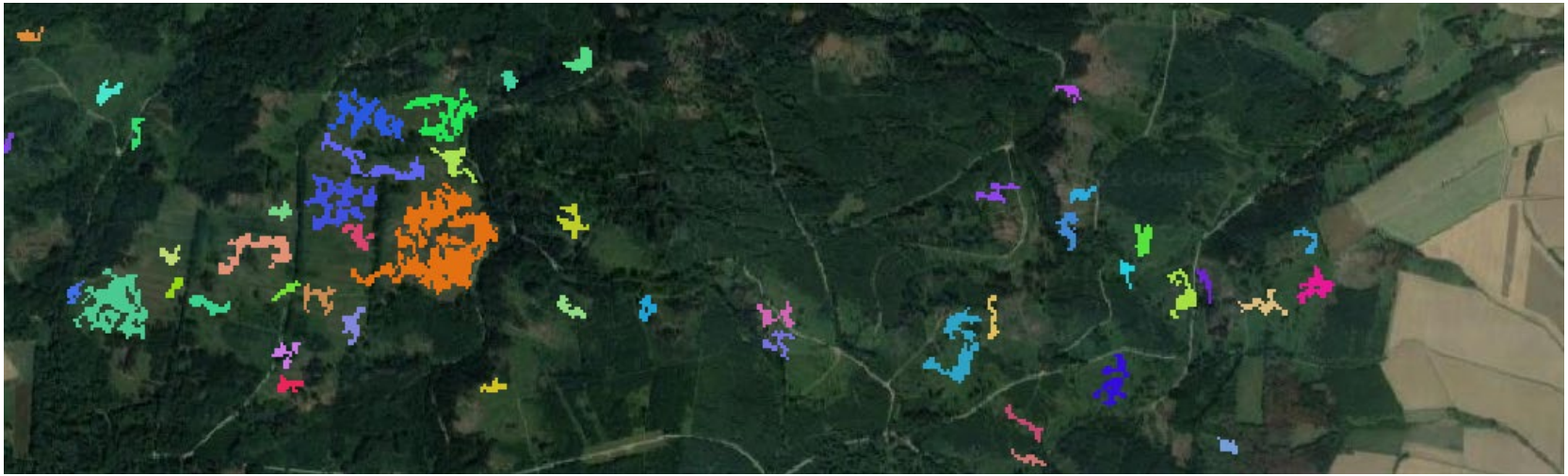
Rapid Sentinel-1-based detection of windthrows – first results of the FNEWs project



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Introduction & relevance

- FNEWs fnews-wald.de/en
  - Automated nationwide remote sensing-based monitoring system for forest damage
  - Consortium of several partners lead by the Thünen institute

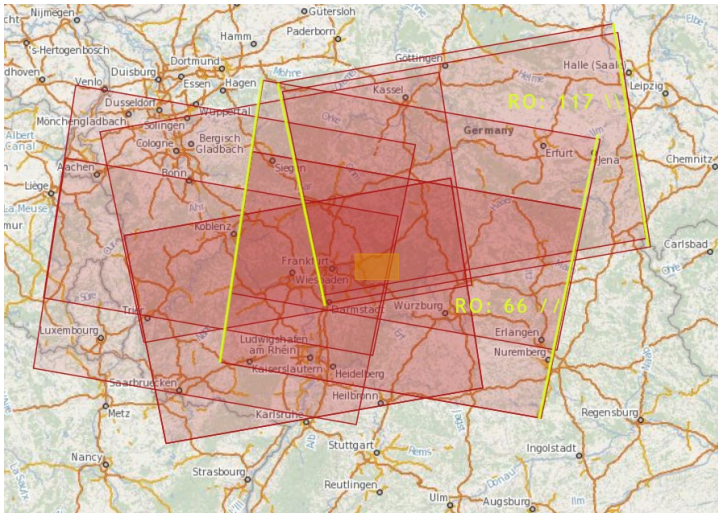
- Synthetic Aperture Radar (SAR) for rapid detection of windthrows
  - Large and disastrous storm events mainly in autumn and winter (Usbeck et al., 2010)
  - Challenging conditions to work with optical data
  - Potential to use Sentinel-1 SAR data for first overview

Usbeck et al., 2010. Increasing storm damage to forests in Switzerland from 1858 to 2007. Agric. For. Meteorol. 150, 47–55. https://doi.org/10.1016/j.agrformet.2009.08.010

FNEWs research questions

- Is it possible to use Sentinel-1 (S1) SAR data to detect windthrows in different forests and winter conditions (e.g. leaf-off trees, snow)?

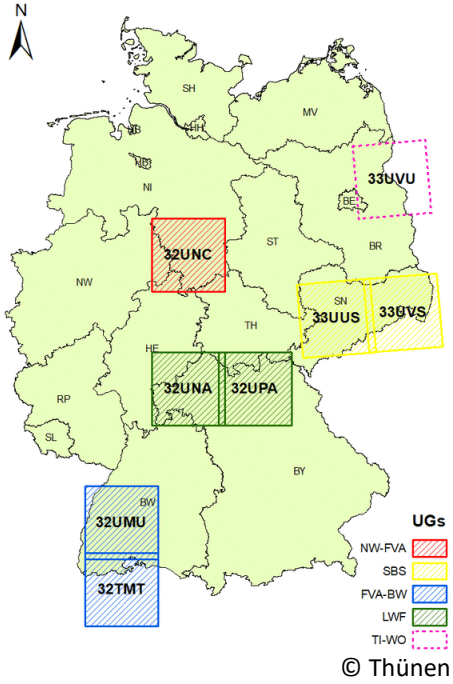
- Is it beneficial to use all available S1 acquisitions or are one ascending and one descending track enough?



Reference data

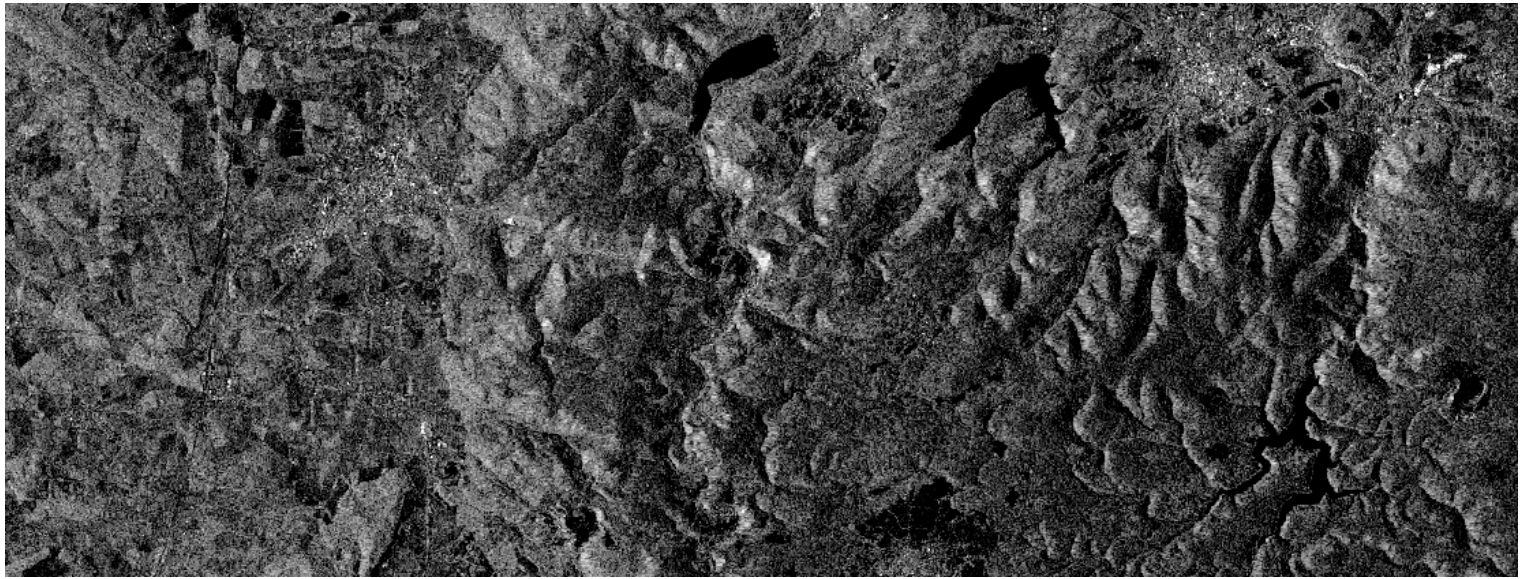
- Delineated areal windthrows (>0.5 ha) and intact forest areas of four different storm events

Location (State)	Storm event	Date	Sentinel-2 tile	n (>0.5ha)
Baden-Württemberg	Burglind	3.1.2018	32TMT	86
Bayern	Bernd	18.8.2019	32UNA	100
Niedersachsen	Friederike	18.1.2018	32UNC	1016
Sachsen	Friederike	18.1.2018	33UUS/33UVS	51



SAR data processing (step 1)

- Radiometric terrain flattening → RTC image (Small, 2011)
  - Geometric AND radiometric correction for terrain-effects
  - SNAP function “Radiometric terrain flattening”



[Contains modified Copernicus Sentinel data 2018]

Small, D., 2011. Flattening Gamma: Radiometric Terrain Correction for SAR Imagery. IEEE Trans. Geosci. Remote Sens. 49, 3081–3093. https://doi.org/10.1109/TGRS.2011.2120616

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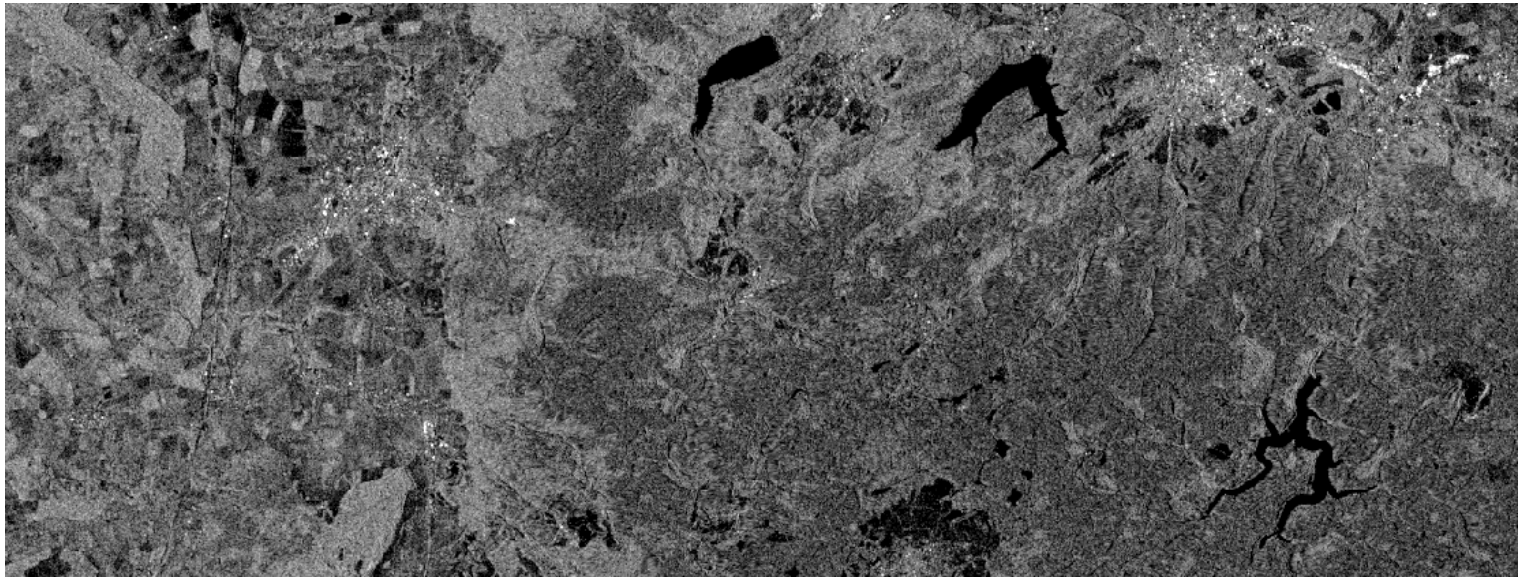

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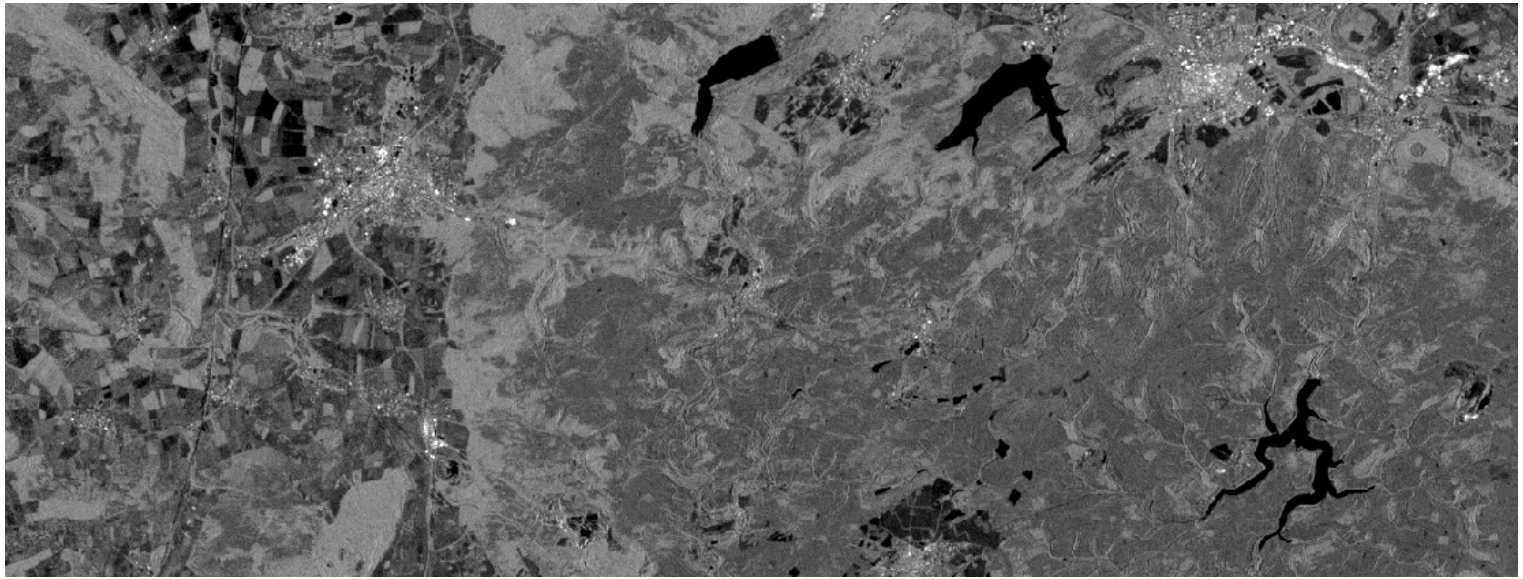
SAR data processing (step 2)

- Local resolution weighting → LRW composite (Small et al., 2022)
  - Combination of several RTC images (ascending und descending) within time window
  - SNAP function “Multitemporal compositing” (new!)

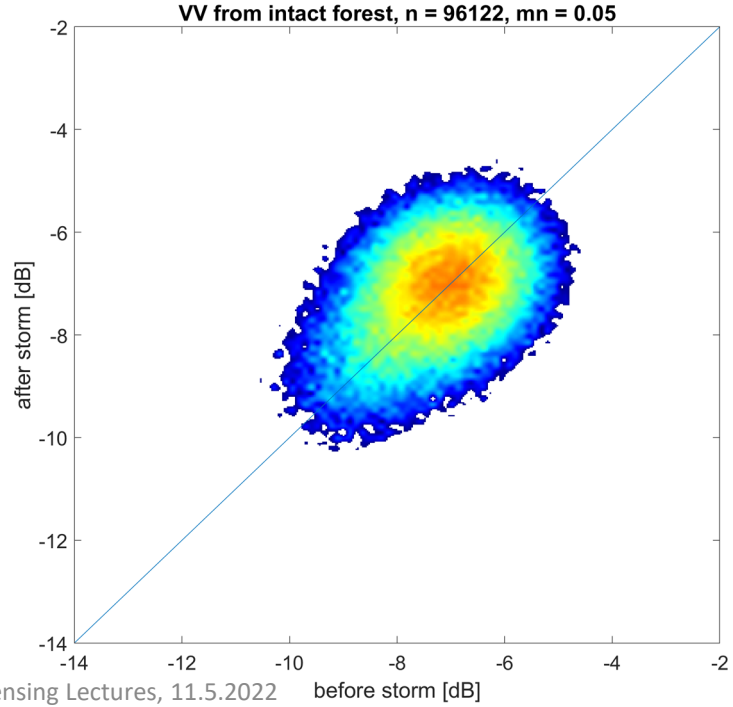


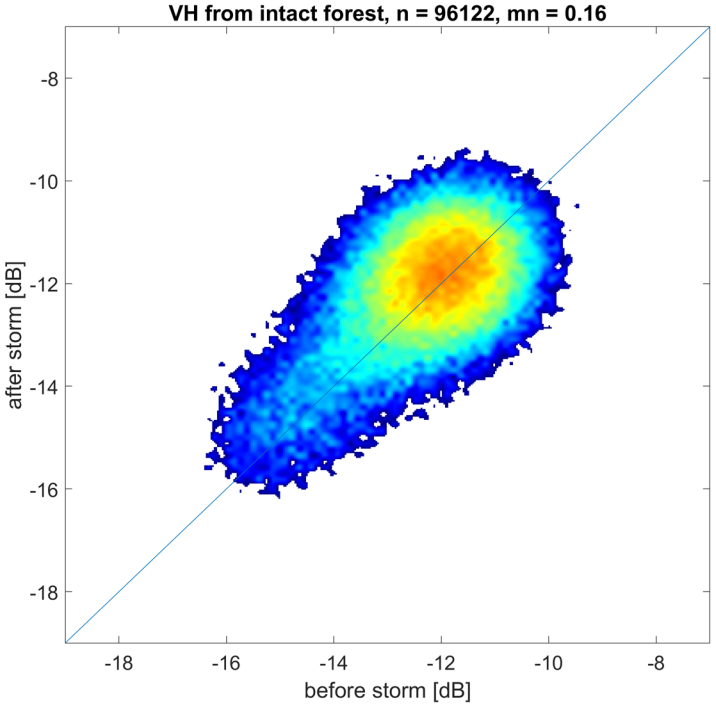
[Contains modified Copernicus Sentinel data 2018]

Small et al., 2022. Wide-Area Analysis-Ready Radar Backscatter Composites. IEEE Trans. Geosci. Remote Sens. 60. https://doi.org/10.1109/TGRS.2021.3055562

Windthrow detection method

- Method is based on tendency for *higher* SAR backscatter (VV- & VH-pol) from windthrown areas *after* the storm





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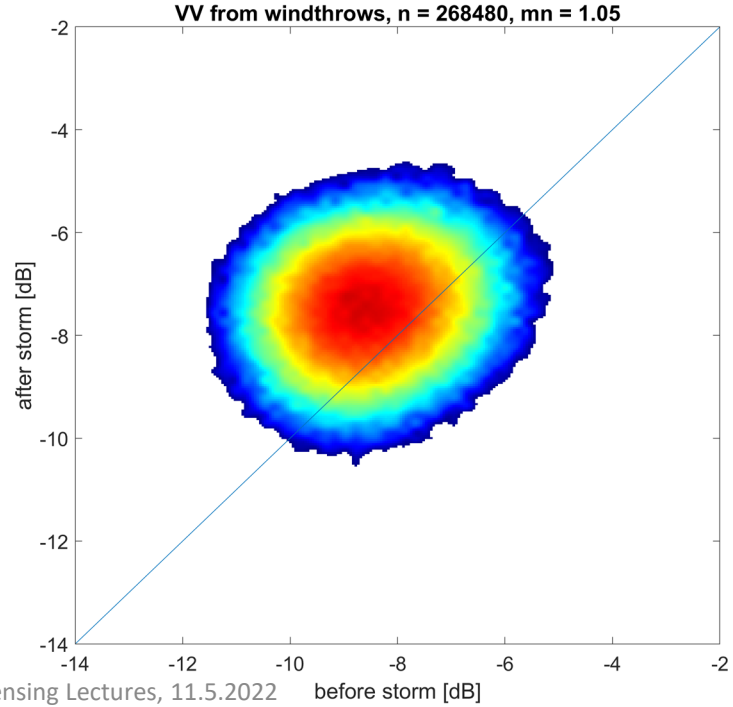
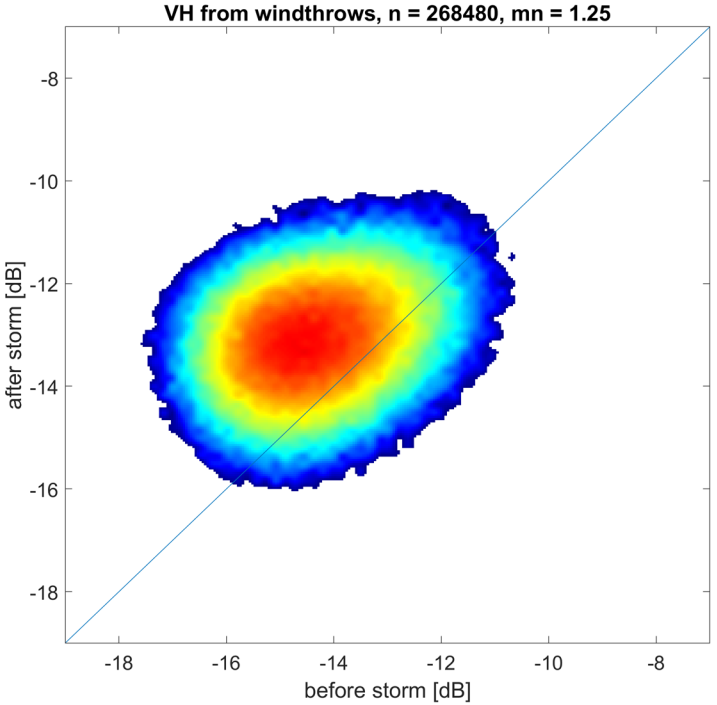


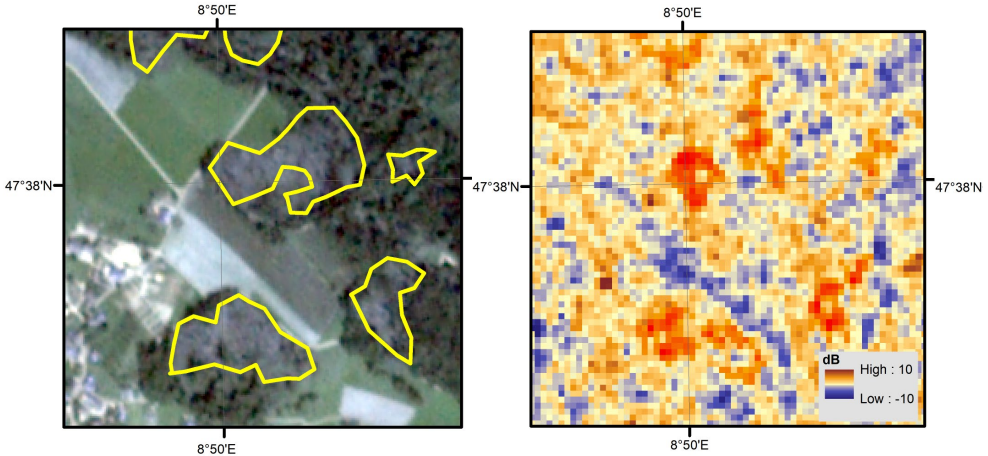


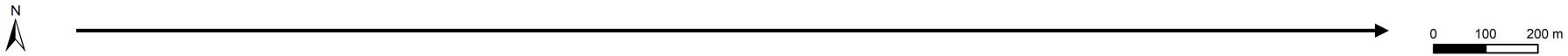
Windthrow detection method (Rüetschi et al., 2019)

- Calculation of LRW composite difference images for both polarisations

  → Heuristic ‘Windthrow Index’

$$WI = \left(\gamma^0_{LRW,VV,t2(post)} - \gamma^0_{LRW,VV,t1(pre)}\right) + \left(\gamma^0_{LRW,VH,t2(post)} - \gamma^0_{LRW,VH,t1(pre)}\right)$$



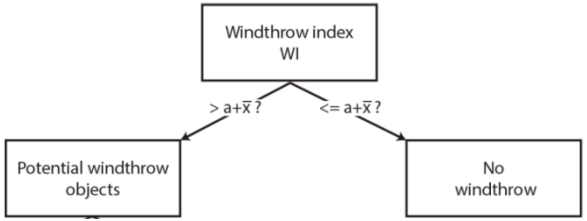


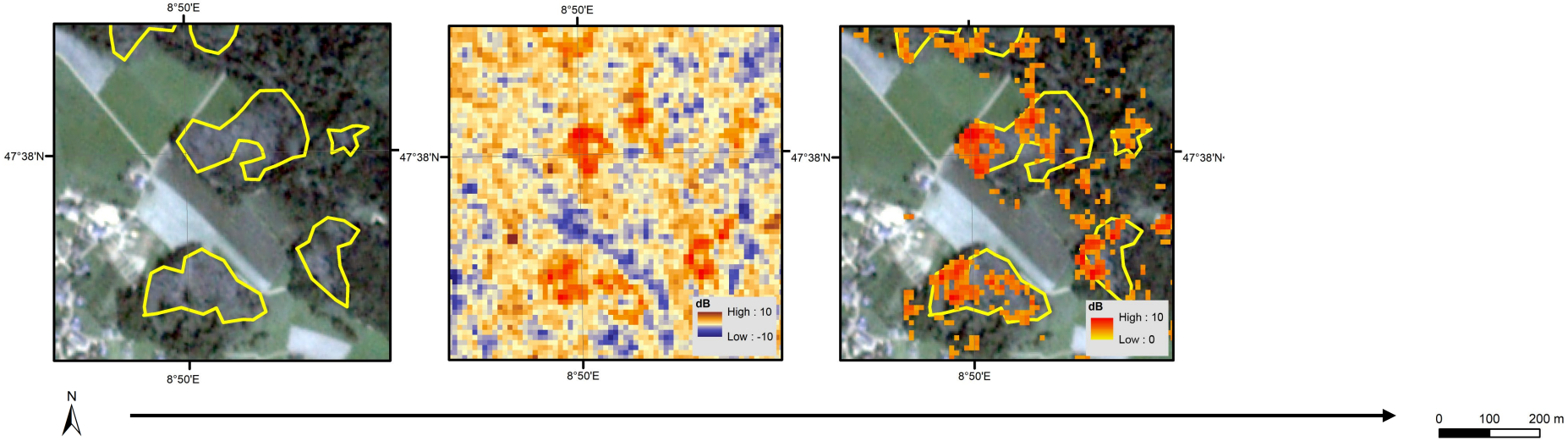
[Planet imagery & Contains modified Copernicus Sentinel data 2017]

Rüetschi et al., 2019. Rapid detection of windthrows using Sentinel-1 C-band SAR data. Remote Sens. 11, 115. https://doi.org/10.3390/rs11020115

Windthrow detection method (Rüetschi et al., 2019)

- Application of a decision tree
  - WI higher than threshold?
  - Threshold defined by
    - Parameter **a**
    - Mean WI value $\bar{x}$ within the whole forest area (Forest mask required)





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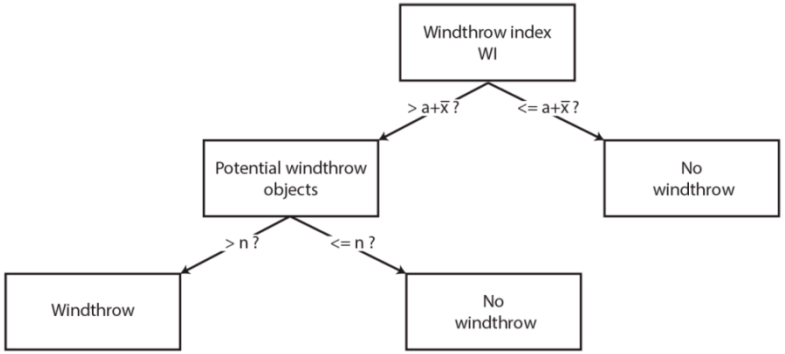
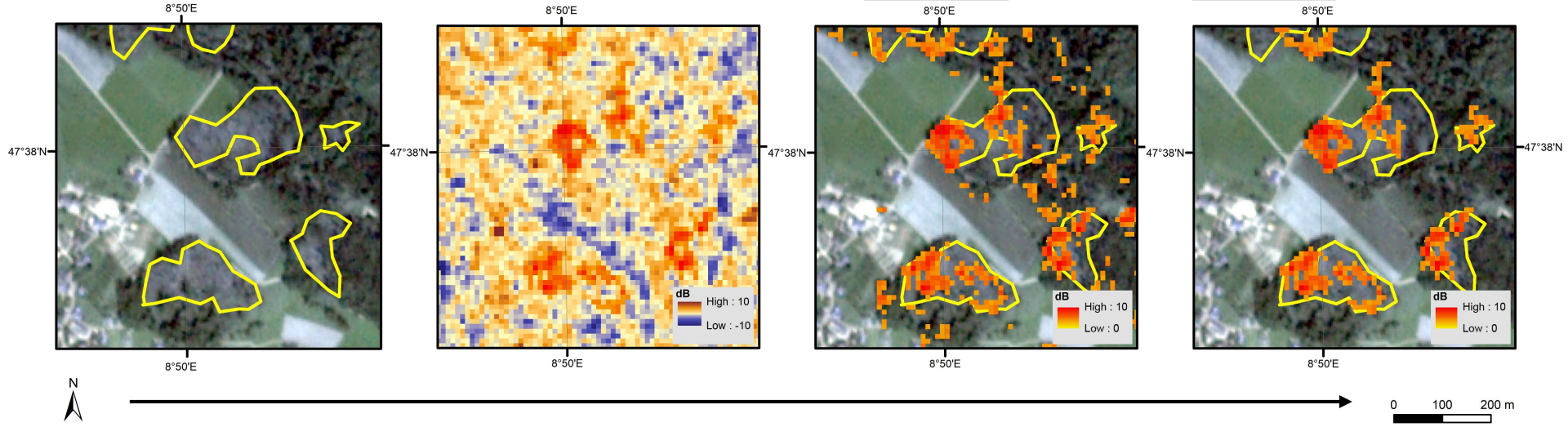
Windthrow detection method (Rüetschi et al., 2019)

- Application of a decision tree
  - Potential windthrow objects large enough?
  - Threshold defined by
    - Parameter **n** (Number of connected pixels)





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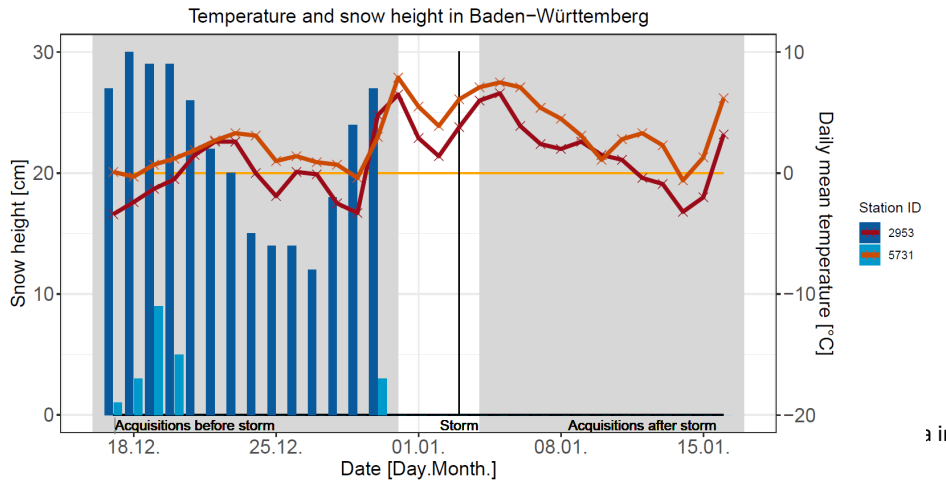
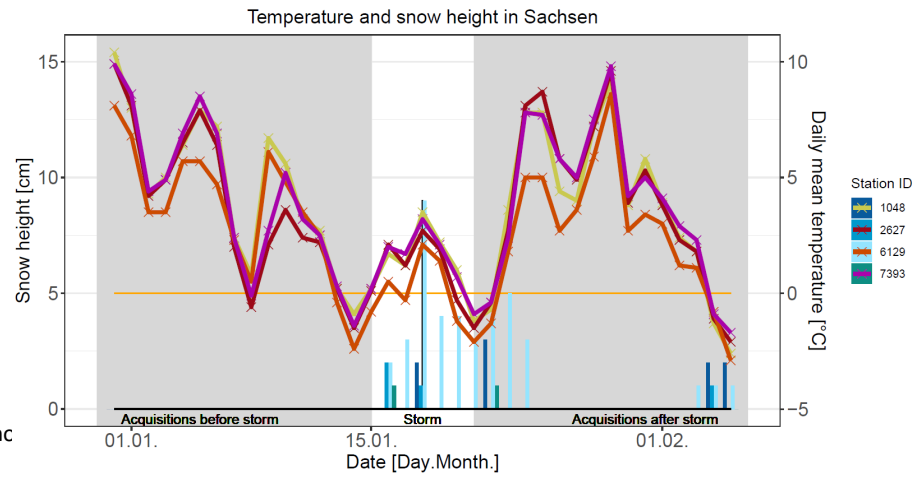
Results – influencing factors

- Meteorological factors on SAR backscatter

Study area	Windthrows VV mn	Intact forest VV mn	Difference
Baden-Württemberg	1.03	0.52	0.51
Bayern	0.29	0.00	0.29
Niedersachsen	1.05	0.05	1.00
Sachsen	-0.14	-0.39	0.25

  - Wet snow decreases C-band backscatter (Koskinen et al. 1997)





Results – influencing factors

- Structural properties of forests – **dominant species** (Lapini et al., 2020)
  - Focus on study areas Bayern (BY, summer) and Niedersachsen (NI, winter)
  - No strong influence observed in Niedersachsen, slight tendency for higher difference from coniferous stands
  - Strong influence on VH-pol. observed in Bayern, negative difference in forest stands with pine

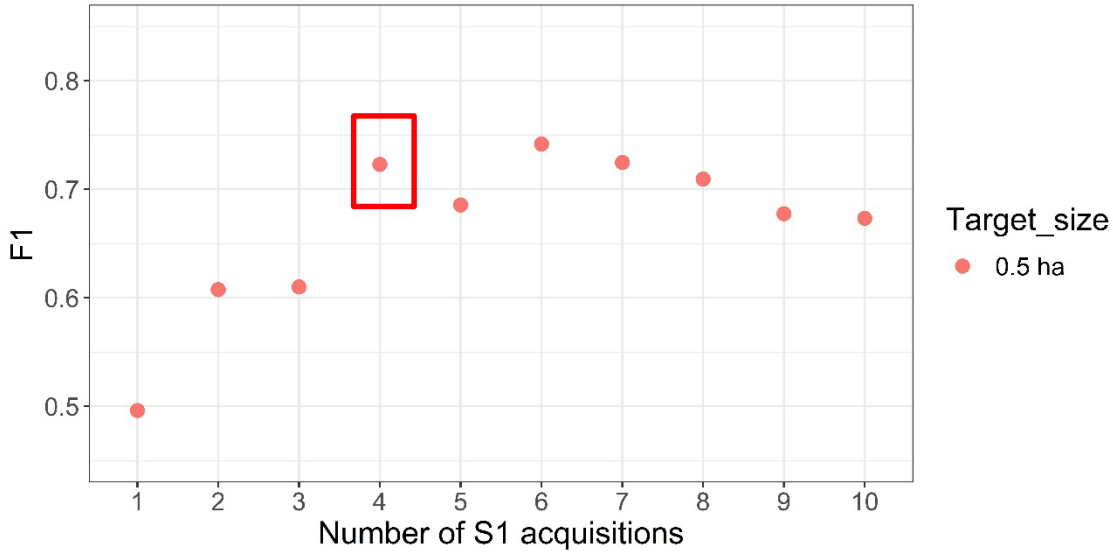
		Windthrows		Intact forest		Difference
		n	VH mn	n	VH mn	VH mn diff
Spruce (>90%)	**BY**	277	-0.3	631	-0.06	-0.24
	NI	54036	1.19	7491	0.28	0.91
Pine (>90%)	**BY**	6218	-0.39	346	0.26	-0.65
	NI	137	1.2	3867	0.29	0.91
Coniferous dom.	**BY**	9465	-0.1	4439	0.11	-0.22
	NI	9697	1.07	10829	0.16	0.9
Broad-leaved dom.	**BY**	3068	0.39	12436	0.04	0.36
	NI	922	0.39	20871	0.14	0.25
Broad-leaved (>90%)	**BY**	1220	0.72	4675	0.01	0.71
	NI	2093	0.85	43176	0.14	0.72

Lapini et al., 2020. Comparison of machine learning methods applied to SAR images for forest classification in mediterranean areas. Remote Sens. 12. https://doi.org/10.3390/rs12030369

Results – windthrow detection accuracy

- Only possible to detect windthrows (F1 > 0.5) in the study area Niedersachsen due to just shown influencing factors
- Deeper analyses possible in Niedersachsen

$$F1 = 2 \cdot \frac{UA \cdot PA}{UA + PA}$$



1 4 7 10 13 16 19 22 25 28 days after the storm

Study area Niedersachsen (areal windthrows >0.5 ha)

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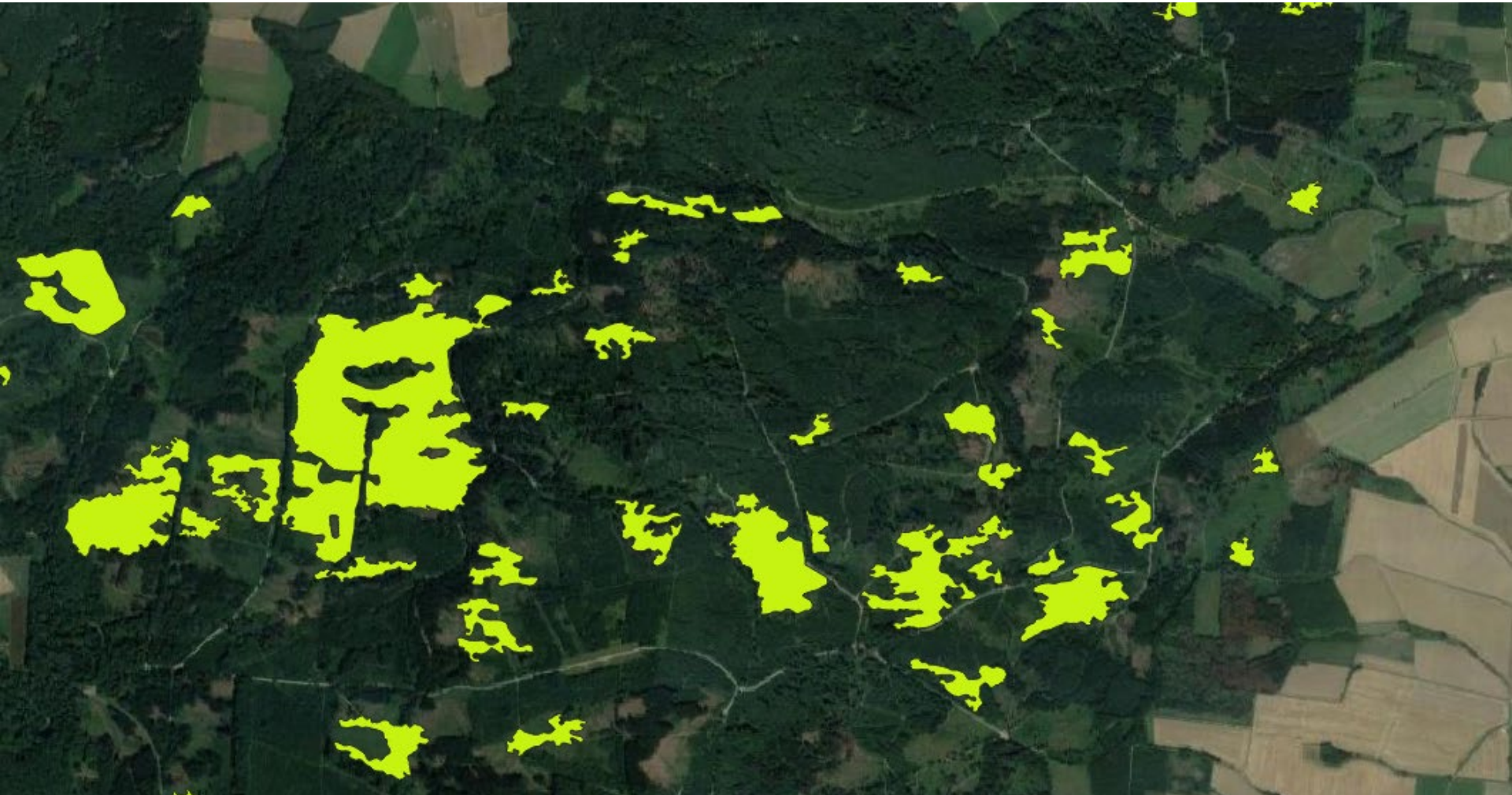

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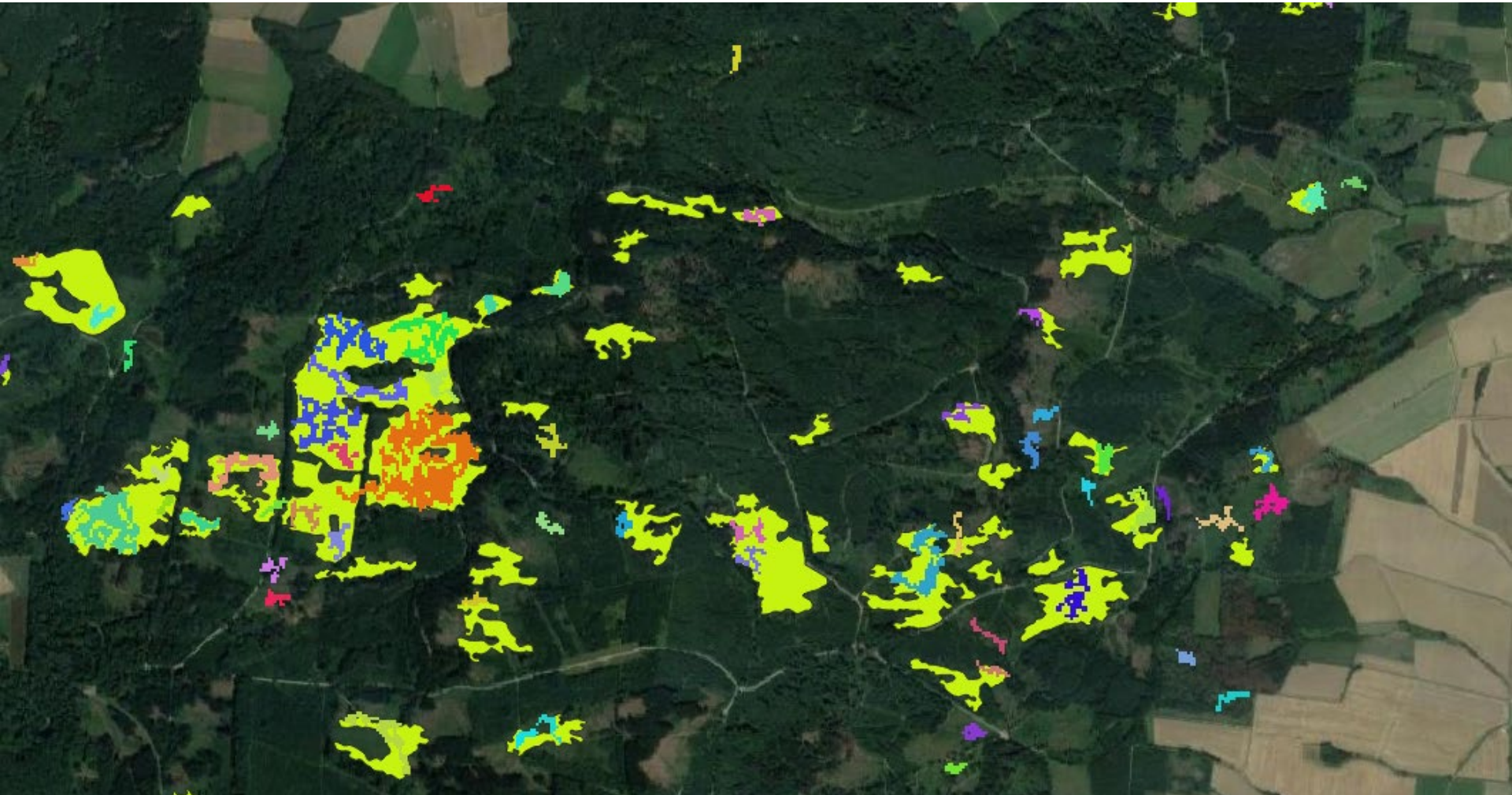

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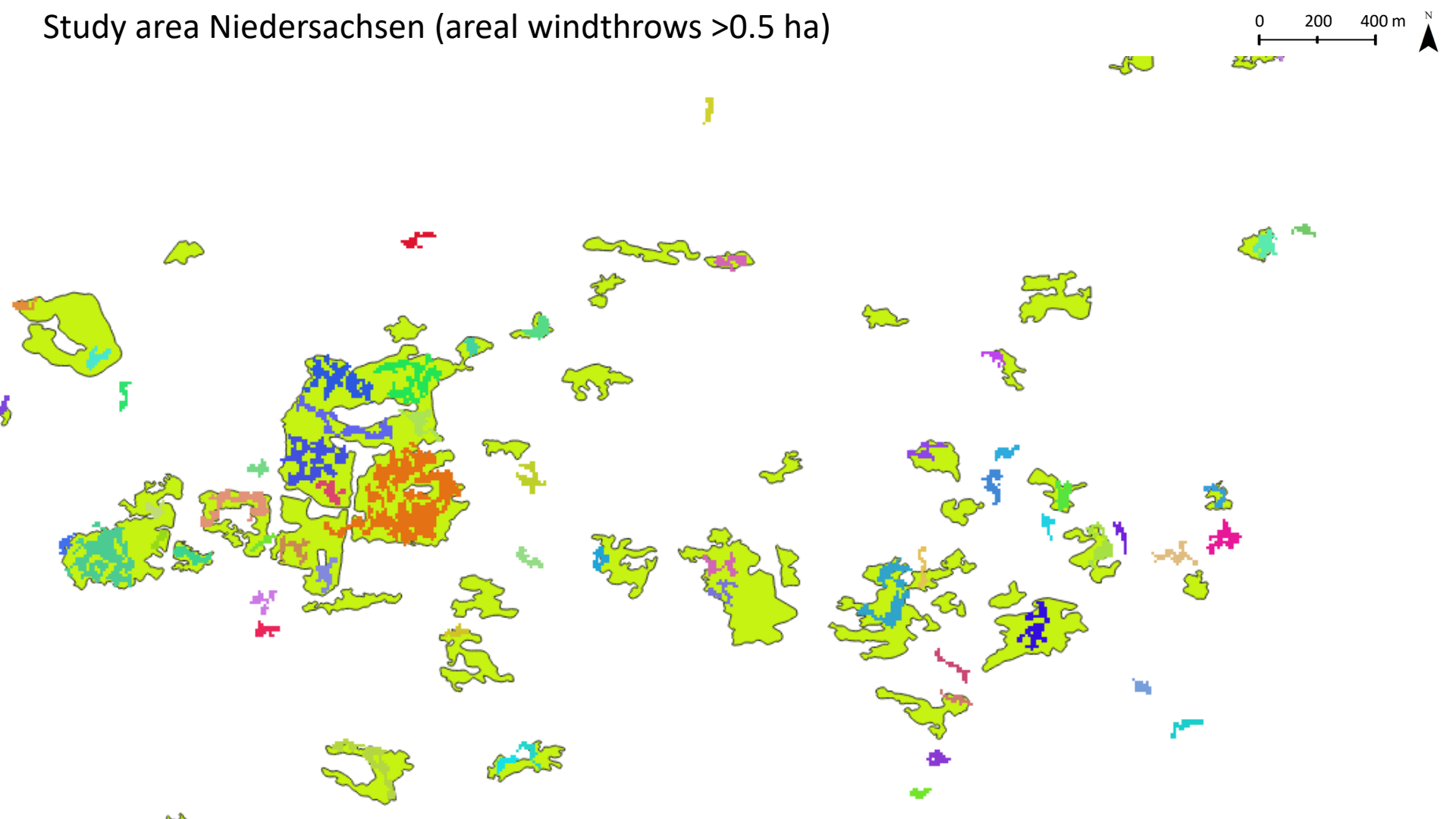

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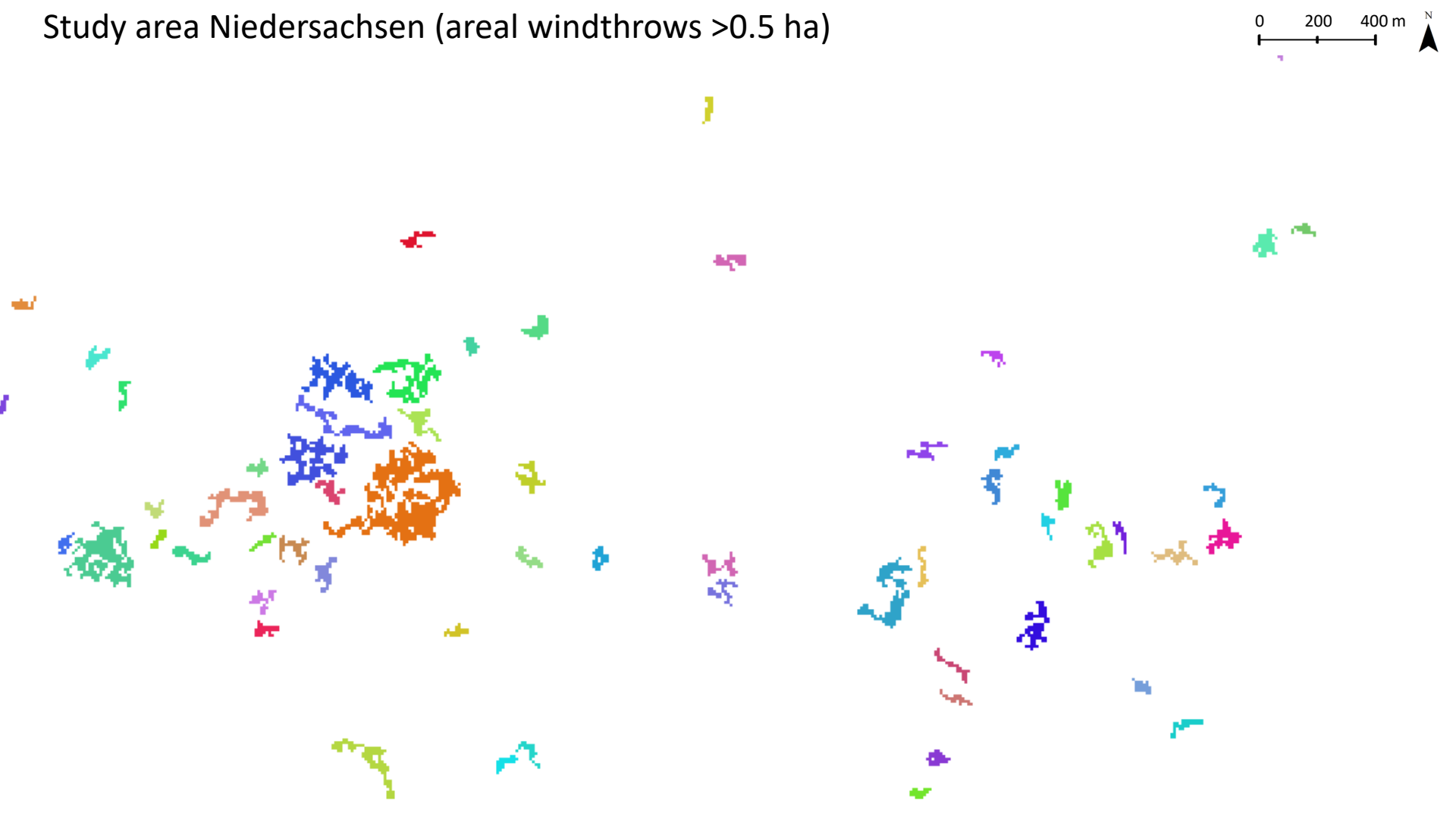
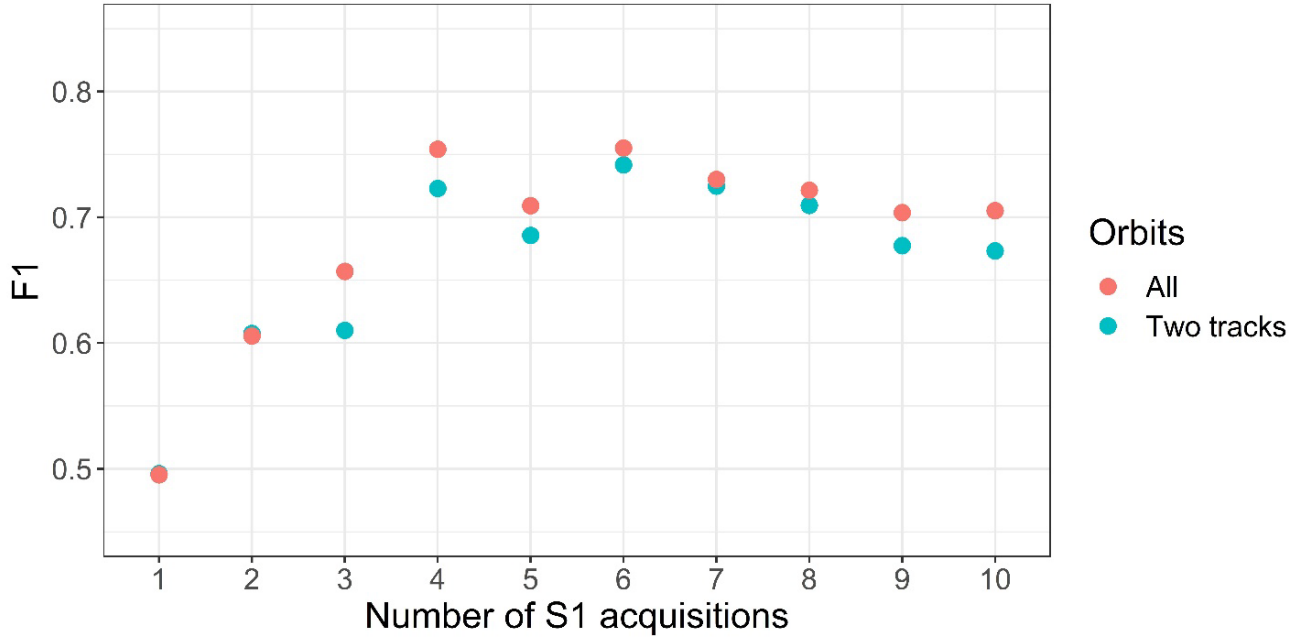
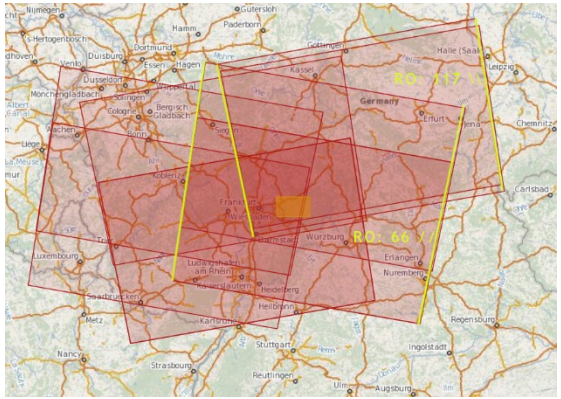


Results – windthrow detection accuracy

- Effect of using all available acquisitions or just from two tracks
  - Higher accuracy when using all acquisitions
  - Trade-off between higher accuracy and lower SAR data pre-processing effort





Conclusions

- Feasible to detect windthrow using S1 SAR data in winter conditions as shown in the study area Niedersachsen

- Further research needed to understand the factors that influence SAR backscatter to enable an operational use
  - Wet snow bias (e.g. Baden-Württemberg, Sachsen)
  - Structural properties of forests (e.g. Bayern)

- Use all available S1 acquisitions increases detection accuracy at the cost of longer time to pre-process the SAR data

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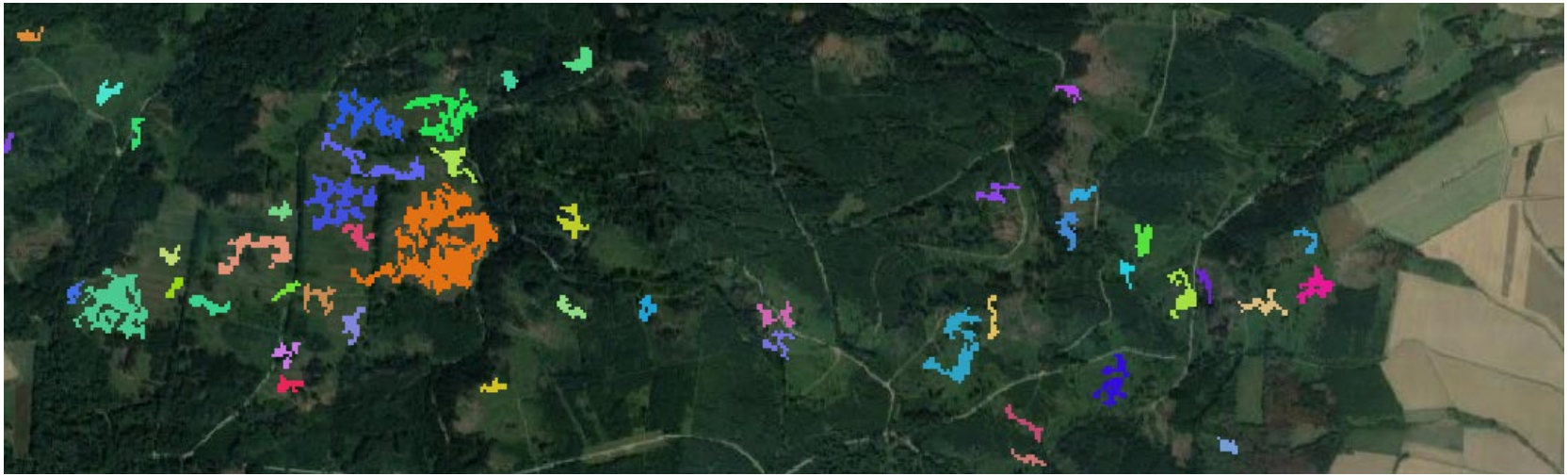

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