Unraveling Fire Permafrost Interactions in Northeastern Siberian Tundra Using InSAR and Machine Learning

Yukon Delta, South-western Alaska, June 7, 2015

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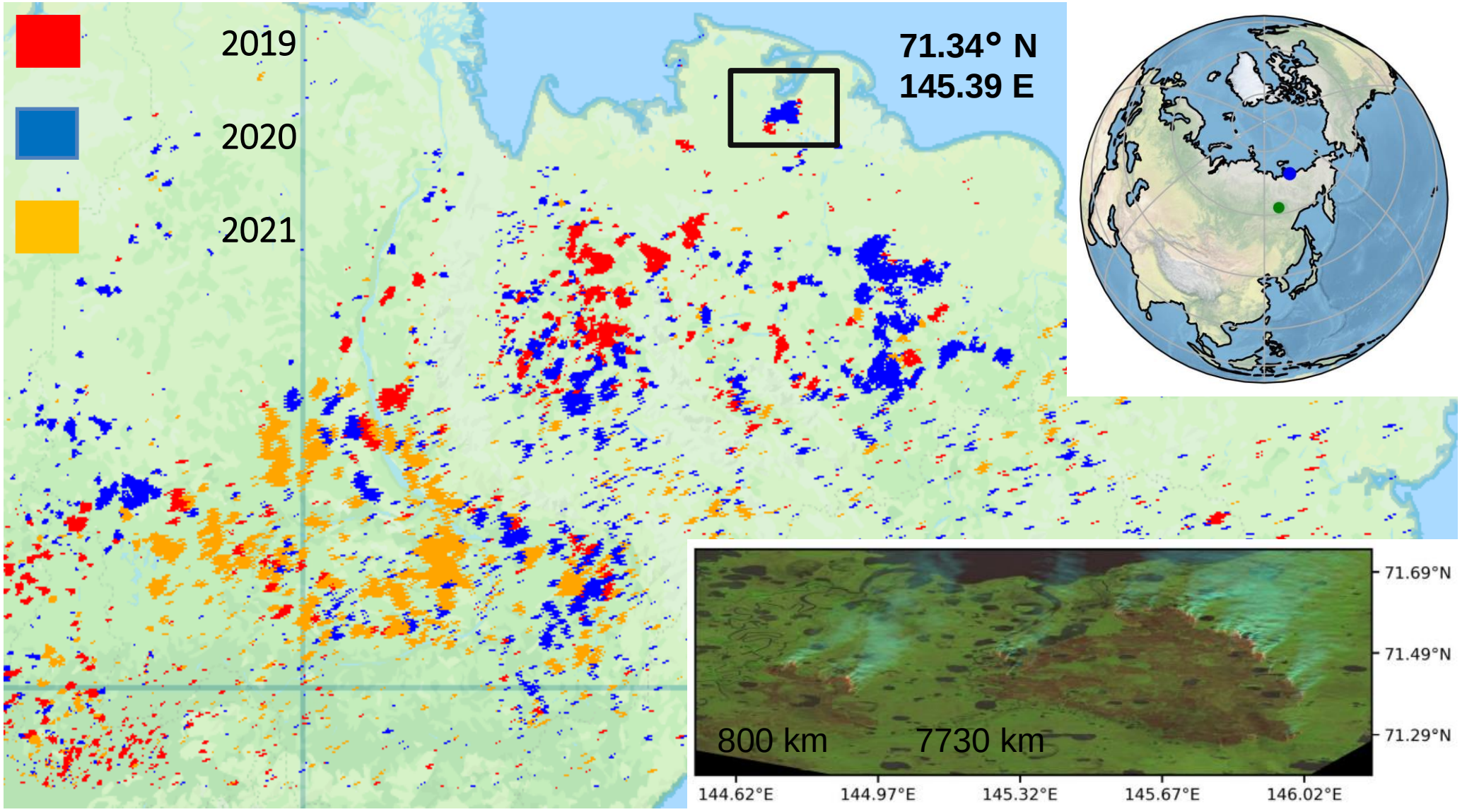
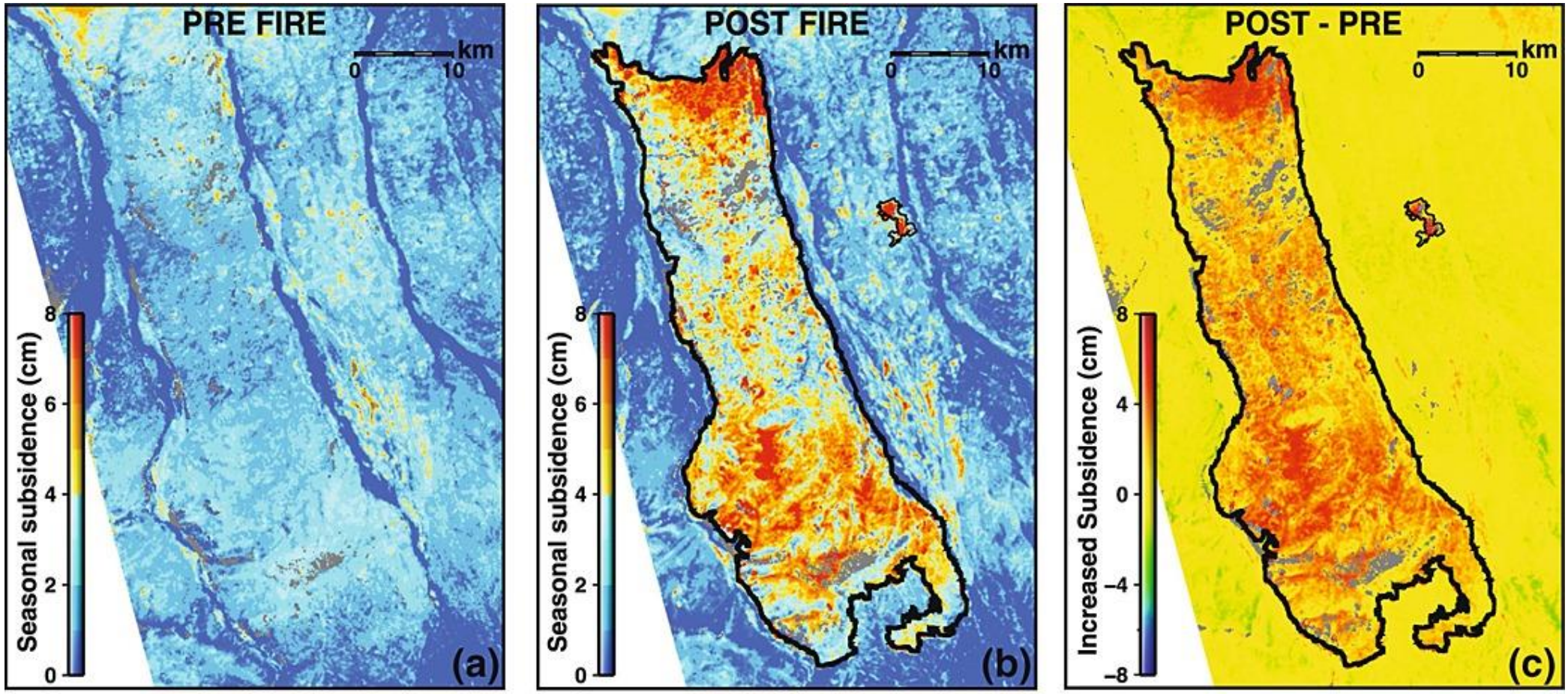
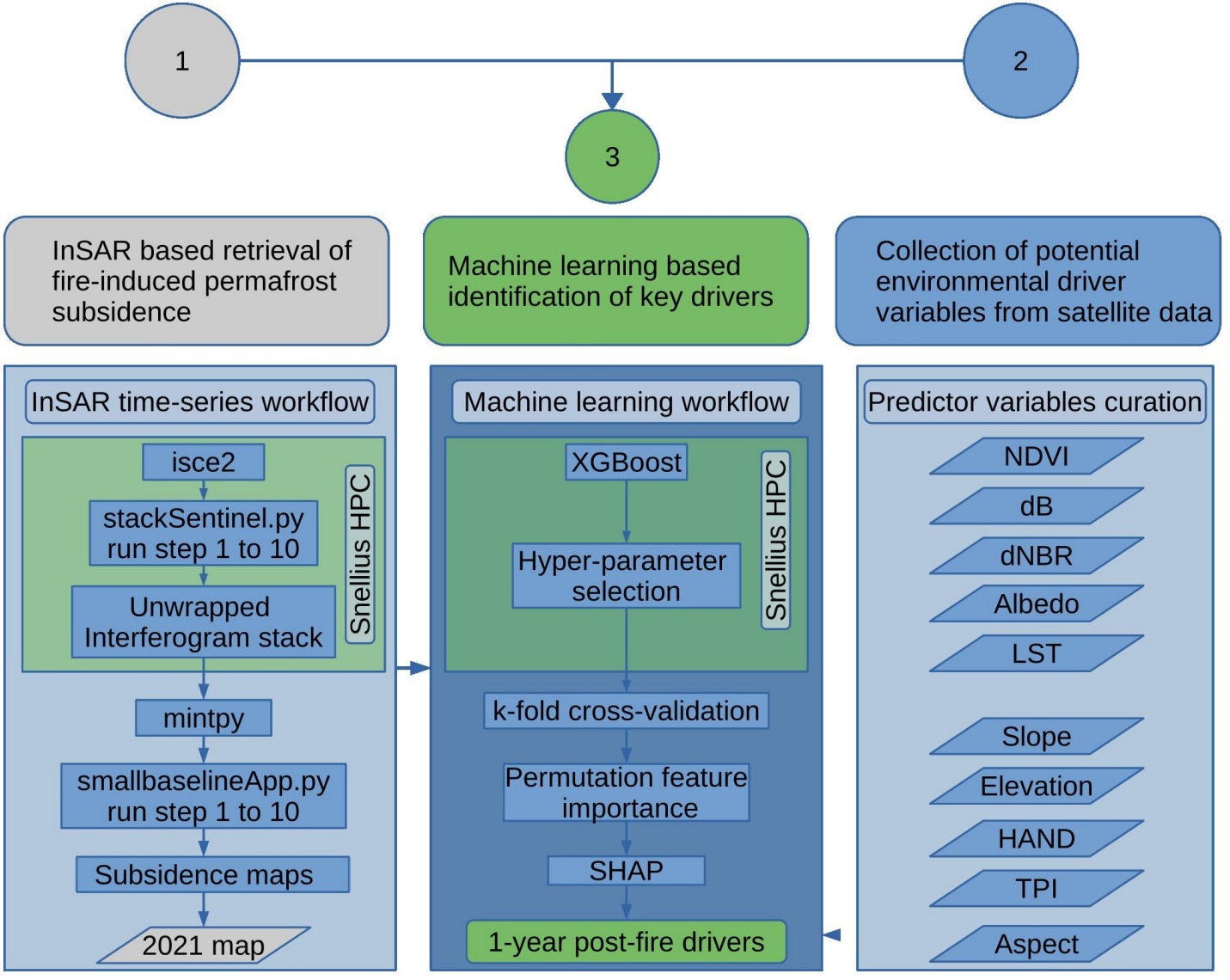

2019
2020
2021
71.34° N
145.39 E
800 km
7730 km
71.69°N
71.49°N
71.29°N
144.62°E
144.97°E
145.32°E
145.67°E
146.02°E



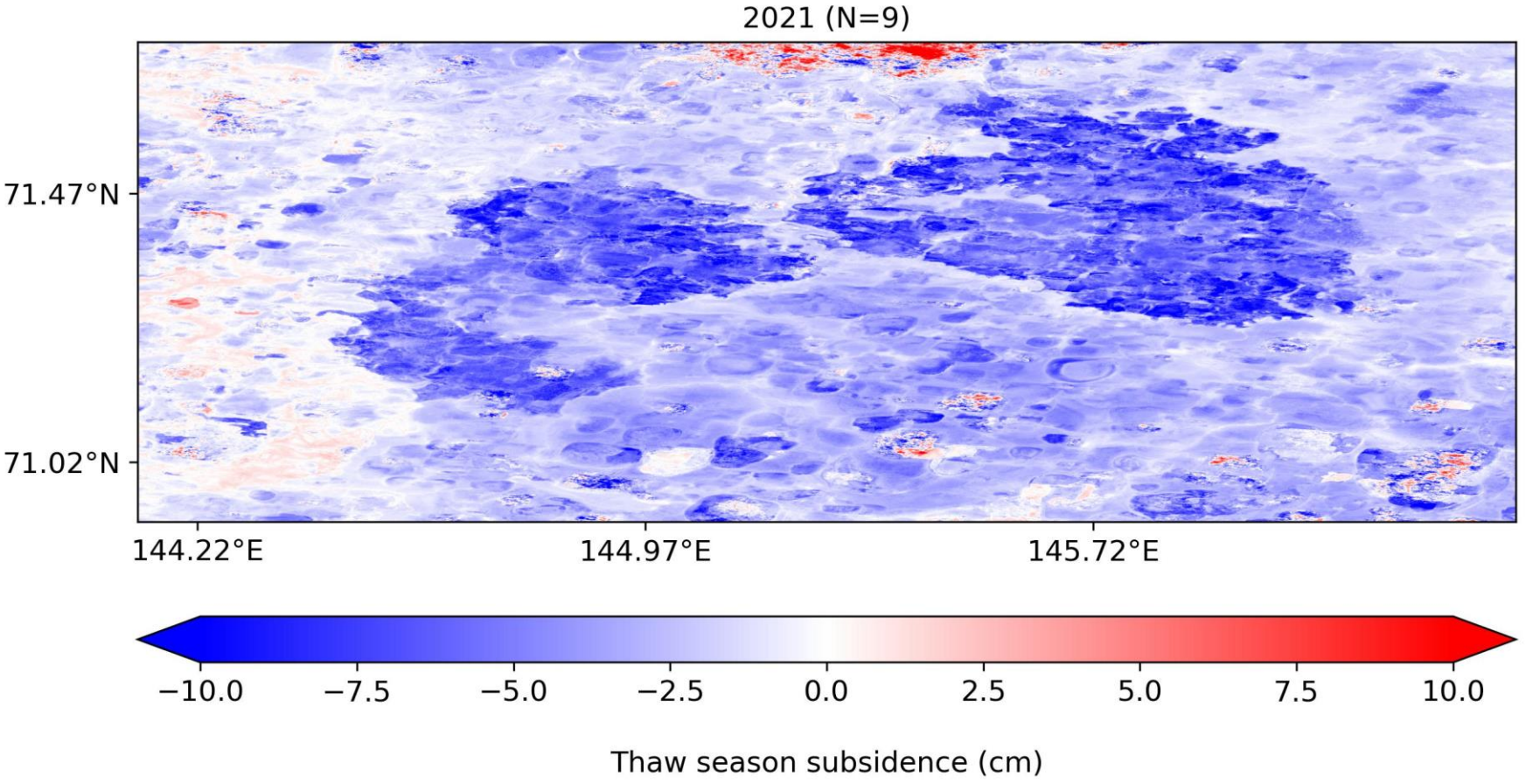
From Liu et al., 2014

Research gap

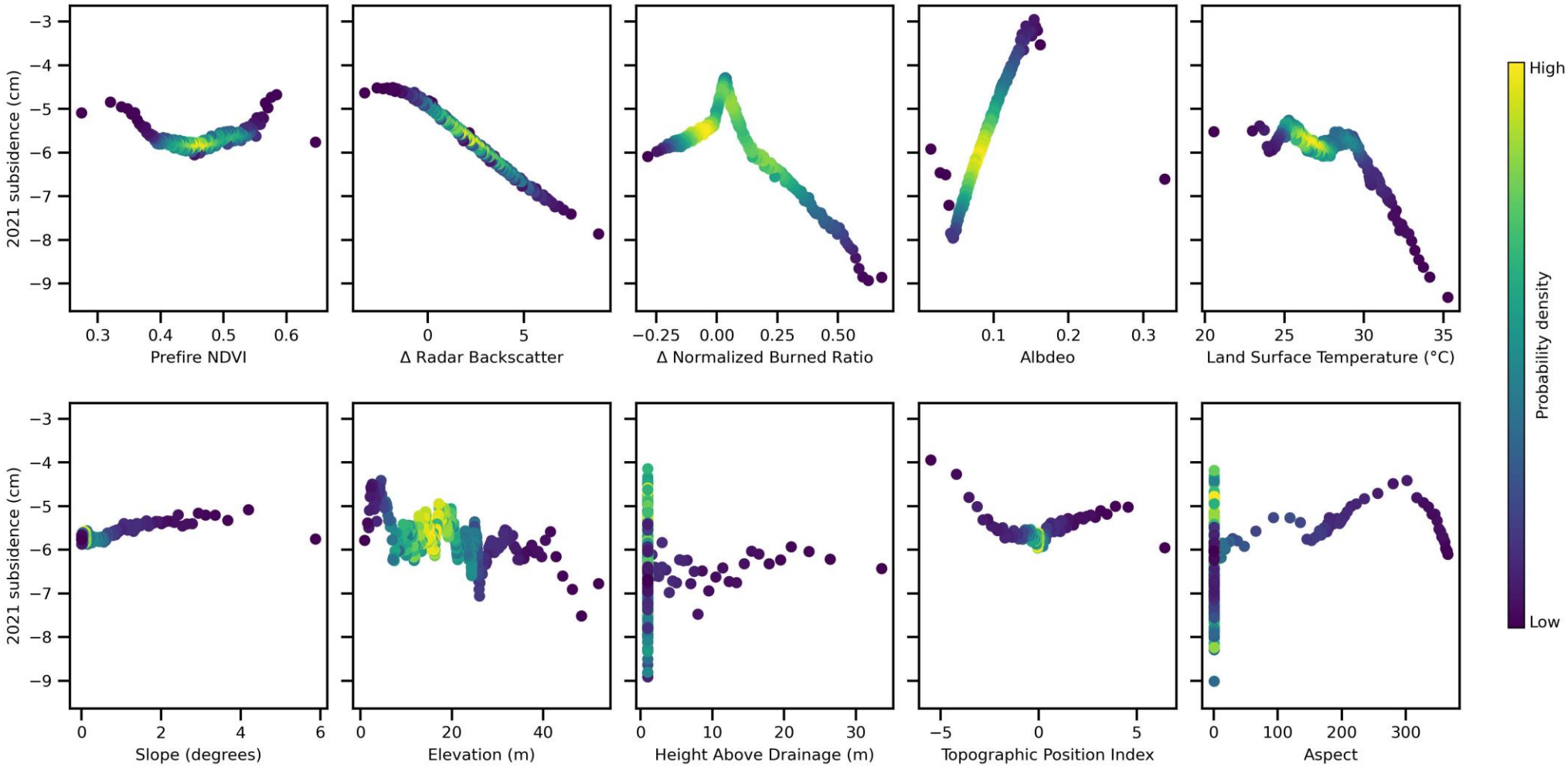
- We **KNOW** that **subsidence is prevalent** in burned areas
- But we **DO NOT KNOW** why? Could it be due to **fire-related** environmental variables, **topographic** variables, or both?
- The **objective** is to fill this knowledge gap **quantitatively**

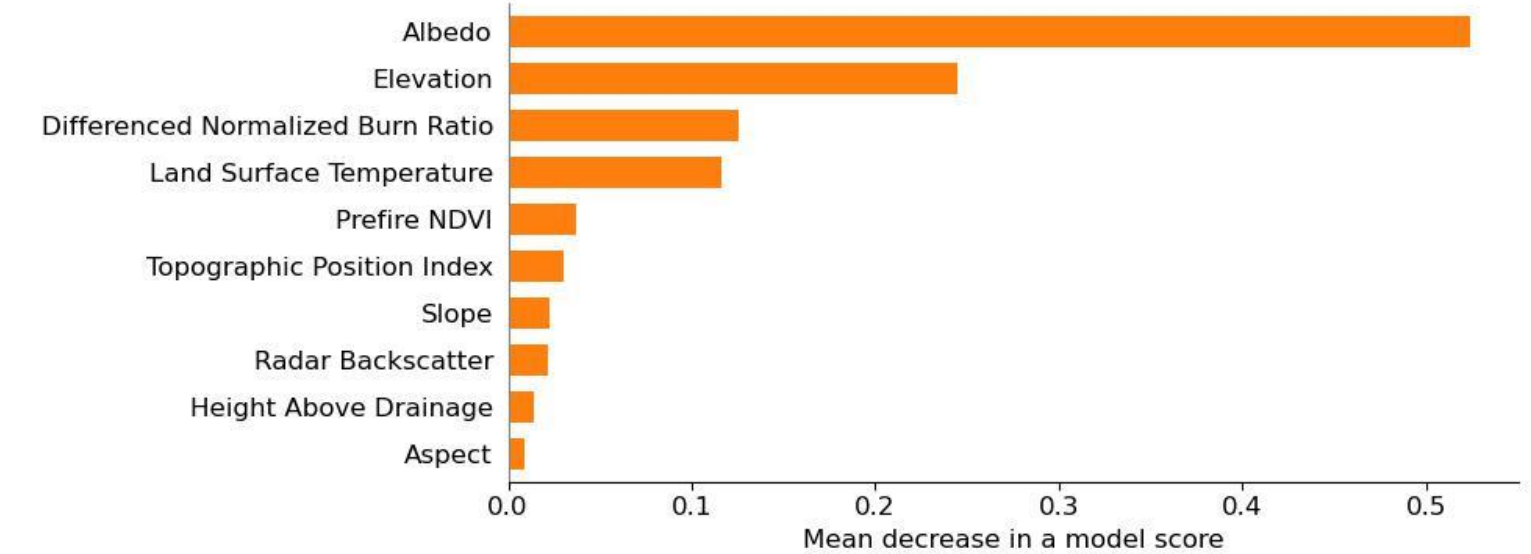

1
2
3
InSAR based retrieval of fire-induced permafrost subsidence
Machine learning based identification of key drivers
Collection of potential environmental driver variables from satellite data
InSAR time-series workflow
isce2
stackSentinel.py run step 1 to 10
Unwrapped Interferogram stack
Snellius HPC
mintpy
smallbaselineApp.py run step 1 to 10
Subsidence maps
2021 map
Machine learning workflow
XGBoost
Hyper-parameter selection
Snellius HPC
k-fold cross-validation
Permutation feature importance
SHAP
1-year post-fire drivers
Predictor variables curation
NDVI
dB
dNBR
Albedo
LST
Slope
Elevation
HAND
TPI
Aspect

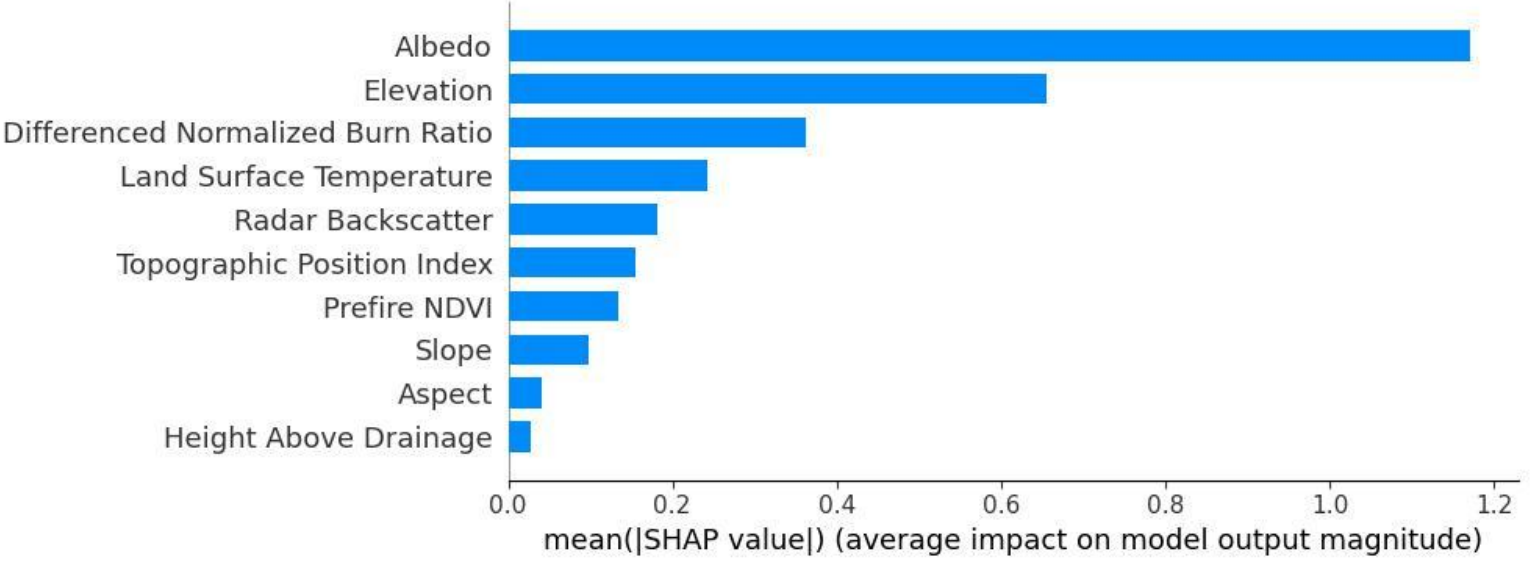
2021 thaw season subsidence

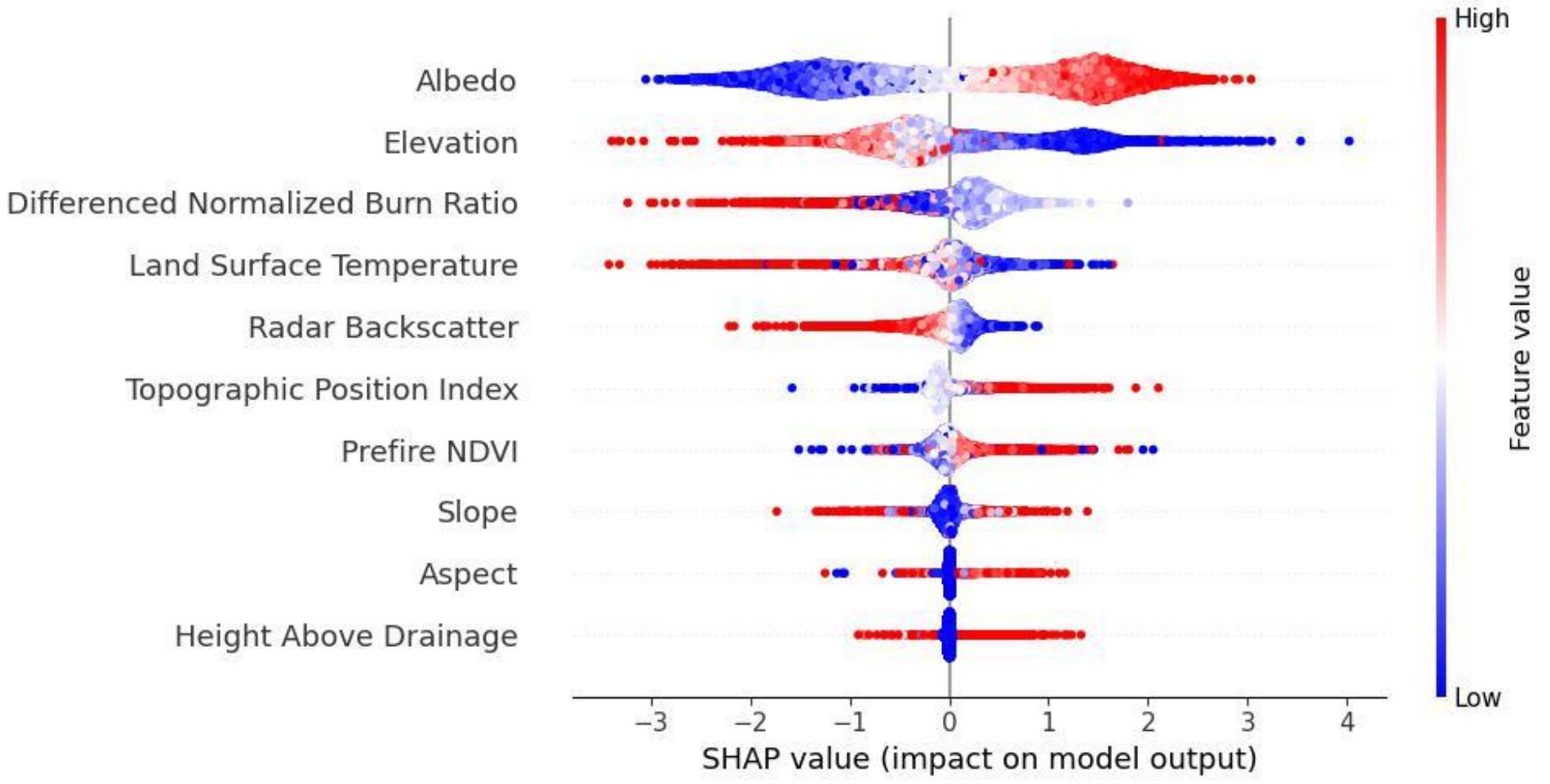


Environmental variables




Albedo
Elevation
Differenced Normalized Burn Ratio
Land Surface Temperature
Prefire NDVI
Topographic Position Index
Slope
Radar Backscatter
Height Above Drainage
Aspect
0.0
0.1
0.2
0.3
0.4
0.5
Mean decrease in a model score


Albedo
Elevation
Differenced Normalized Burn Ratio
Land Surface Temperature
Radar Backscatter
Topographic Position Index
Prefire NDVI
Slope
Aspect
Height Above Drainage
0.0
0.2
0.4
0.6
0.8
1.0
1.2
mean(|SHAP value|) (average impact on model output magnitude)


Albedo
Elevation
Differenced Normalized Burn Ratio
Land Surface Temperature
Radar Backscatter
Topographic Position Index
Prefire NDVI
Slope
Aspect
Height Above Drainage
−3
−2
−1
0
1
2
3
4
SHAP value (impact on model output)
High
Feature value
Low

Conclusions

- **InSAR and machine learning technique are promising** for studying fire permafrost interactions in tundra
- **Fire**-driven environmental **variables** are **driving permafrost subsidence** than topographic variables
- **Scaling up** the analysis is fundamental to better understand the subsidence patterns and drivers
- **What holds the future** of numerous and massive fire scars in tundra?

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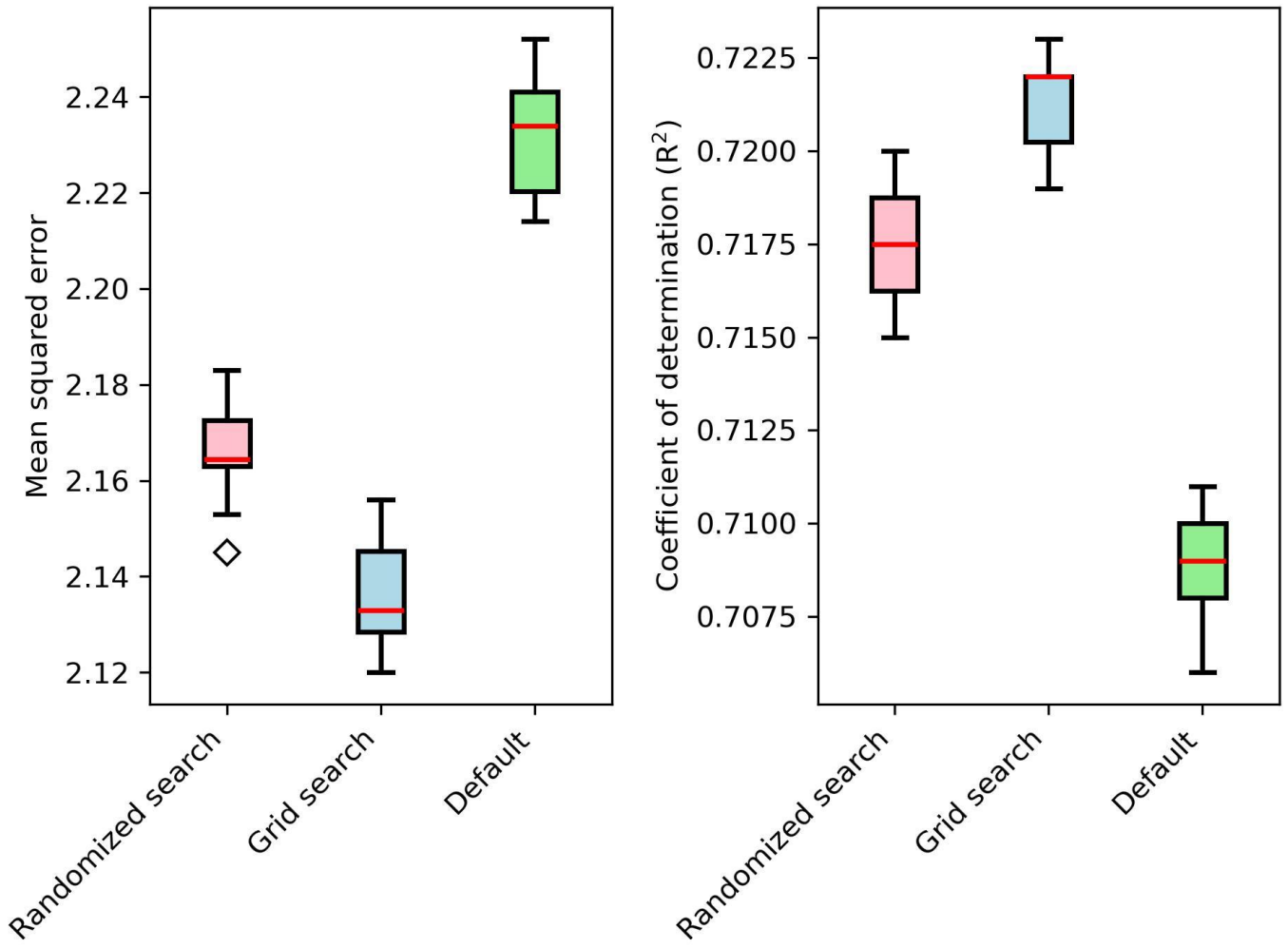
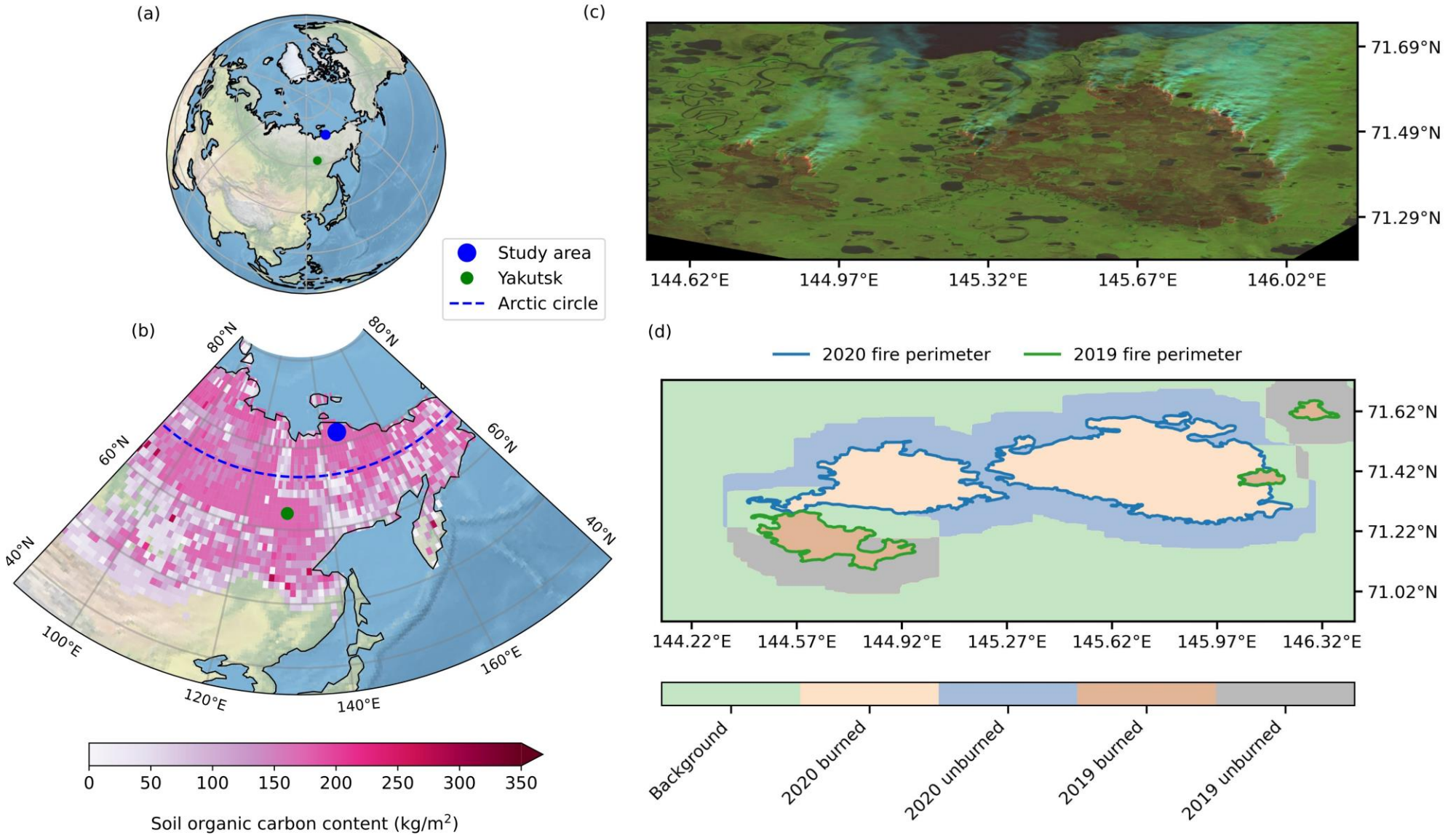
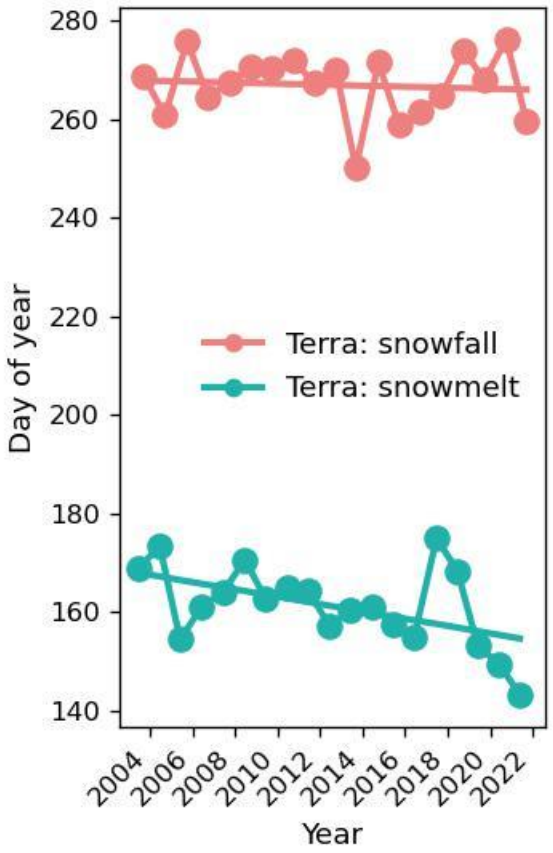
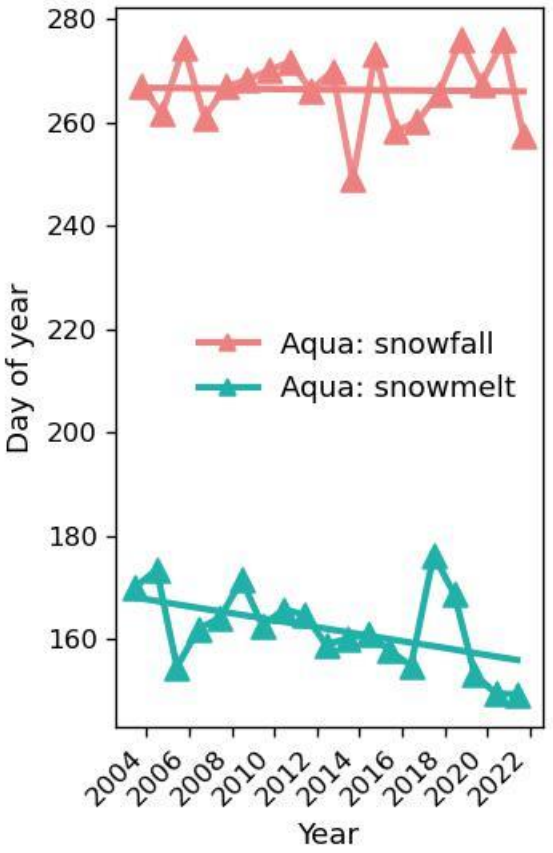
Appendix

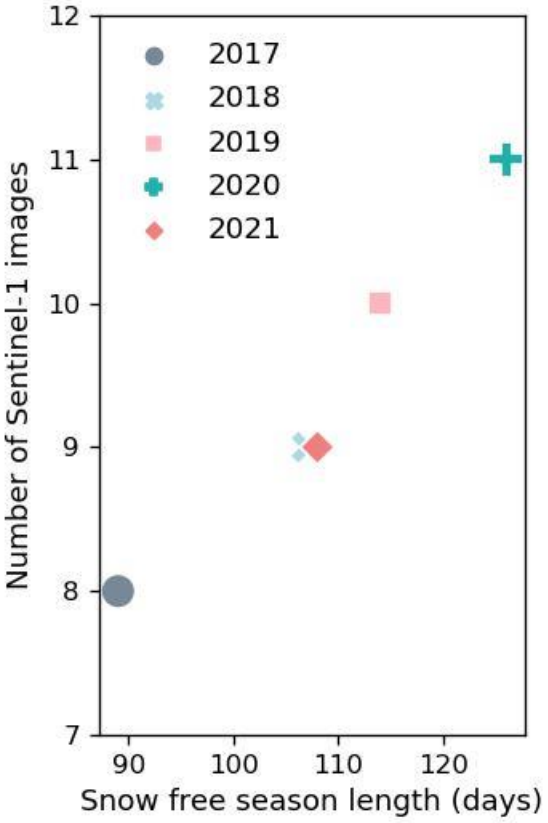

Mean squared error
2.24
2.22
2.20
2.18
2.16
2.14
2.12
Randomized search
Grid search
Default
Coefficient of determination (R^2)
0.7225
0.7200
0.7175
0.7150
0.7125
0.7100
0.7075
Randomized search
Grid search
Default


(a)
Study area
Yakutsk
Arctic circle
(b)
80°N
60°N
40°N
100°E
120°E
140°E
160°E
0
50
100
150
200
250
300
350
Soil organic carbon content (kg/m²)
(c)
71.69°N
71.49°N
71.29°N
144.62°E
144.97°E
145.32°E
145.67°E
146.02°E
(d)
2020 fire perimeter
2019 fire perimeter
71.62°N
71.42°N
71.22°N
71.02°N
144.22°E
144.57°E
144.92°E
145.27°E
145.62°E
145.97°E
146.32°E
Background
2020 burned
2020 unburned
2019 burned
2019 unburned

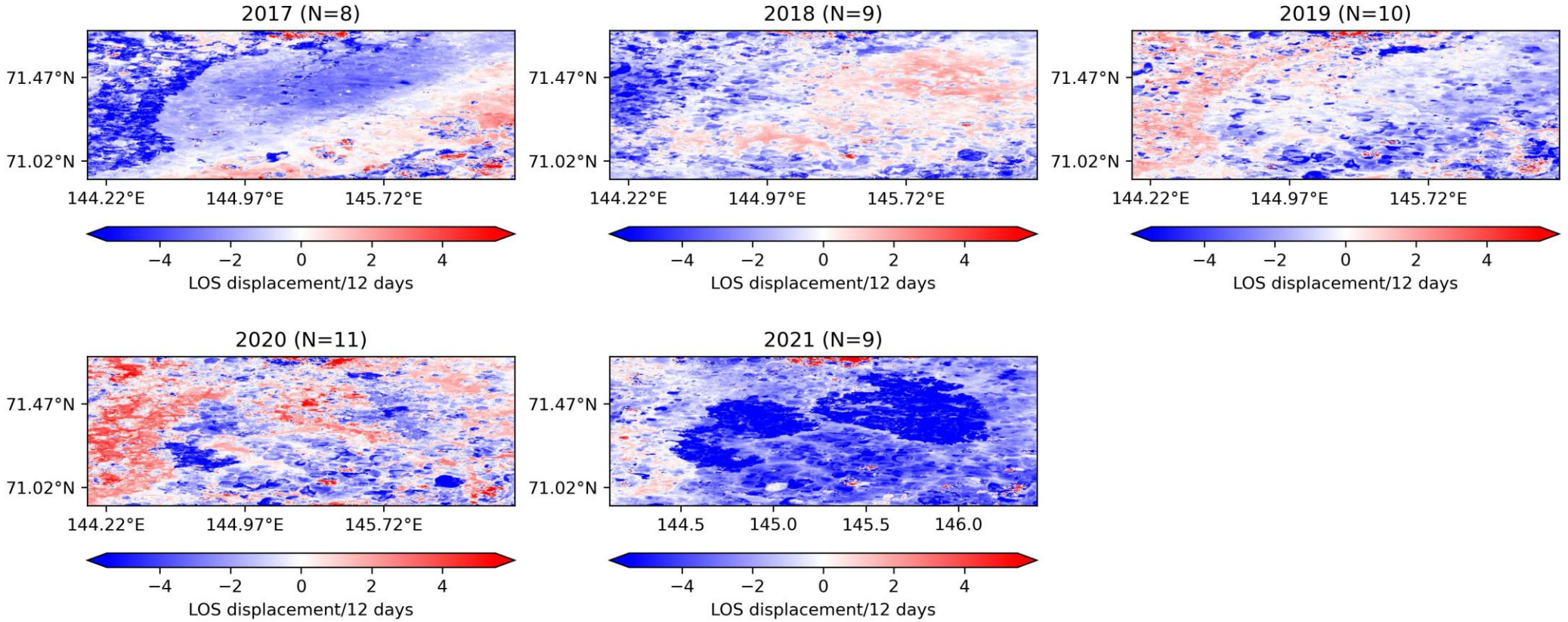
Snow free duration



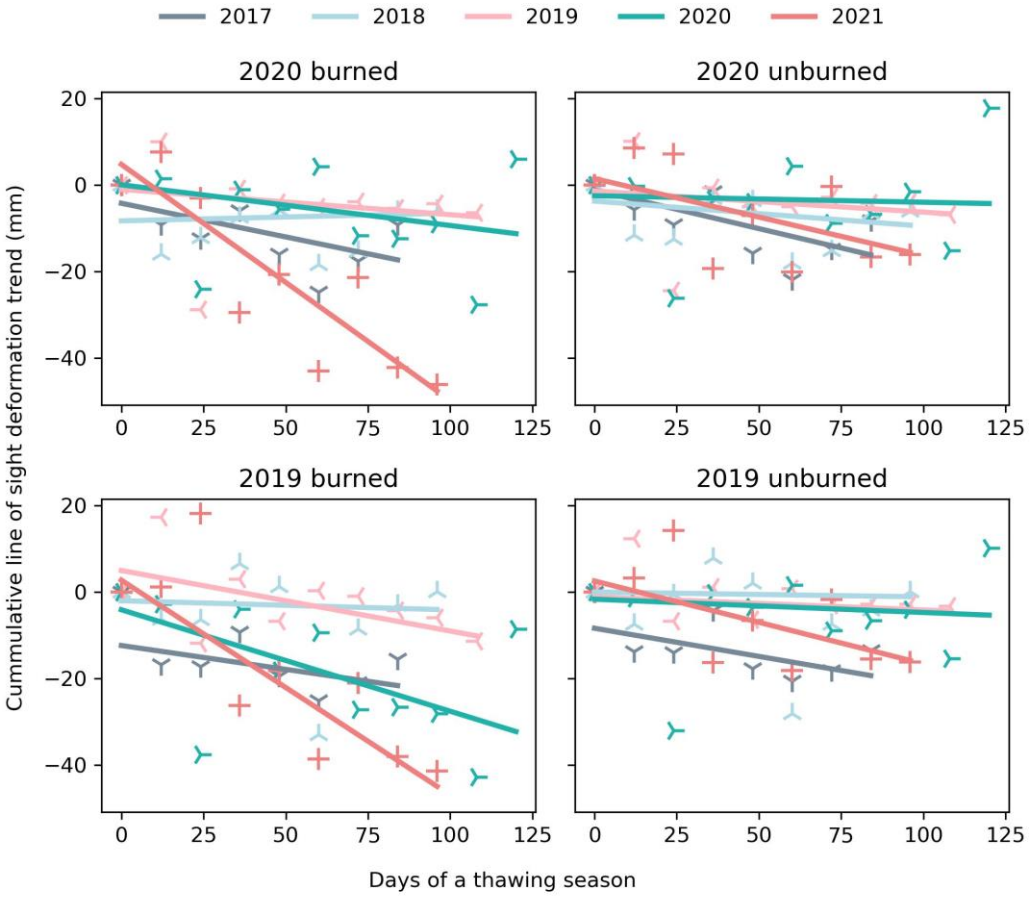


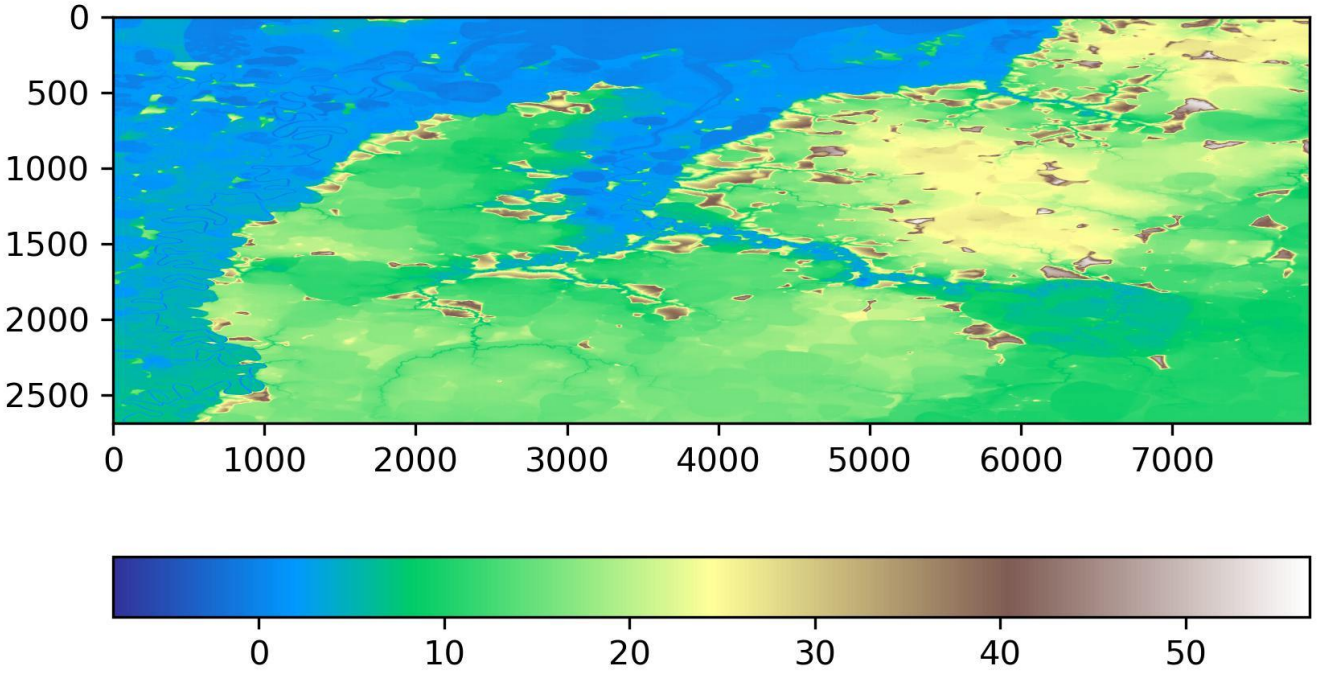


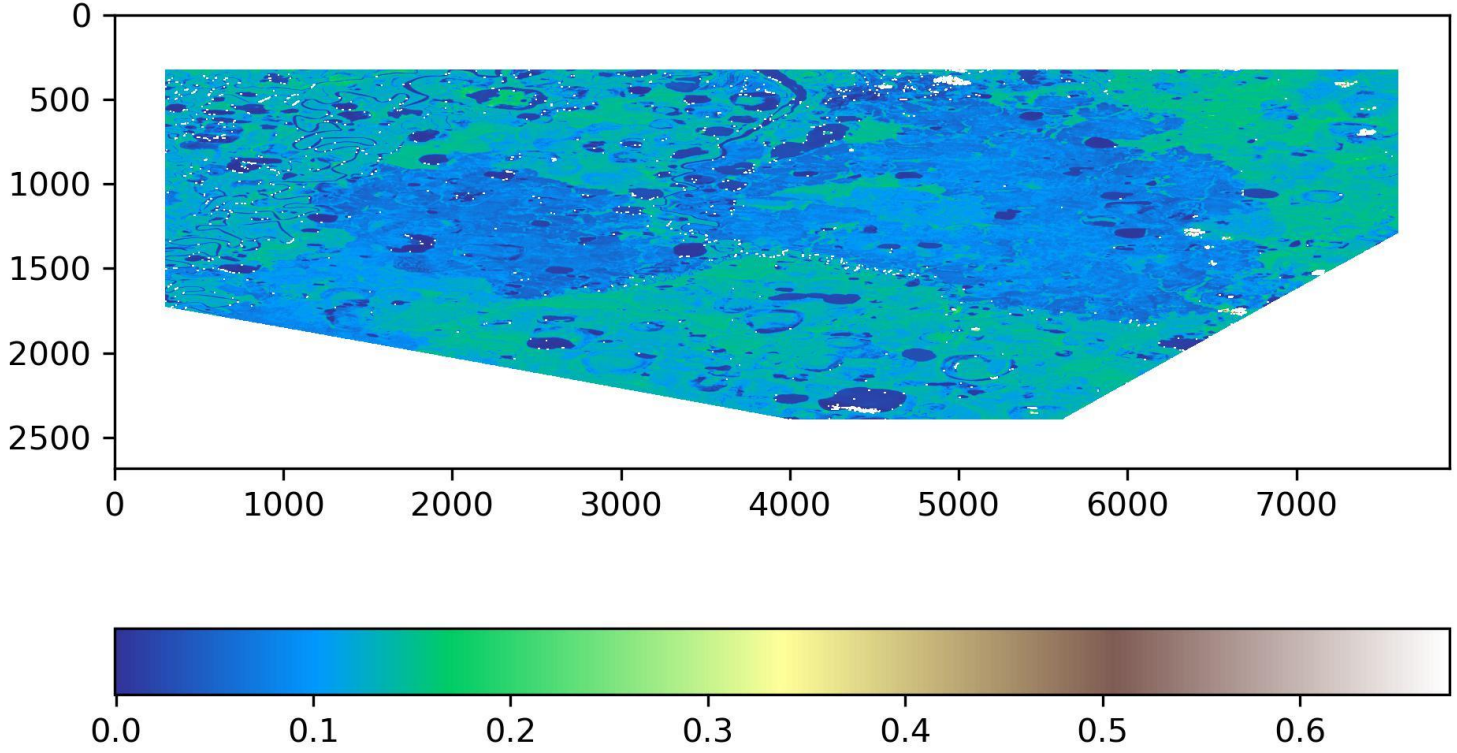
Rate of deformation

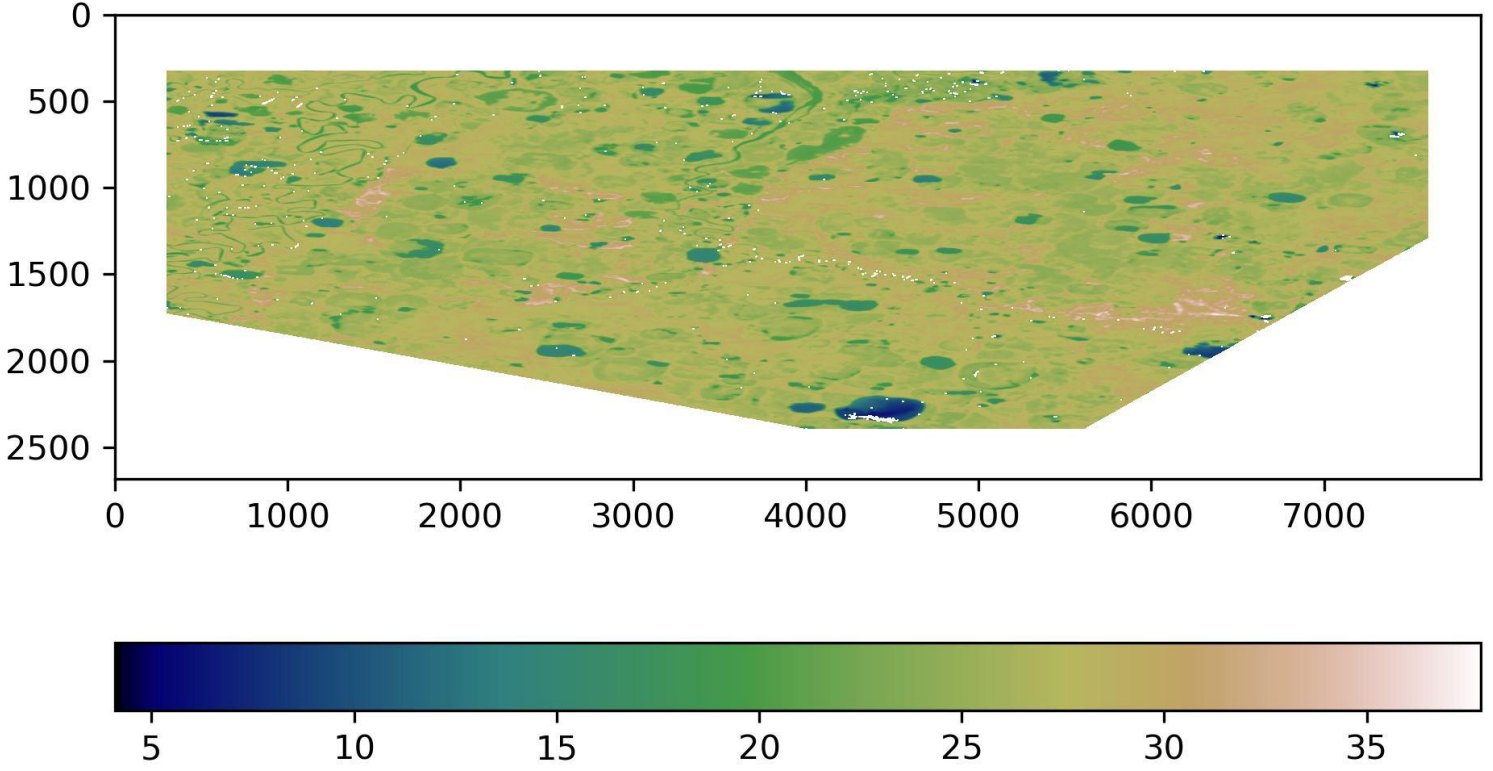


Deformation signals

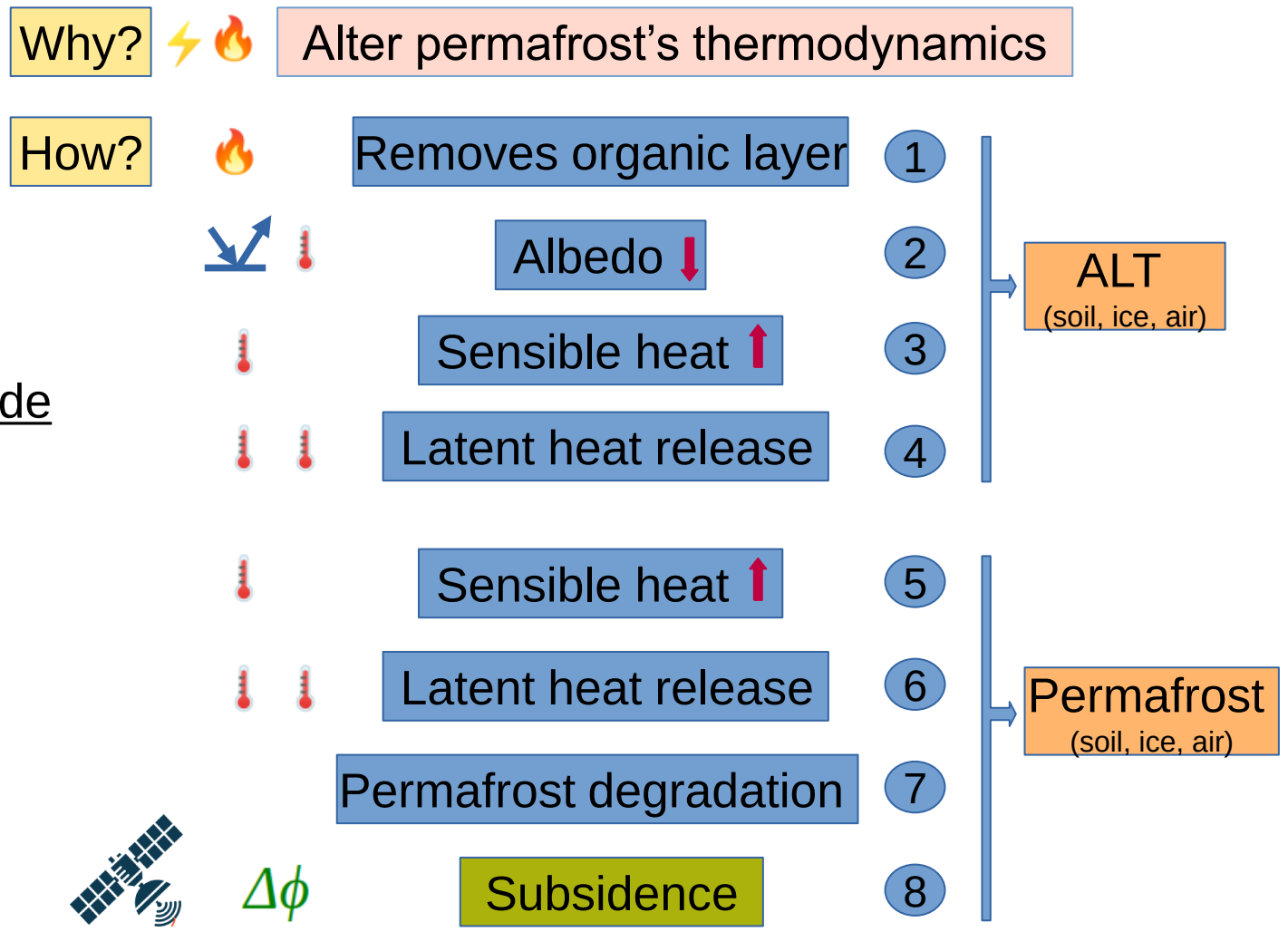



0
500
1000
1500
2000
2500
0
1000
2000
3000
4000
5000
6000
7000
0
10
20
30
40
50


0
500
1000
1500
2000
2500
0
1000
2000
3000
4000
5000
6000
7000
0.0
0.1
0.2
0.3
0.4
0.5
0.6


0
500
1000
1500
2000
2500
0
1000
2000
3000
4000
5000
6000
7000
5
10
15
20
25
30
35

Mechanisms:



Feedback magnitude

- Biomass
- Fire severity
- Weather

InSAR

InSAR: a technique of creating an interferogram