InSAR Detection and Field Evidence for Thermokarst after a Tundra Wildfire, using ALOS-PALSAR

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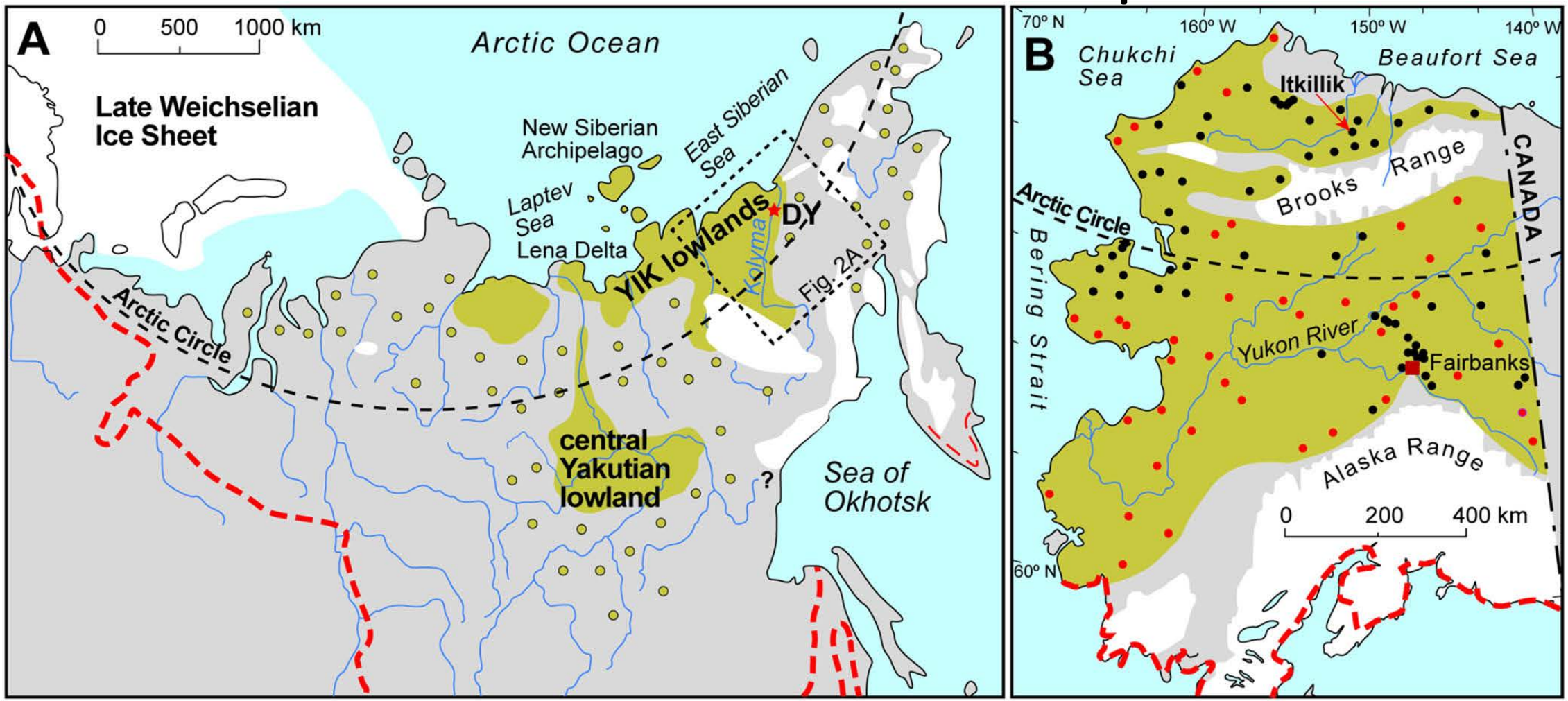
Impacts of Ice-rich Permafrost Thaw (Thermokarst)

Sylan, Churapcha, Central Yakutia

Photos by A. N. Fedorov

Distribution of Yedoma ice complex



Northern Asia

Alaska

(Murton et al., 2015)

Change in Permafrost · Carbon Budget ⇔ Climate Change?

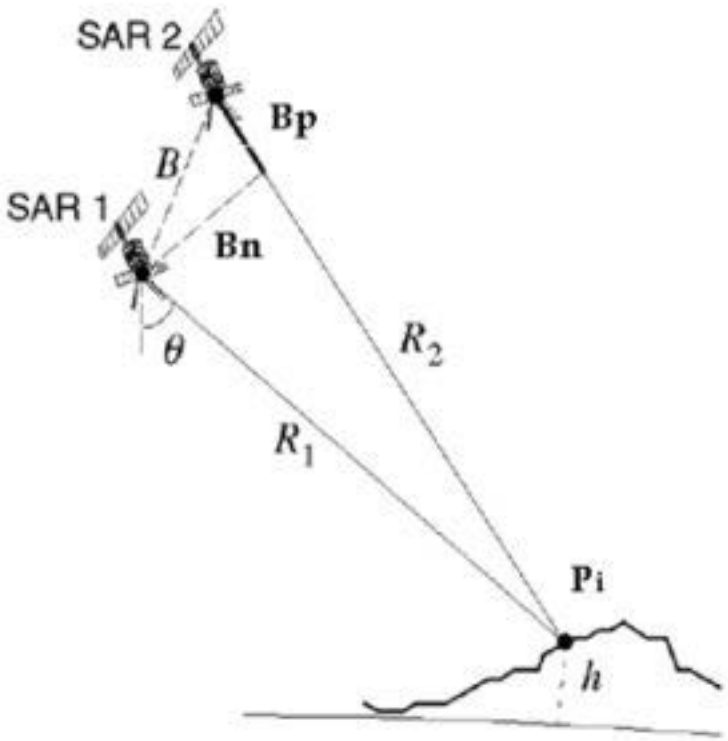
Sparsely distributed yedoma

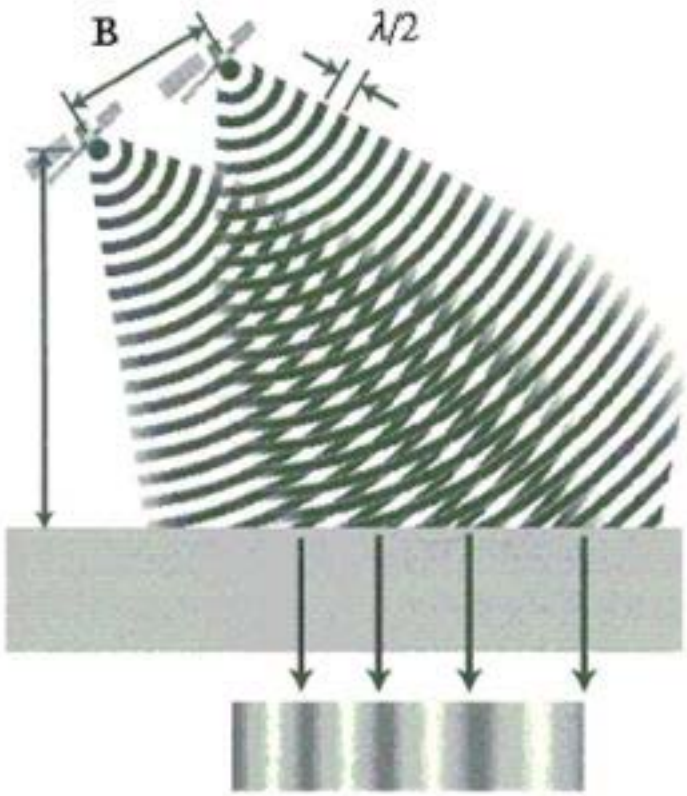
Present-day permafrost boundary

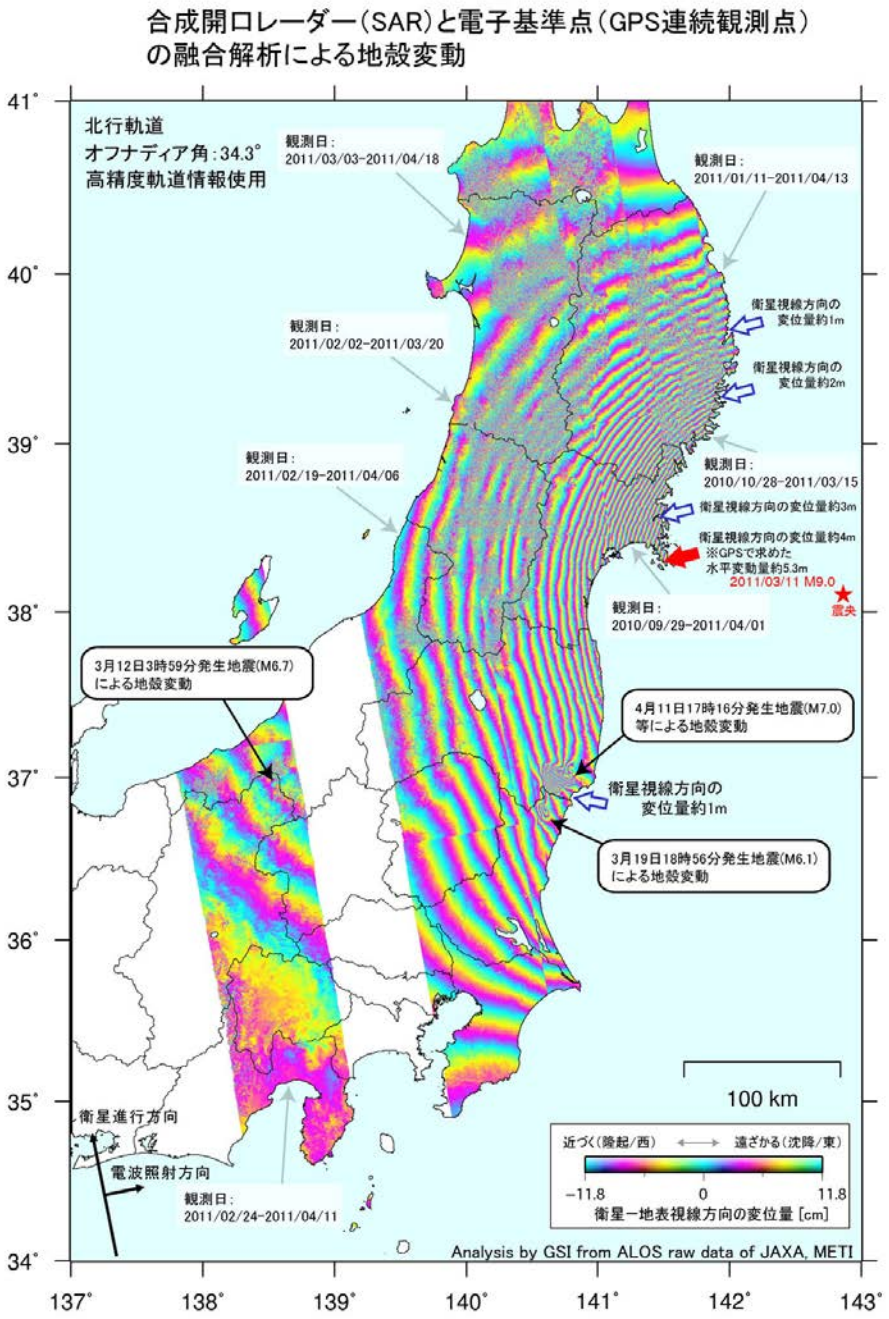
Possible yedoma locations

Objective: to Quantify Permafrost Degradation using Satellite

SAR Interferometry (InSAR)

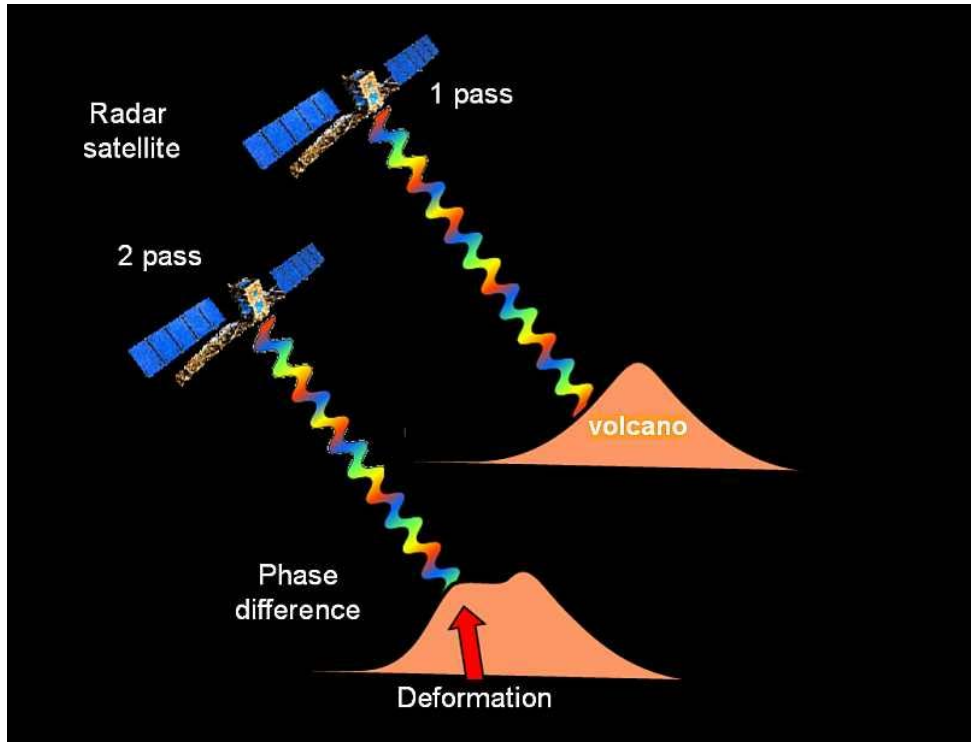




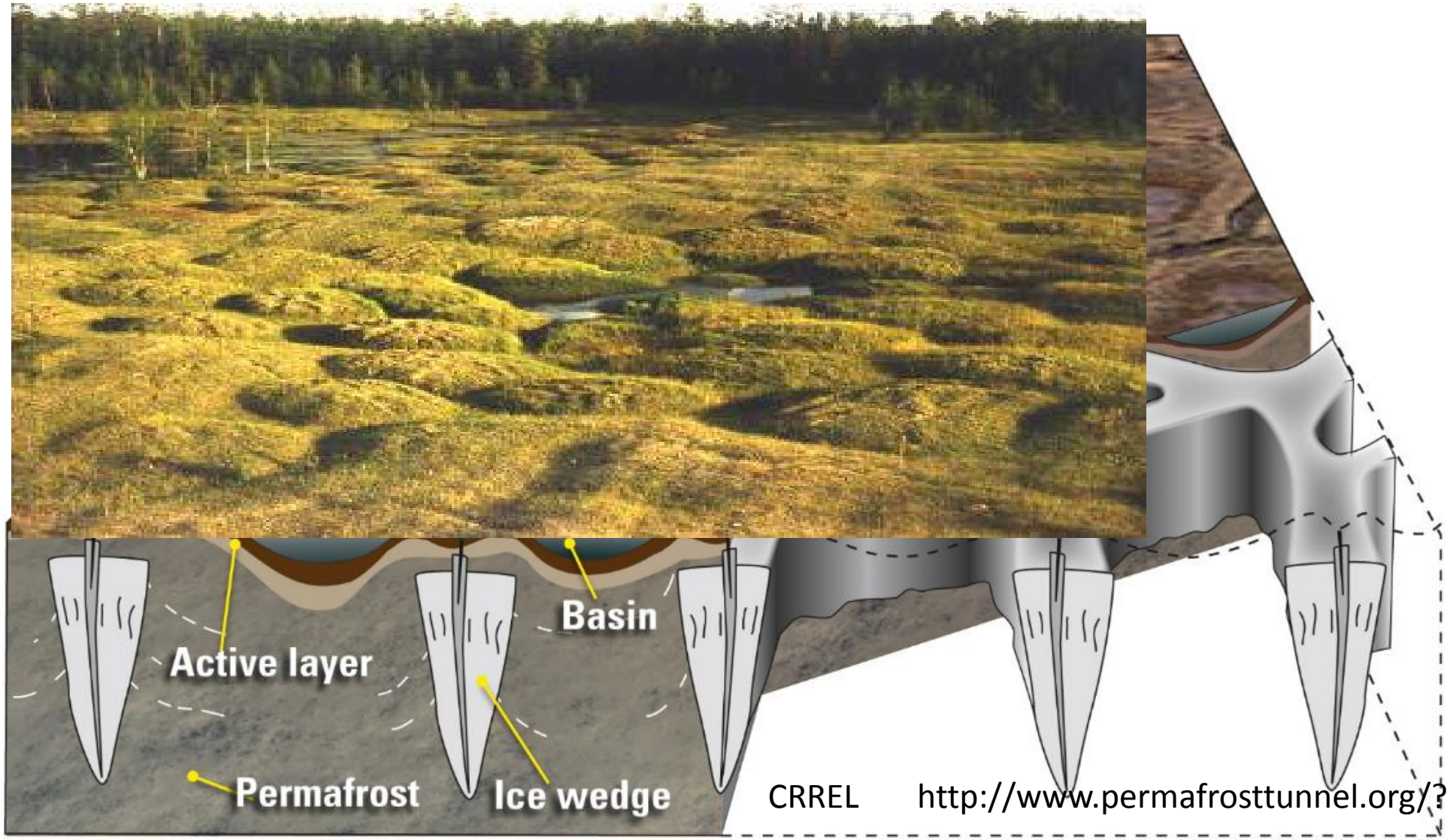


Large-scale Ground Movement after the Miyagi-Oki Earthquake (3.11)

Detecting inflation of volcano



Ice Wedge Polygons



CRREL http://www.permafrosttunnel.org/?page_id=9

Past attempts :

X- / C-band (3 / 6 cm) InSAR not successful

requires coherent surface roughness

L-band (23cm) InSAR (ALOS-PALSA)
Some attempts to detect

- **Seasonal surface movement**
- **Thermokarst**

not supported by field study

Anaktuvuk Fire **July 2007**

~2.1Tg release of carbon --- Annual carbon sink by Arctic tundra (Mack et al., 2011)

Datasets:

- ALOS/PALSAR 2006-2010 (5 years)
- DEM ALOS/PRISM (6.5m)
- WorldView2 Historic high-resolution images

Master Date	Slave Date	Bprep
2006/09/03	2006/06/03	−1350
2007/07/22	2007/03/06	−1009
2009/07/27	2008/07/24	922
2009/09/11	2009/07/27	−626
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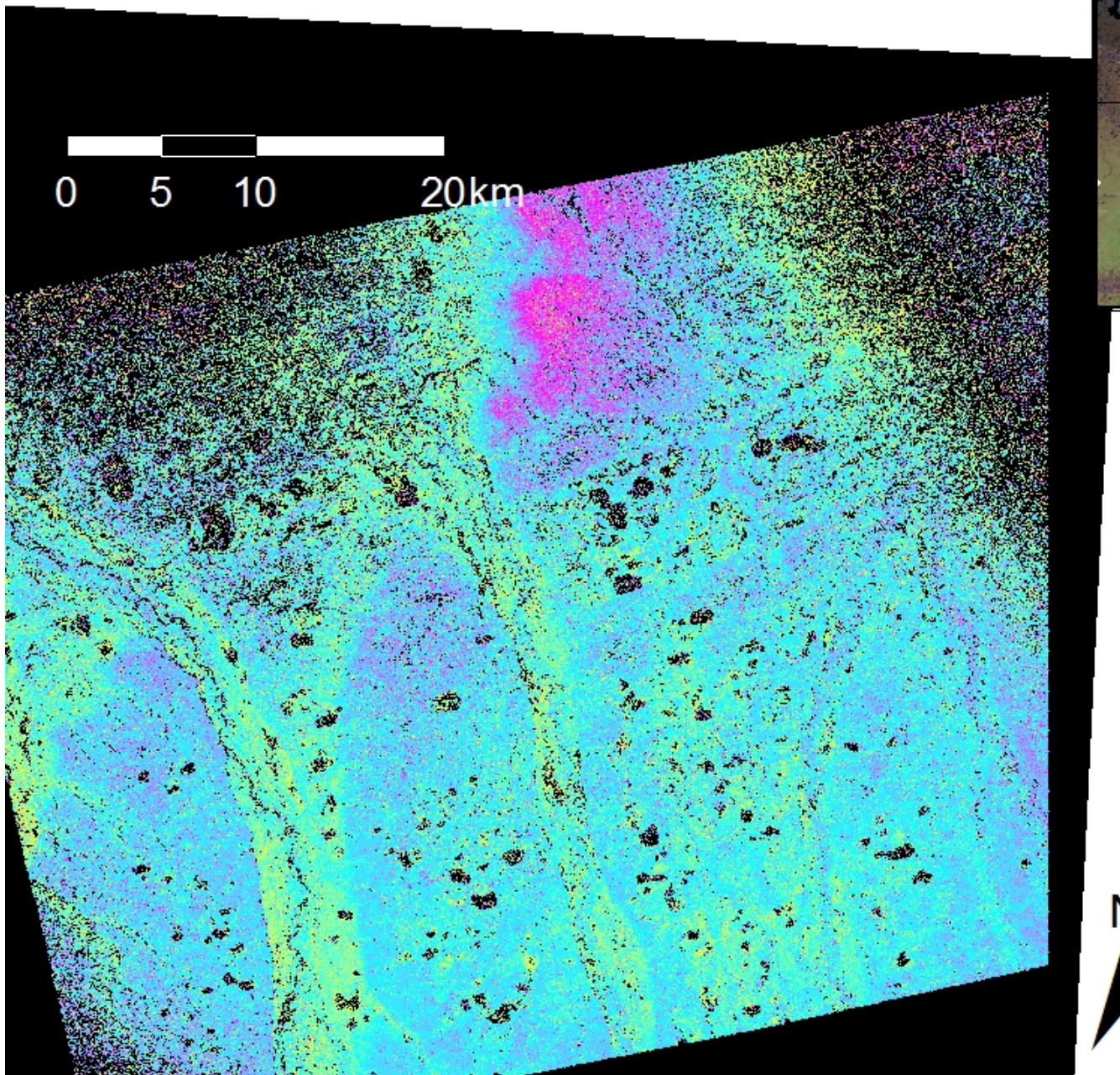
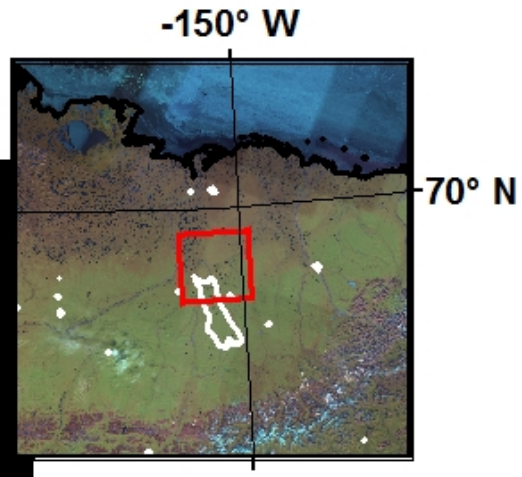
2010/07/30	2009/07/27	−4288
2010/09/14	2008/06/08	1525
2010/09/14	2010/07/30	−398

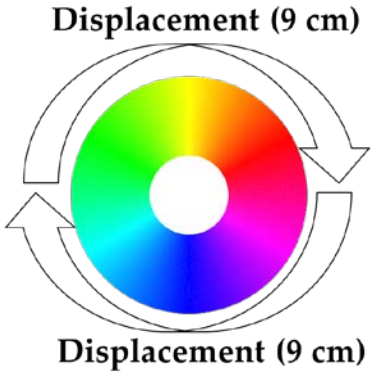
Error sources to be considered

- Large-scale ionosphere effect
- Snow cover
- Ambiguity due to inaccurate DEM (Large baselines)
- Vegetation recovery / seasonal change
- Seasonal surface movement by freeze/thaw in active layer (Frost heave / Thaw settlement)
- Change in soil moisture
- Change in surface roughness (Surface erosion)

Pre-Fire

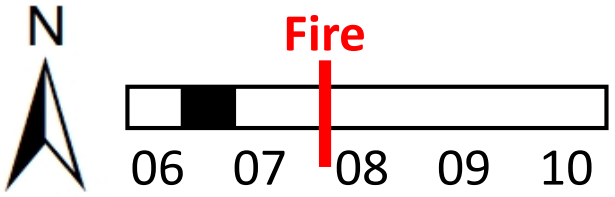






Before Fire
Jun → Sep 2006
(3-month)

- Uniform interferogram
- Little surface change



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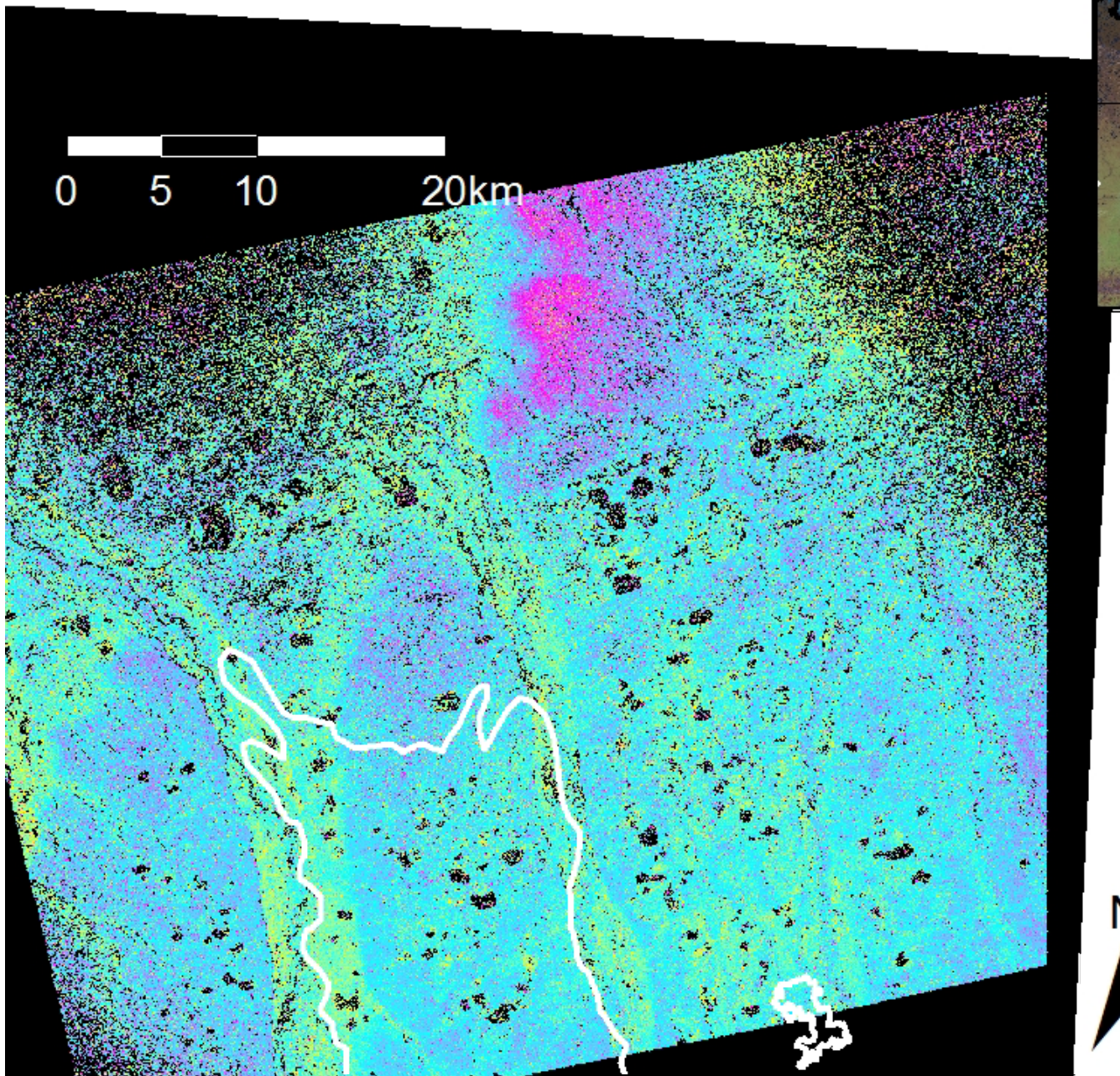

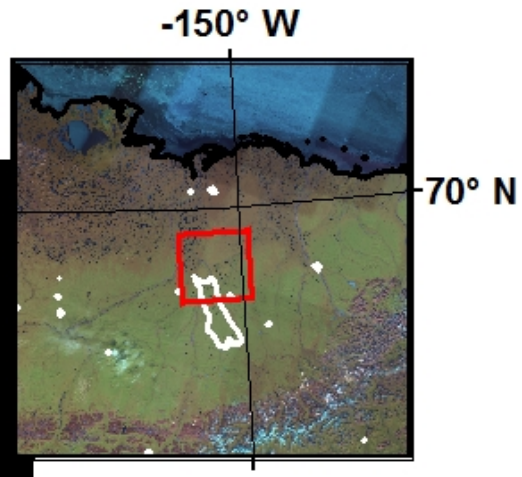

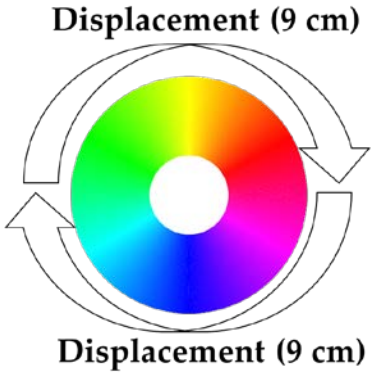

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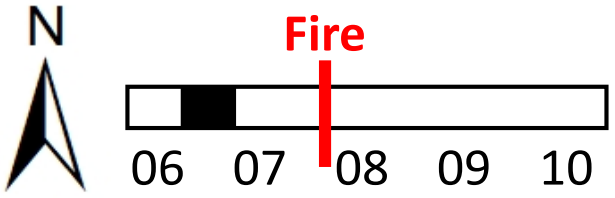
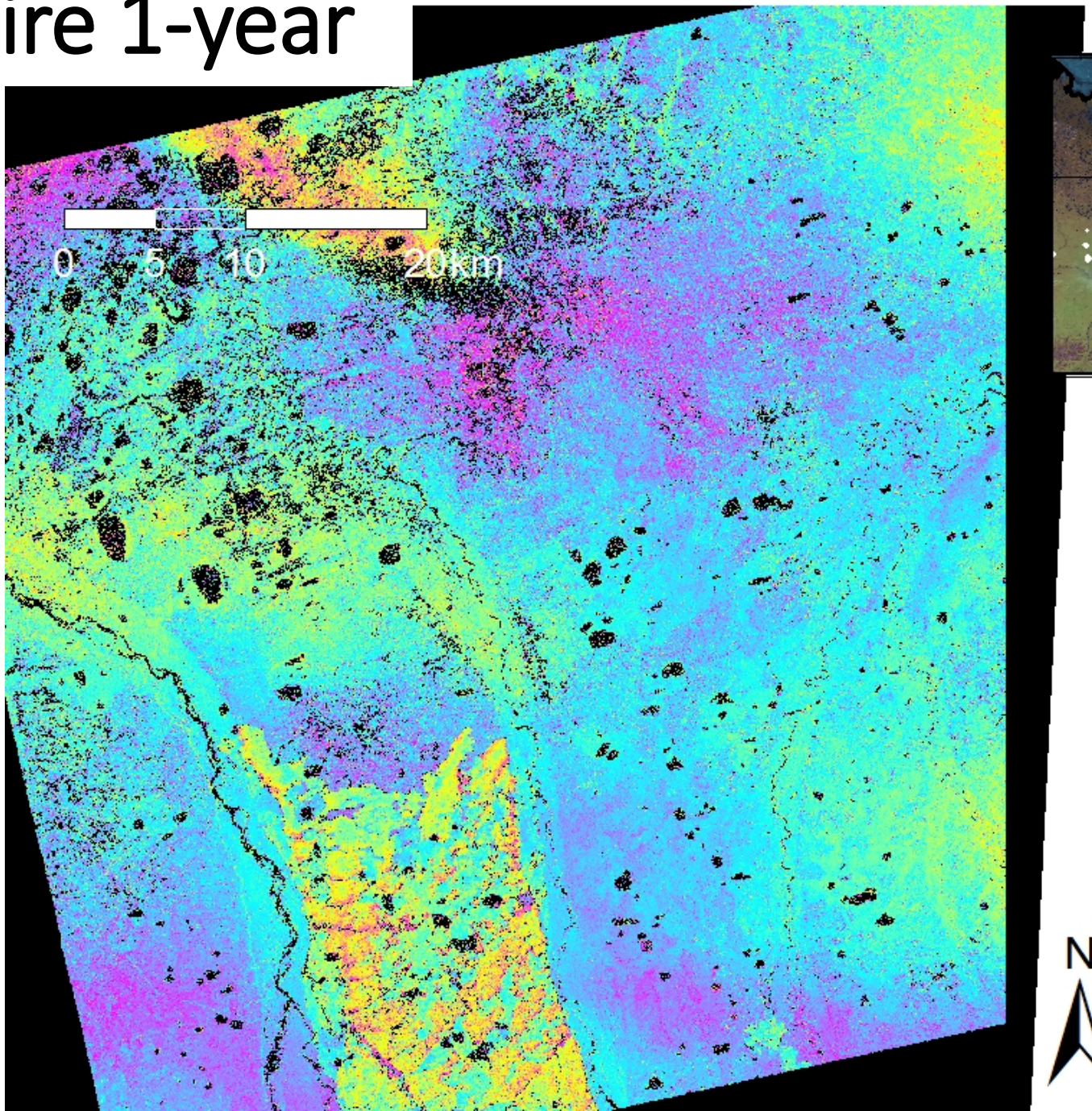
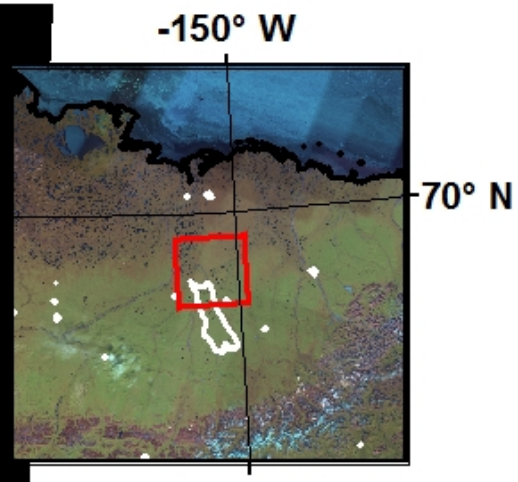
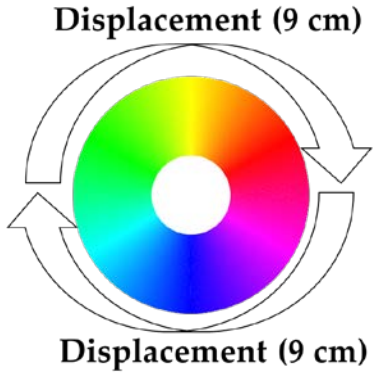


Post-Fire 1-year



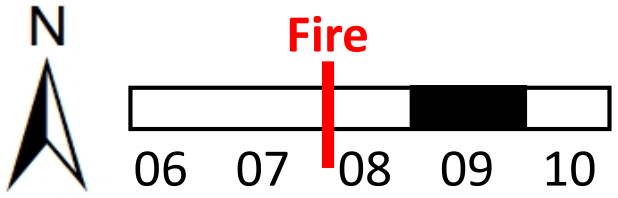




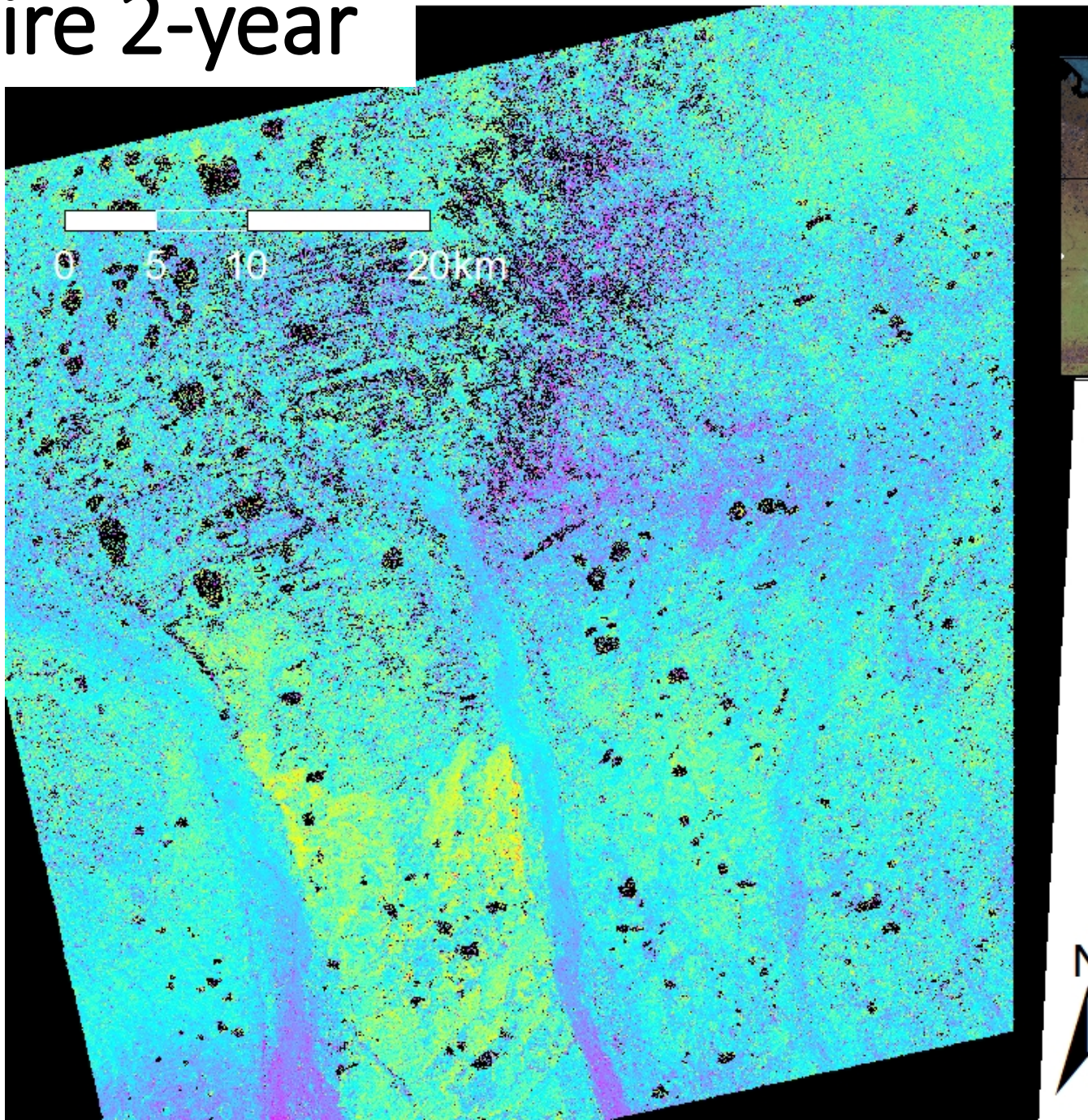
Fire in Sep 2007

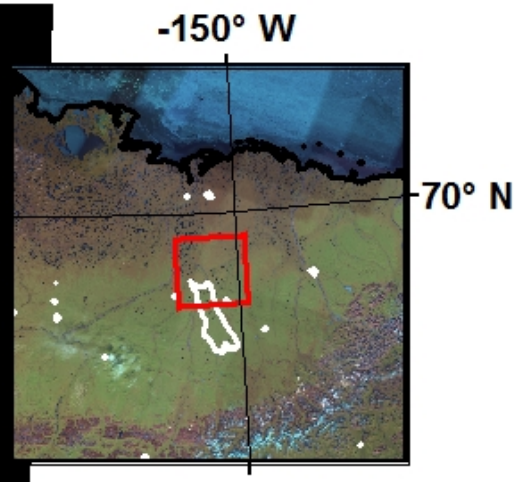
Jul 2008 → Jul 2009 (1-year)

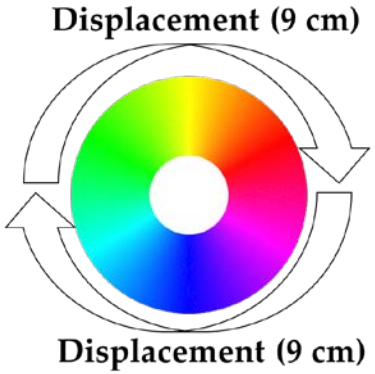
Marked signals of subsidence exclusively in the fire scar



Post-Fire 2-year

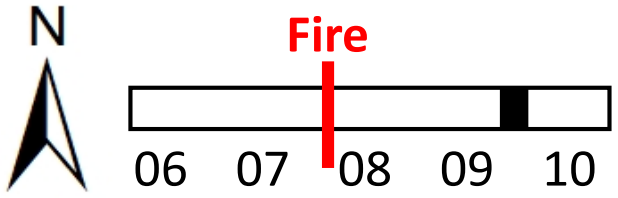




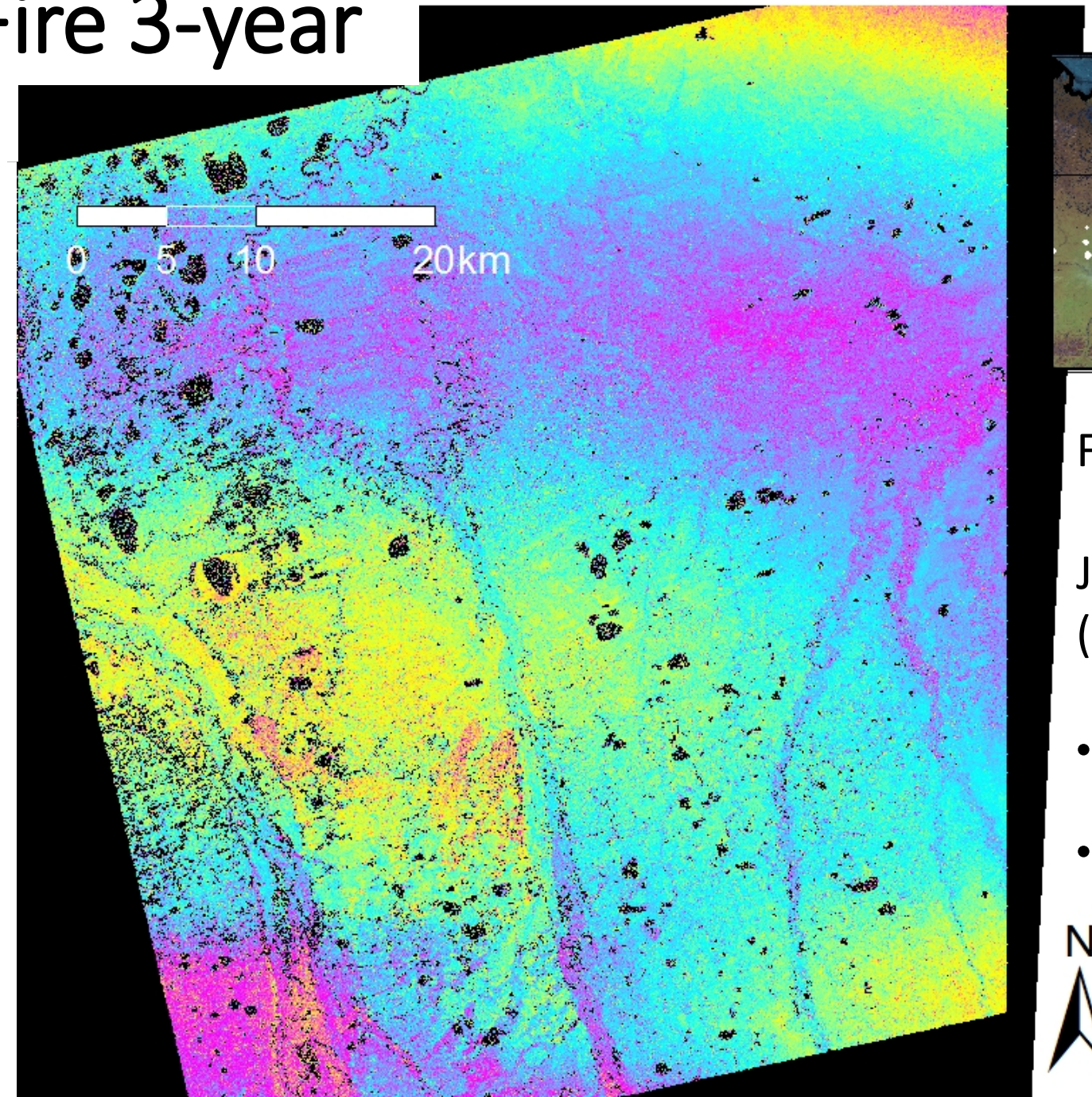


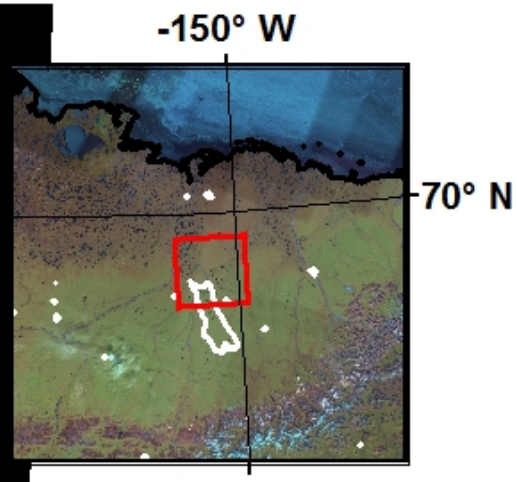
Fire in Sep 2007

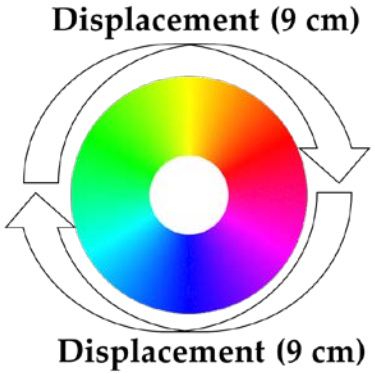
Jul 2009 → Sep 2009
(1.5-month)



Post-Fire 3-year



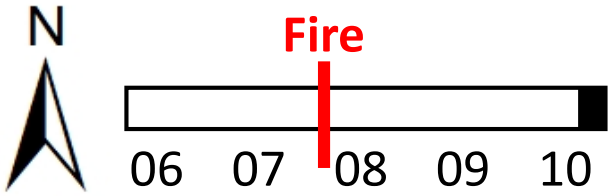




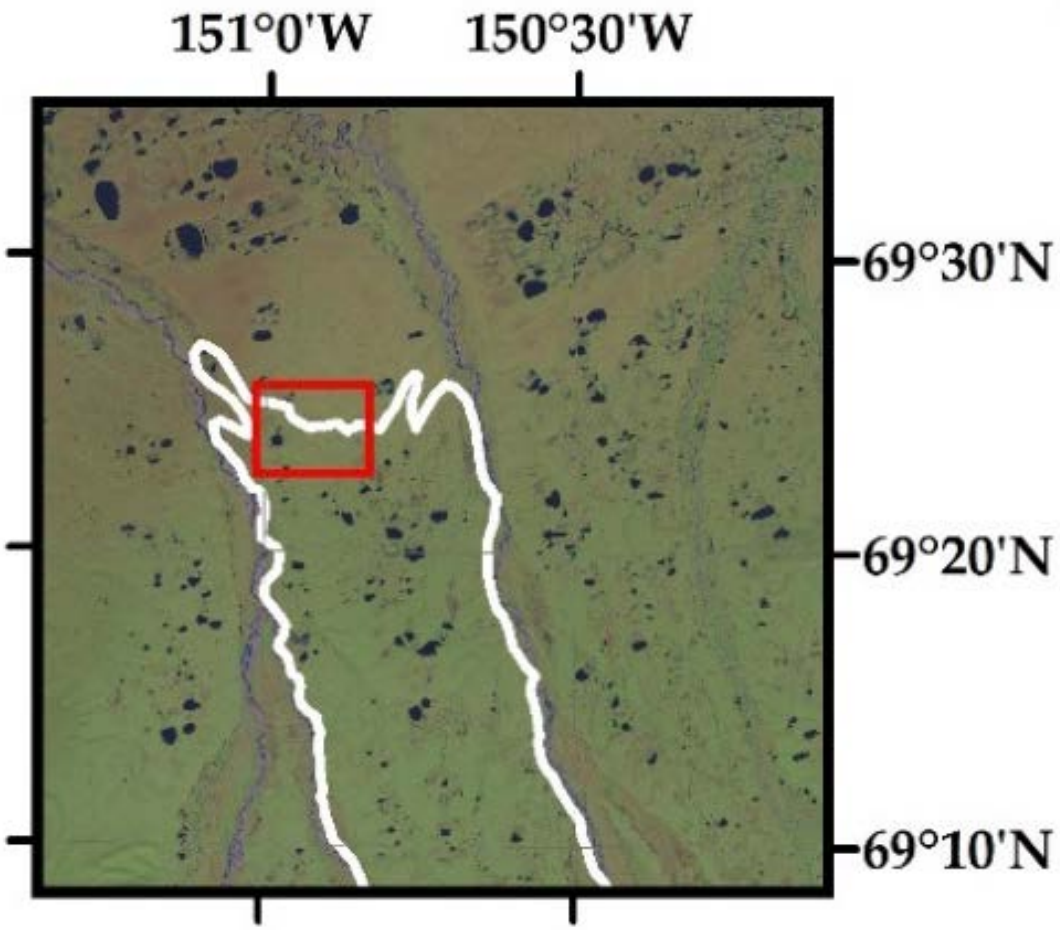
Fire in Sep 2007

Jul 2010 → Sep 2010 (1.5-month)

- Continuation of subsidence in fire scar
- Subsidence outside of the fire scar?

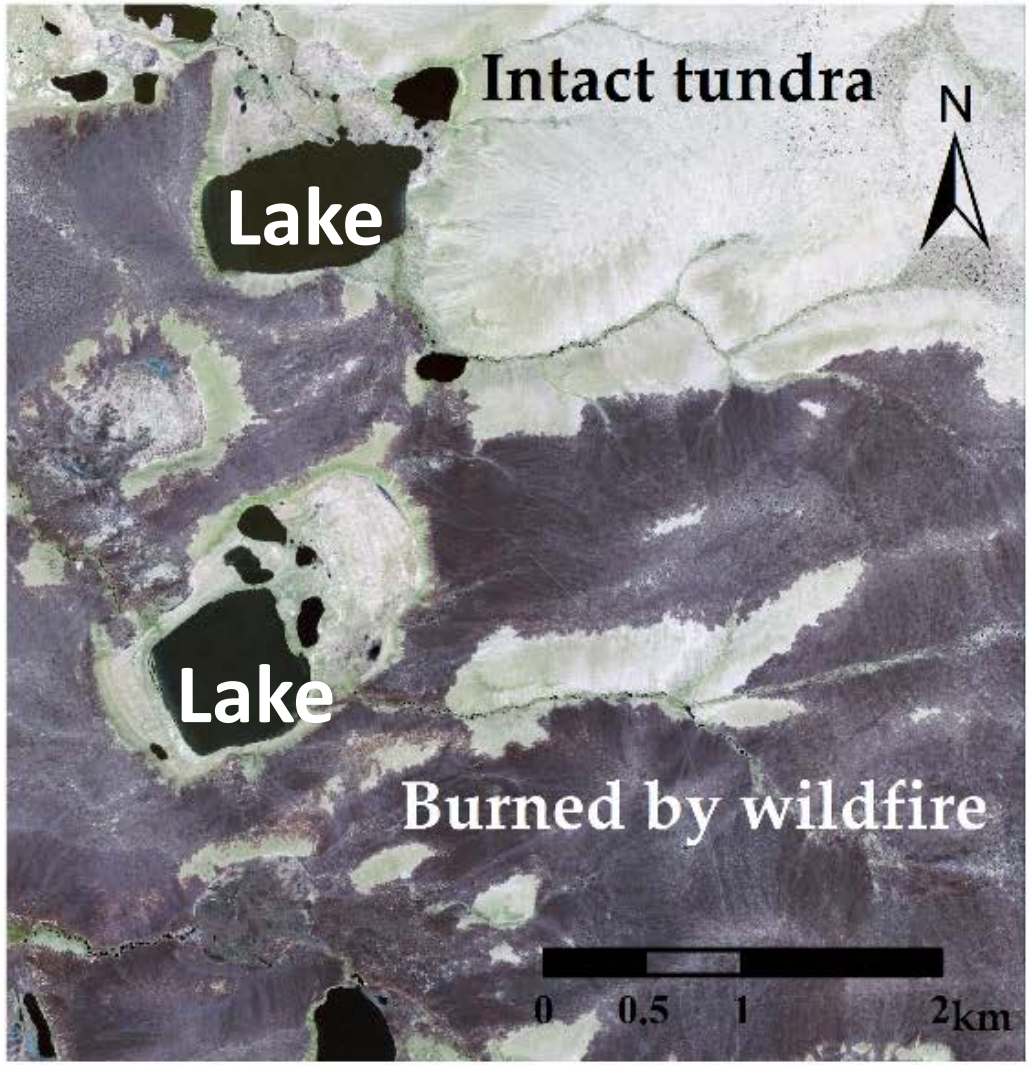


Target Area

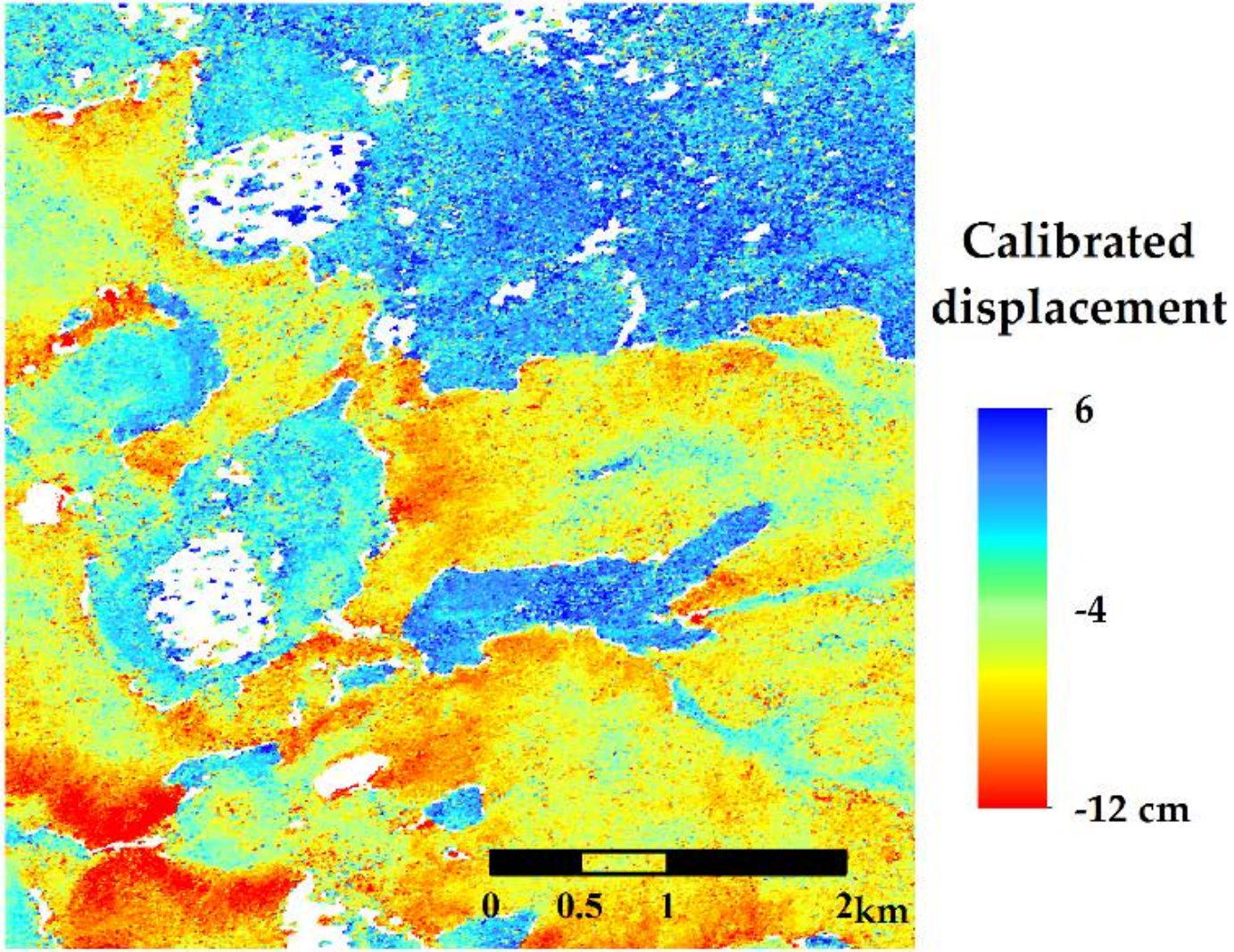


2008 Jul→ 2009 Jul （Post-Fire 1-year）

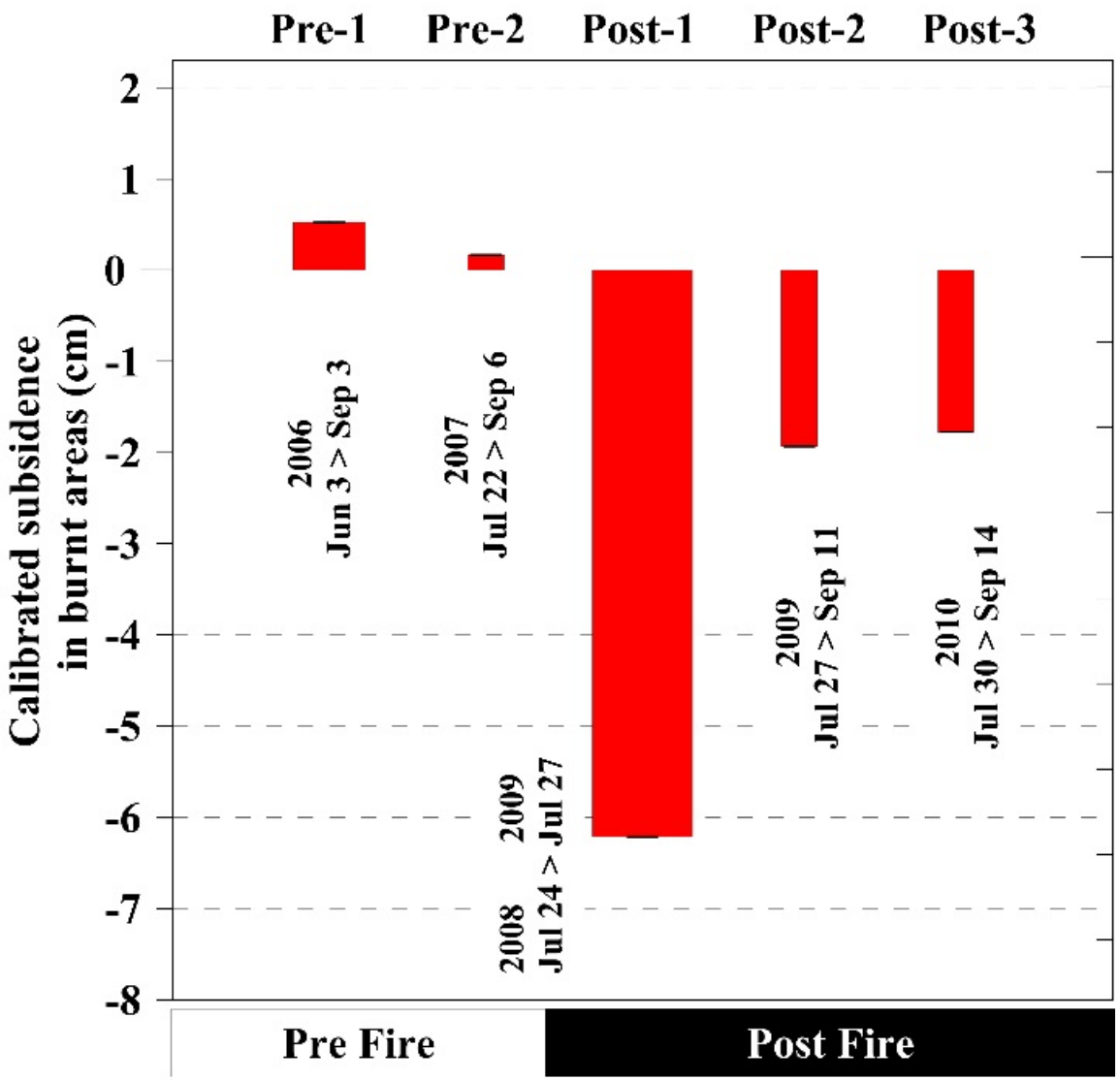
Anaktuvuk River Fire area in Alaska



Spatial distribution of thermokarst subsidence



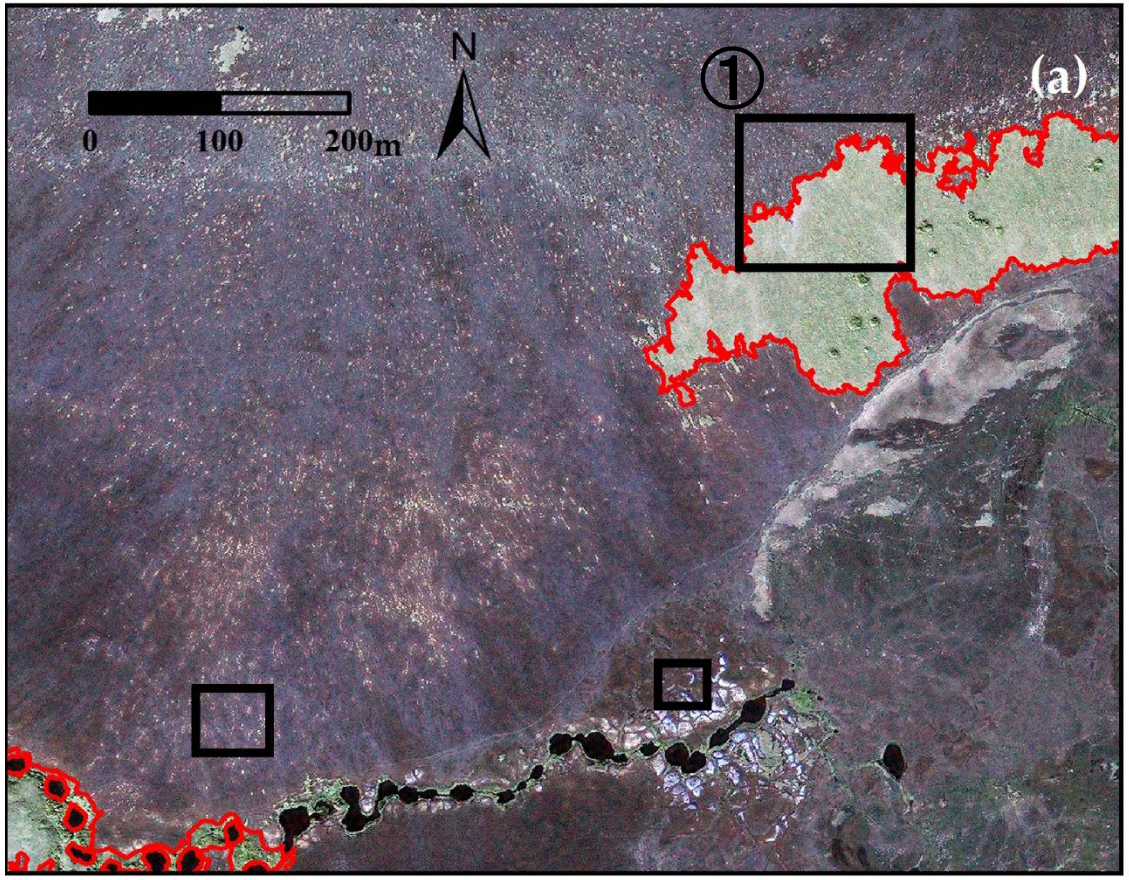
Surface displacement before and after the fire

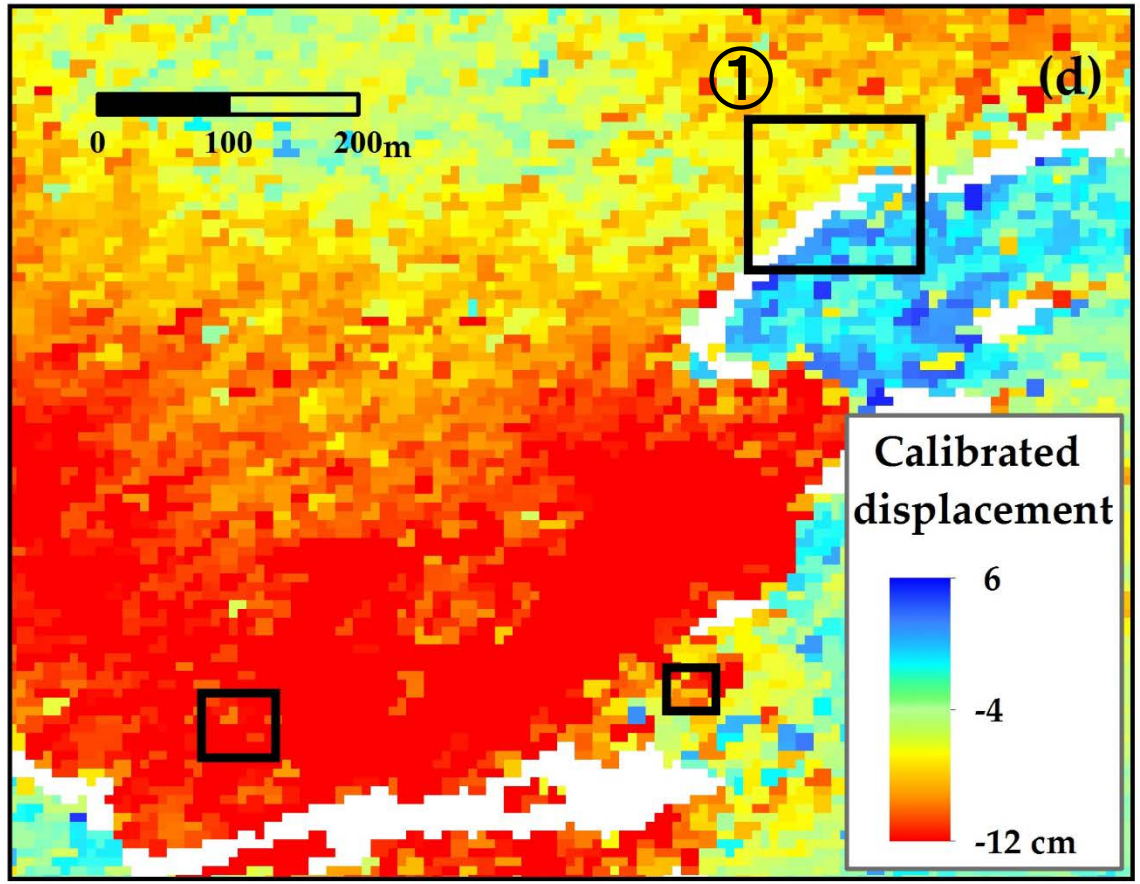


Pre-Fire pairs:
Within seasonal surface movement and/or errors
Post-Fire:
Larger subsidence than error sources

Post-Fire
1-year → Ave. 6 cm
2-year → Ave. 2 cm
3-year → Ave. 2 cm
* Bar width indicates length of observation (InSAR pair interval)

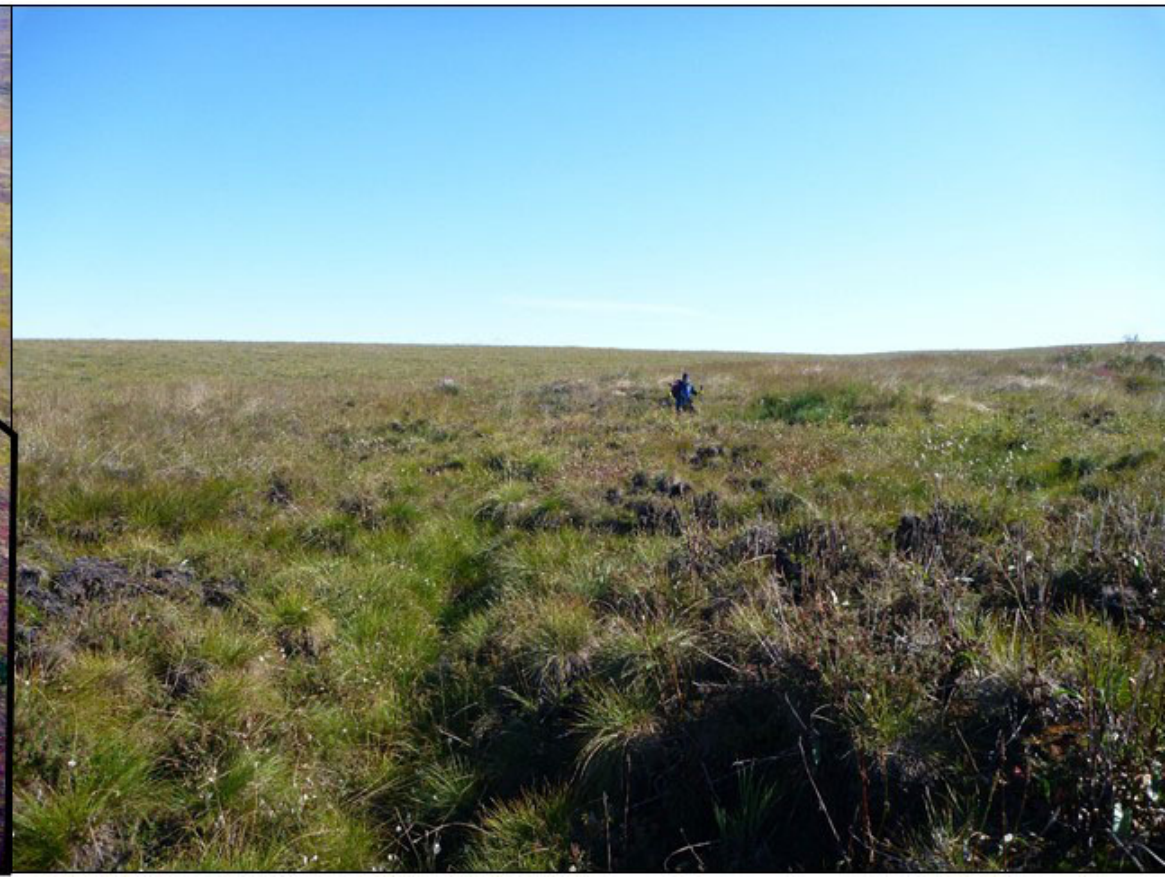
Close-up in field plots





*Decorrelation along the fire boundary

Field survey at area ①



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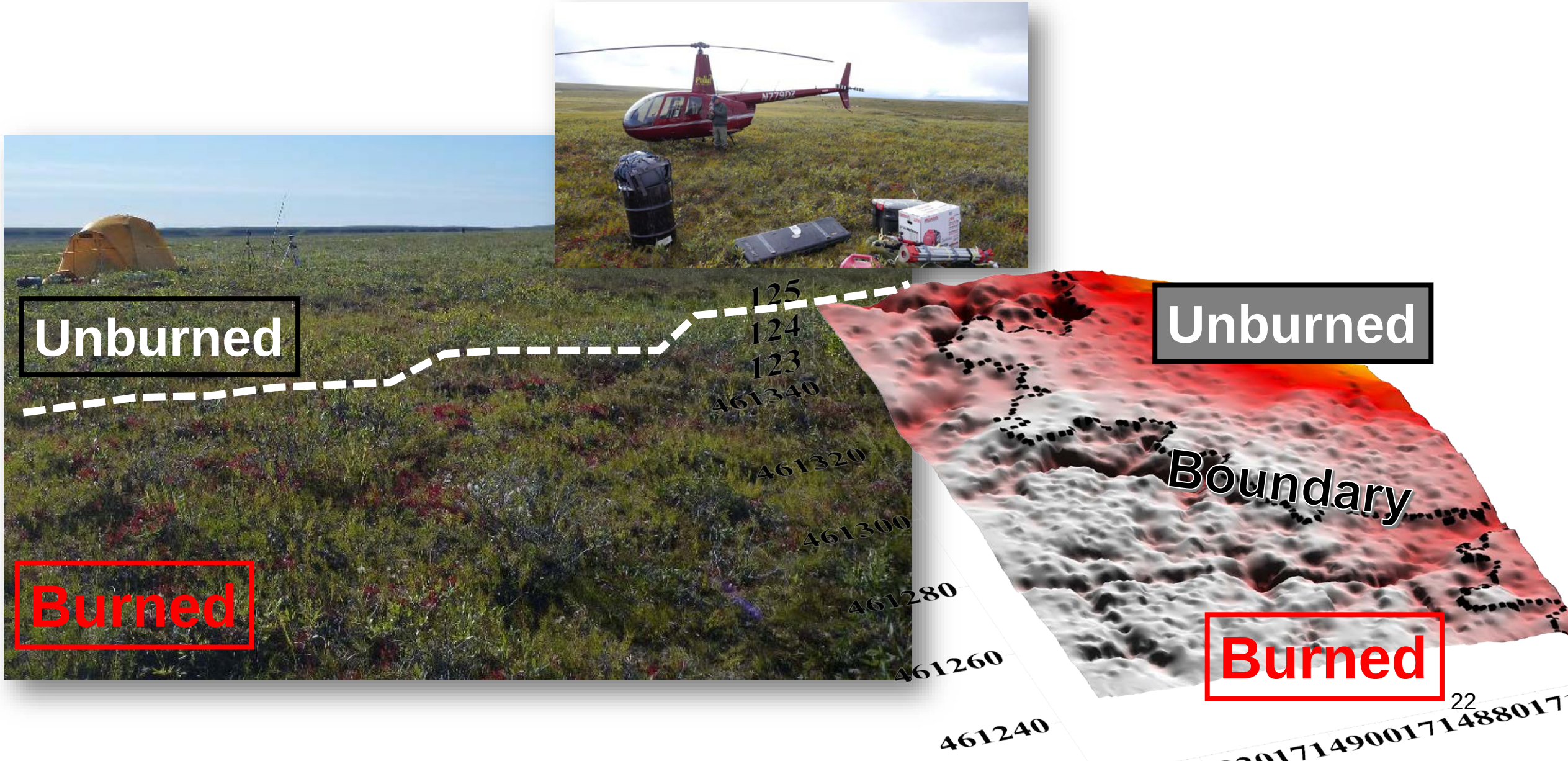
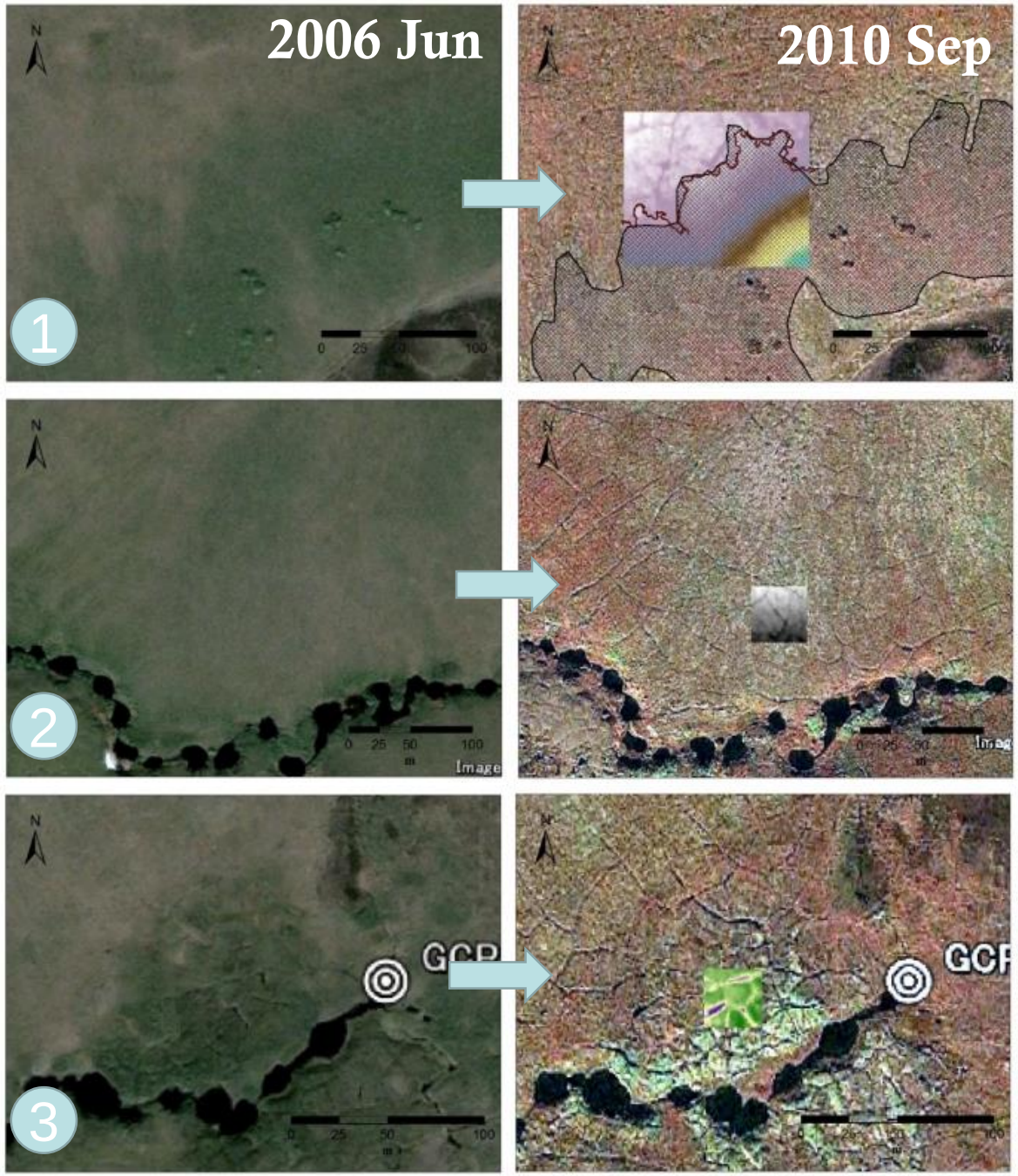
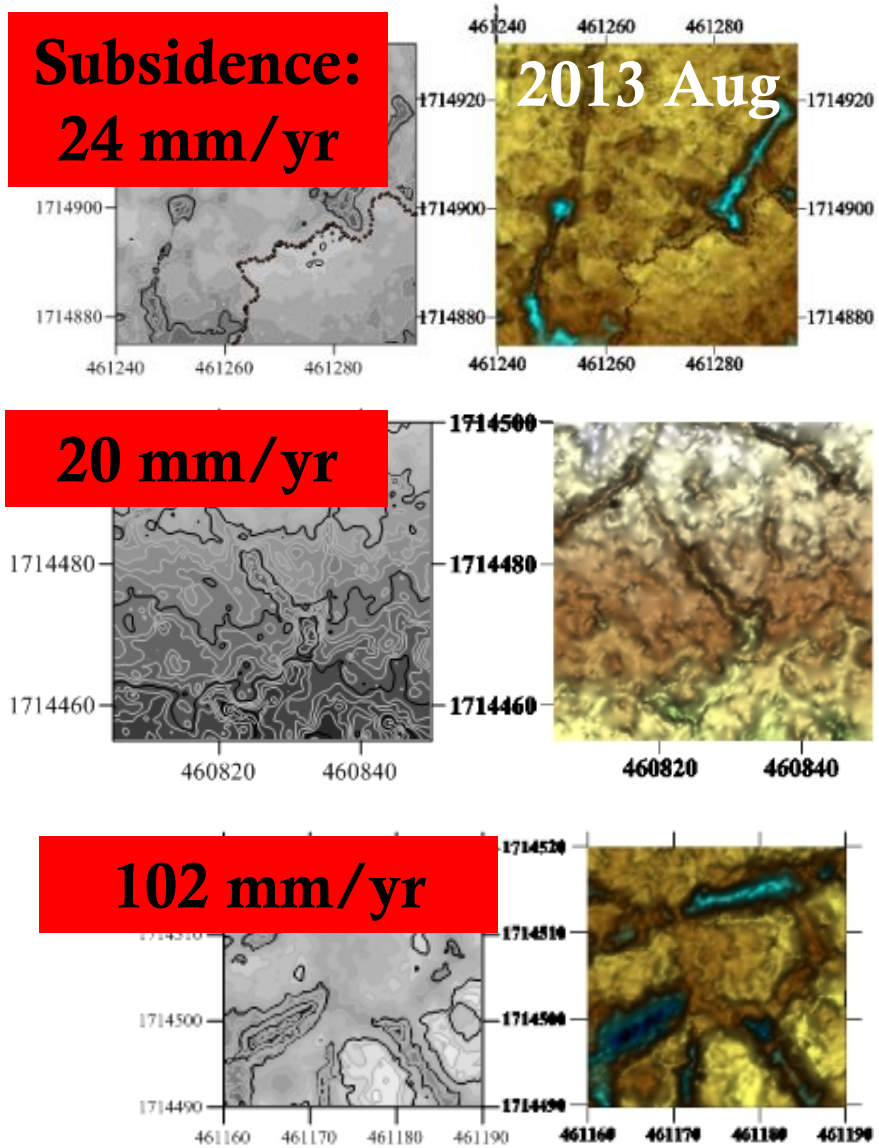


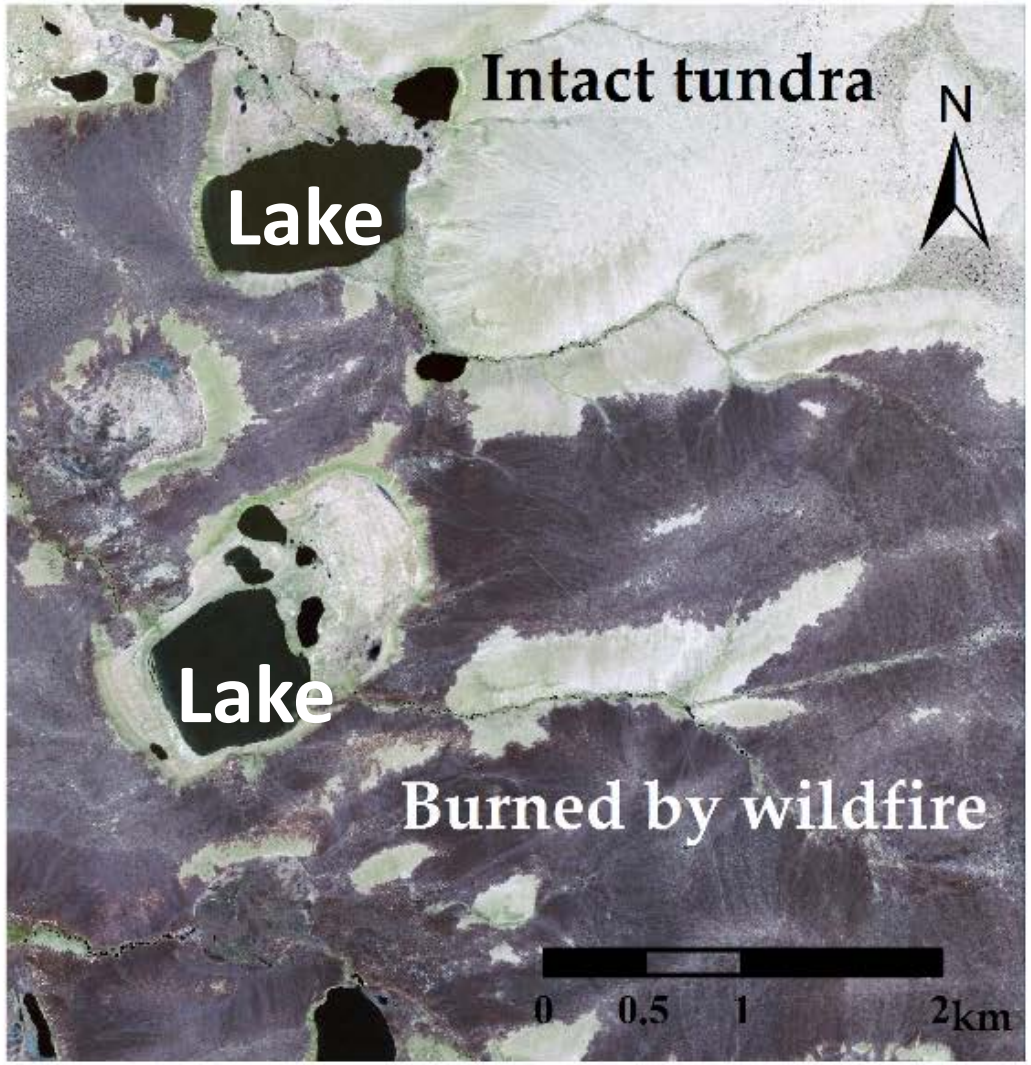
Change in surface texture (left) Micro-topography 6 years after the fire





2008 Jul→ 2009 Jul （Post-Fire 1-year）

Anaktuvuk River Fire area in Alaska



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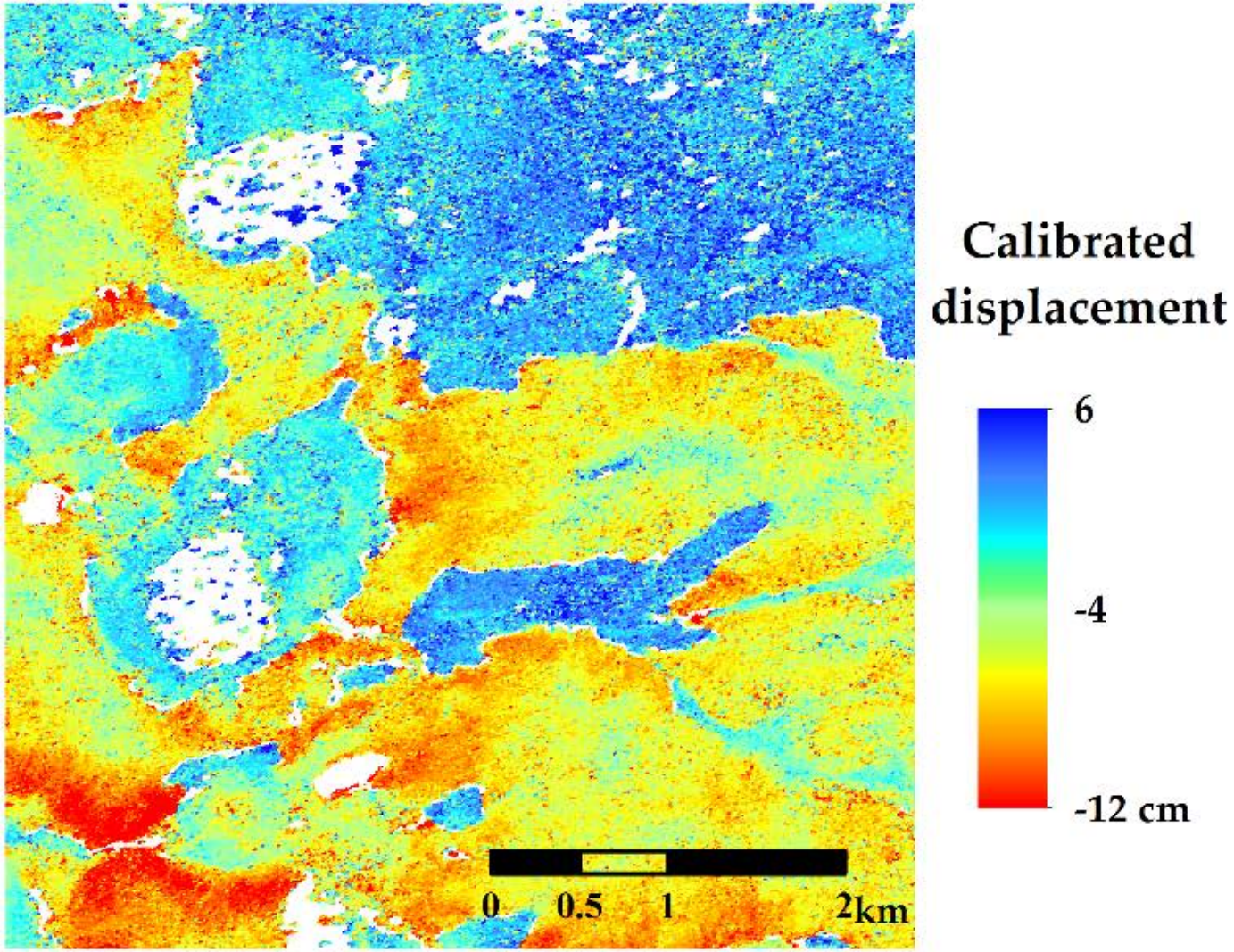
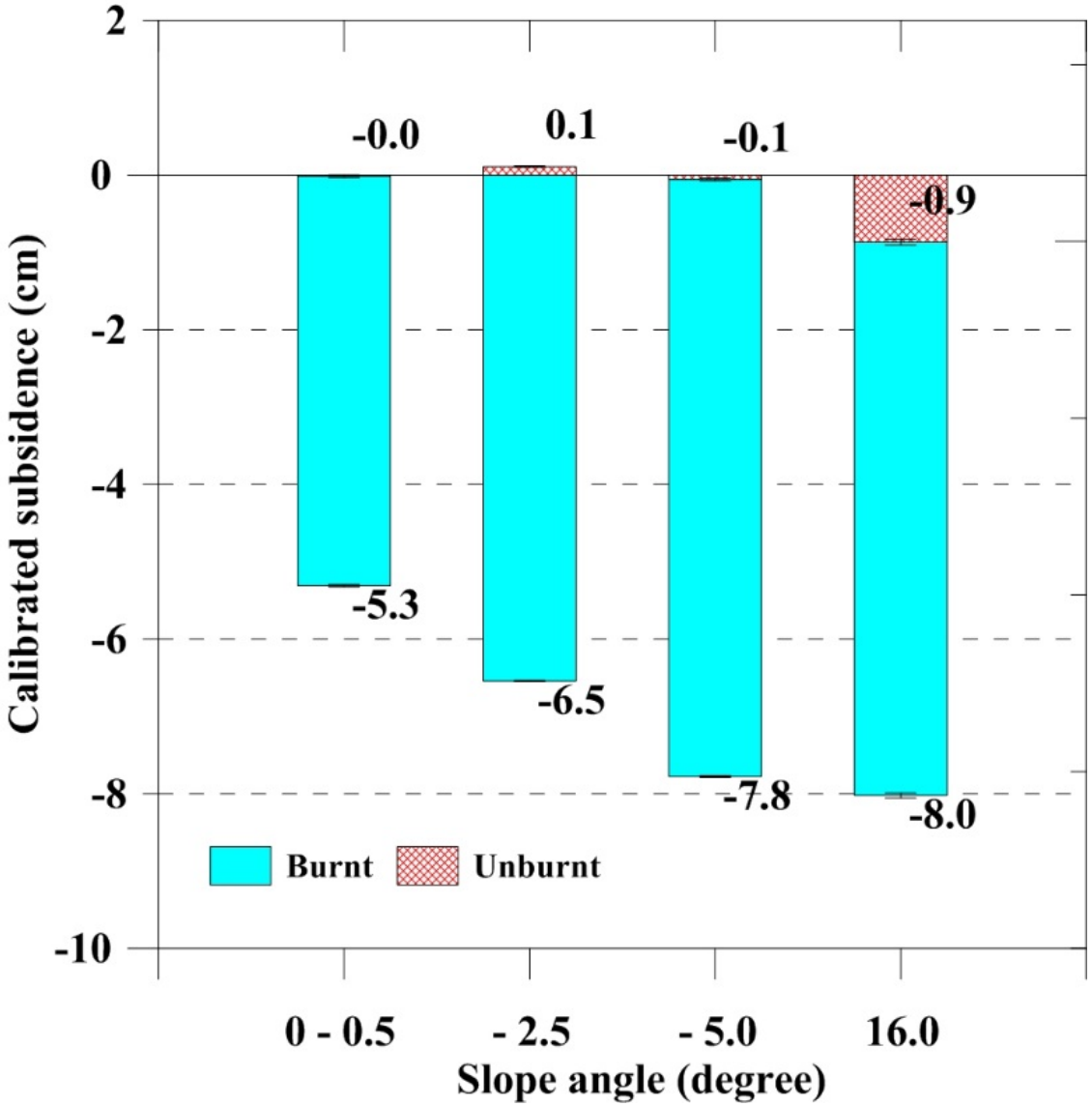


Thermokarst subsidence depends on slope angle



Larger angle
→ Larger subsidence

Peripheral slopes around thermokarst lakes
More active thermokarst

Conclusion

- The two-pass differential InSAR technique using ALOS-PALSAR (L-band microwave) has been shown capable of capturing thermokarst subsidence at a spatial resolution of tens of meters, with supporting evidence from field data and optical satellite images

  →Can be used to understand thermokarst processes / Hazard mapping

  →Provides critical information for large-scale estimates of GHG release upon permafrost thaw

Challenges:

- Differential subsidence along ice wedges vs. InSAR signals.
- More ground truth
- Inundation

incidence_angle: 38.7603 degrees

x: distance in line-of-sight

y: distance in Ndir

$$y = x * \cos(38.76)$$

$$= (\text{L-band wavelength})/2 * \cos(38.76)$$

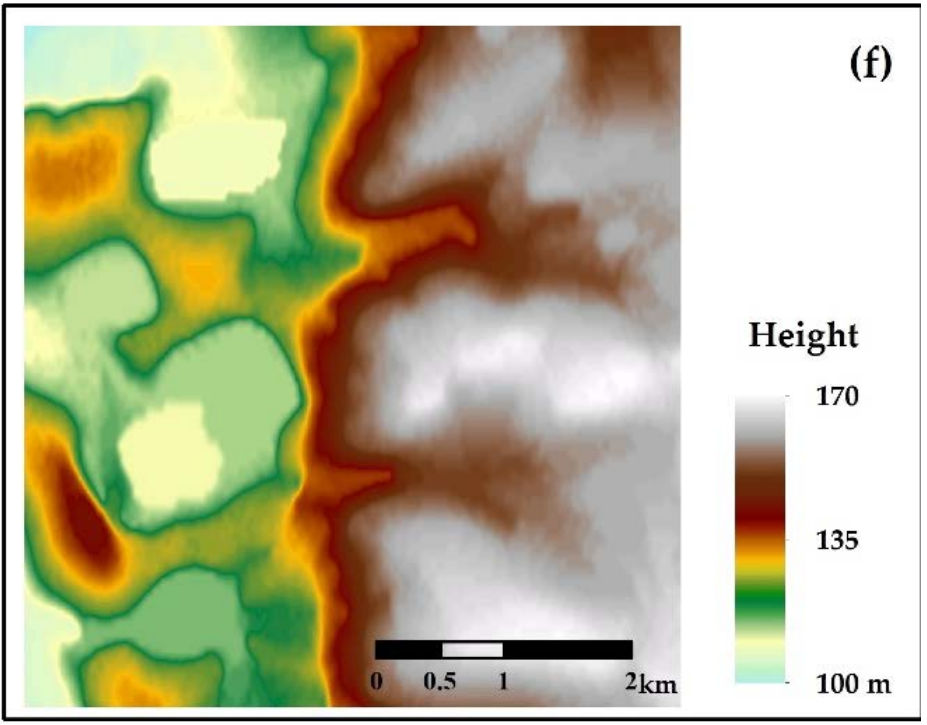
$$= 11.8 \text{ cm} * 0.77977$$

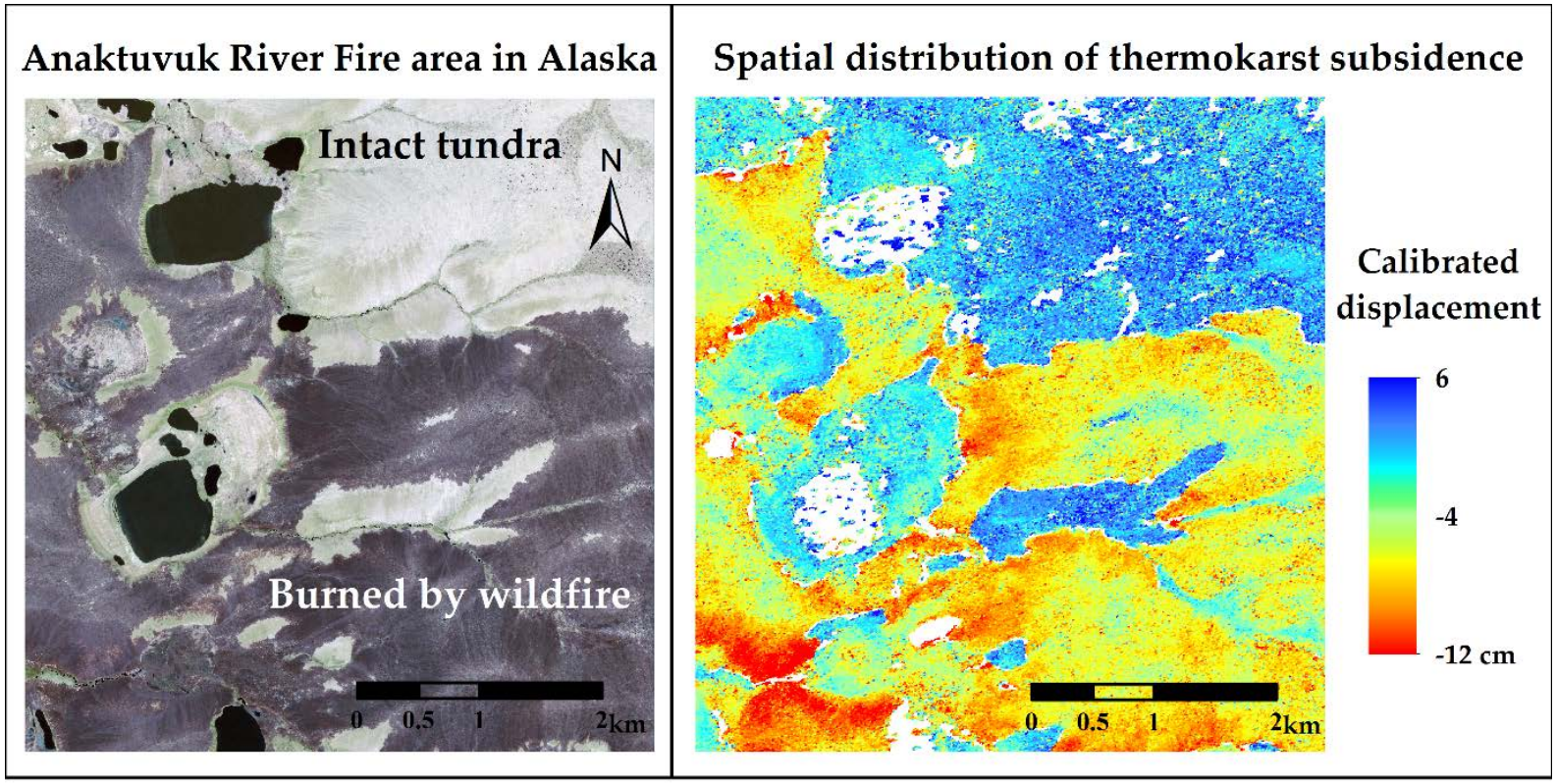
$$= 9.2 \text{ cm}$$

サーモカルストによる地表面変化例

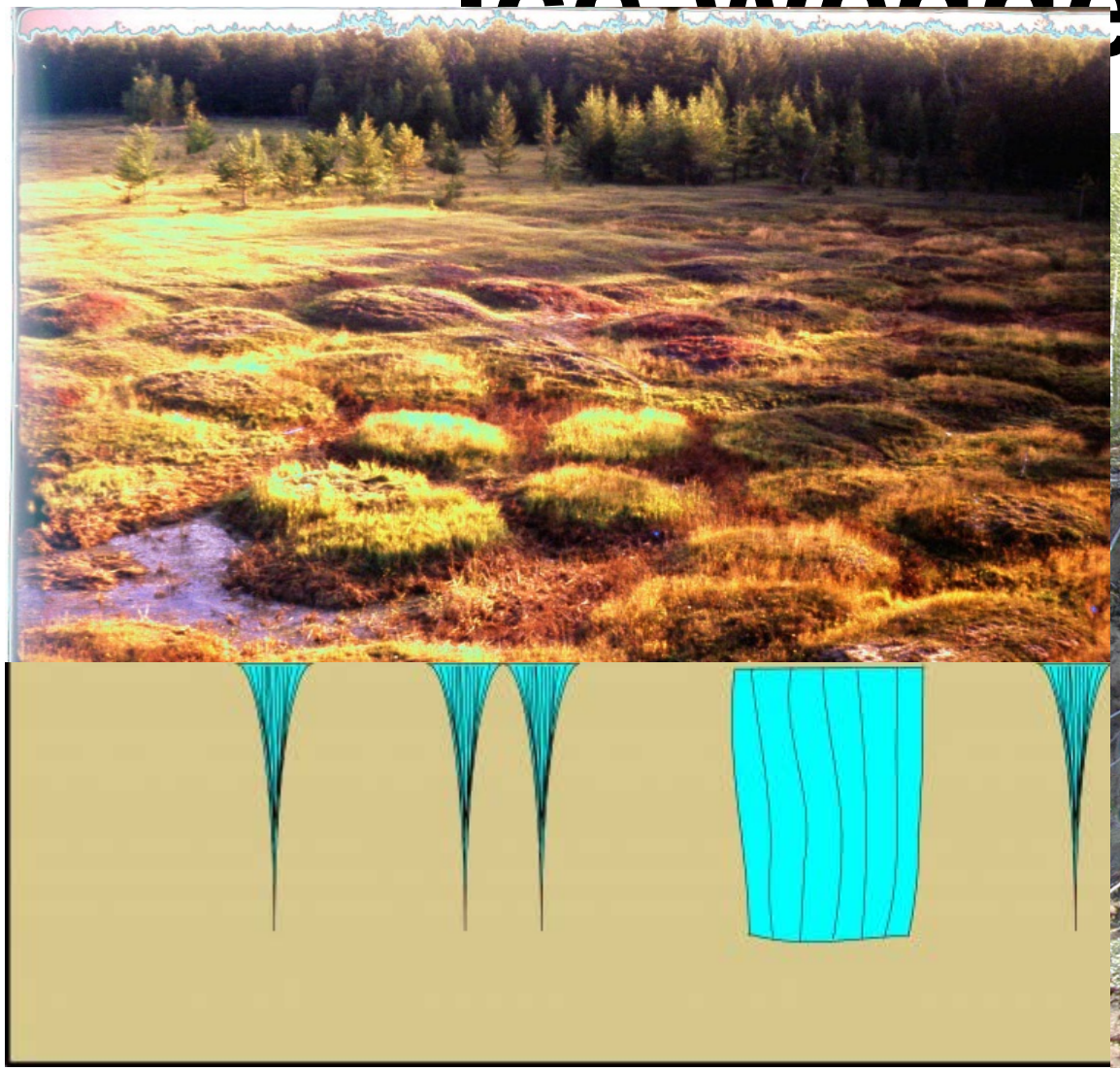
2006 Jun

2010 Sep


(f)
Height
170
135
100 m
0 0.5 1 2km


Anaktuvuk River Fire area in Alaska
Intact tundra
N
Burned by wildfire
0 0.5 1 2km
Spatial distribution of thermokarst subsidence
Calibrated displacement
6
-4
-12 cm
0 0.5 1 2km

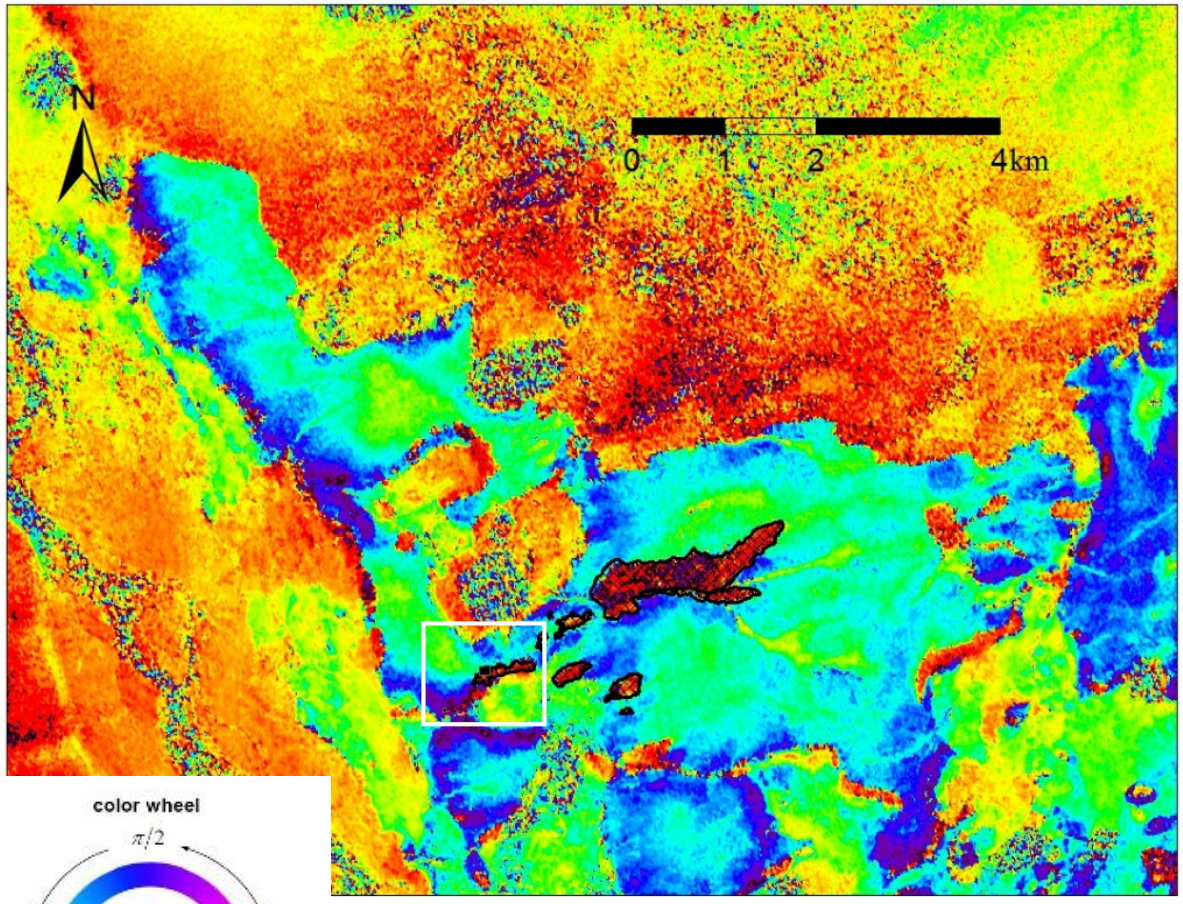
Ice Wedge Polygon

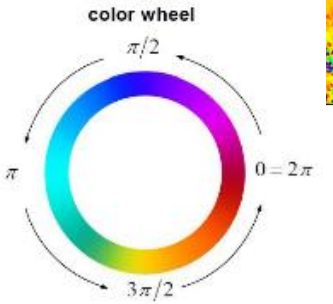


CRREL http://www.permafrosttunnel.org/?page_id=9

2-pass vs. Time Series InSAR

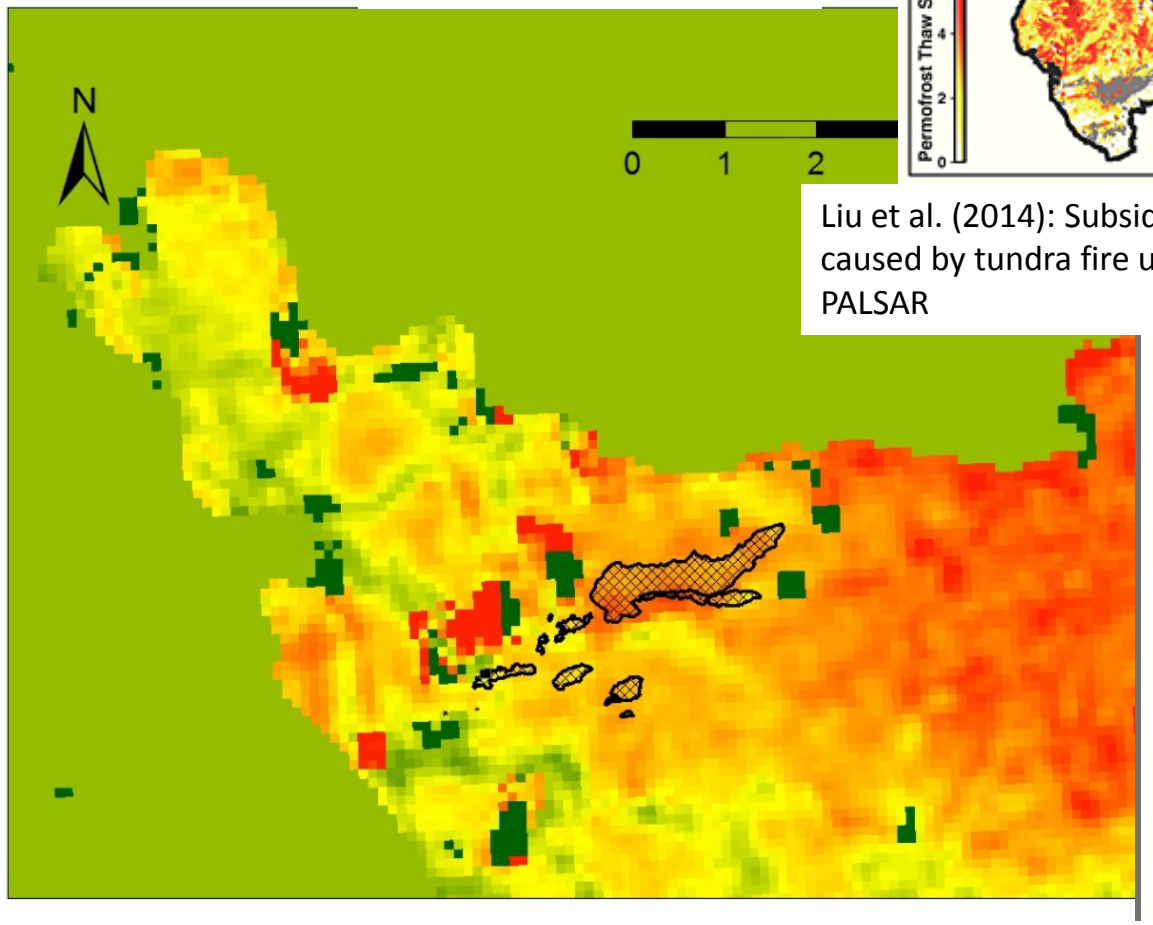
Interferogram 2008 Jul → 2009 Jul

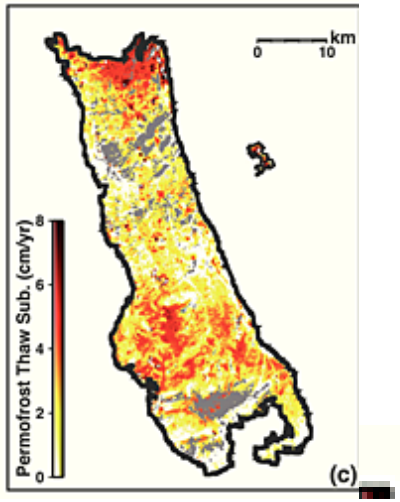




Water surface
Burned / Unburned

Subsidence

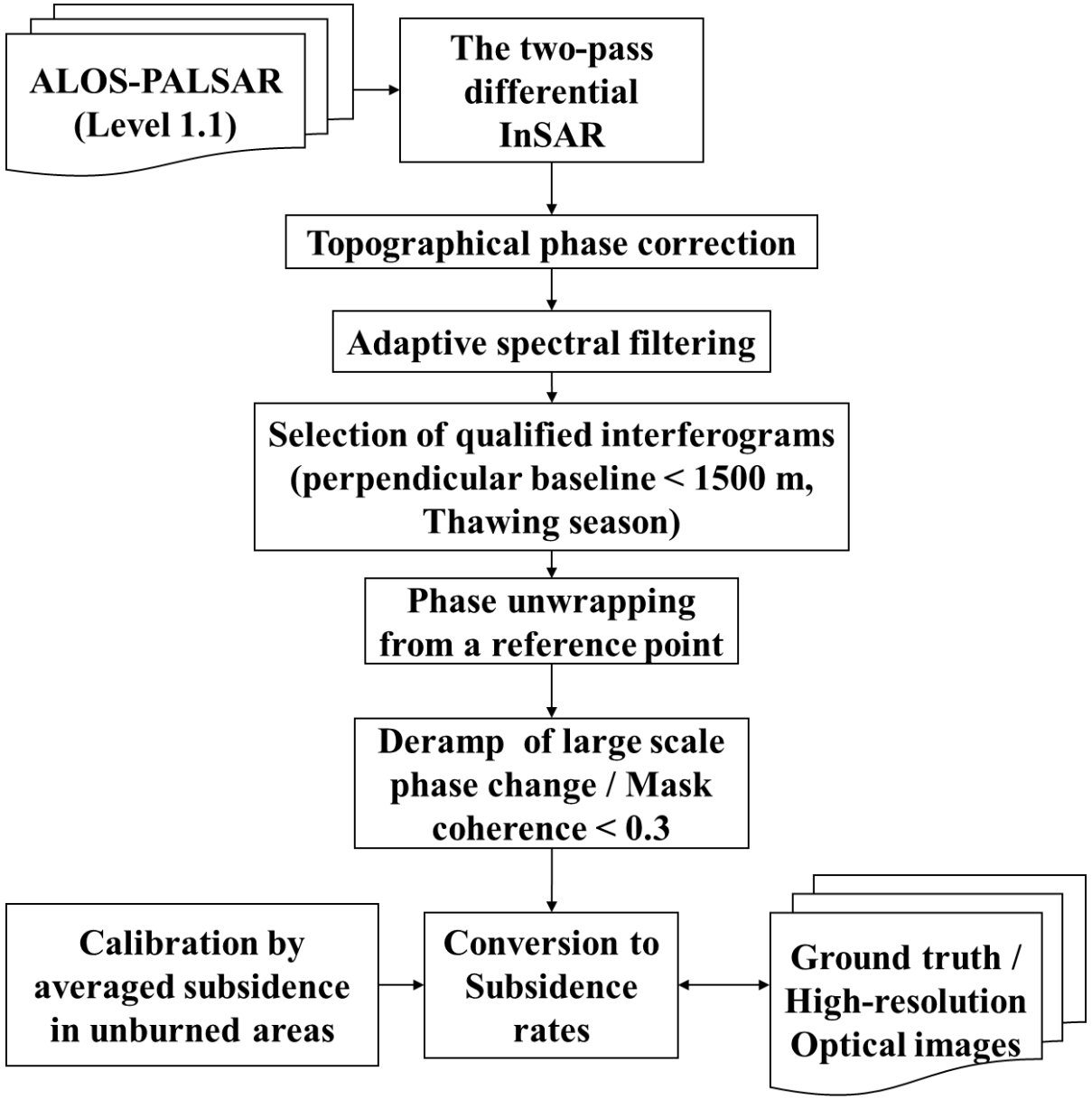




Liu et al. (2014): Subsidence caused by tundra fire using ALOS-PALSAR

Discrepancy between ground truth and subsidence estimation

Workflow:



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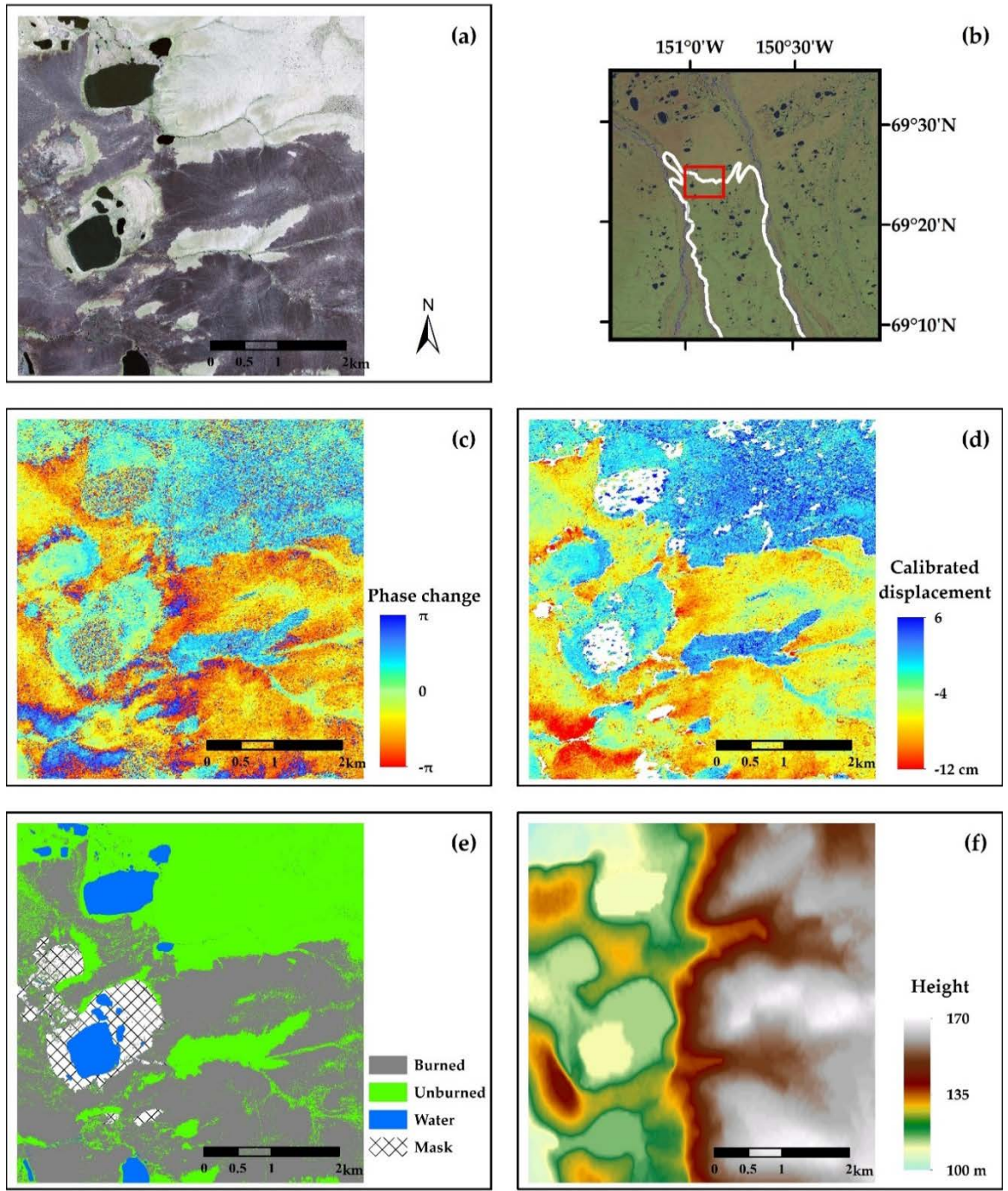
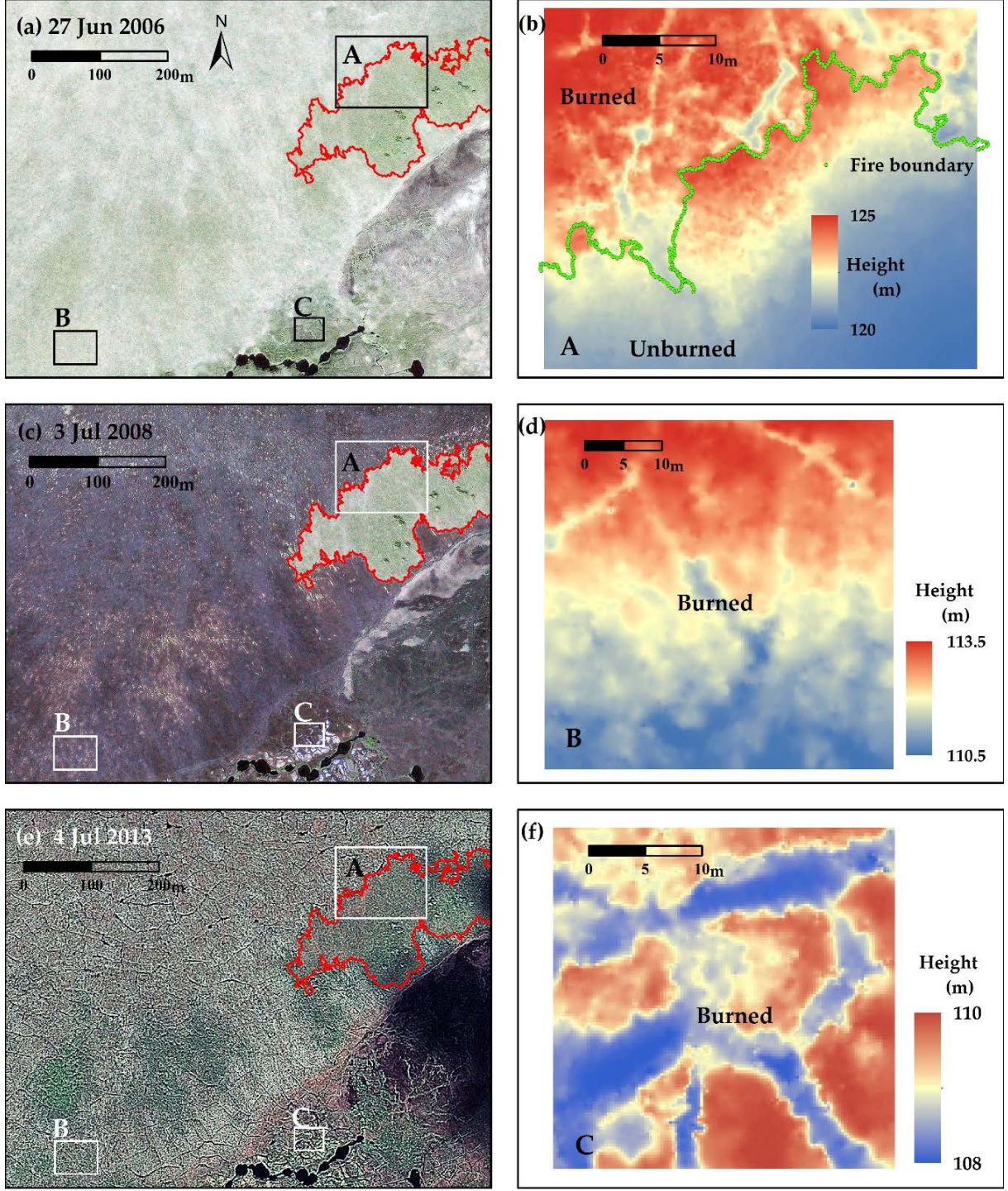

(a)
N
0 0.5 1 2km
(b)
151°0'W
150°30'W
69°30'N
69°20'N
69°10'N
(c)
Phase change
π
0
-π
0 0.5 1 2km
(d)
Calibrated displacement
6
-4
-12 cm
0 0.5 1 2km
(e)
Burned
Unburned
Water
Mask
0 0.5 1 2km
(f)
Height
170
135
100 m
0 0.5 1 2km


(a) 27 Jun 2006
N
0
100
200m
A
B
C
(b)
0
5
10m
Burned
Fire boundary
125
Height
(m)
120
A
Unburned
(c) 3 Jul 2008
0
100
200m
A
B
C
(d)
0
5
10m
Burned
Height
(m)
113.5
110.5
B
(e) 4 Jul 2013
0
100
200m
A
B
C
(f)
0
5
10m
Burned
Height
(m)
110
108
C