Monitoring small-scale changes in Forest coverage

Comparing passive and active Sentinel data over Białowieża forest

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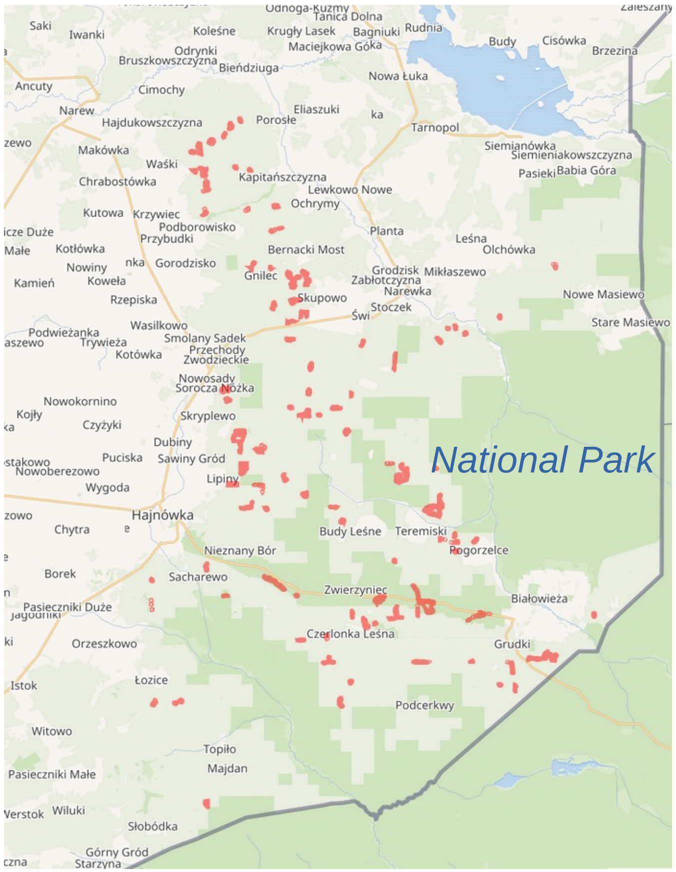
Logging activities in a Natura 2000 site: Białowieża (PL)

Deforestation in the Białowieża Forest. (Photo: Greenpeace Polska, CC BY-ND 2.0)

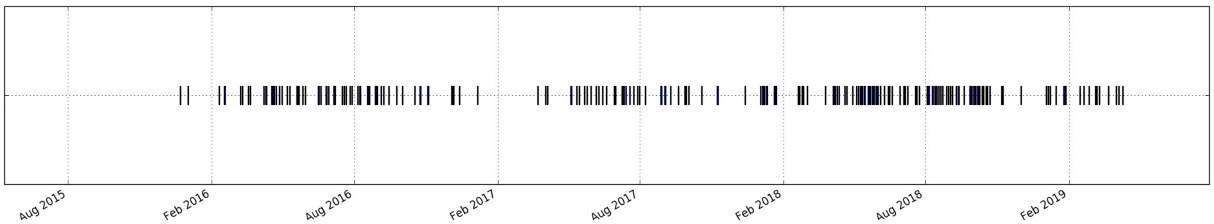
European Commission

Białowieża (PL)



Deforested patches from visual inspection (G. Caudullo)

Sentinel 2 time series temporal coverage



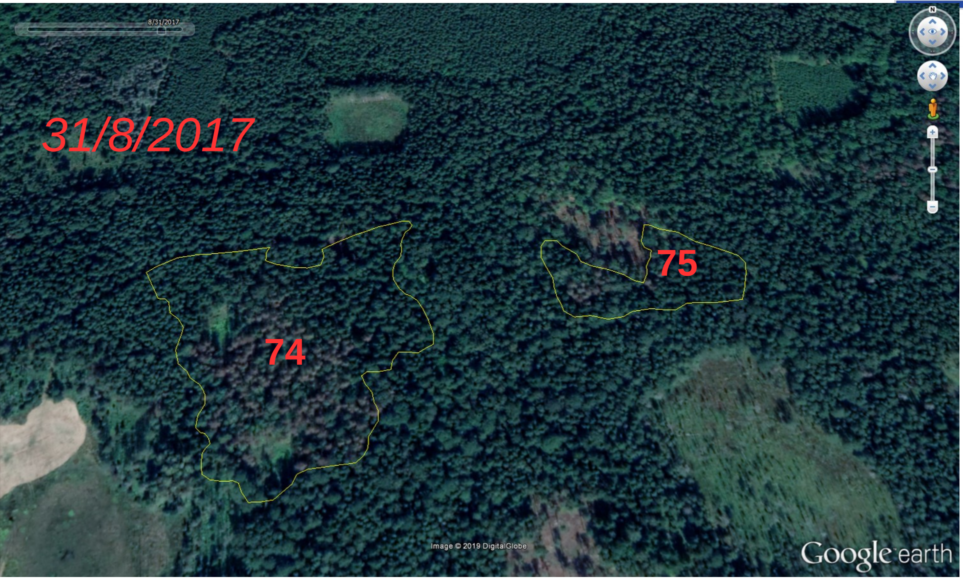
The AOI is ~1122 km², of which 105 km² National Park

Elevation
min = 126 m a.s.l.
max = 208
range = 82
mean = 163
sd = 12.8

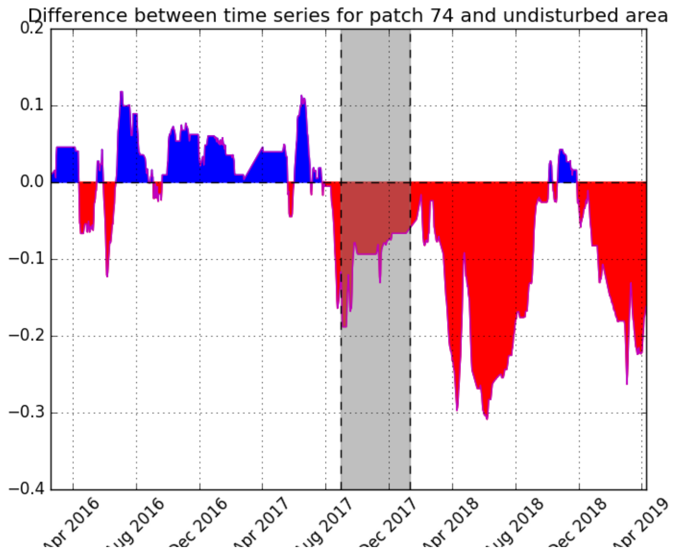
Slope:
min = 0
max = 17.95
mean = 1.46
sd = 1.1

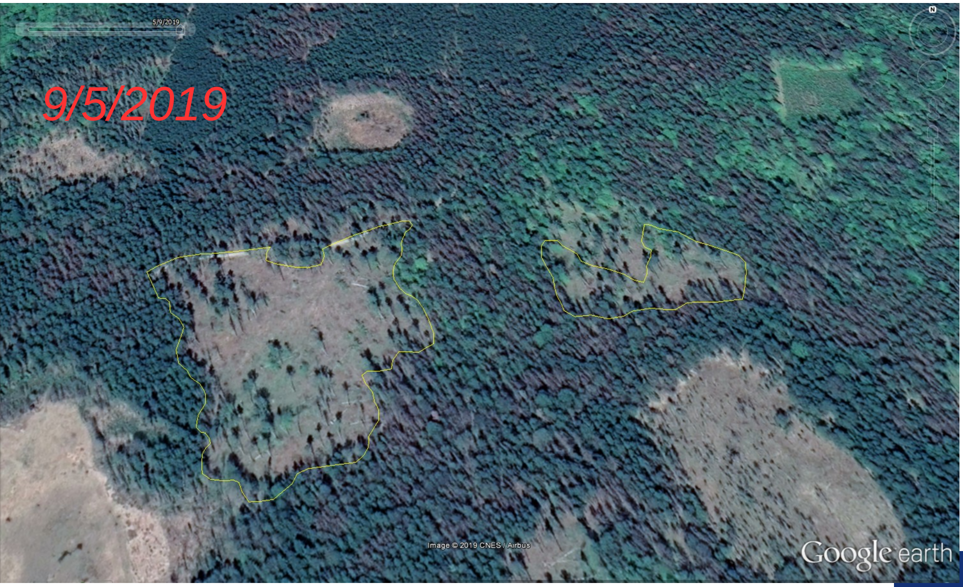
WH:
- Signal / noise ratio similarity
- Phenological homogeneity

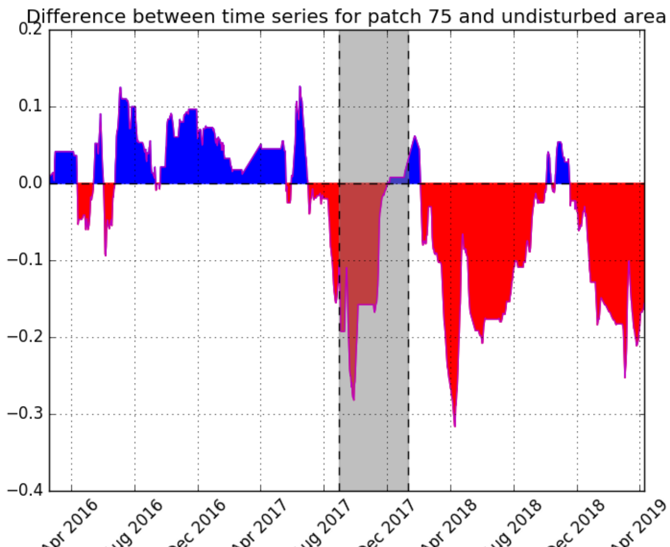
Difference index $\Delta_i = TS_i - NP$


31/8/2017
74
75
Google earth

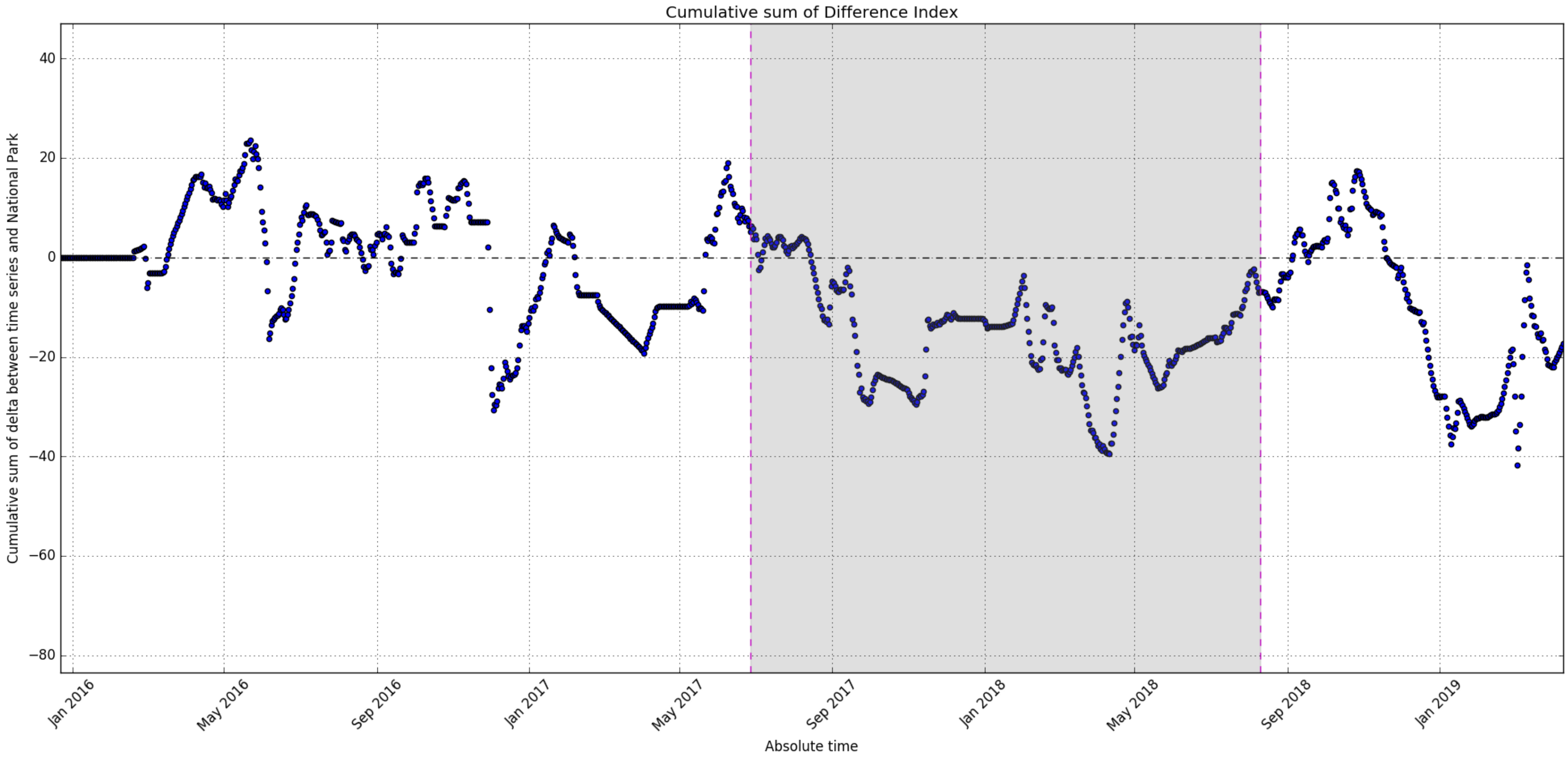
NDVI


Difference between time series for patch 74 and undisturbed area
0.2
0.1
0.0
−0.1
−0.2
−0.3
−0.4
Apr 2016
Aug 2016
Dec 2016
Apr 2017
Aug 2017
Dec 2017
Apr 2018
Aug 2018
Dec 2018
Apr 2019


9/5/2019
Google earth


Difference between time series for patch 75 and undisturbed area
0.2
0.1
0.0
−0.1
−0.2
−0.3
−0.4
Apr 2016
Aug 2016
Dec 2016
Apr 2017
Aug 2017
Dec 2017
Apr 2018
Aug 2018
Dec 2018
Apr 2019

Cumulative sum of difference index



Where to look?

NDVI Anomalies

Departure of NDVI from long-term average, normalized by long-term variability

Generated by subtracting the long-term mean from the current value for that month of the year for each pixel

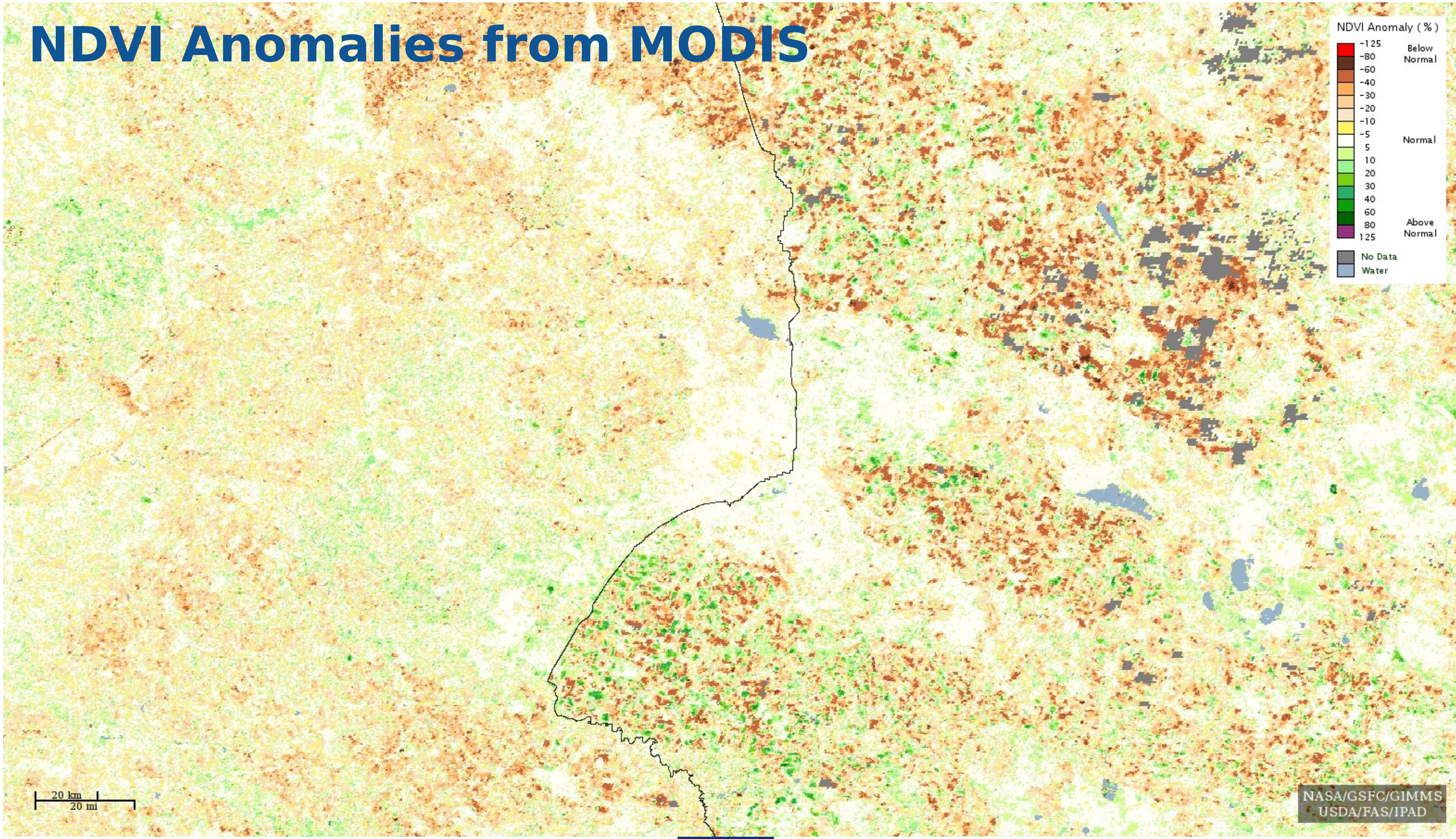
Indicate if the vegetation **greenness** at a particular location is typical for that period or if the vegetation is more or less green

Limitations

Sentinel 2: good resolution but time series too short for stats

MODIS: resolution insufficient to detect small changes in the forest coverage

NDVI Anomalies from MODIS



Exploring **SAR**

Applications of SAR in Forest Monitoring

- Deforestation and forest degradation
- Forest structure estimation
- Biomass estimation
- Mangrove monitoring

Side-Looking Airborne Radar (SLAR)

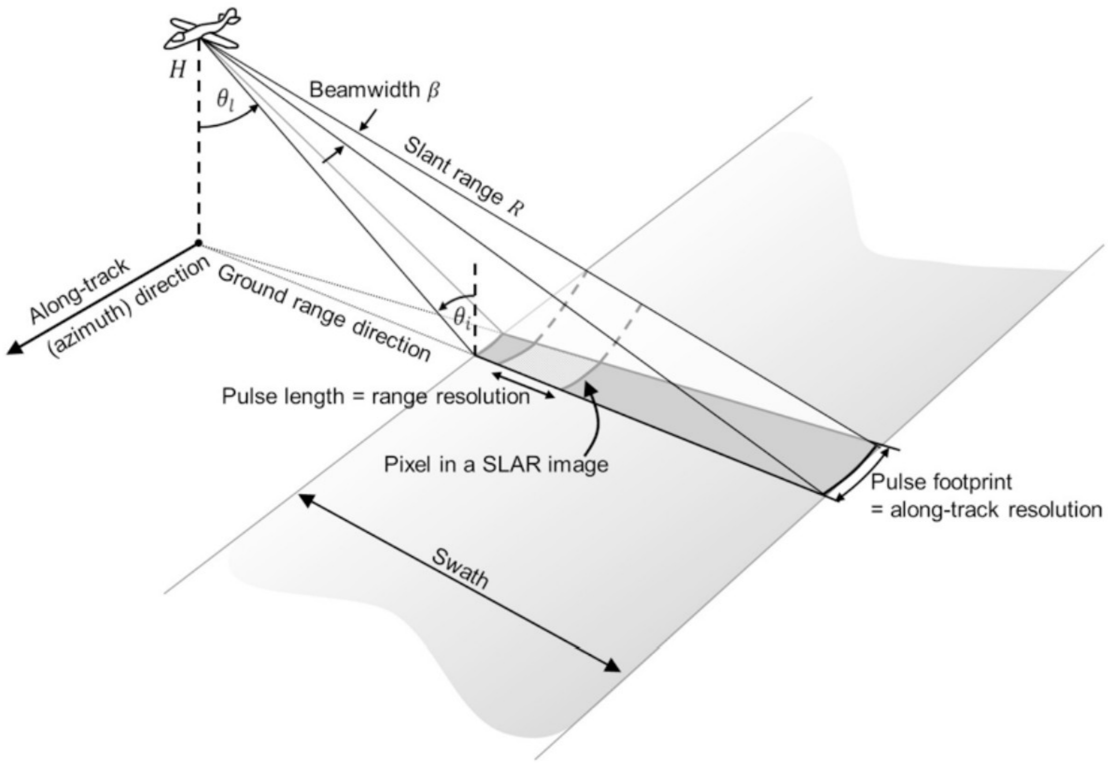
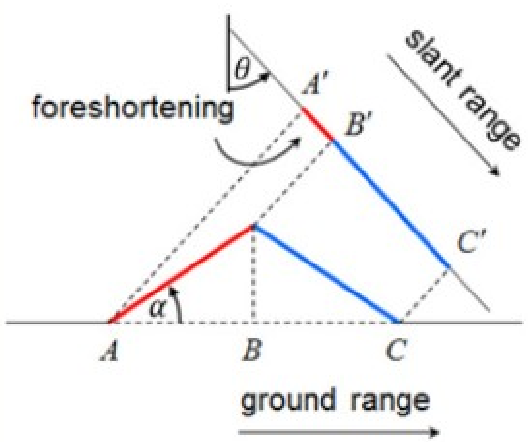


Image after Flores-Anderson, Africa Ixmuca, et al. "The SAR Handbook: Comprehensive Methodologies for Forest Monitoring and Biomass Estimation." (2019).

Main **geometric distortions** on SAR images with their dependence on acquisition geometry: (a) foreshortening, (b) layover, and (c) shadow

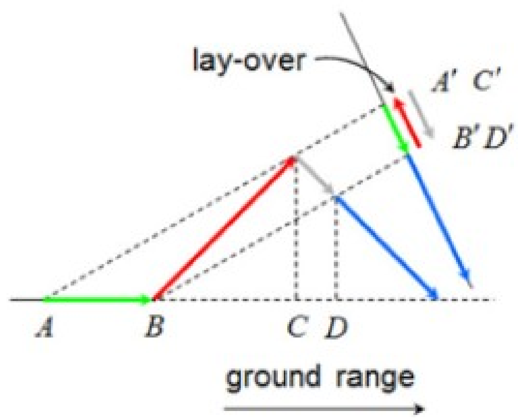
FORESHORTENING

- Sensor-facing slope foreshortened in image
- Foreshortening effects *decrease* with increasing look angle



LAYOVER

- Mountain top overlain on ground ahead of mountain
- Layover effects *decrease* with increasing look angle



SHADOW

- Area behind mountain cannot be seen by sensor
- Shadow effects *increase* with increasing look angle

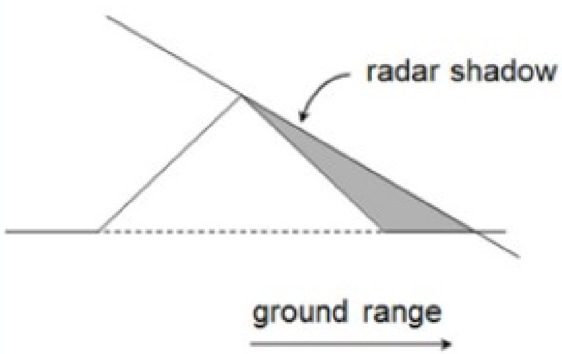


Image after Flores-Anderson, Africa Ixmuca, et al. "The SAR Handbook: Comprehensive Methodologies for Forest Monitoring and Biomass Estimation." (2019).

SAR signal penetration by sensor wavelength λ

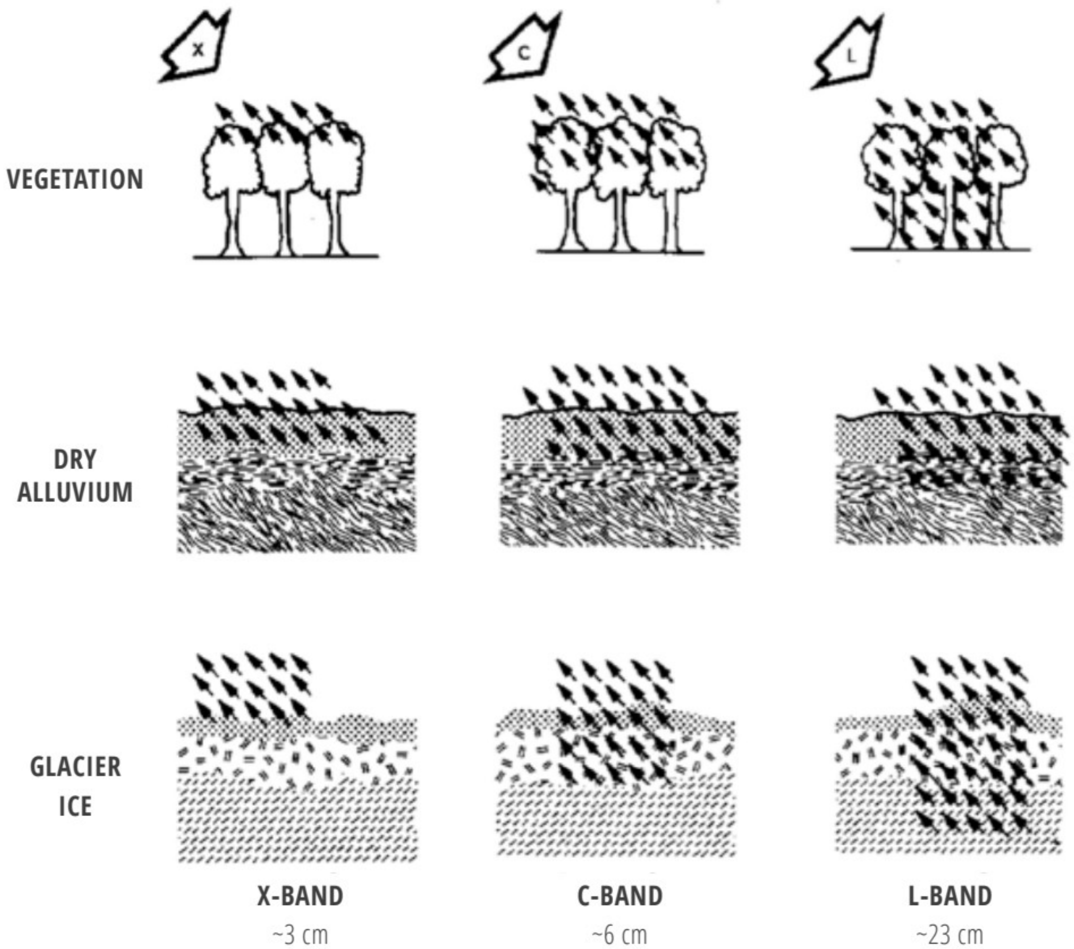


Image after Flores-Anderson, Africa Ixmuca, et al. "The SAR Handbook: Comprehensive Methodologies for Forest Monitoring and Biomass Estimation." (2019).

Designation of microwave bands

BAND	FREQUENCY		WAVELENGTH		TYPICAL APPLICATION
Ka	27 – 40	GHz	1.1 – 0.8	cm	Rarely used for SAR (airport surveillance)
K	18 – 27	GHz	1.7 – 1.1	cm	Rarely used (H_2O absorption)
Ku	12 – 18	GHz	2.4 – 1.7	cm	Rarely used for SAR (satellite altimetry)
X	8 – 12	GHz	3.8 – 2.4	cm	High-resolution SAR (urban monitoring; ice and snow, little penetration into vegetation cover; fast coherence decay in vegetated areas)
C	4 – 8	GHz	7.5 – 3.8	cm	SAR workhorse (global mapping; change detection; monitor-ing of areas with low to moderate vegetation; improved pen-etration; higher coherence); Ice, ocean, maritime navigation
S	2 – 4	GHz	15 – 7.5	cm	Little but increasing use for SAR-based Earth observation; agriculture monitoring (NISAR will carry an S-band channel; expands C-band applications to higher vegetation density)
L	1 – 2	GHz	30 – 15	cm	Medium resolution SAR (Geophysical monitoring; biomass and vegetation mapping; high penetration; InSAR)
P	0.3 – 1	GHz	100 – 30	cm	Biomass. First P-band spaceborne SAR will be launched ~2020; vegetation mapping and assessment. Experimental SAR.

Table after Flores-Anderson, Africa Ixmuca, et al. "The SAR Handbook: Comprehensive Methodologies for Forest Monitoring and Biomass Estimation." (2019).

Schematic sketch of the three main **scattering types** considered for SAR data

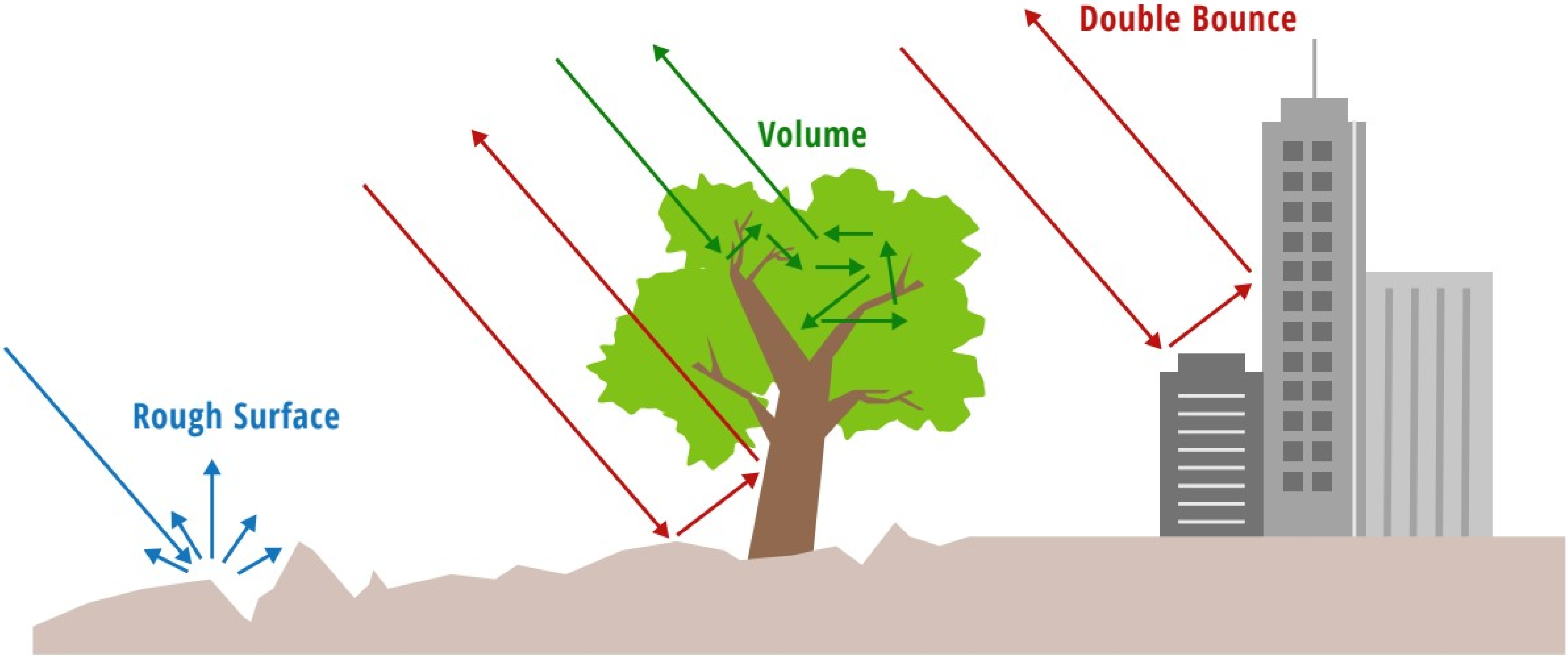


Image after Flores-Anderson, Africa Ixmuca, et al. "The SAR Handbook: Comprehensive Methodologies for Forest Monitoring and Biomass Estimation." (2019).

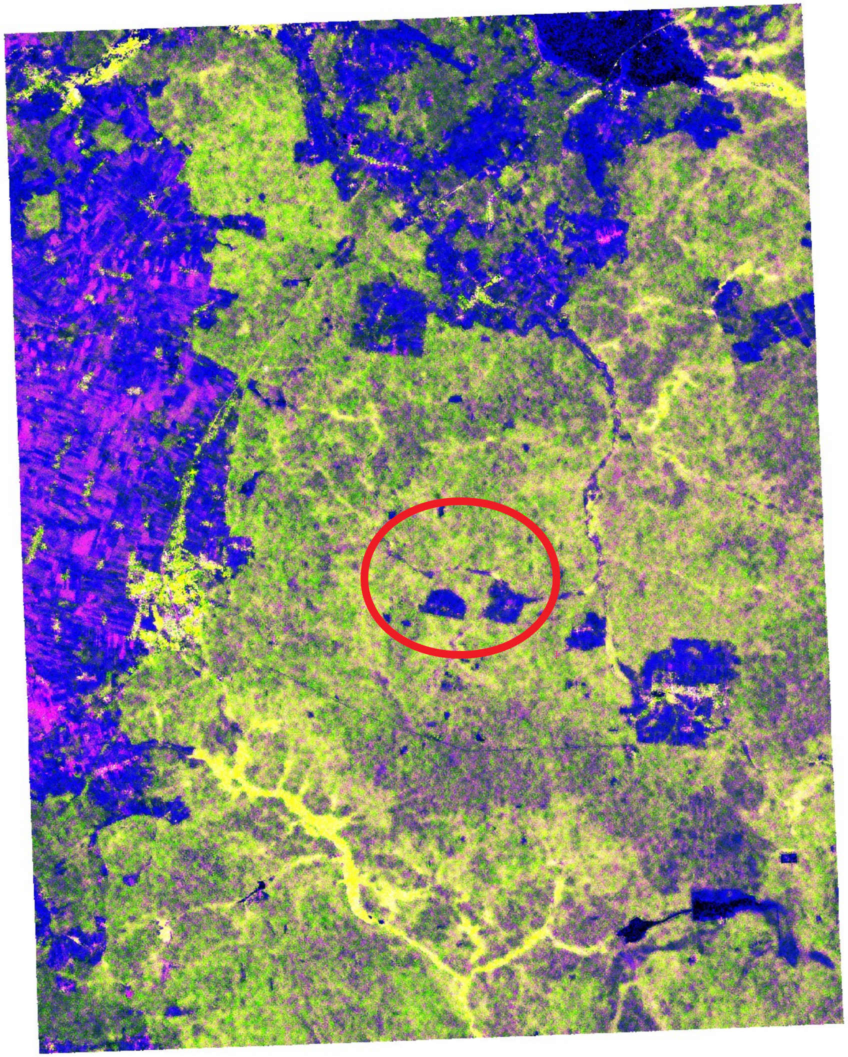
Each polarimetric channel prefers certain scattering types:

RELATIVE SCATTERING STRENGTH BY POLARIZATION:	
Rough Surface Scattering	$\lvert S_{VV} \rvert > \lvert S_{HH} \rvert > \lvert S_{HV} \rvert$ or $\lvert S_{VH} \rvert$
Double Bounce Scattering	$\lvert S_{HH} \rvert > \lvert S_{VV} \rvert > \lvert S_{HV} \rvert$ or $\lvert S_{VH} \rvert$
Volume Scattering	Main source of $\lvert S_{HV} \rvert$ and $\lvert S_{VH} \rvert$

- Strong scattering in $|S_{HH}|$ indicates a predominance of **double-bounce scattering** (e.g., stemmy vegetation, manmade structures)
- Strong $|S_{VV}|$ relates to **rough surface scattering** (e.g., bare ground, water)
- Spatial variations in $|S_{HV}|$ indicate the distribution of **volume** scatters (e.g., vegetation, high-penetration soil types)

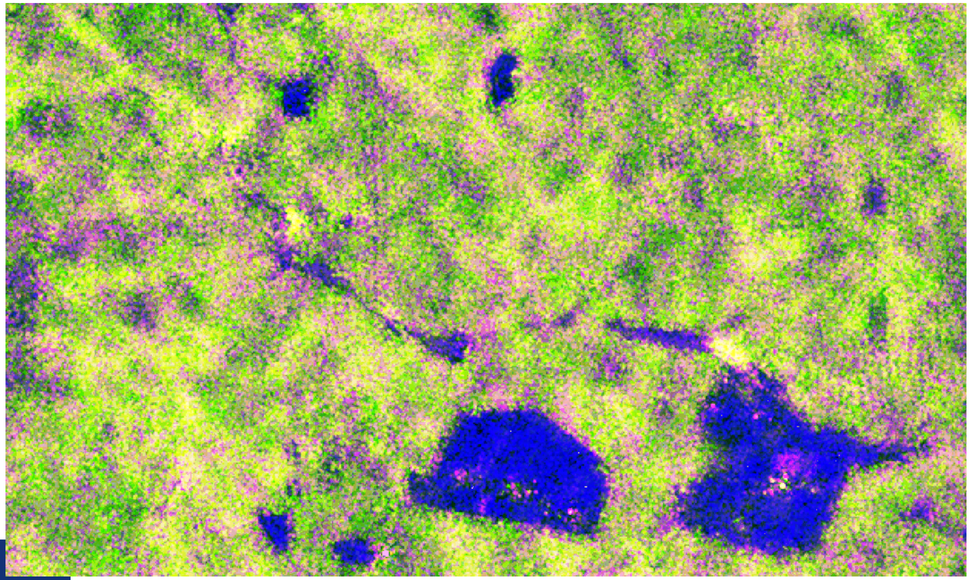
To enhance the visibility of differences between the channels, it is possible to create **false color composites** of SAR scenes, assigning RGB colors to different channels

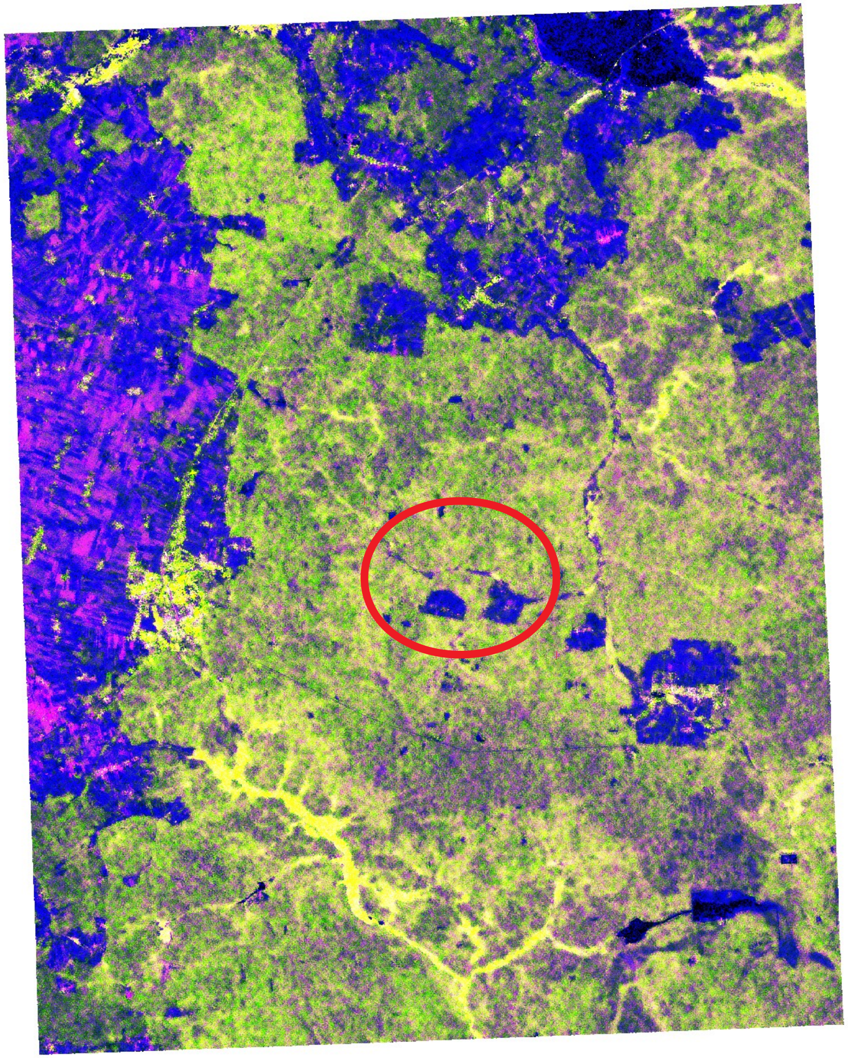
Sentinel-1 : VV and VH channels



An RGB color combination of C-band SAR scenes from the Sentinel-1 sensor over Białowieża on 14/11/2018

VV - red
VH - blue
VV-VH - green





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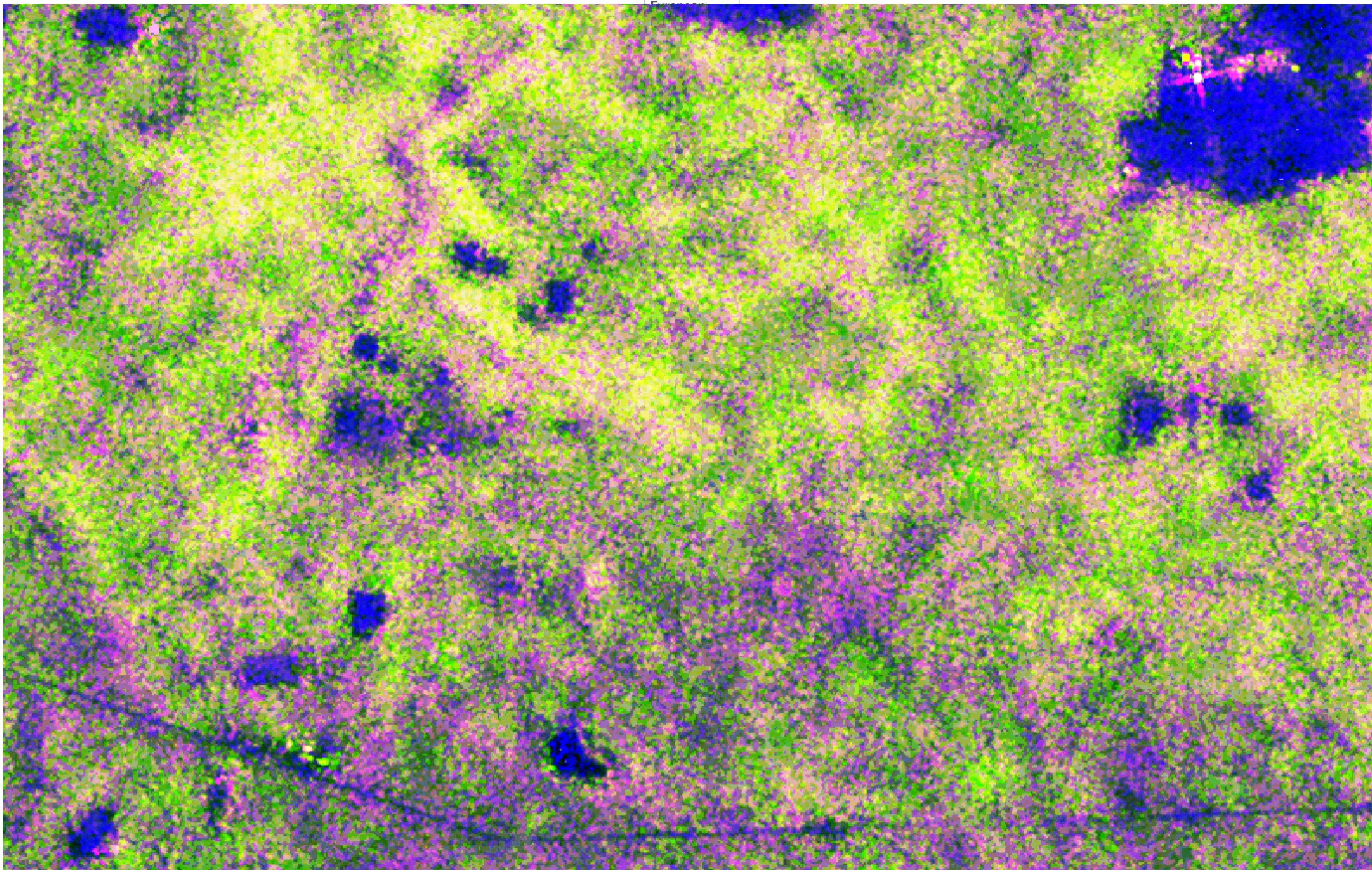


Using SAR data for mapping deforestation

Sensor parameters – wavelength / frequency, incidence angle, look directions, transmit and receive polarization – are typically **stable** from a satellite SAR, **backscatter variations over time can be attributed only to change in forest structure and moisture conditions**.

Complementary to optical data:

(1) Not affected by **atmospheric** or sun **illumination** variations

(2) Longer wavelengths and active penetration into forest canopies interact directly with **structure and moisture conditions**

Using SAR data for mapping deforestation

Response to deforestation

Change **from volume to surface scattering**. Cross-polarized backscatter decreases significantly.

Moisture conditions of soils become more visible. Can enhance signals at C-band and introduce ambiguities.

Getting the data

JEODPP

JEO-lab:

Filter over
- Study area
- Time
datemin: 2015-08-01
datemax: 2019-06-14
- Orbit
- Polarization

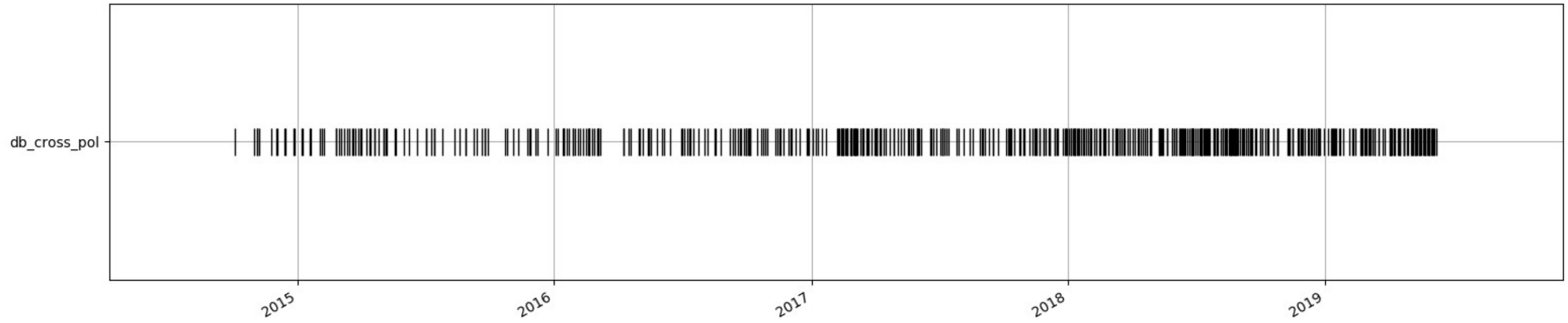
Preprocessing (geocoding)

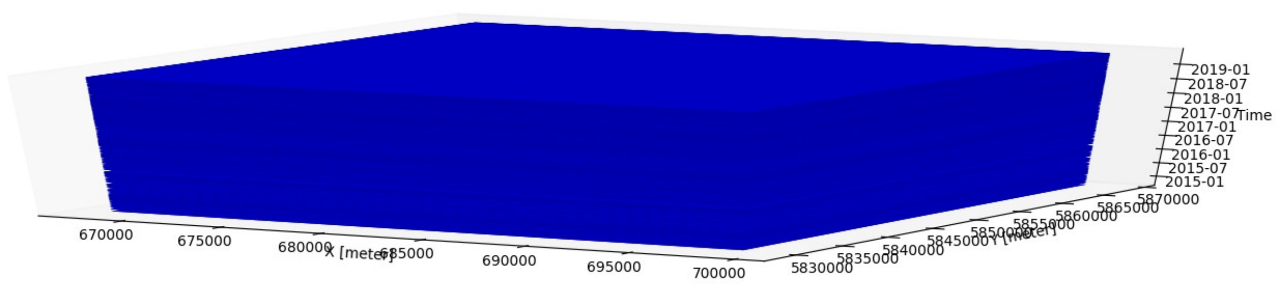
JEO-desk:

Crop the data to AOI

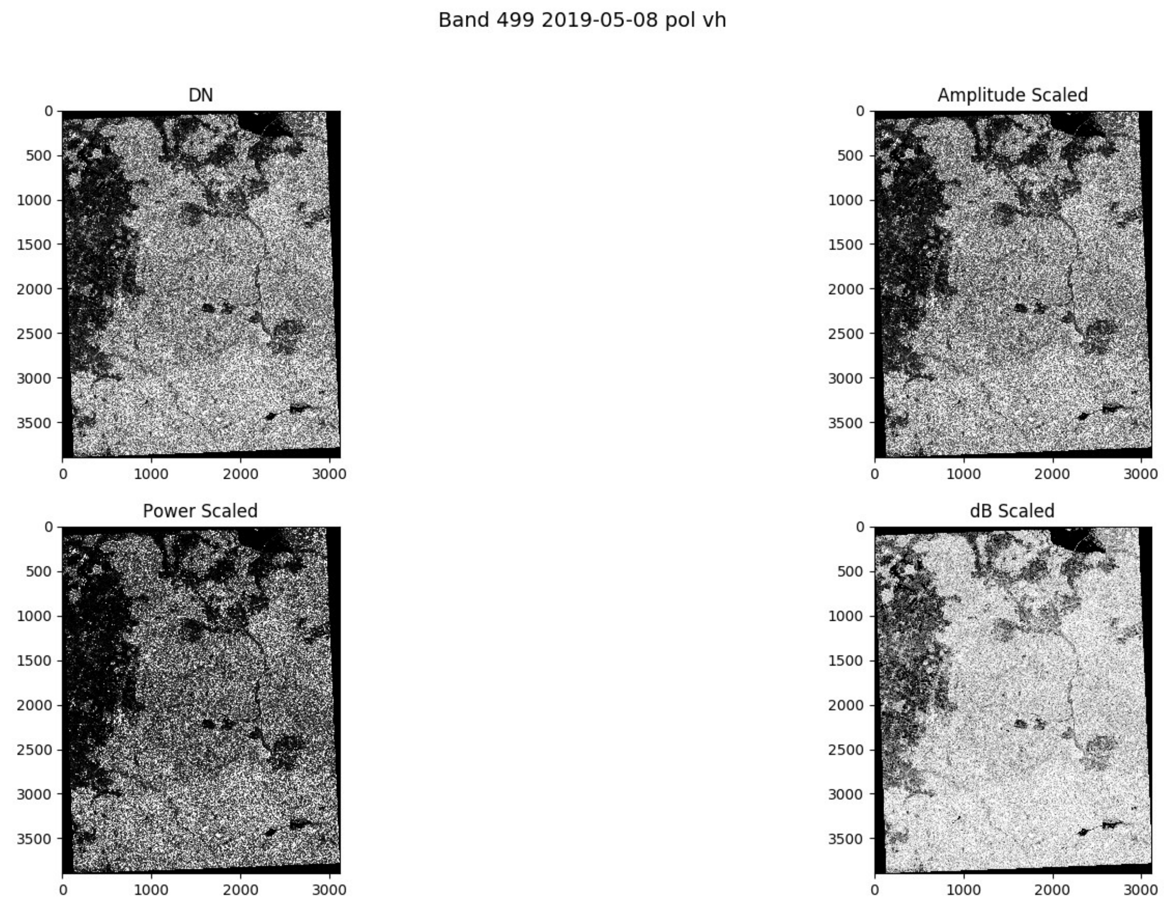
Creating time series data stack

GRASS GIS: Space time raster dataset (strds)

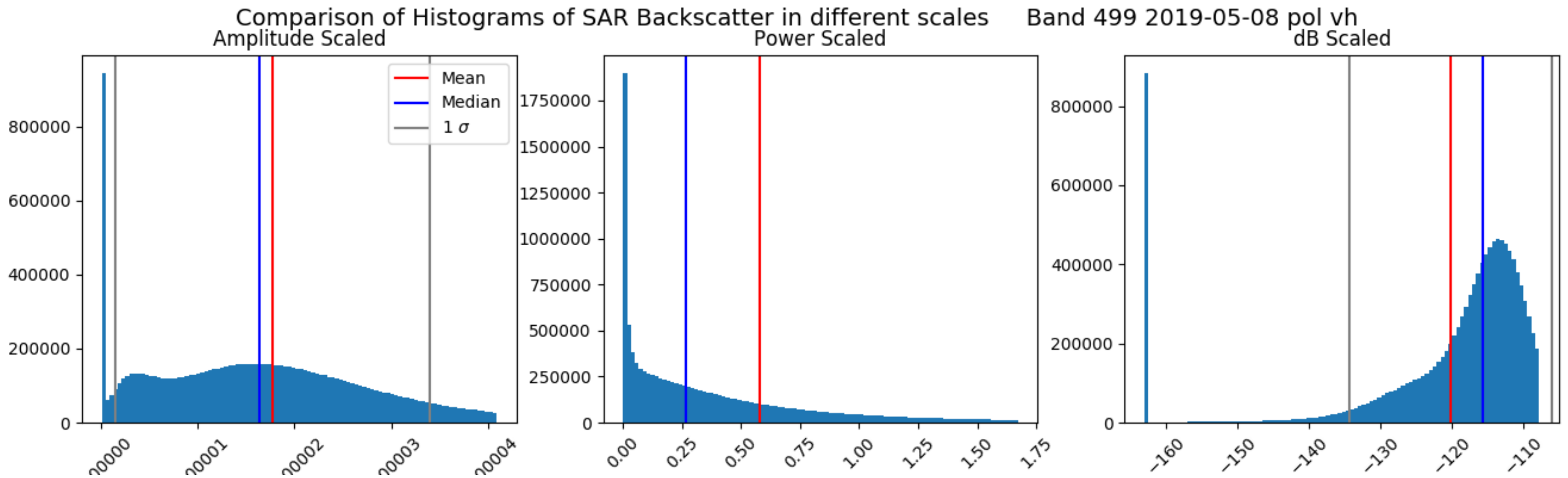




Scaling the data



Scaling the data



Computation of metrics for change detection

In the resulting map, each pixel value is a function of the values of the corresponding pixels in the time series

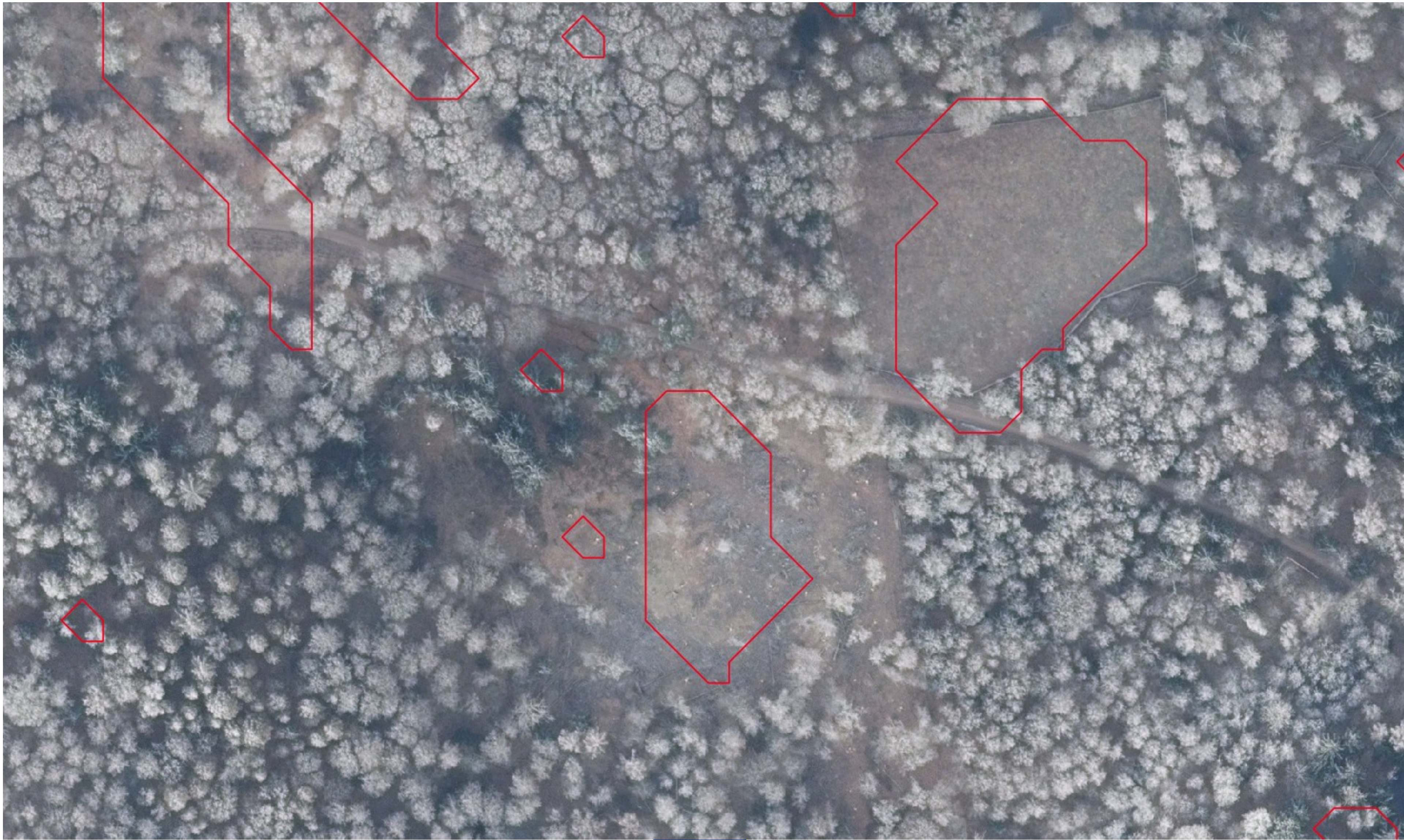
Considering the whole time series from 2015-08-01 to 2019-06-14

Mean, Median, Max, Min, Variance, Range (Max-Min), 5^{th} Percentile, 95^{th} Percentile, **Prange (95^{th} - 5^{th} Percentile)**, Coefficient of Variation (Variance/Mean)

Prange (power) → Histogram → Threshold → Vector polygons

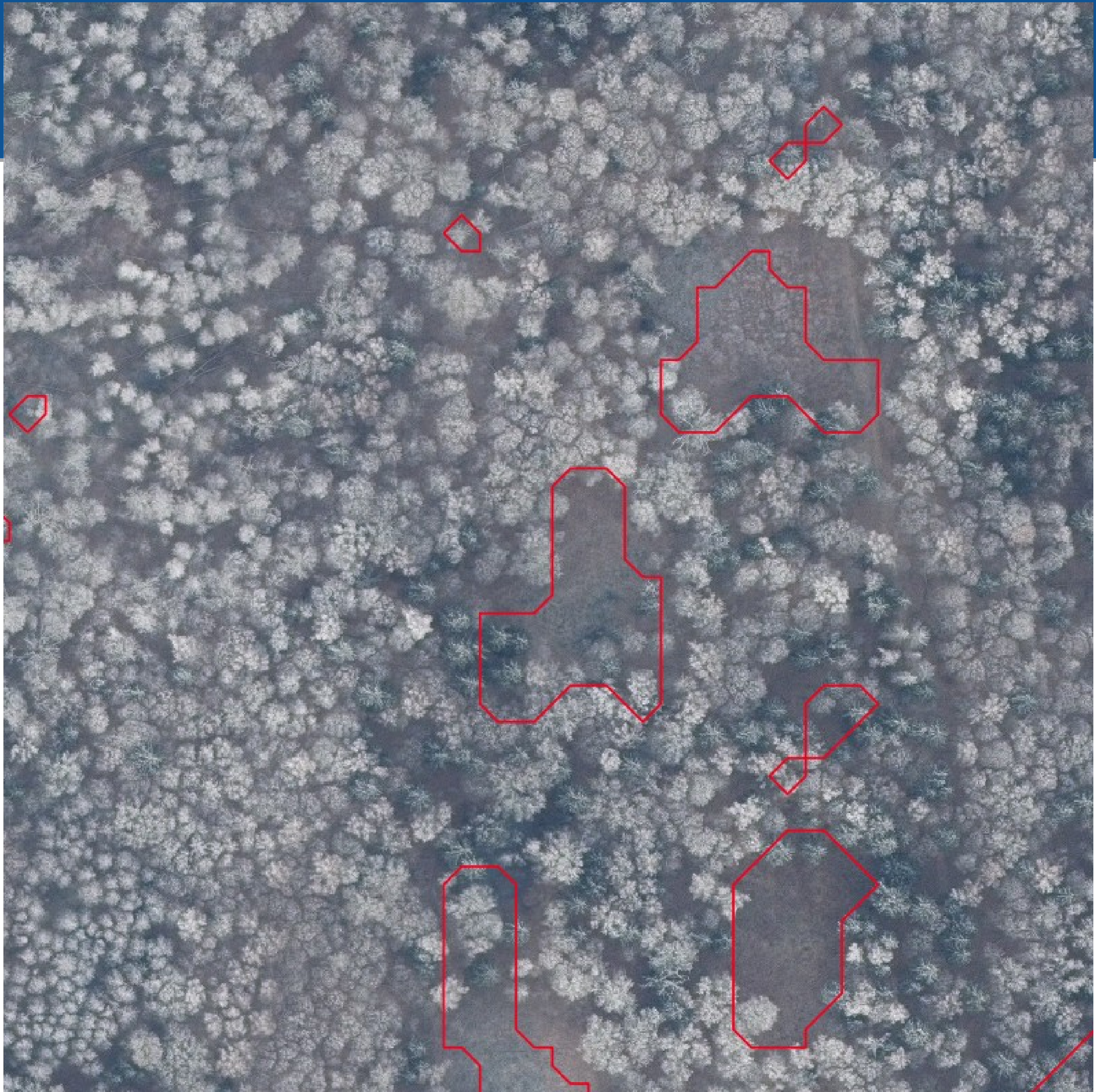
Results

Base image WV3 10-01-2018

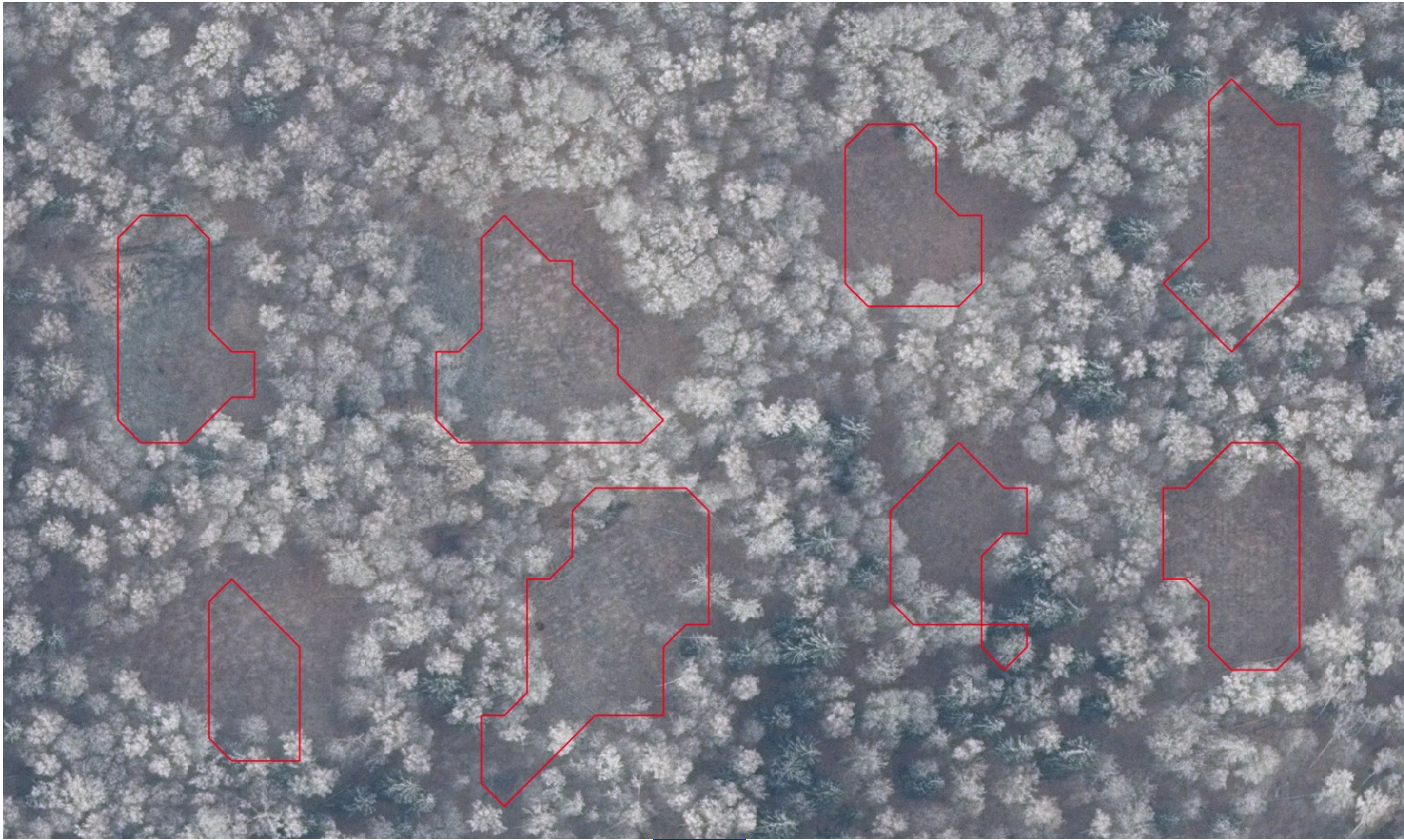


Results

Base image WV3 31-08-2017

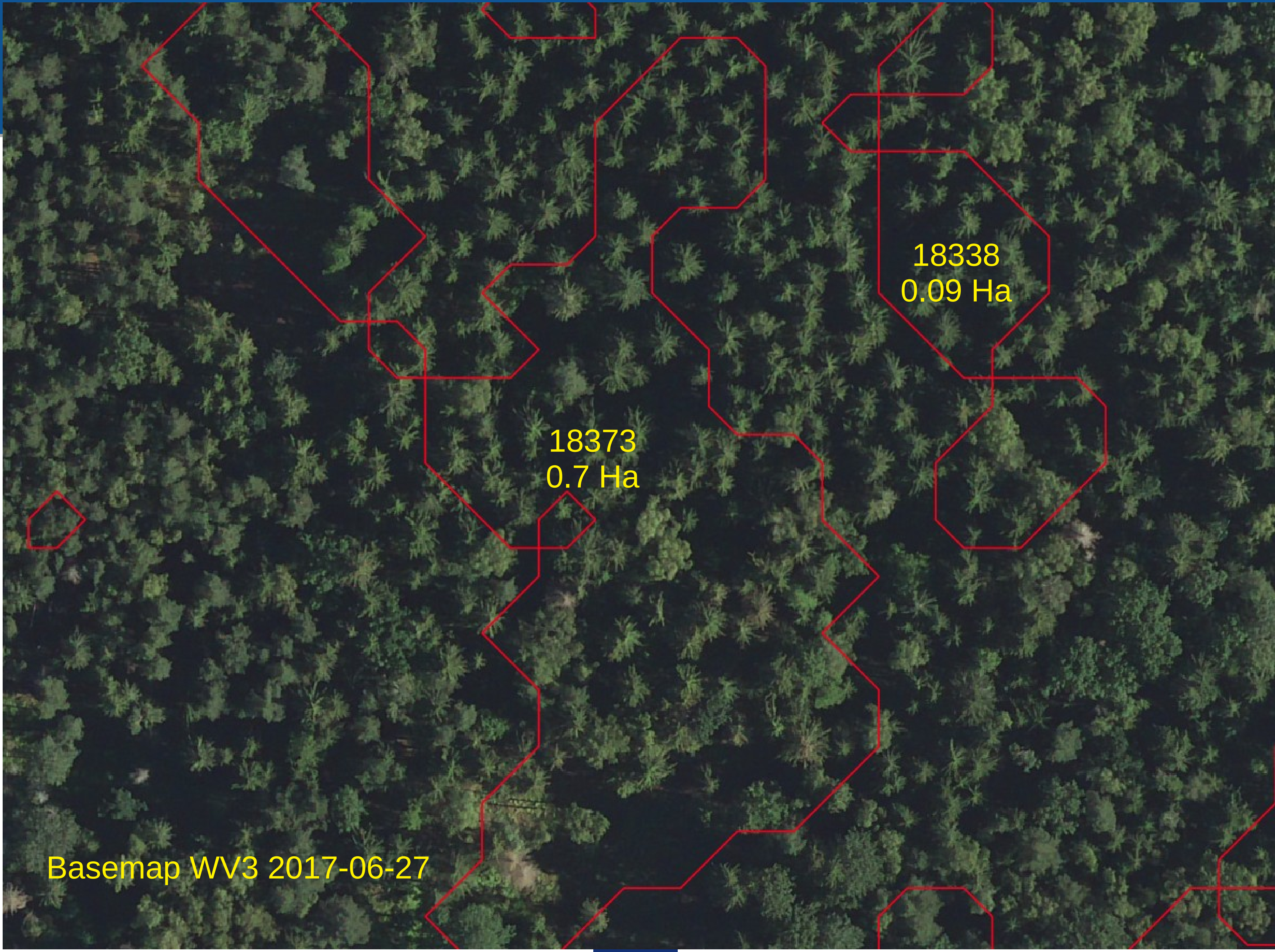


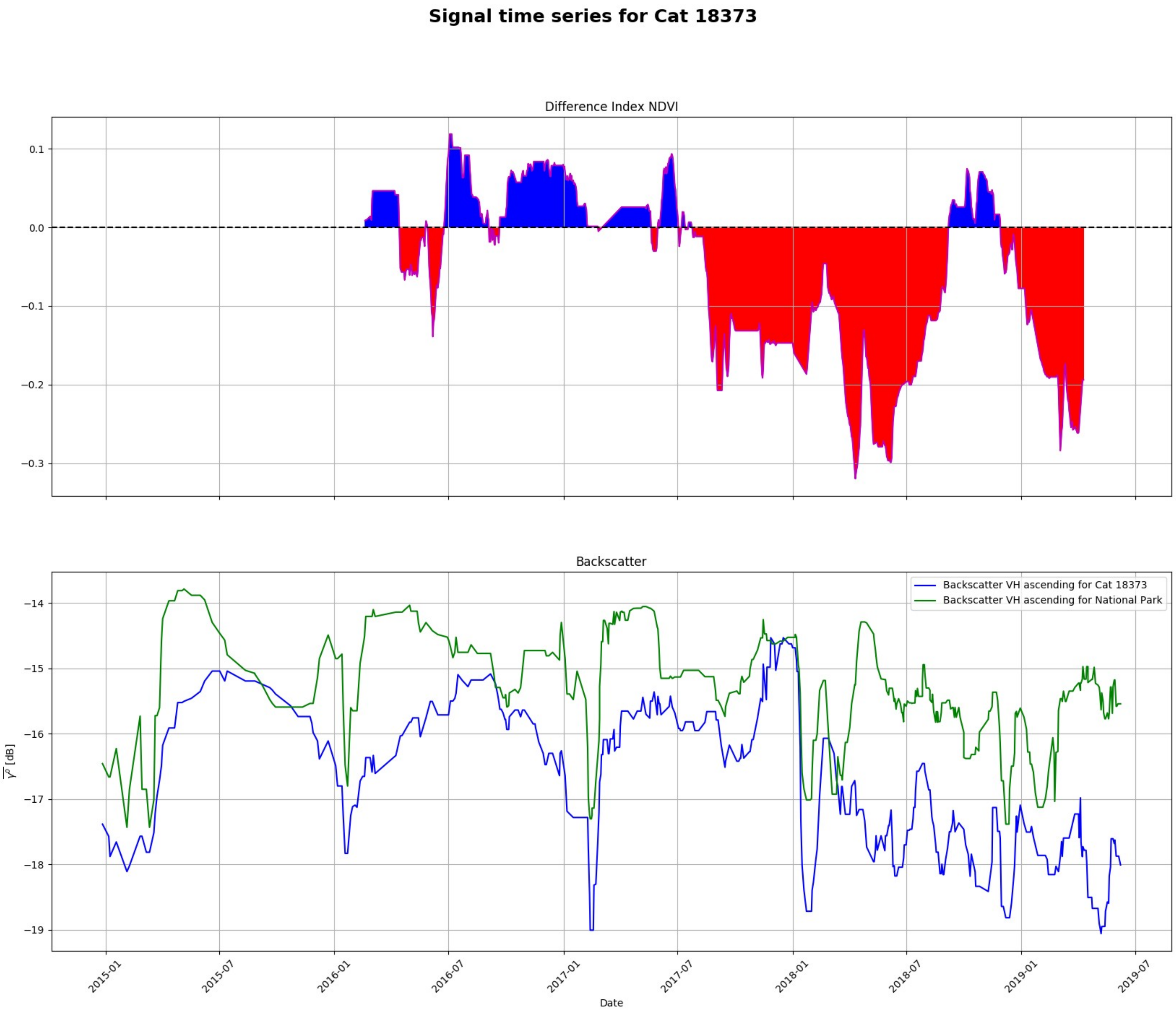
Results



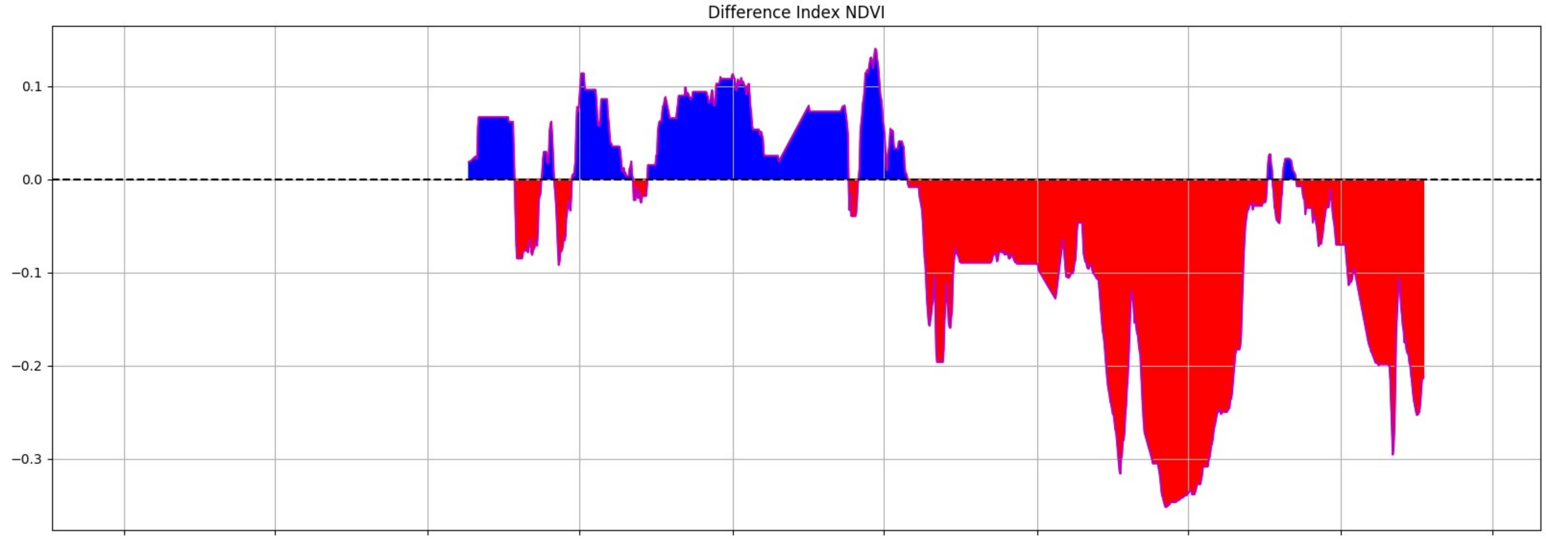

18338
0.09 Ha
18373
0.7 Ha
Basemap WV3 2018-01-10

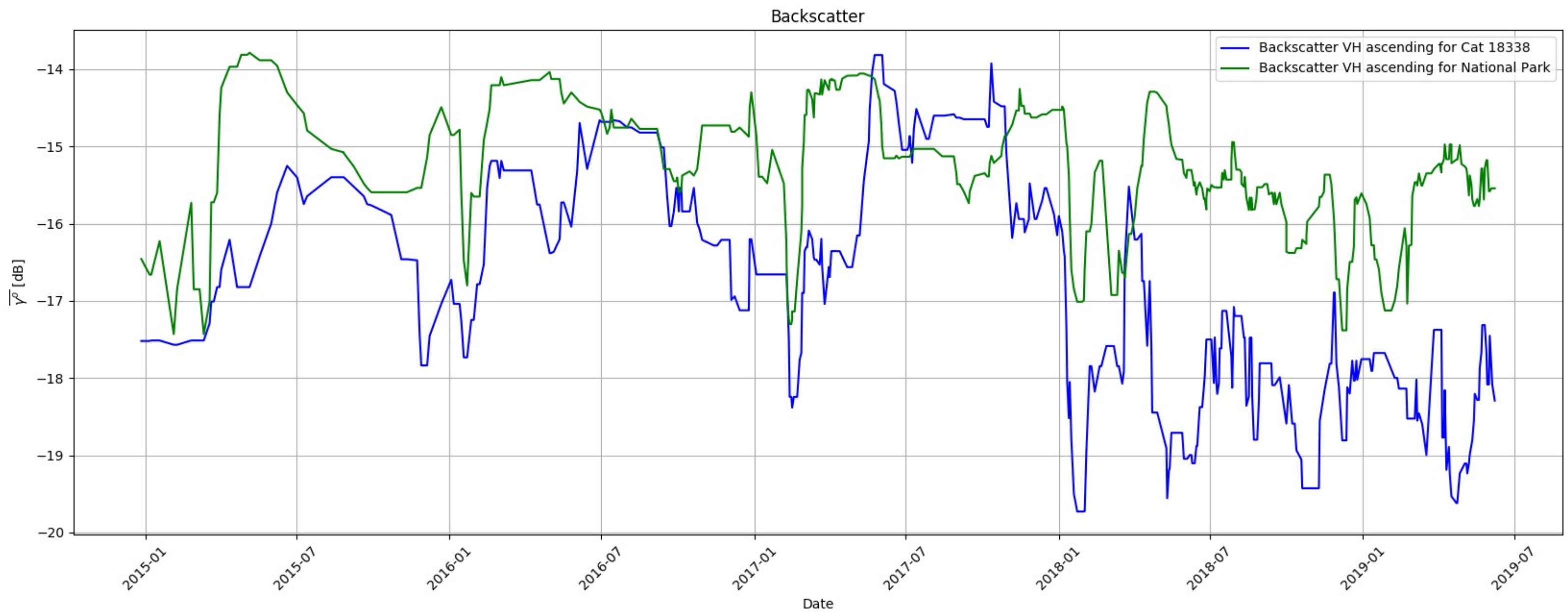

18338
0.09 Ha
18373
0.7 Ha
Basemap WV3 2017-08-31


18338
0.09 Ha
18373
0.7 Ha
Basemap WV3 2017-06-27


Signal time series for Cat 18373
Difference Index NDVI
0.1
0.0
−0.1
−0.2
−0.3
Backscatter
Backscatter VH ascending for Cat 18373
Backscatter VH ascending for National Park
−14
−15
−16
−17
−18
−19
γ⁰ [dB]
2015-01
2015-07
2016-01
2016-07
2017-01
2017-07
2018-01
2018-07
2019-01
2019-07
Date

Signal time series for Cat 18338



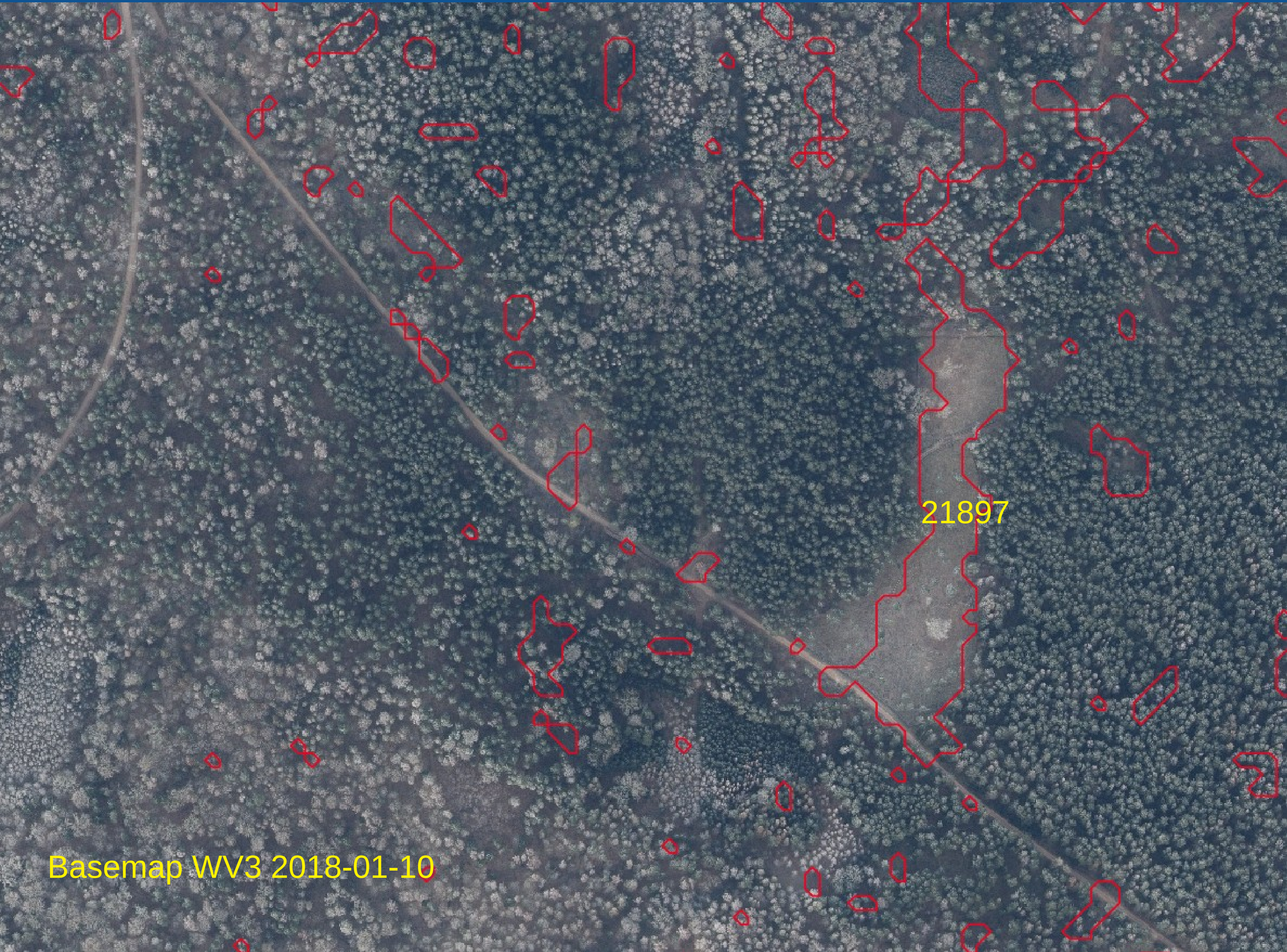


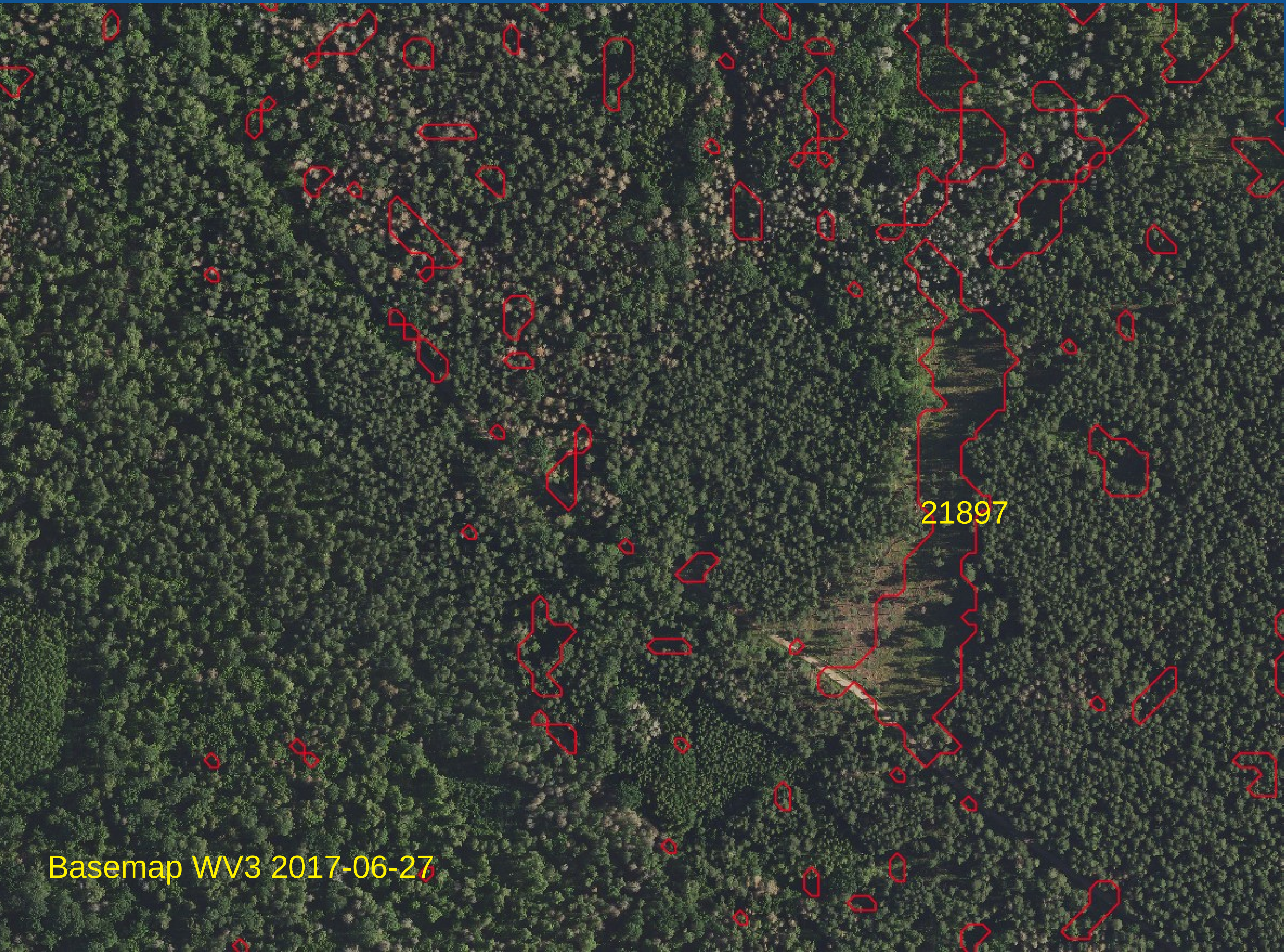
Conclusions

- False color composites of SAR scenes → snapshots in time of forest coverage
- Small scale changes in forest coverage → mapped using pixel-level statistics of time series S-1 imagery
- Zonal statistics of backscatter over polygons through time → insights of sudden changes in forest coverage such as clearcuts
- Zonal statistics of NDVI → add information regarding vegetation condition

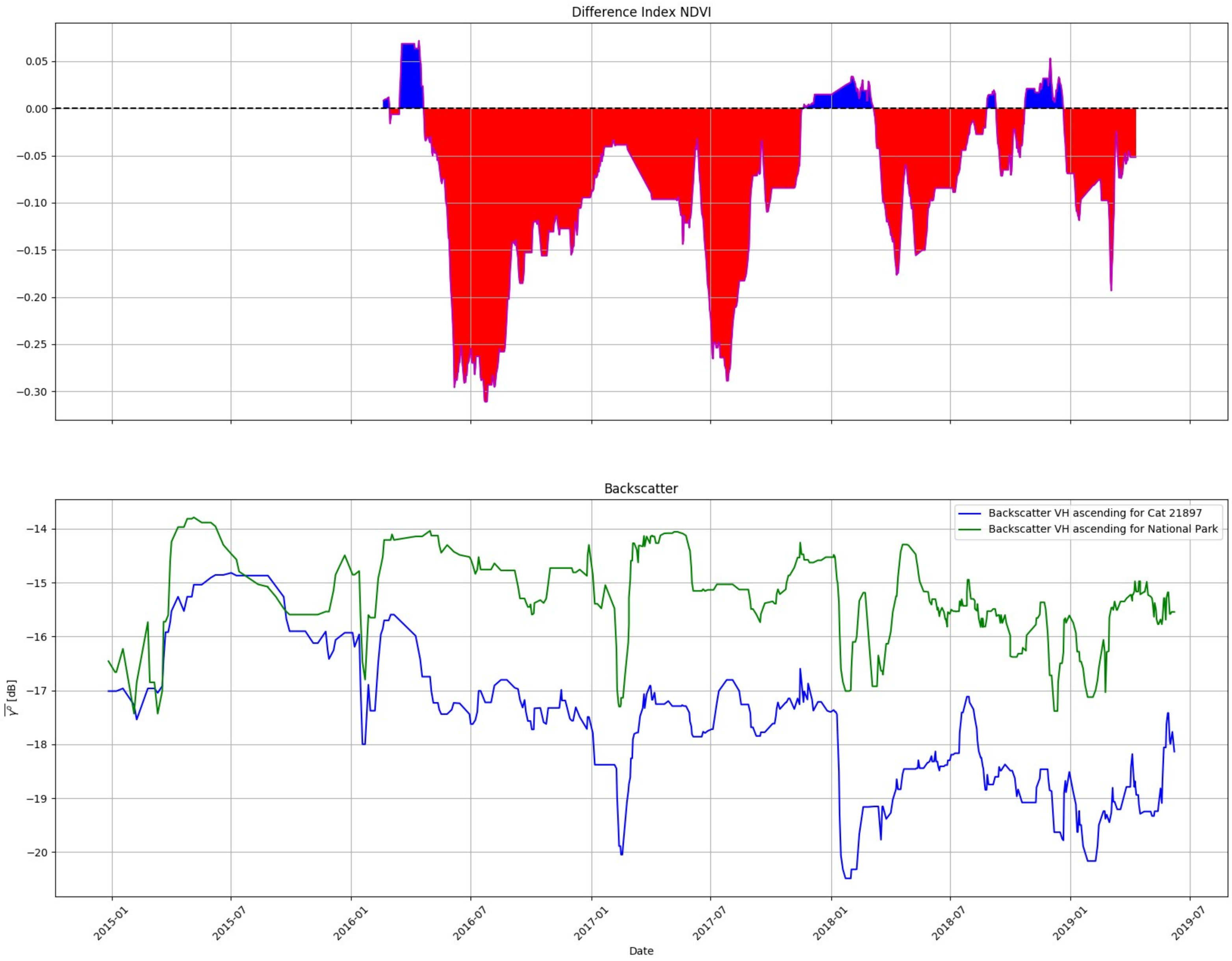
European Commission

Thank you!


21897
Basemap WV3 2018-01-10


21897
Basemap WV3 2017-06-27

Signal time series for Cat 21897

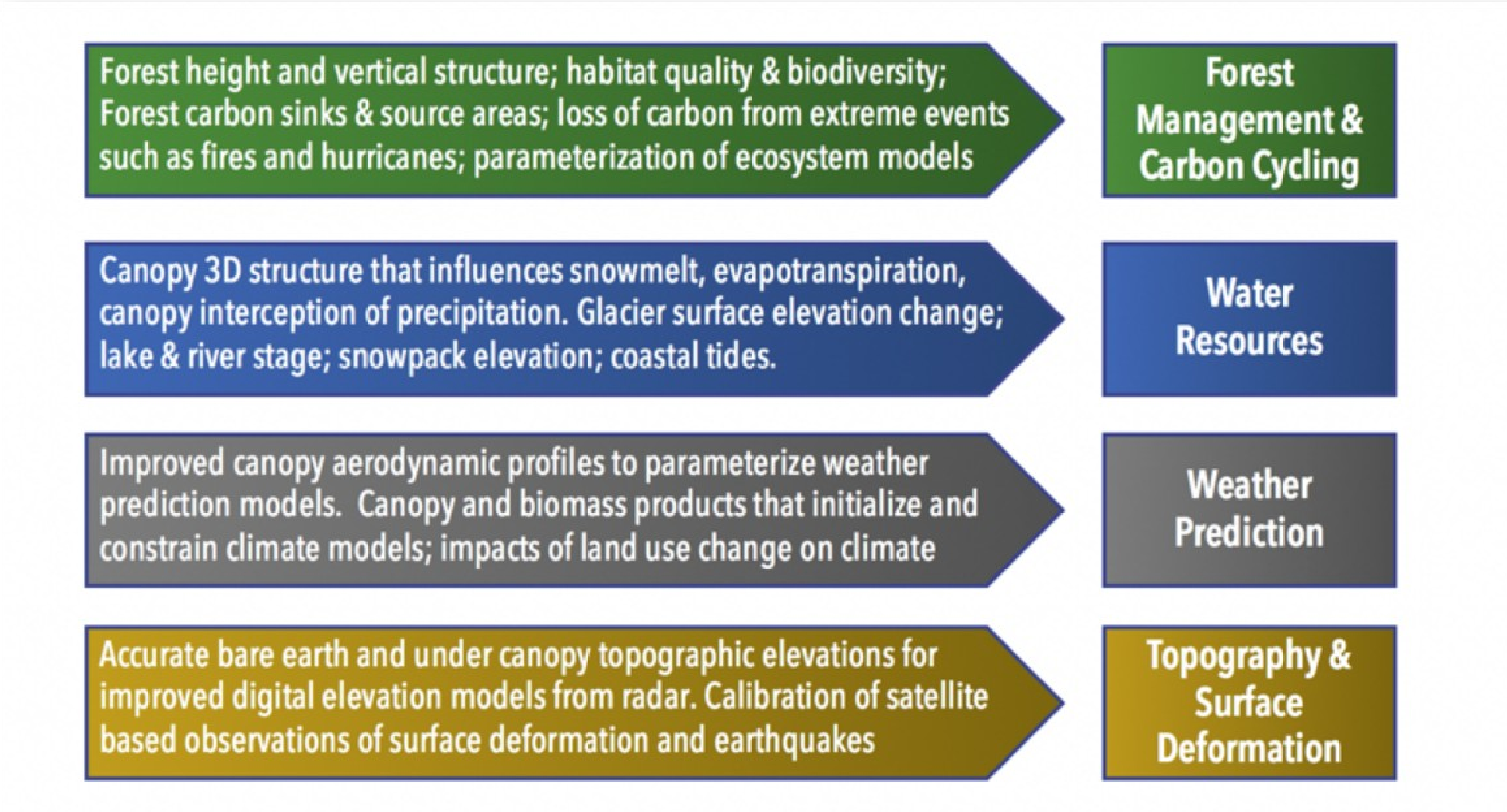


Upcoming space missions relevant for forest monitoring

NISAR (NASA-ISRO Synthetic Aperture Radar) : Launch 2021; L-band (λ = 24.6cm); Repeat cycle: 12 days; access: Free and Open

Biomass mission (ESA) : Launch 2021; P-band (λ = 70.0cm); Repeat cycle: 17 days; access: Free and Open

GEDI mission (NASA) (**LiDAR**) : Launch 2018



GEDI'S CANOPY AND SURFACE 3D MEASUREMENTS ADDRESS KEY CHALLENGES IN A VARIETY OF SCIENTIFIC AREAS.

Source: https://gedi.umd.edu/applications/application-overview/