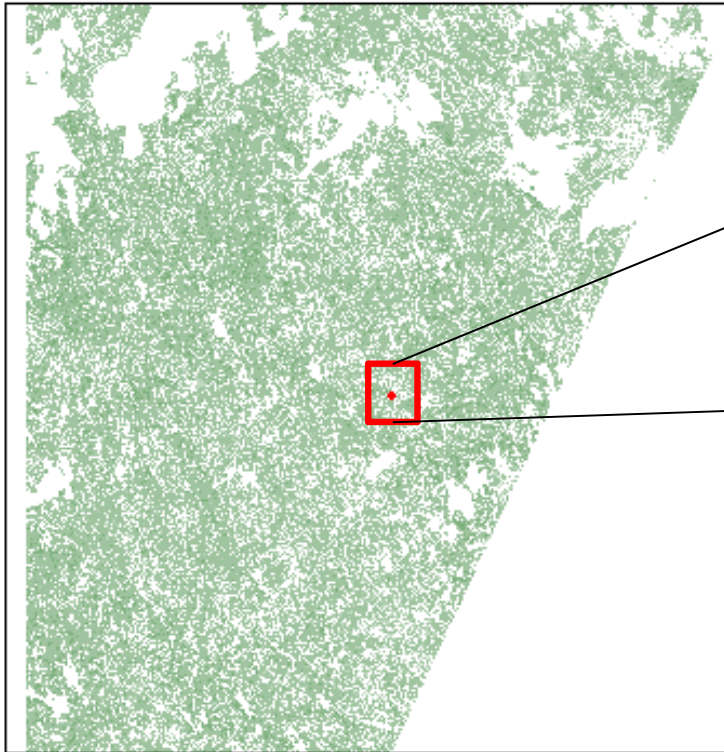
Eddy-covariance tower footprint

Hyytiälä, annual GPP, 2014 (gC/m²/y)

Annual GPP measured at Hyytiälä 2000-2010
mean: 1049.2 gC/m²/y
min: 977.2
max: 1130.9

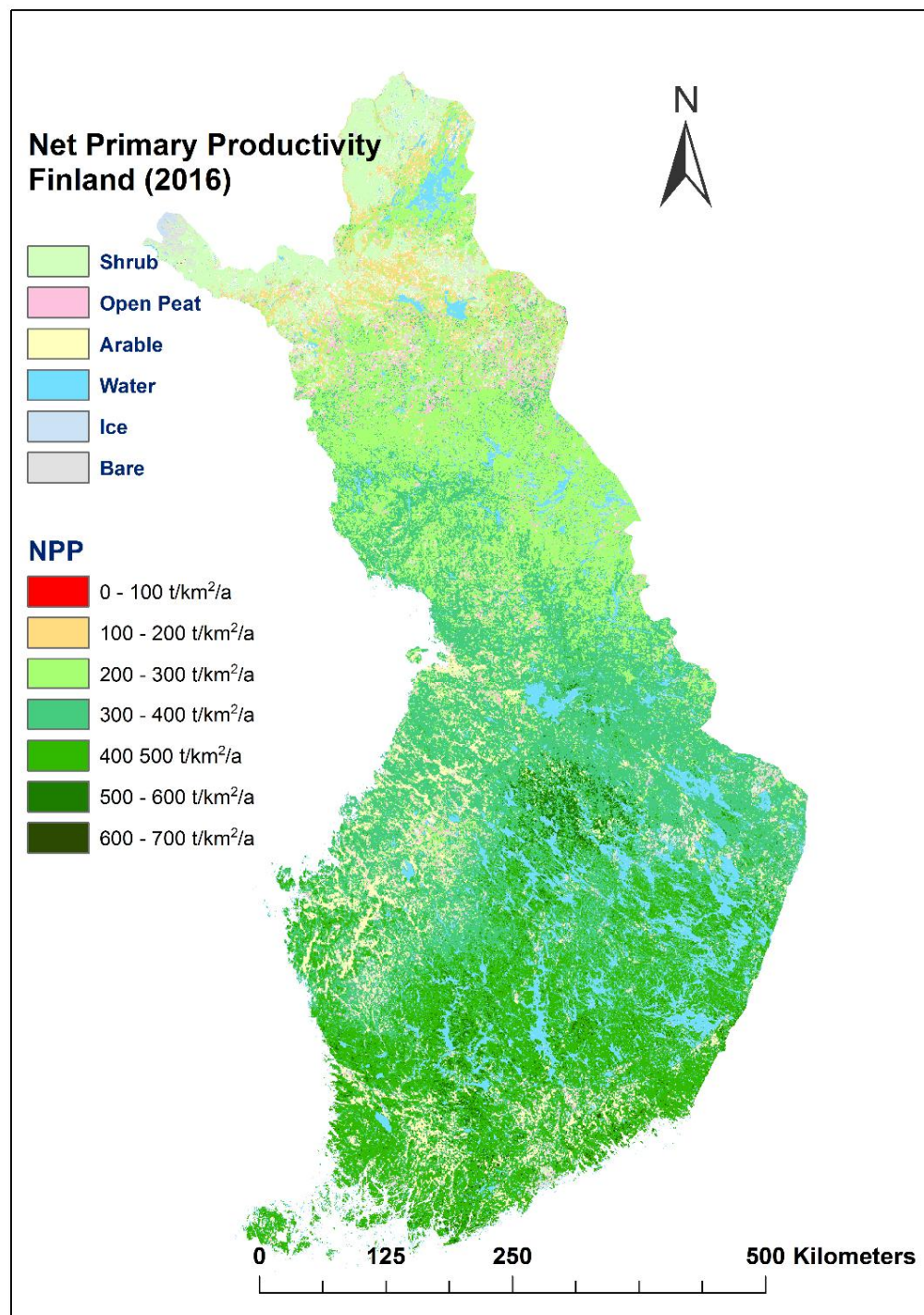
Annual GPP using EO: 1143.922 gC/m²/y

Eddy-covariance tower footprint

Sodankylä, annual GPP, 2014 (gC/m²/y)

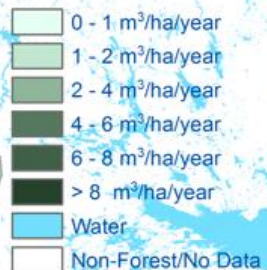
Annual GPP measured at Sodankylä 2000-2009
mean: 584.9 gC/m²/y
min: 465.6
max: 678.5

Annual GPP using EO: 573.1 gC/m²/y



Predicted Mean Annual Stem Volume Increment in Finland

Satellite Data: SuomiNPP



Predicted Land Cover Class, Boreal Region

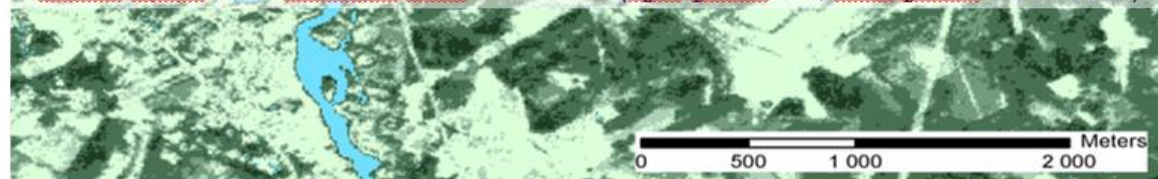
Satellite Data: SuomiNPP



False colour extract of Sentinel-2 data (pixel resolution = 10 m)



Forest Basal Area estimate from Sentinel-2 (light green = 0, dark green > 20 m²/ha)



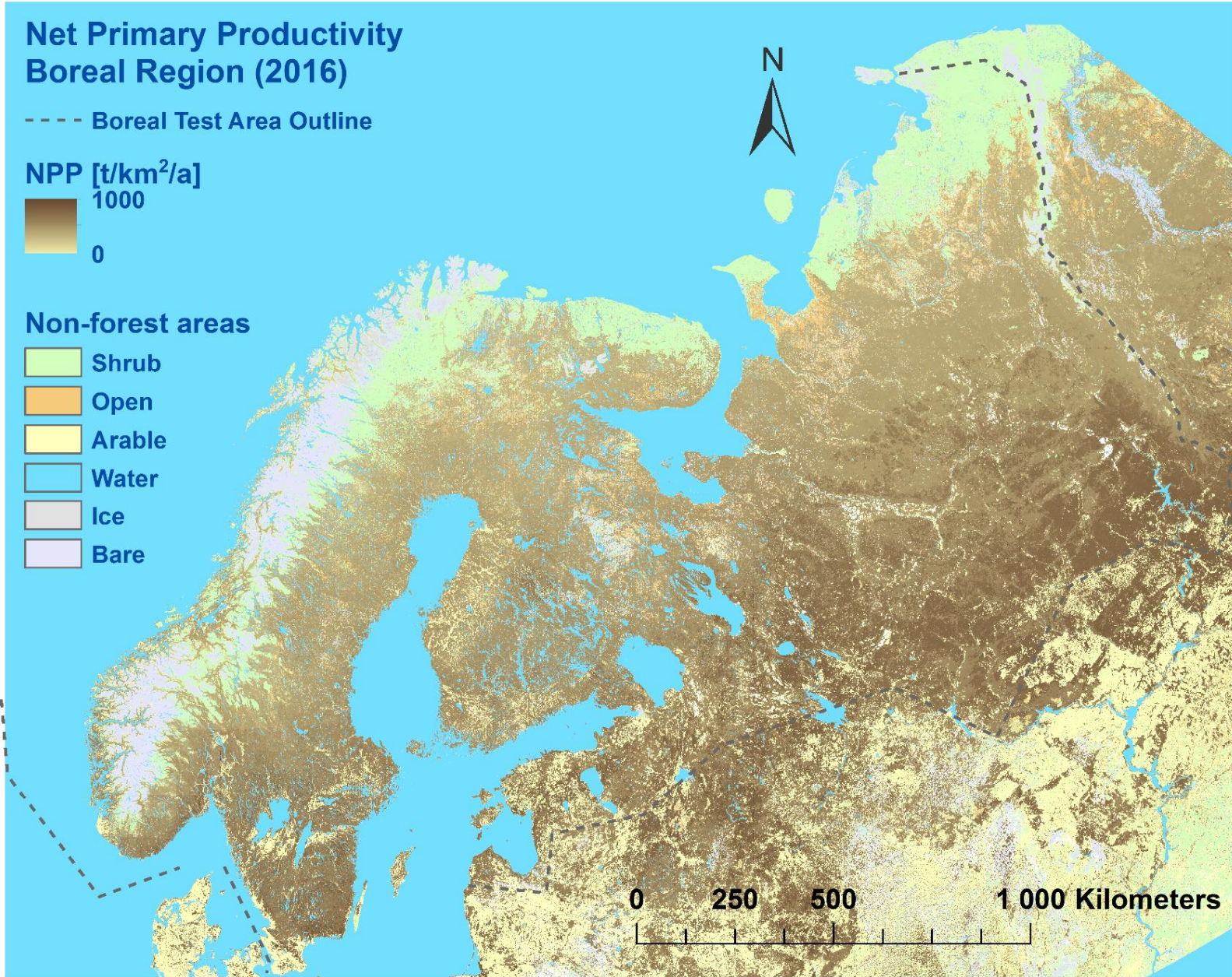
Net Primary Productivity Boreal Region (2016)

--- Boreal Test Area Outline

NPP [$t/km^2/a$]



Non-forest areas



GPP Variability in Finland

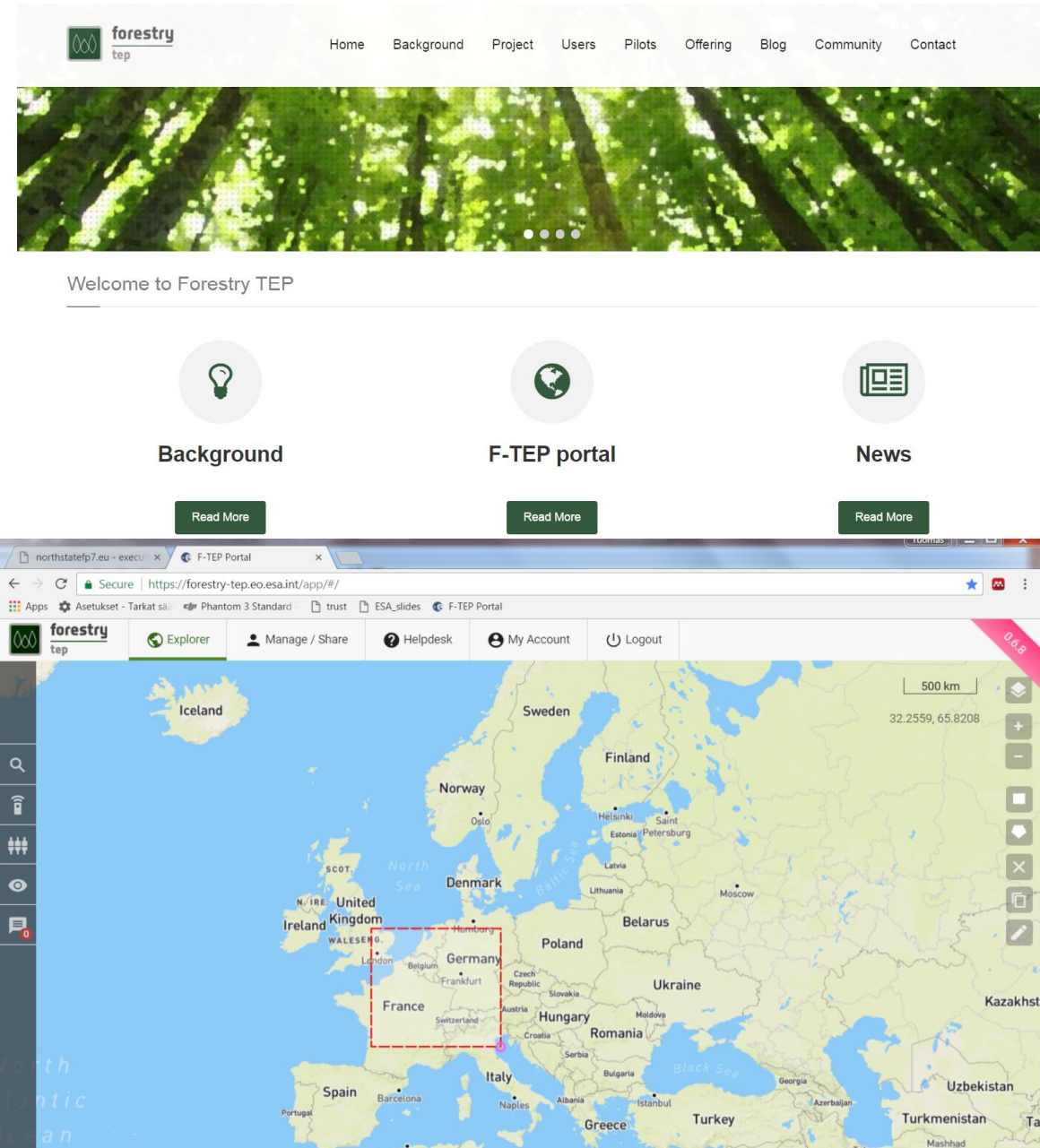
Table 1. Summary statistics of annual gross primary production for Finland. The values in the columns correspond to the mean, the 5th and the 95th percentiles and the total GPP.

GPP	Mean (gC m ⁻² y ⁻¹)	5% (gC m ⁻² y ⁻¹)	95% (gC m ⁻² y ⁻¹)	Total (MtC y ⁻¹)
Finland	537.8551	310.2163	758.2301	144.255

- NPP 62 % of GPP
- Good match between the satellite based predictions and flux tower data at tower locations in Hyytiälä and Sodankylä

Gaps and barriers, lessons learned

- IT infrastructure and (Copernicus) image delivery have been a bottleneck – DIAS will help
- Analysis of big data masses – platforms to process data in a cloud <https://forestry-tep.eo.esa.int/>
- Scaling up of actual carbon balance, i.e. Net Ecosystem Exchange that includes soil respiration, needs
 - Information on forest growth
 - Ground reference data – availability a major bottleneck
 - Models for soil respiration
- Tree covered and open peatlands
 - Location – challenge from space particularly when with tree cover
 - Carbon assimilation models needed
- Can be progressed stepwise: GPP and NPP first – up-scaling already possible





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