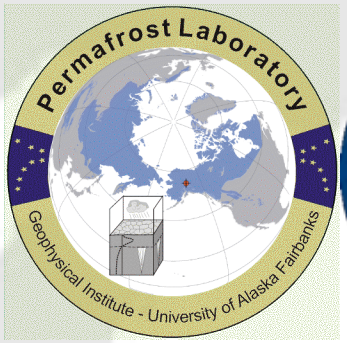
Monitoring thaw lake dynamics using high-resolution remote sensing

Examples from the Cape Espenberg area (Seward Peninsula) and the Kolyma lowland (Siberia)

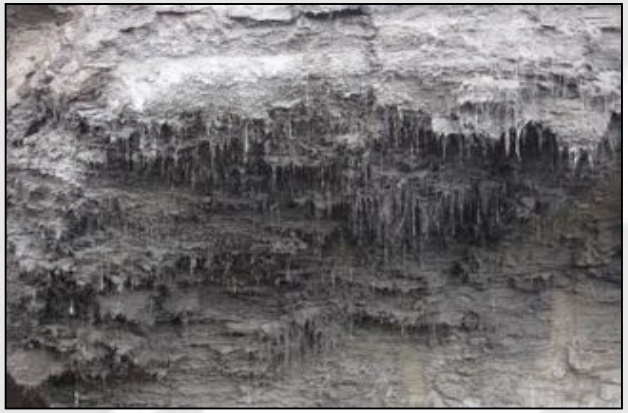
Guido Grosse

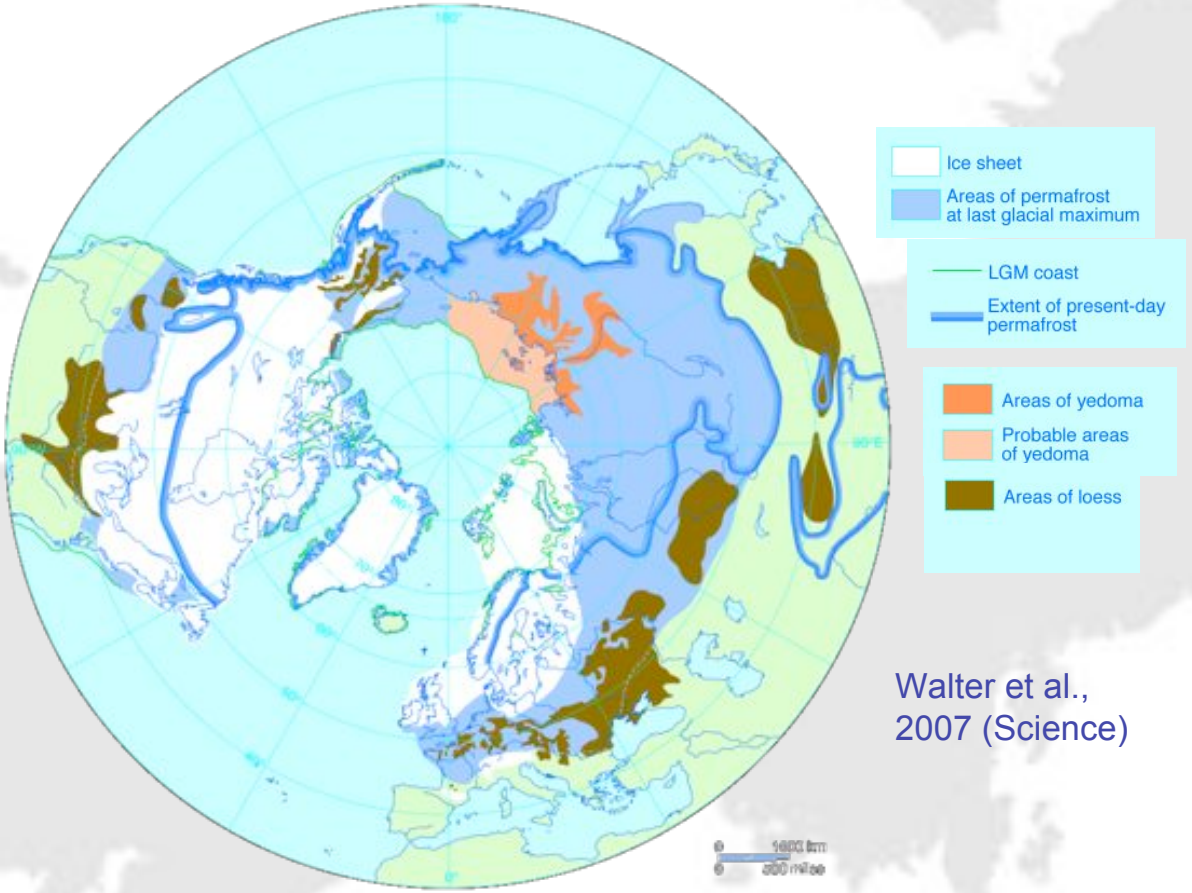
in collaboration with Katey Walter, Lawrence Plug, Vladimir Romanovsky, Mary Edwards, Lee Slater, Meghan Tillapaugh and Melanie Engram



High-Resolution Imagery for Analysis of Environmental Change in Northern Alaska (17 October 2008)

Distribution of Ice-Rich Yedoma Deposits





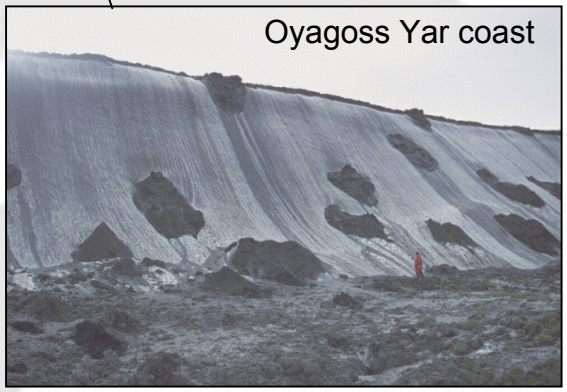
Walter et al., 2007 (Science)

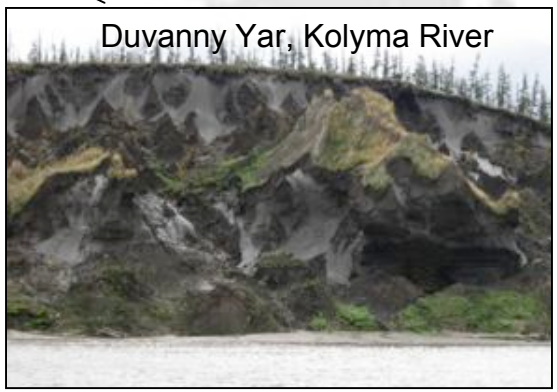
- *Thickness of the deposit is between 5-100m*
- *Present day total coverage is > 1x10^6 km*
- *Gravimetric ground ice contents in the sediments between 60-120%*
- *Including the ice wedges, total volumetric ice content of up to >75%*
- *Organic carbon content averages between 2-5%*
- *Accumulation during several 10 000 years*
- *Stores about 500 Gt of organic carbon in thaw-vulnerable permafrost*

Zimov et al 2006 (Science), Schirrmeister et al., 2008 (NICOP)

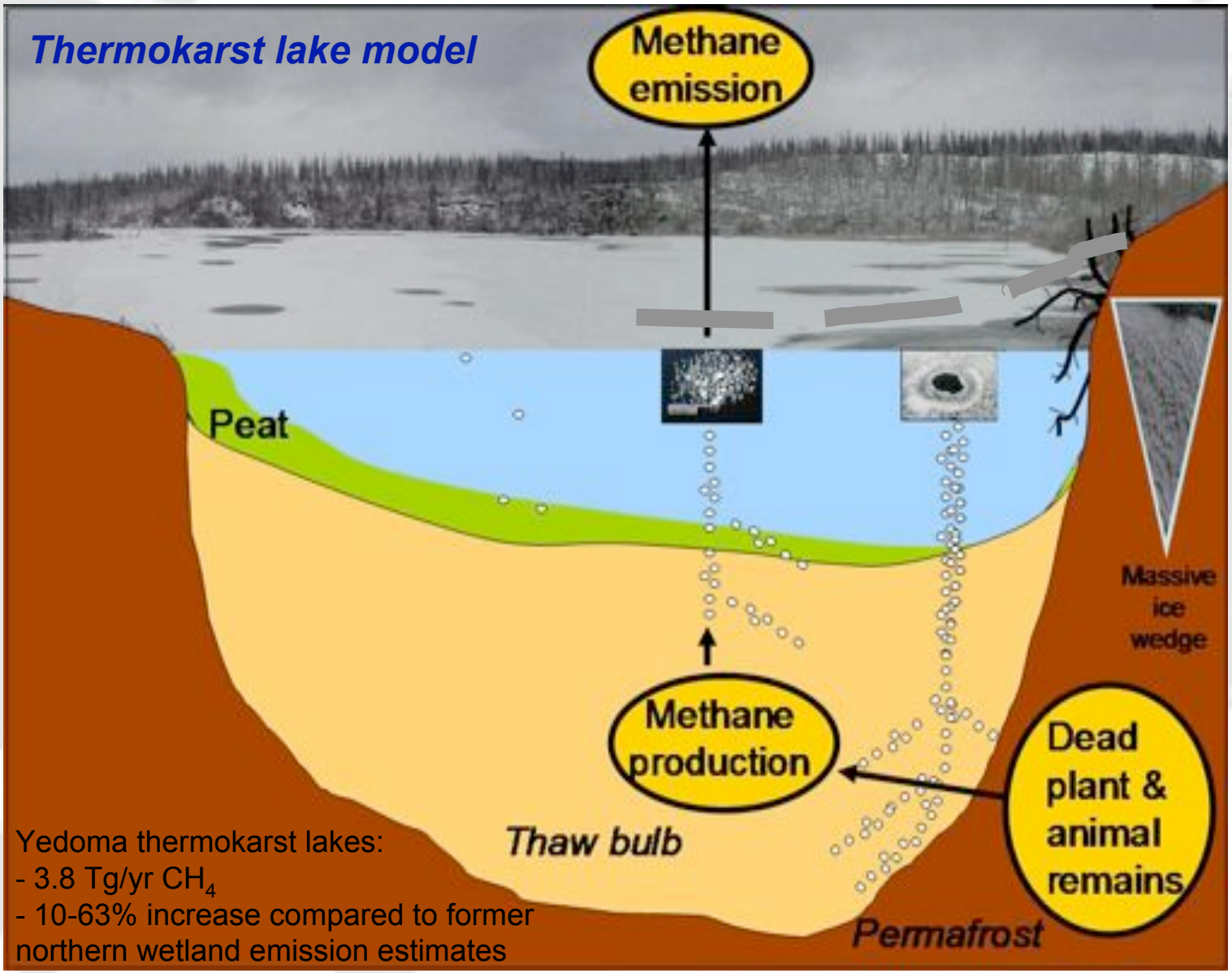
Ice-rich Yedoma Permafrost in Beringia

???





Thermokarst and C-Cycle

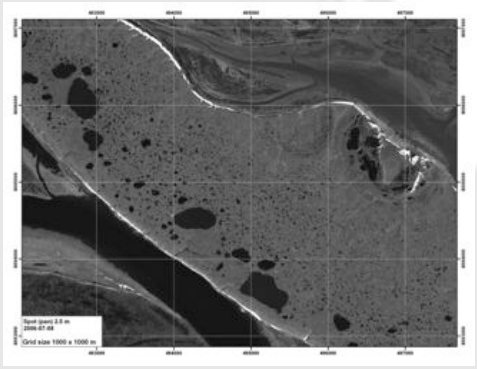


Walter et al, 2007 (Phil. Trans. Royal Soc. A)

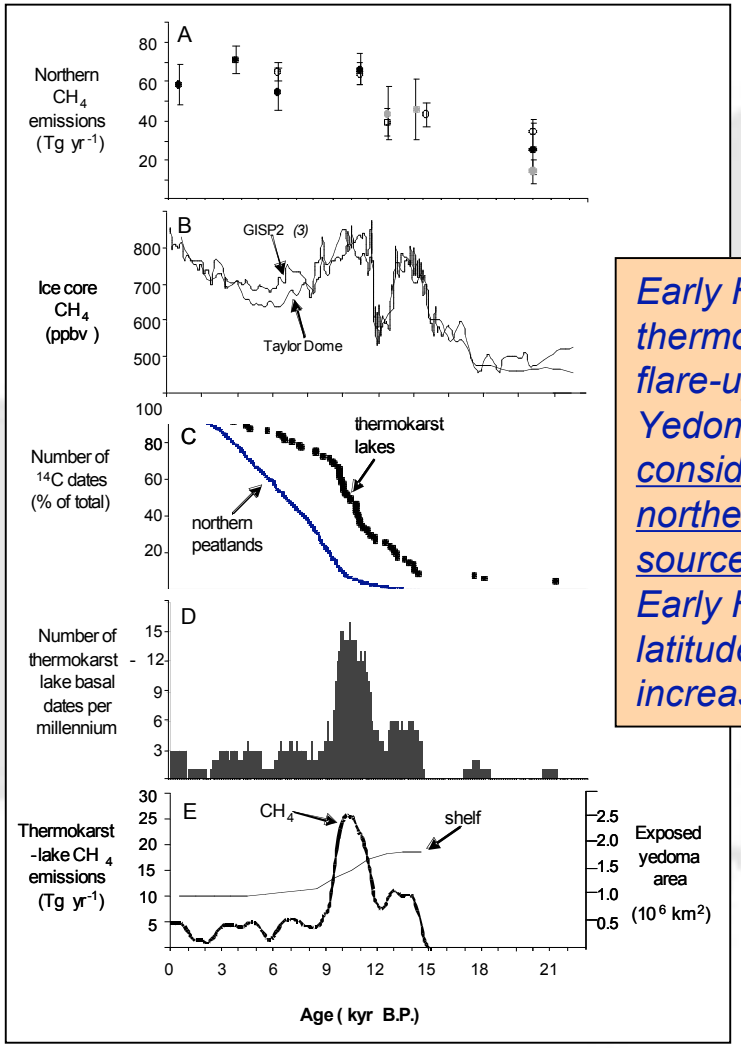
Thermokarst and C-Cycle

Thermokarst Lakes as a Source of Atmospheric CH_4 During the Last Deglaciation

Olenek Channel, Lena Delta



Kolyma Lowland



Early Holocene thermokarst lake flare-up in ice-rich Yedoma was a considerable northern methane source (33-87% of Early Holocene high latitude methane increase).

Walter et al, 2007 (Science)

Thermokarst Lakes: Permafrost Degradation and C-cycling in the Arctic

Carbon Cycle Sciences
2008-2011

National Science Foundation
WHERE DISCOVERIES BEGIN
IPY OPP
2008-2011

Assessing the spatial and temporal dynamics of thermokarst, methane emissions, and related carbon cycling in Siberia and Alaska
G. Grosse, K. Walter, V. Romanovsky

IPY: Understanding the impacts of thermokarst lakes on C-cycling and climate change
K. Walter, G. Grosse , L. Plug, M. Edwards, L. Slater

Thermokarst Lake Dynamics

Remote sensing, change detection, spatial upscaling
G. Grosse, USA

Integration into Earth system models
P. Valdes, UK

Paleoecology and paleoenvironmental dynamics
M. Edwards, USA+UK

Biogeochemistry and greenhouse gas fluxes *K. Walter, USA*

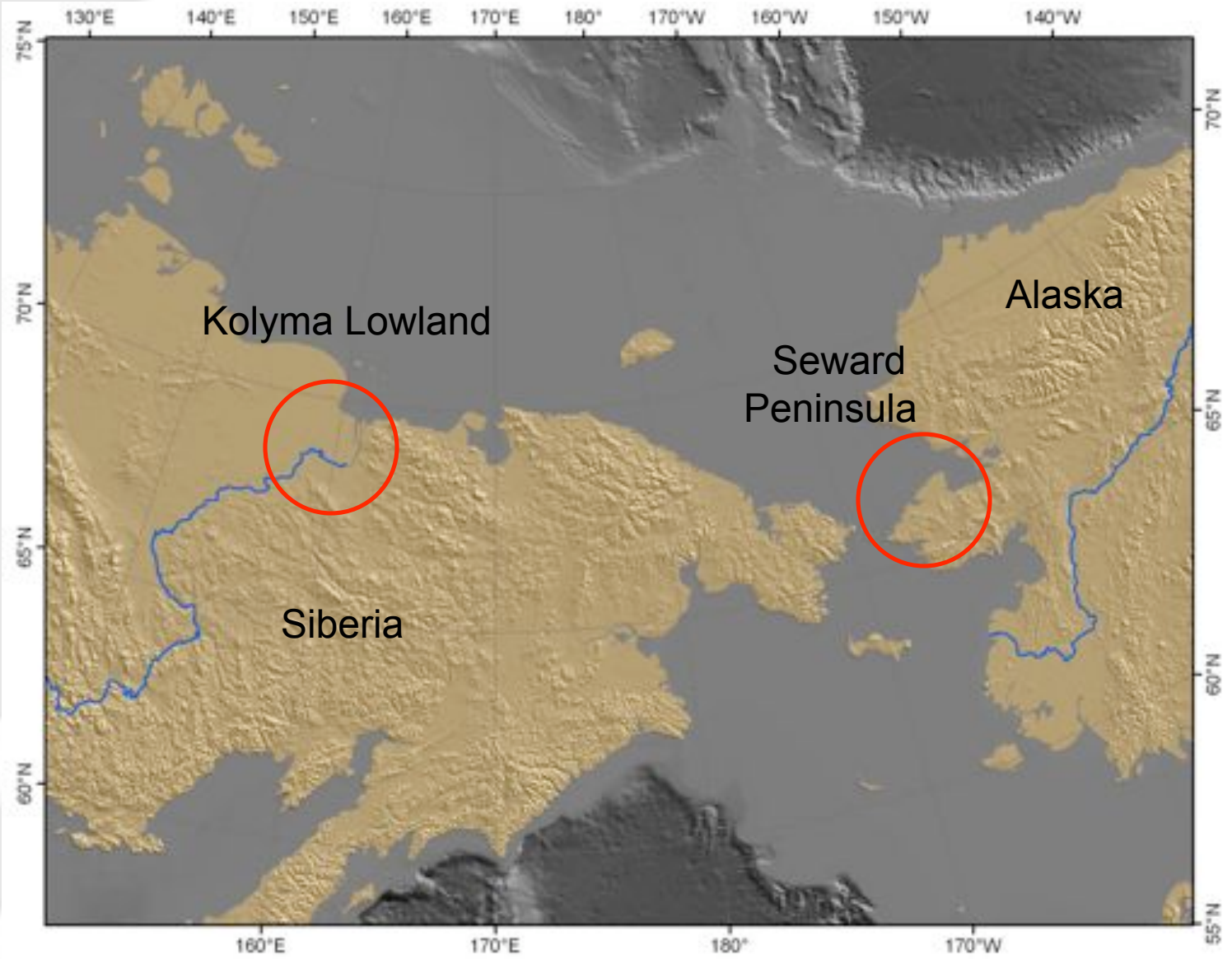
Numerical modeling of lakes and landscapes *L. Plug, CAN*

Geophysics of thaw bulbs and sediment gas contents
L. Slater, USA

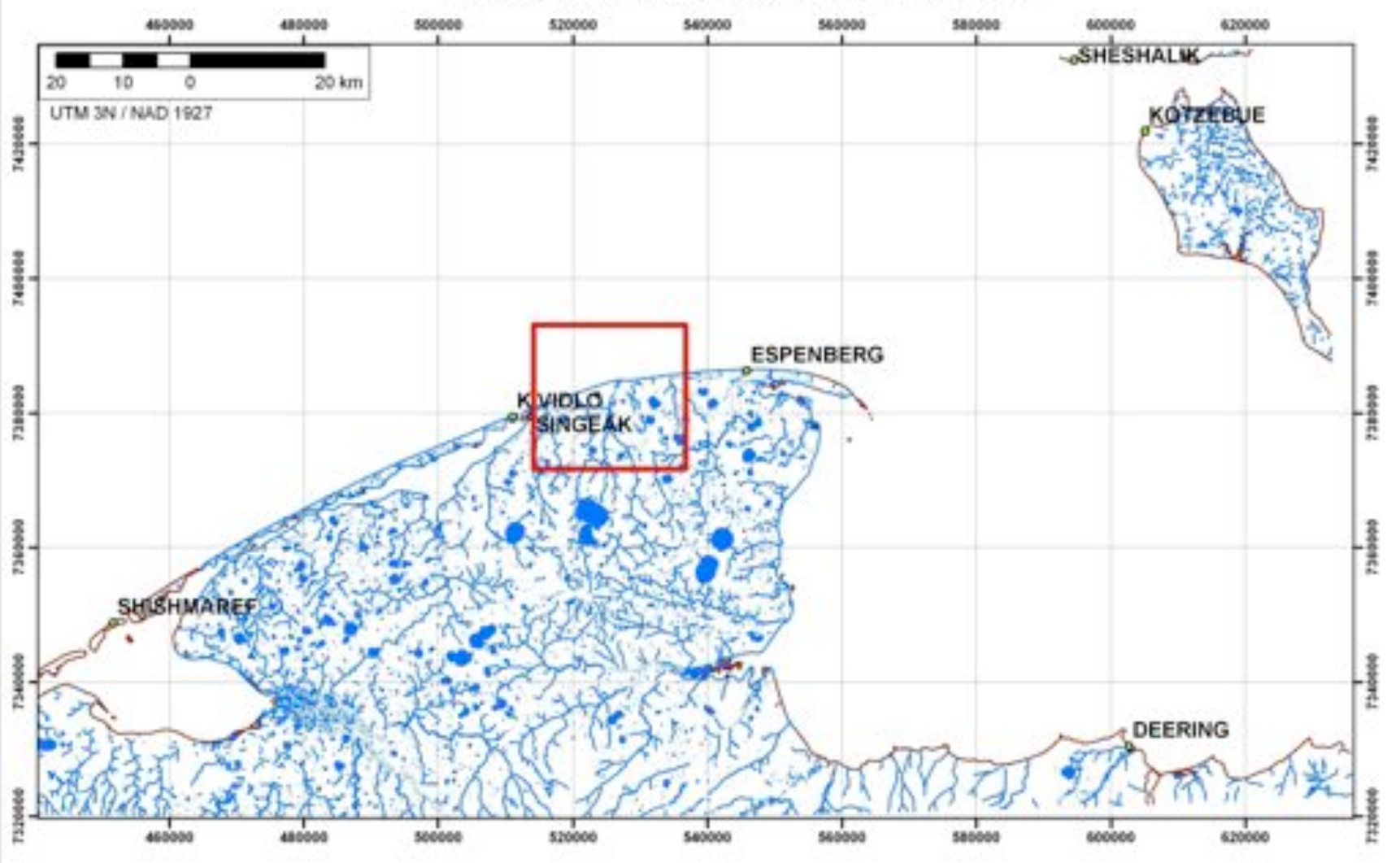
Permafrost modeling
V. Romanovsky, USA

Carbon cycling
S. Zimov, Russia

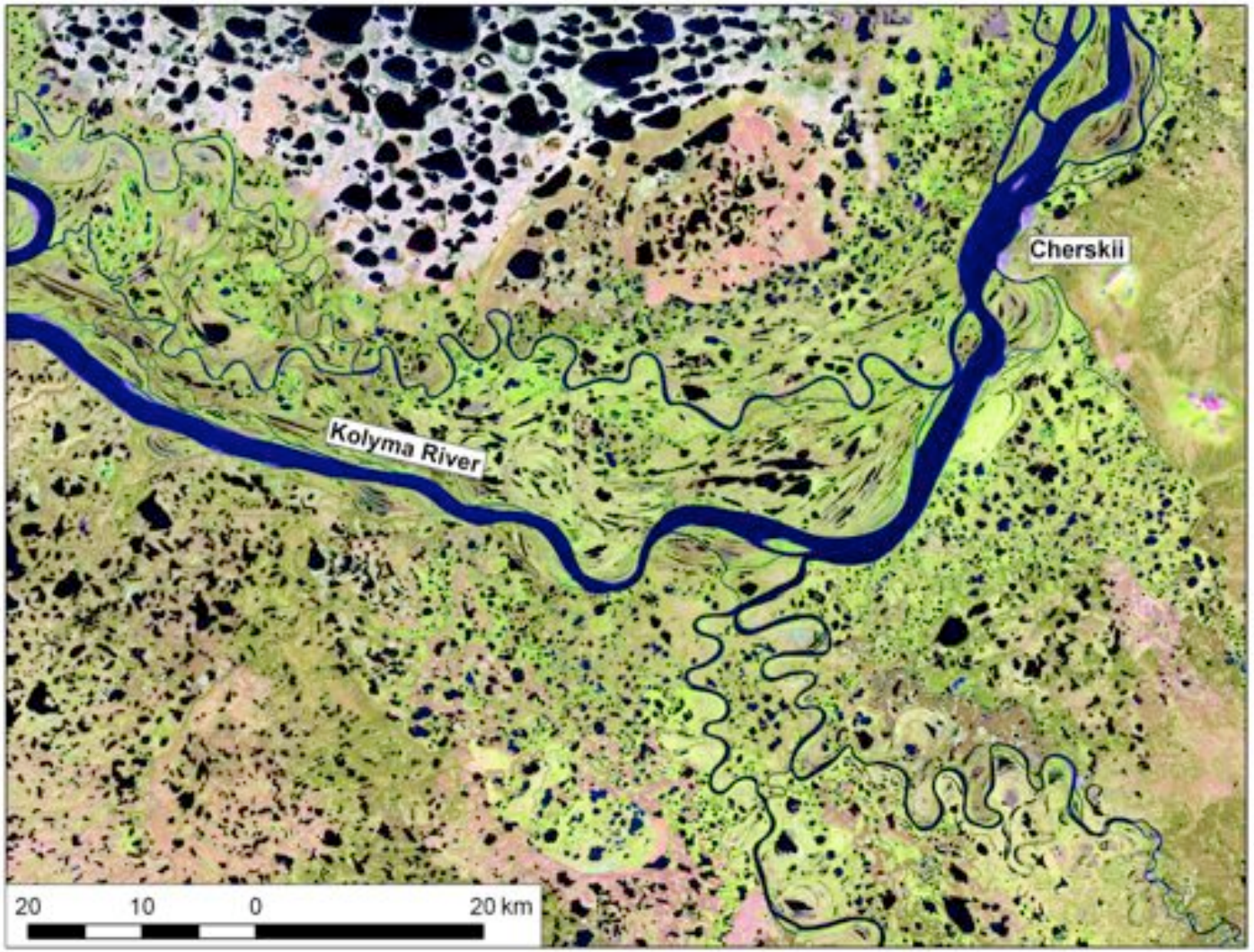
Study Areas


130°E
140°E
150°E
160°E
170°E
180°
170°W
160°W
150°W
140°W
75°N
70°N
65°N
60°N
55°N
Kolyma Lowland
Siberia
Seward
Peninsula
Alaska
160°E
170°E
180°
170°W

Northern Seward Peninsula

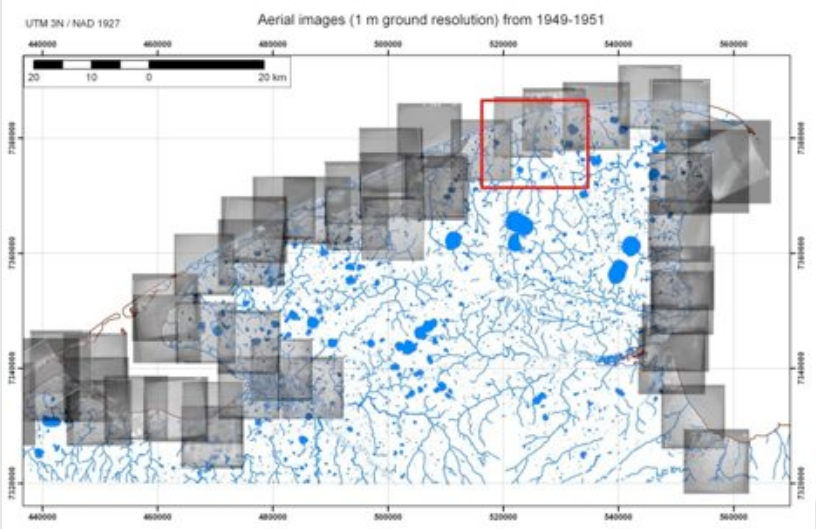


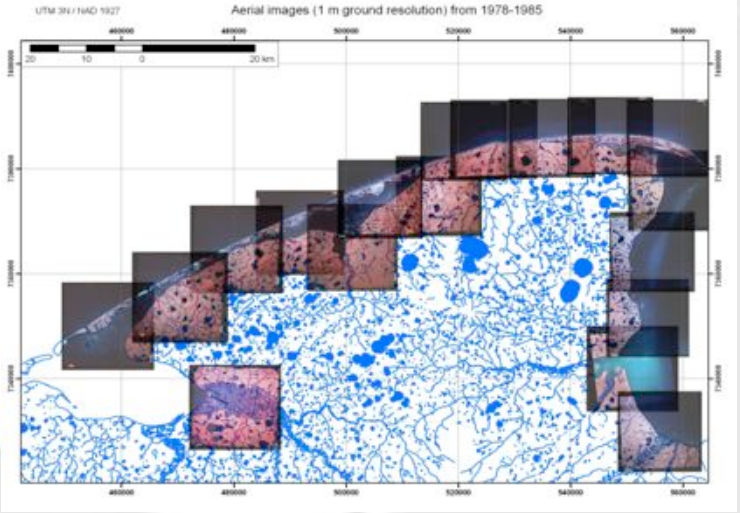
Kolyma Lowland, Cherskii region

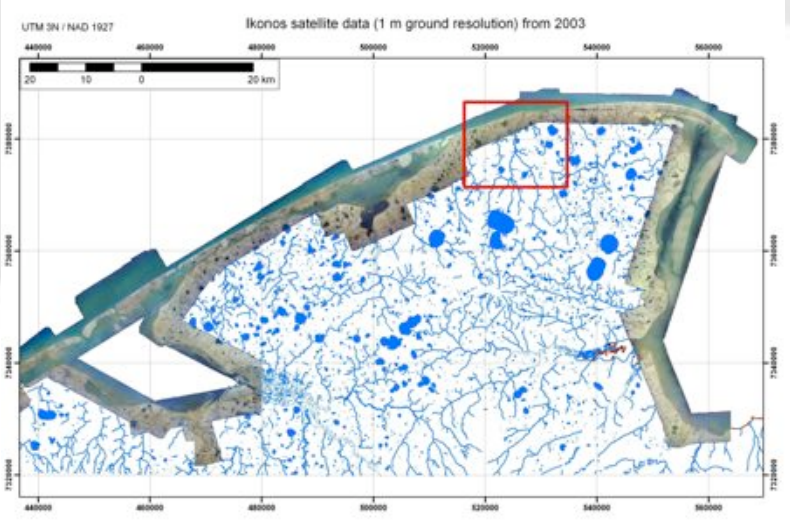


Remote Sensing Datasets

	Seward Peninsula	Kolyma Lowland
1949-1960	Air photos (1m)	-
1960-1970	Corona KH-4 (8m)	Corona KH-4A (2.5m), Gambit KH-7 (1m)
1970-1980	Air photos (1m)	-
1980-1990	Air photos (1m)	-
1990-2000	-	-
2000-2010	Air photos (0.6m) Ikonos-2 (1m) LIDAR (0.5m) TerraSAR-X (1m)	Ikonos-2 (1m) ALOS PRISM (2.5m) TerraSAR-X (1m) Quickbird (0.8) SPOT-5 (2.5)
	> 55 years coverage	> 40 years coverage



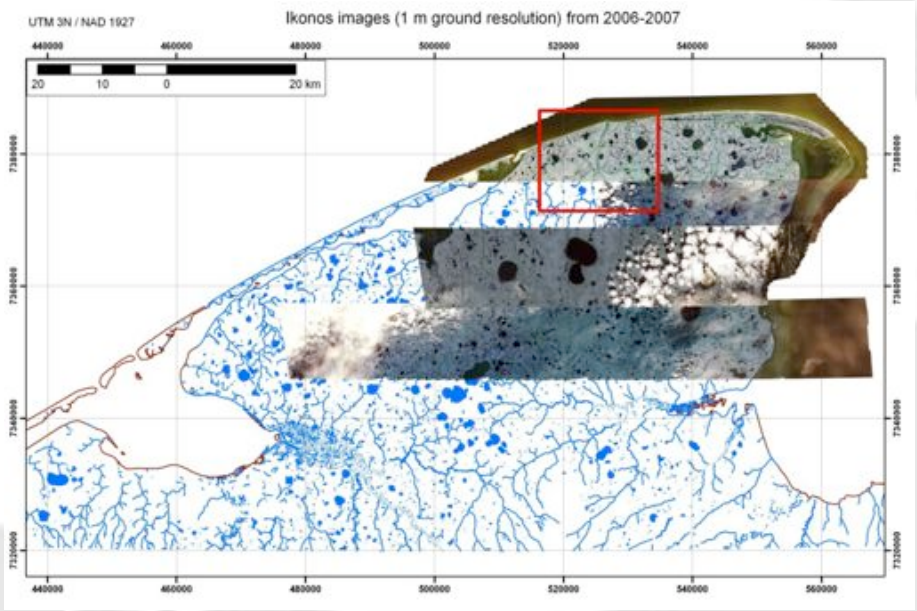




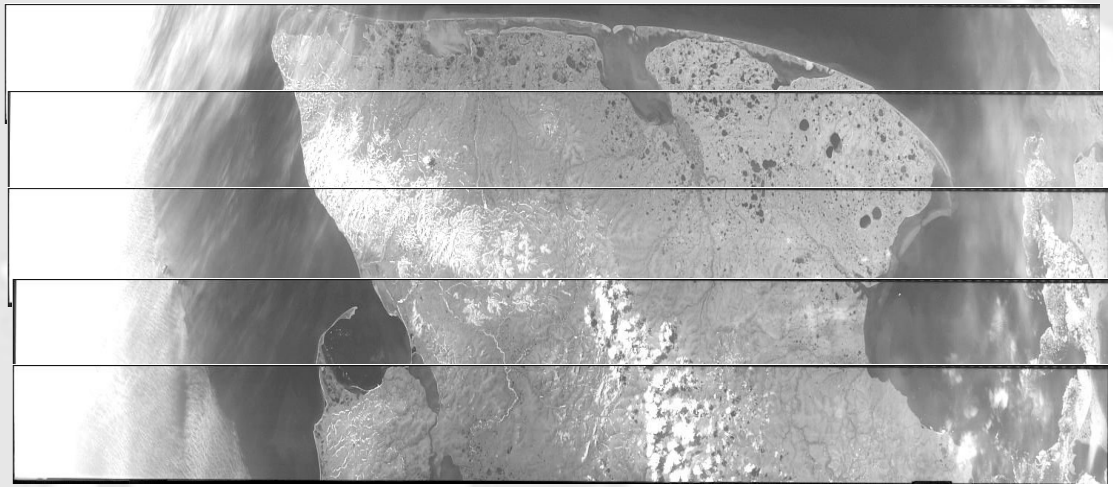
Orthorectified Aerial Imagery

- Manley et al
- ~1950, ~1980, 2003
- ground resolution: 1 m, 1 m, 0.6 m
- panchromatic, color-infrared, color

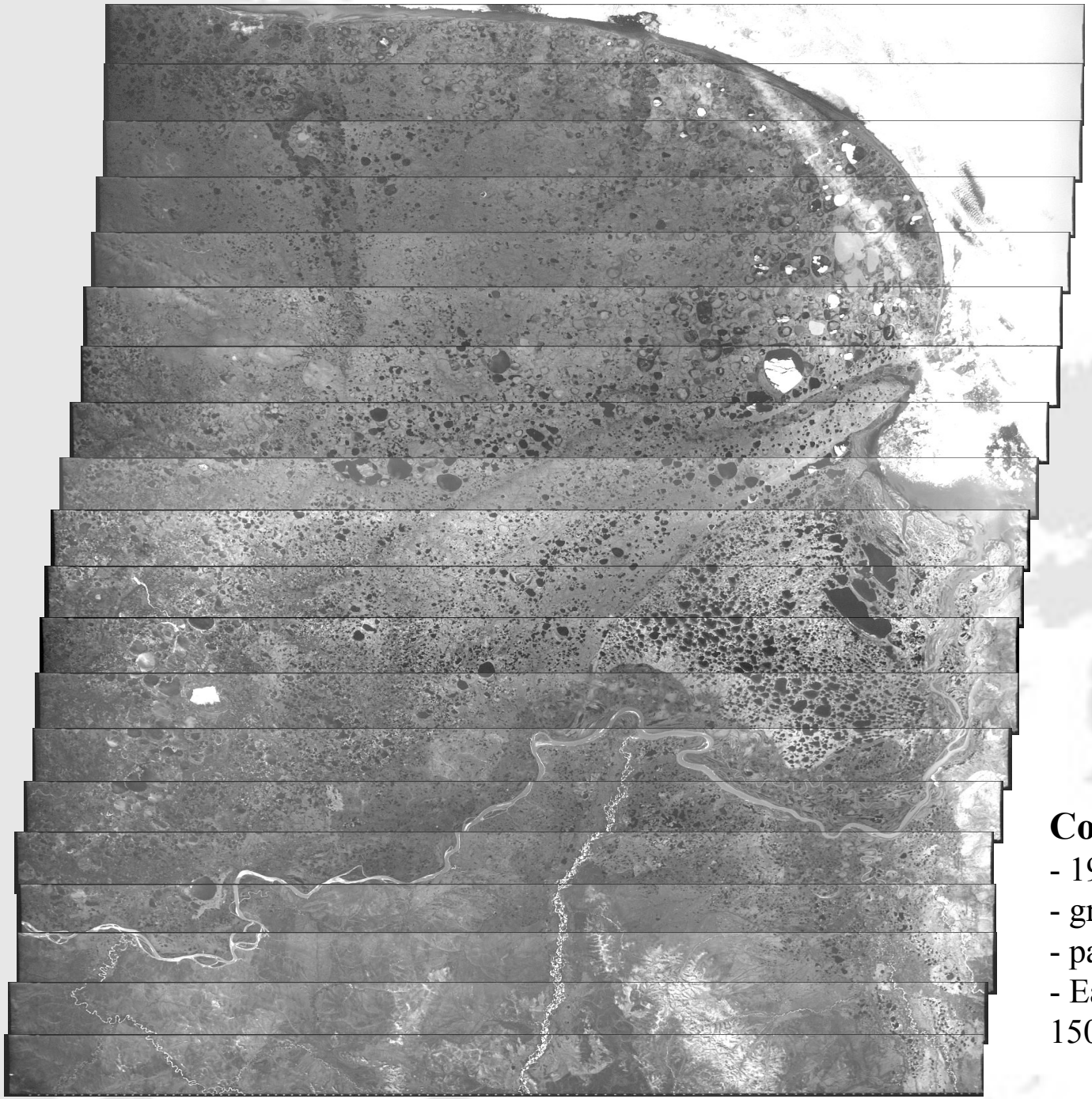
Ikonos-2
- 2006 / 2007
- ground resolution: 1 m
- multispectral



Imagery provided by NPS

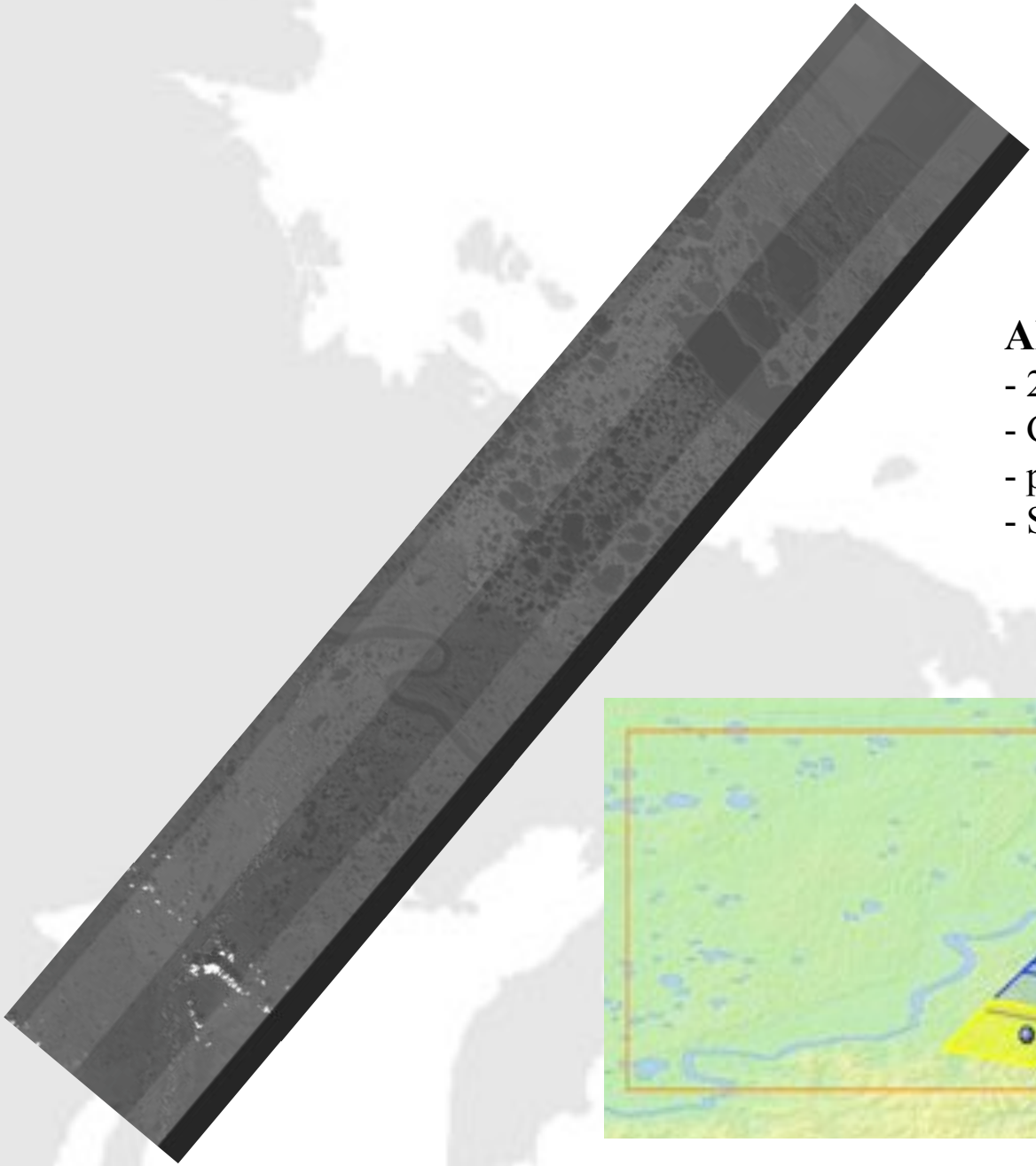


Corona KH-4
- 1962-06-28
- ground resolution: 25 ft (~8m)
- panchromatic



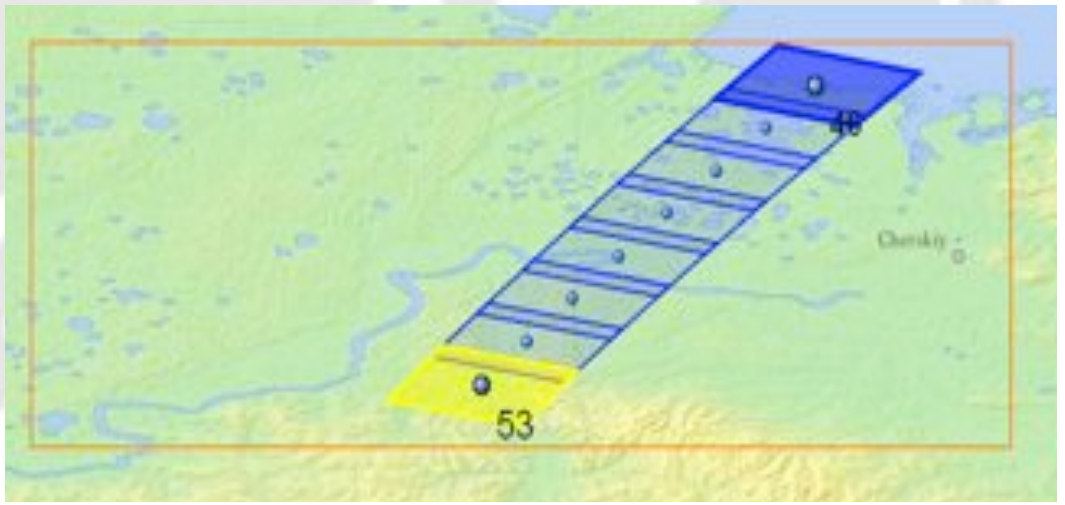
Corona KH-4A

- 1965-07-21
- ground resolution: 2.5 m
- panchromatic
- Each image stripe is about 150x17 km

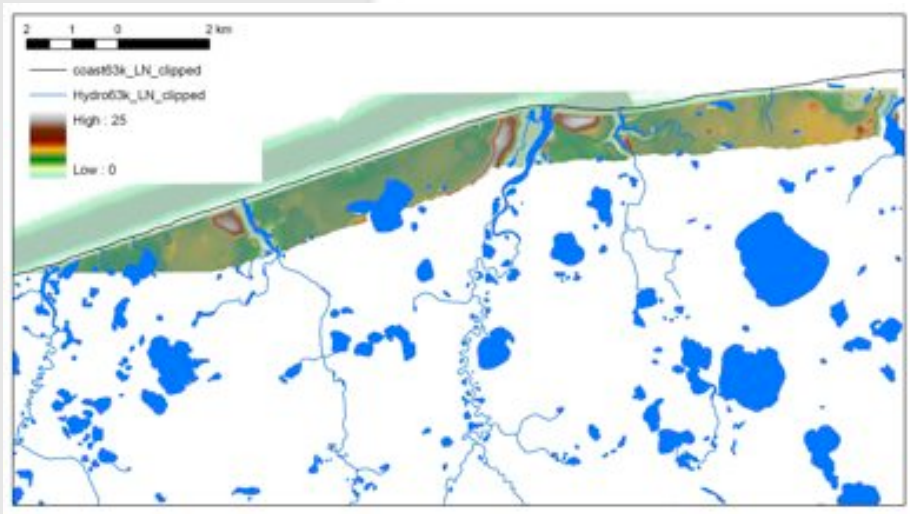


ALOS PRISM

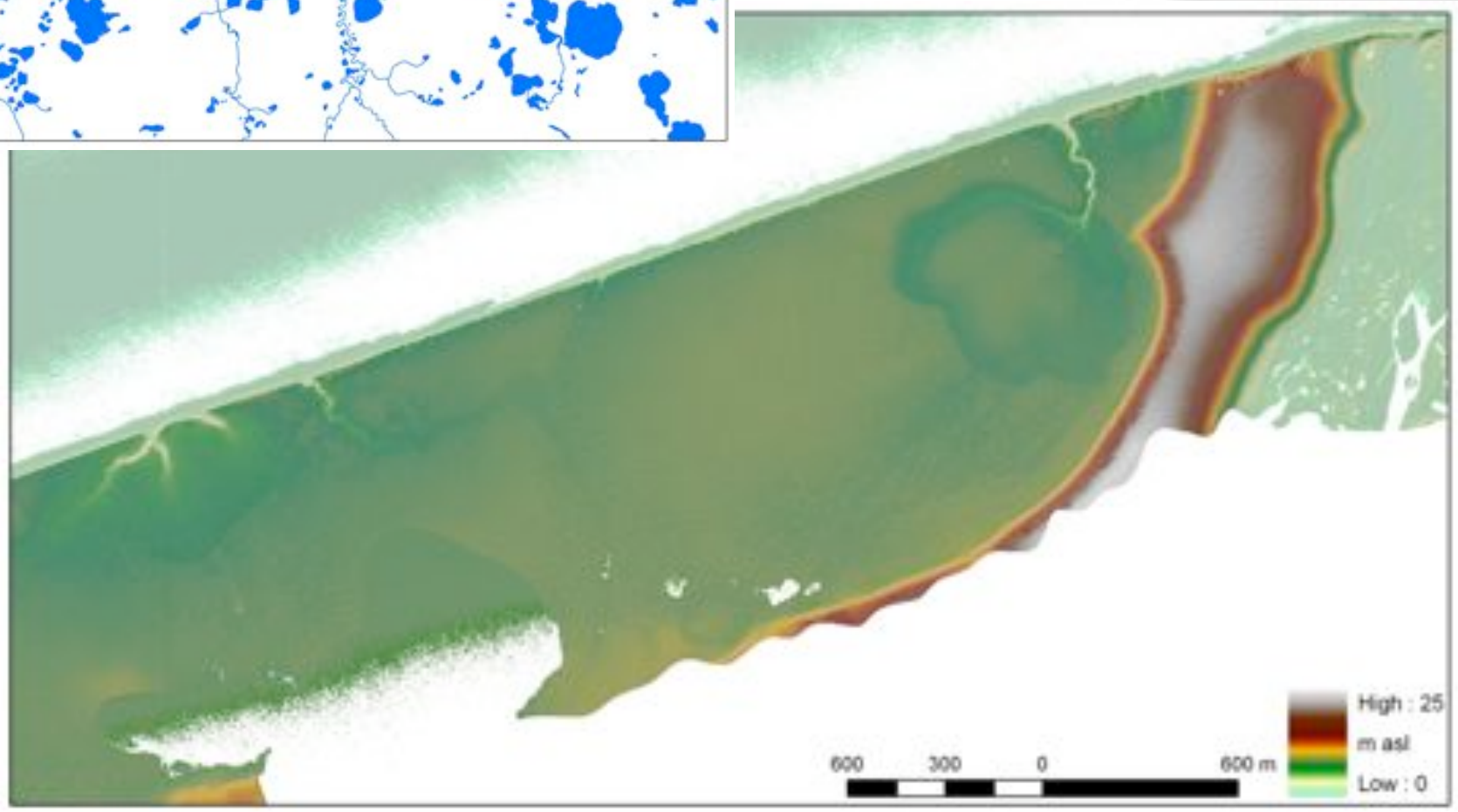
- 2007-07-29
- Ground resolution: 2.5m
- panchromatic
- Stereo triplets



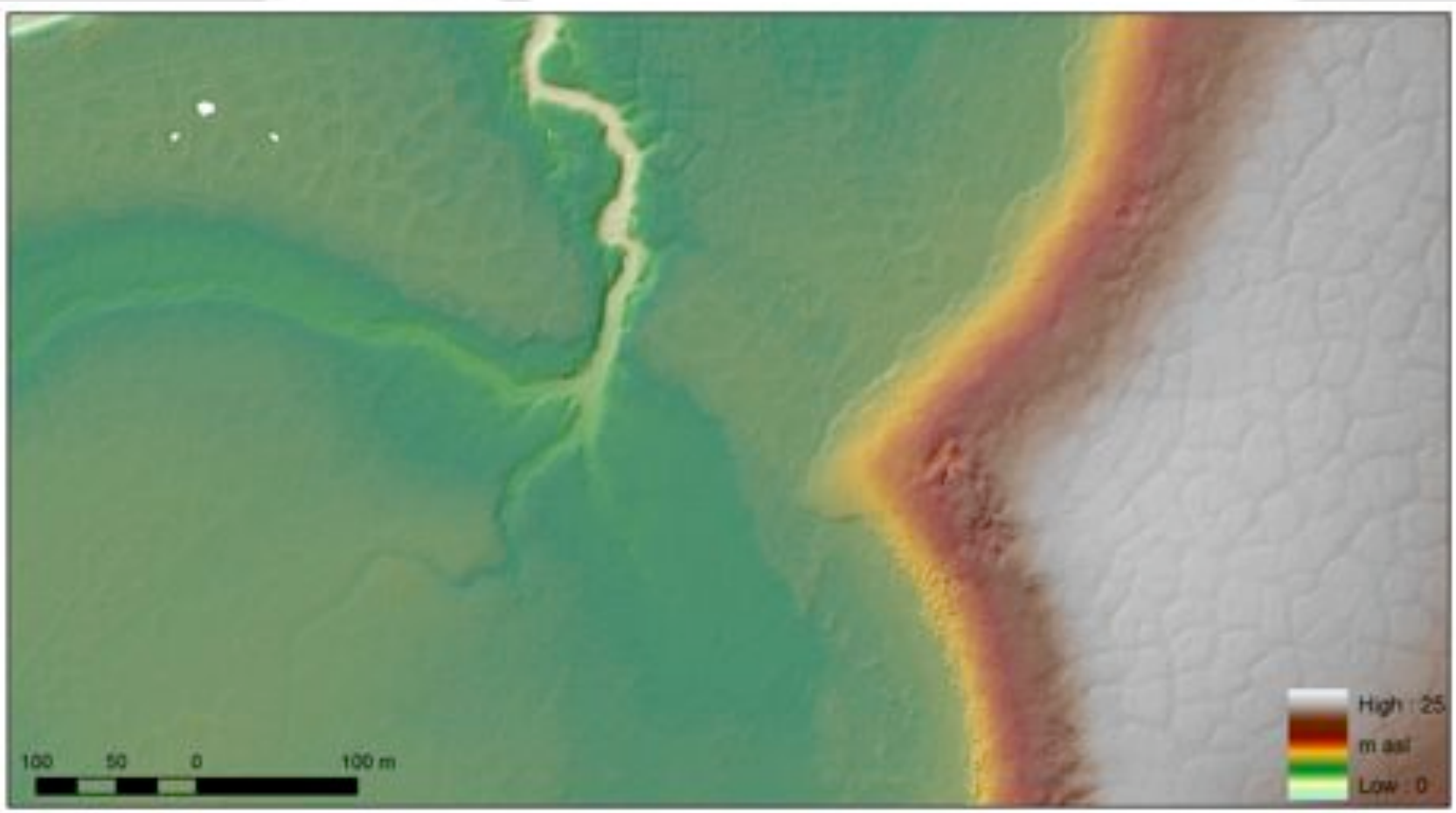
Gambit KH-7
- 1965-06-01
- ground resolution: 1 m
- panchromatic
- covers vicitiniy of city of Cherskii



LIDAR
- 2004
- point spacing: 0.5 m
- NOAA



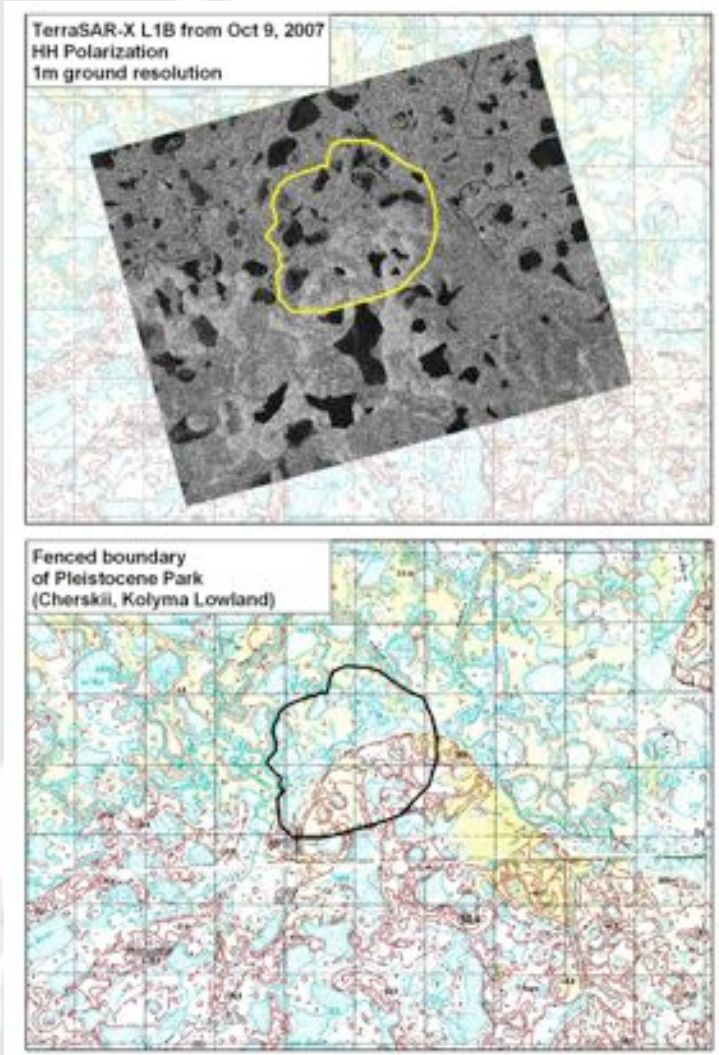
LIDAR
- 2004
- point spacing: 0.5 m
- NOAA

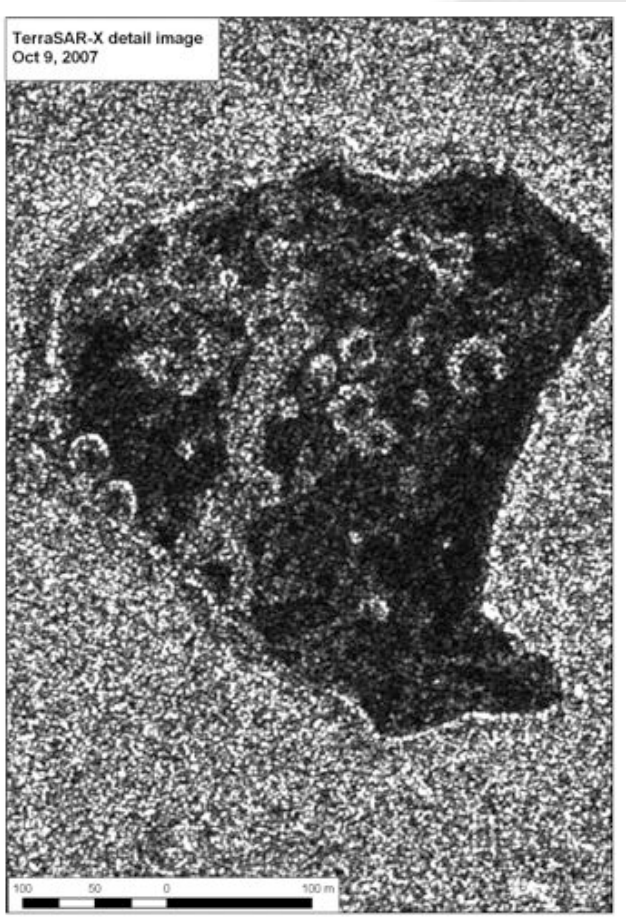


TerraSAR-X

- X-band SAR
- Spotlight mode with 1 m ground resolution
- Dual polarization possible
- 2008 Seward Peninsula; 2009 Kolyma Lowland

-Testing the identification and quantification of methane bubbles in thermokarst lake ice





Software Tools

Image processing and spatial data analysis

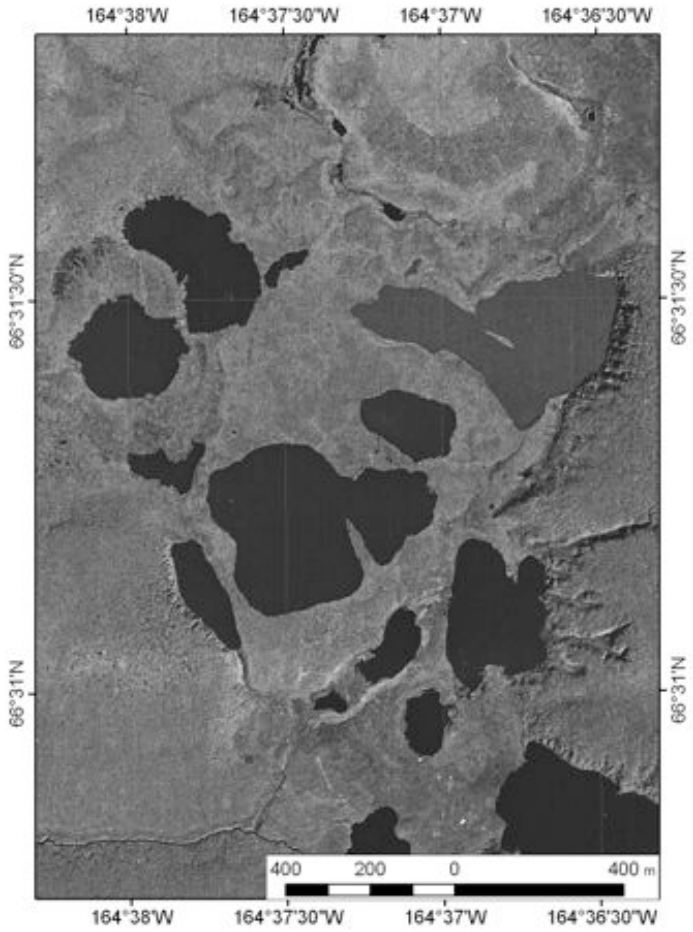
- ENVI (ITT)
- Erdas Imagine (Leica Geosystems)
- ArcGIS (ESRI)

Object-based image classification

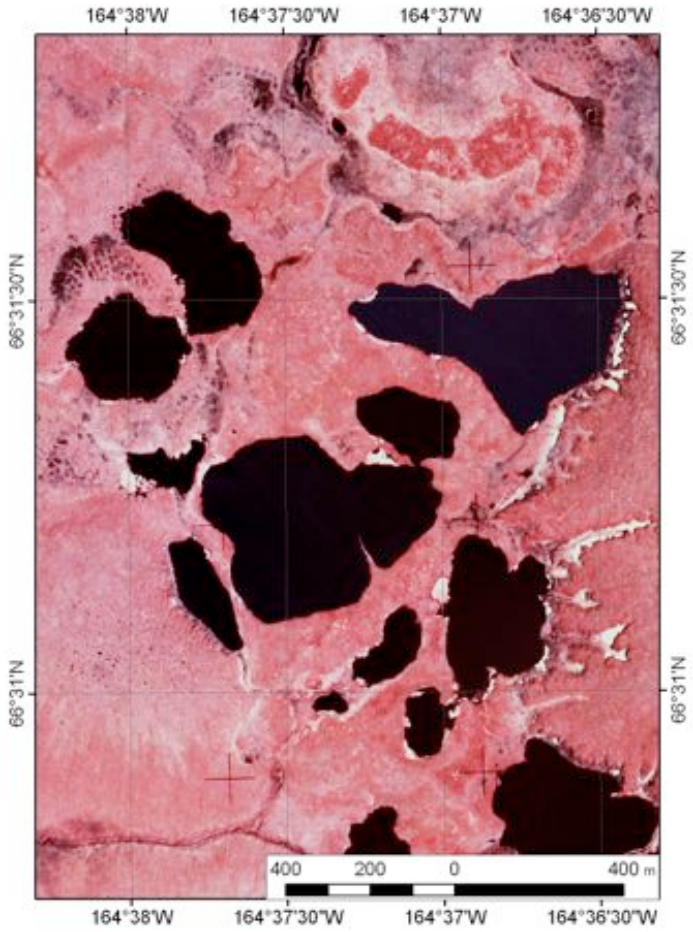
- ArcGIS Feature Analyst (ESRI)
- Definiens Developer (eCognition)

Seward Peninsula

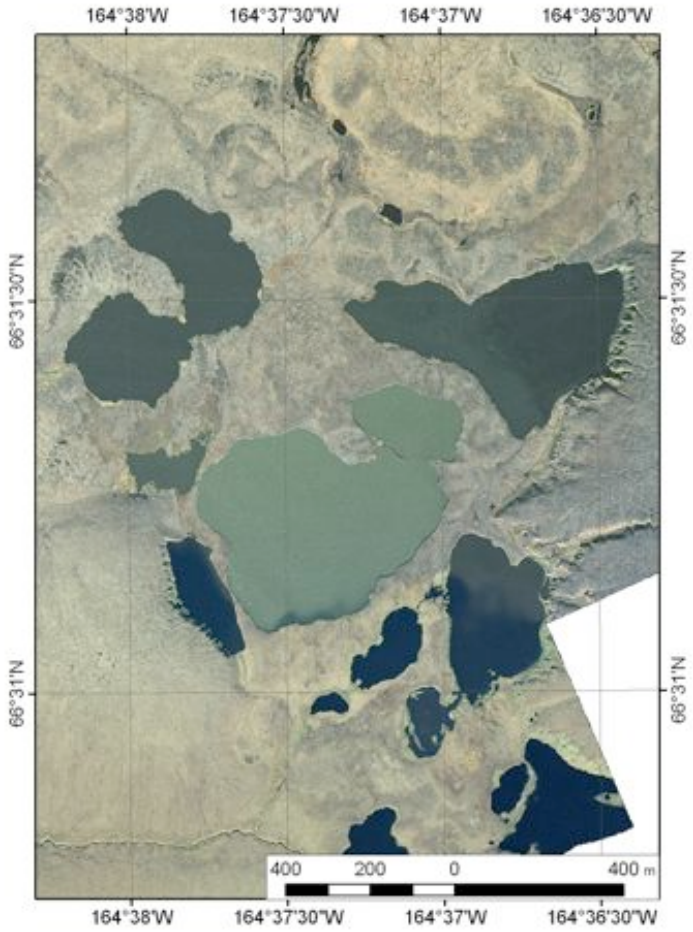
1951



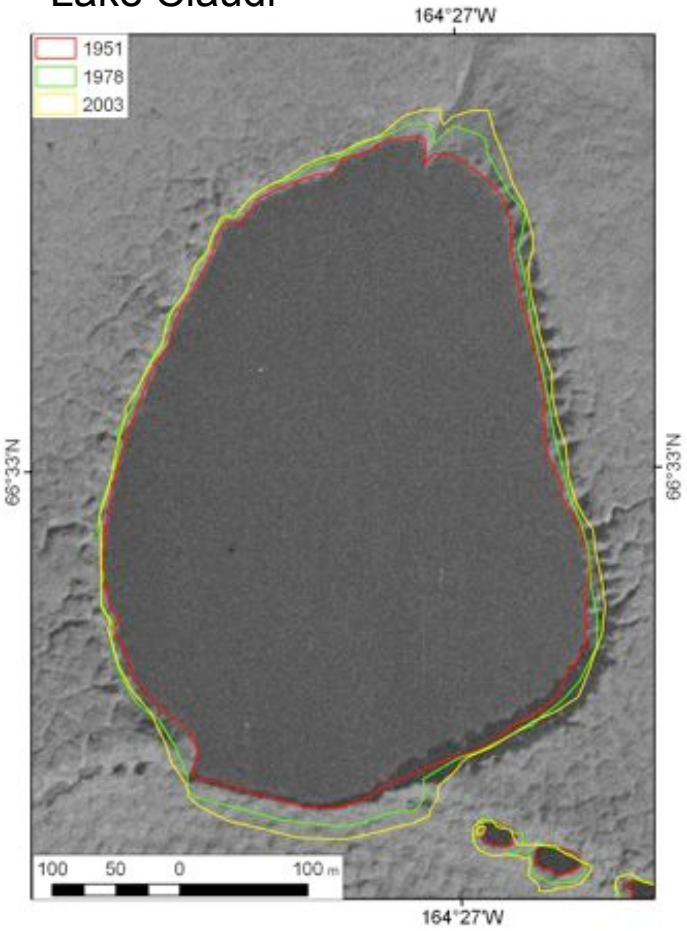
1978

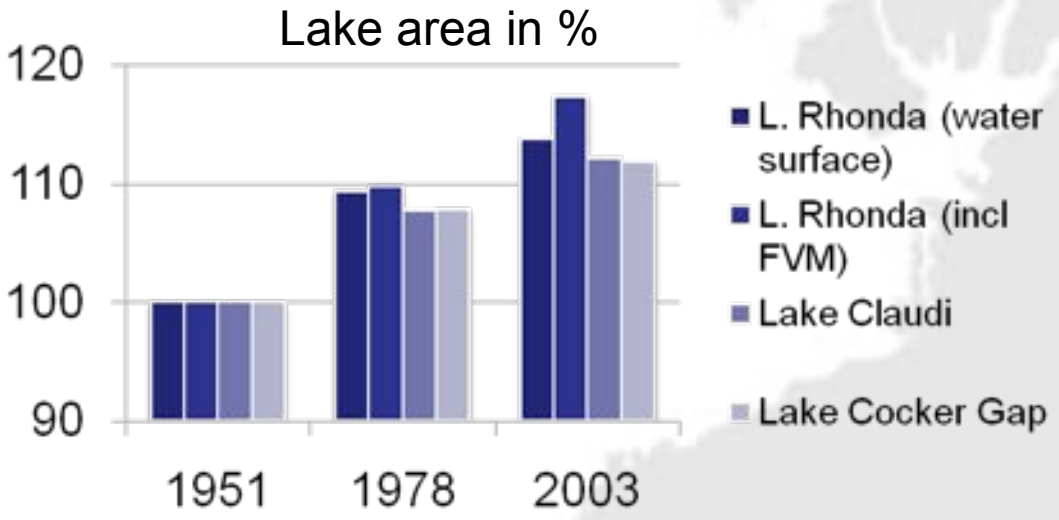

164°38'W
164°37'30"W
164°37'W
164°36'30"W
66°31'30"N
66°31'N
400
200
0
400 m

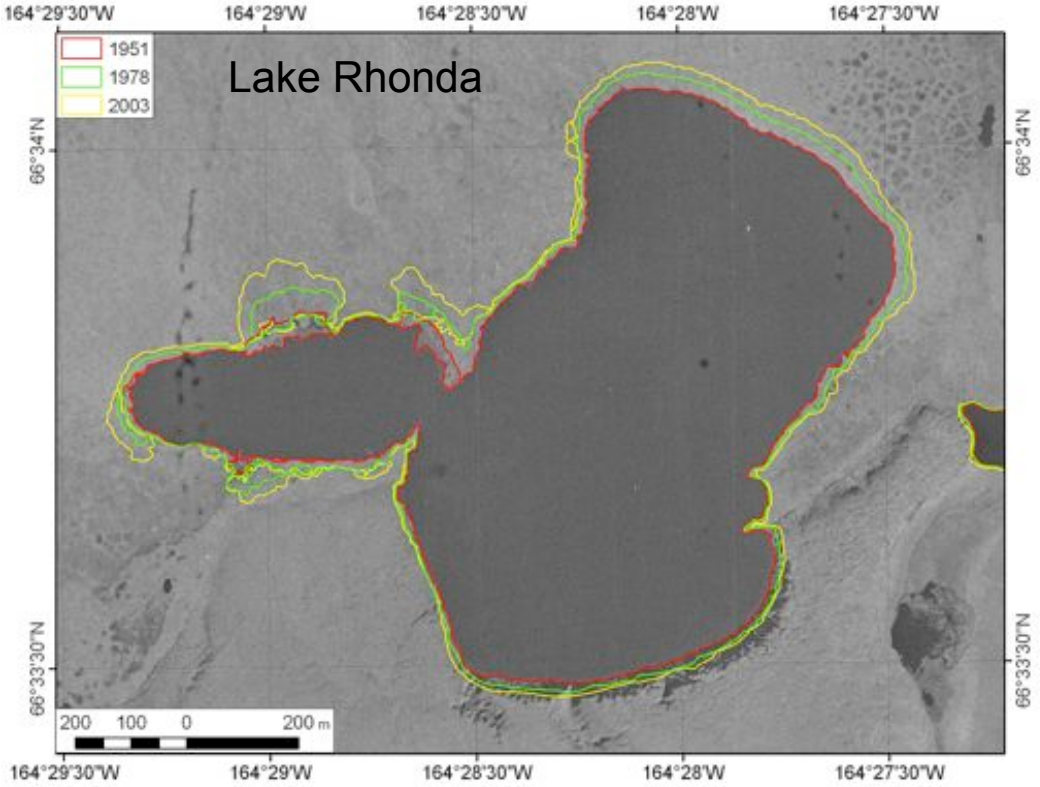
2003

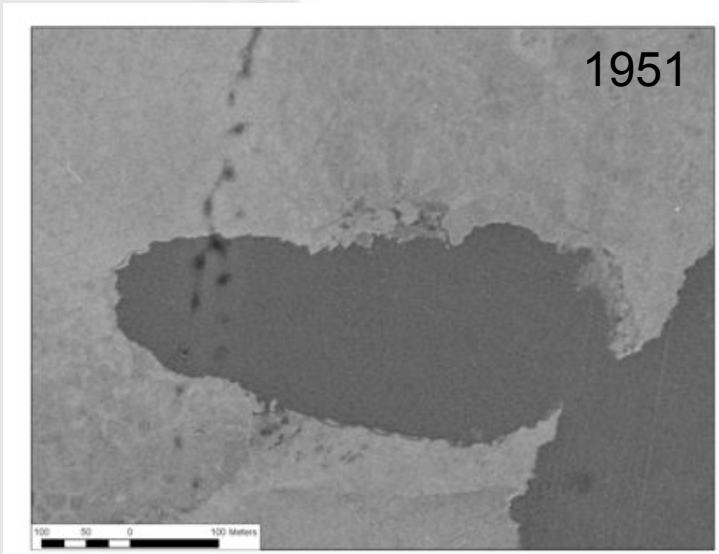

164°38'W
164°37'30"W
164°37'W
164°36'30"W
66°31'30"N
66°31'N
400
200
0
400 m

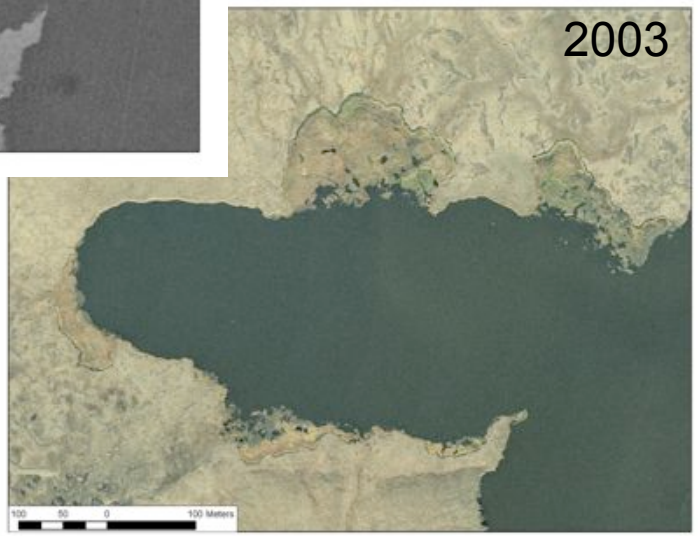
Lake Claudi

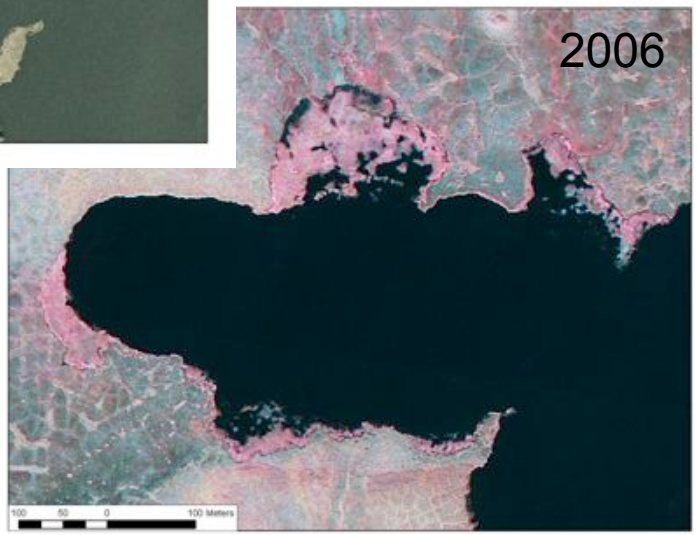

164°27'W
1951
1978
2003
66°33'N
100 50 0 100 m


Lake area in %
120
110
100
90
1951
1978
2003
L. Rhonda (water surface)
L. Rhonda (incl FVM)
Lake Claudi
Lake Cocker Gap


Lake Rhonda
164°29'30"W
164°29'W
164°28'30"W
164°28'W
164°27'30"W
1951
1978
2003
66°34'N
66°33'30"N
200 100 0 200 m

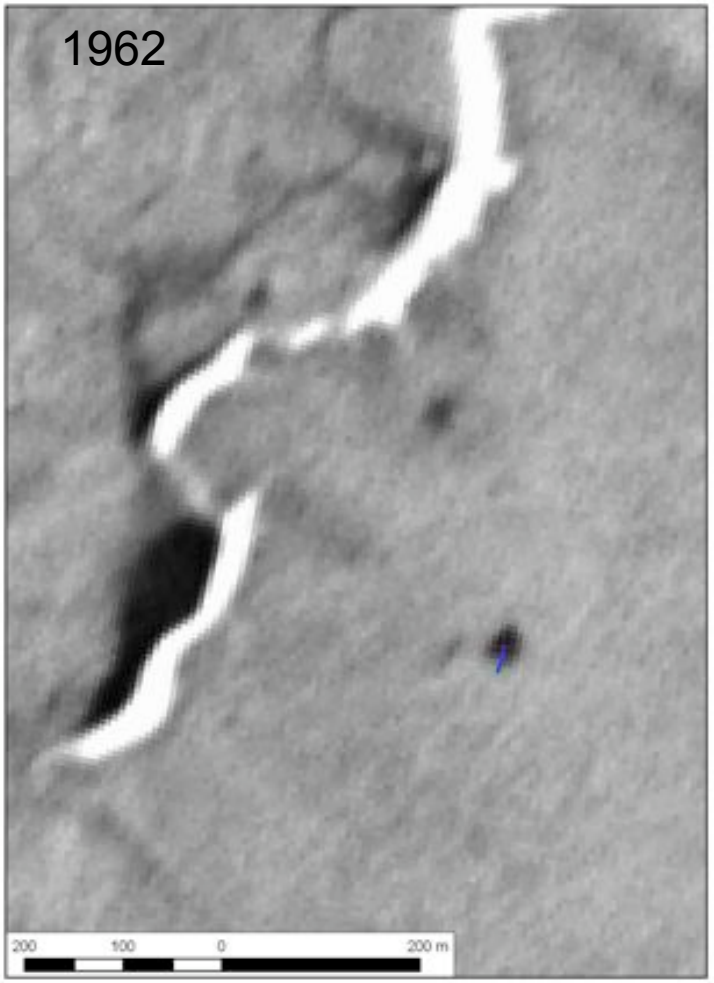






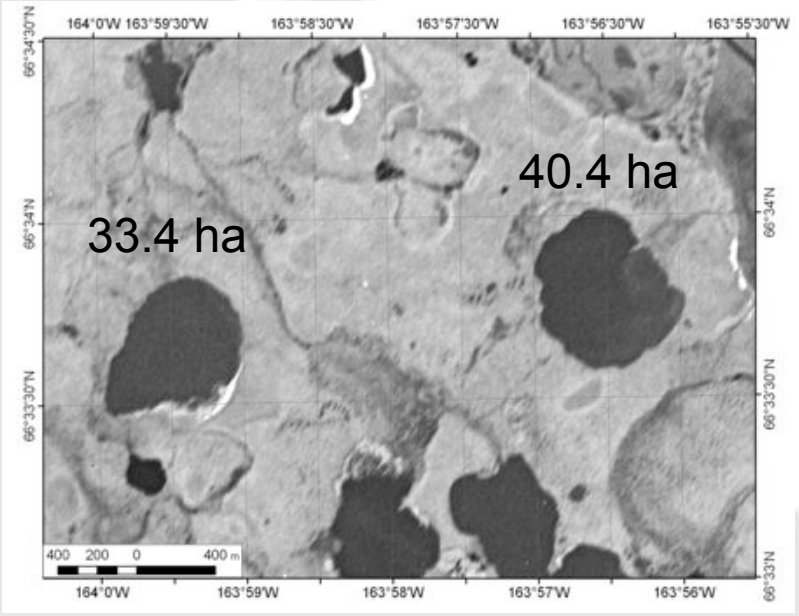
Permafrost collapse zones
and floating vegetation mats

Only observation of formation of new lake

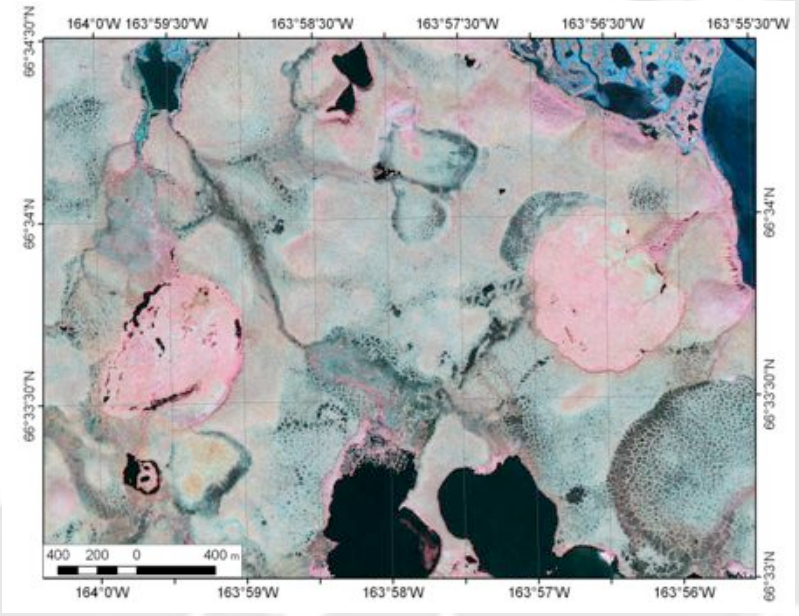


Lake Drainage

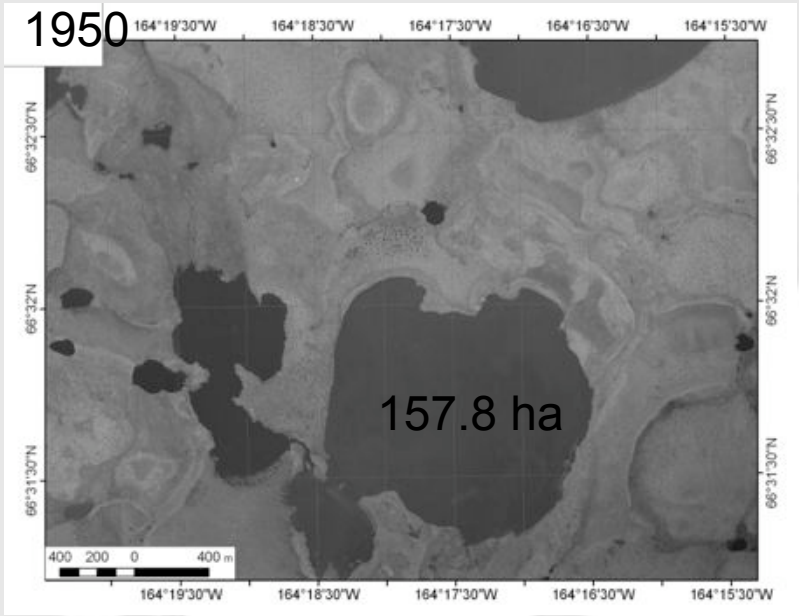
1962



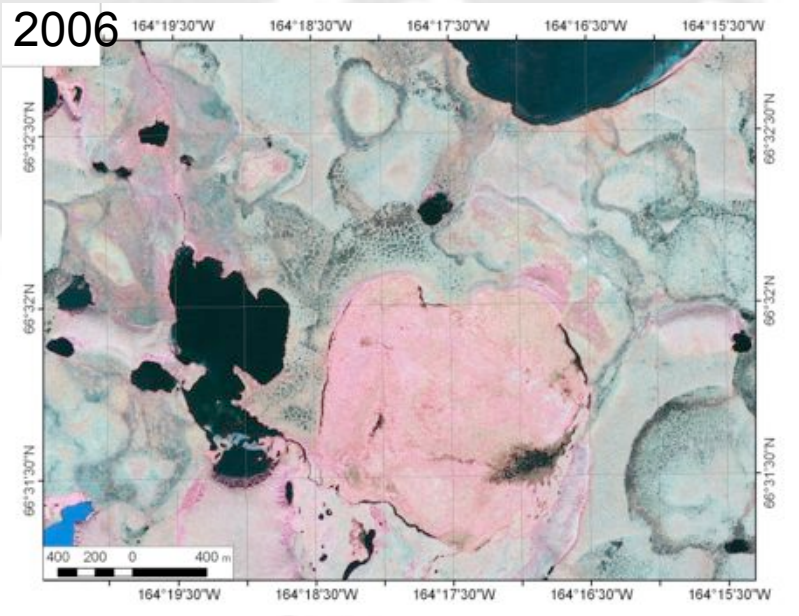
2006



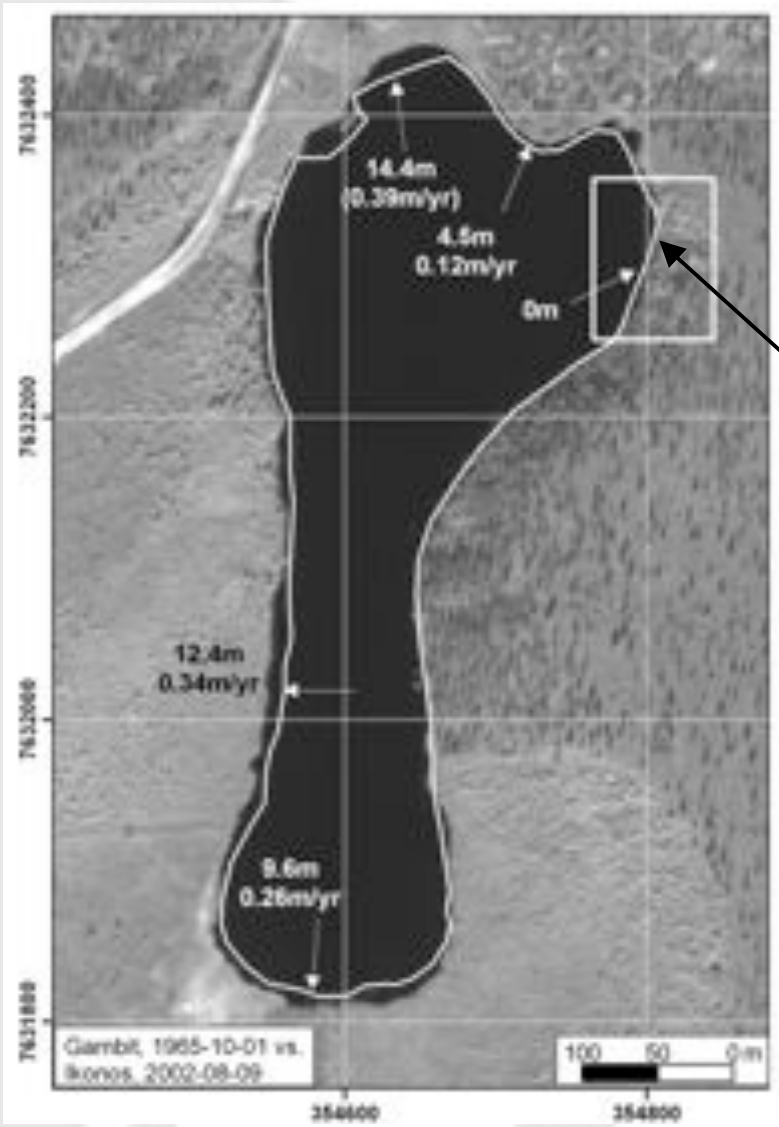
1950



2006



Temporal Changes of Thermokarst Lakes in Siberian Yedoma



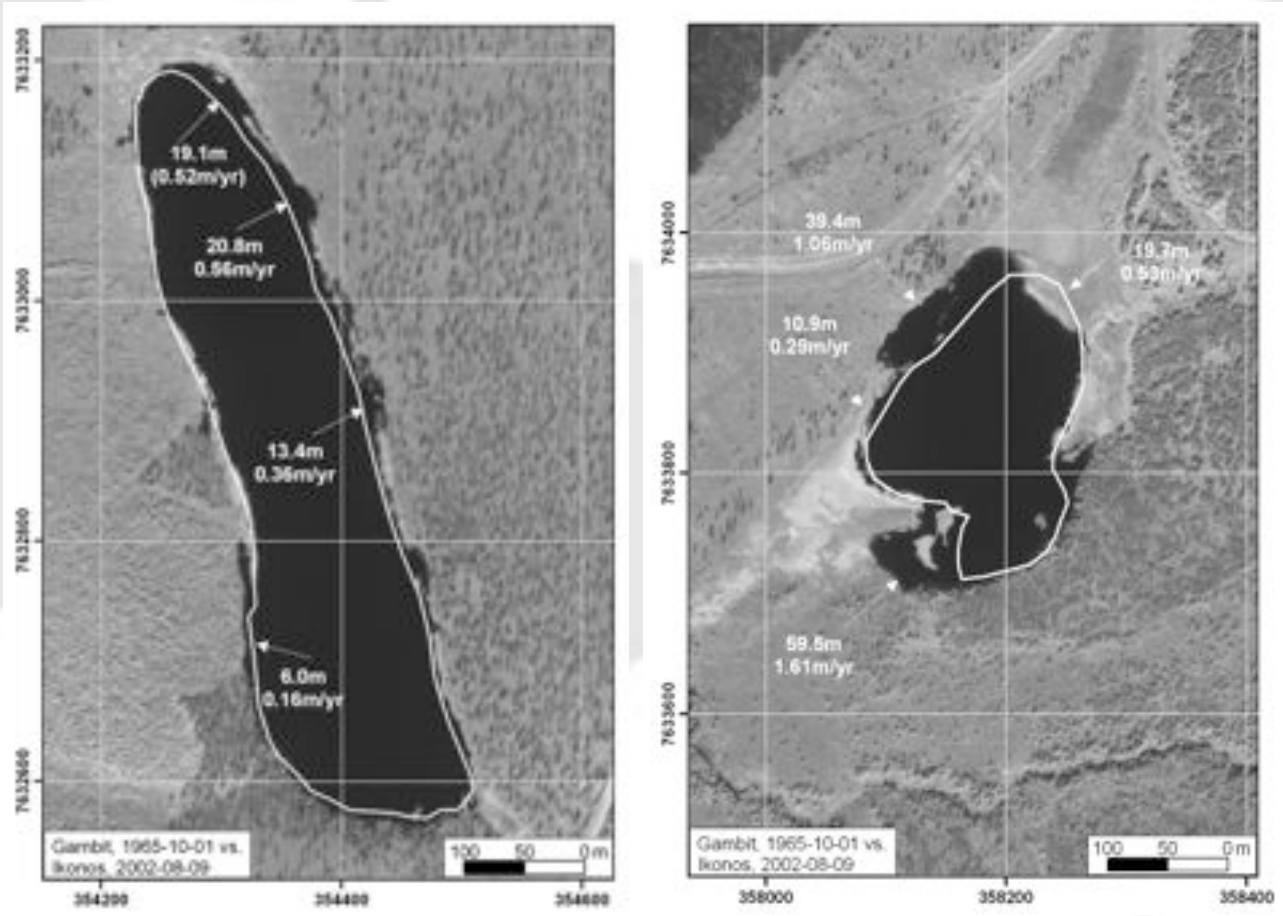
Thermo-erosion along shore bluffs of thermokarst lakes in the Cherskii region (Gambit 1965 vs. Ikonos-2 2002) (1 m ground resolution)

September 2007

Distribution and Temporal Changes of Thermokarst Lakes in Siberian Yedoma

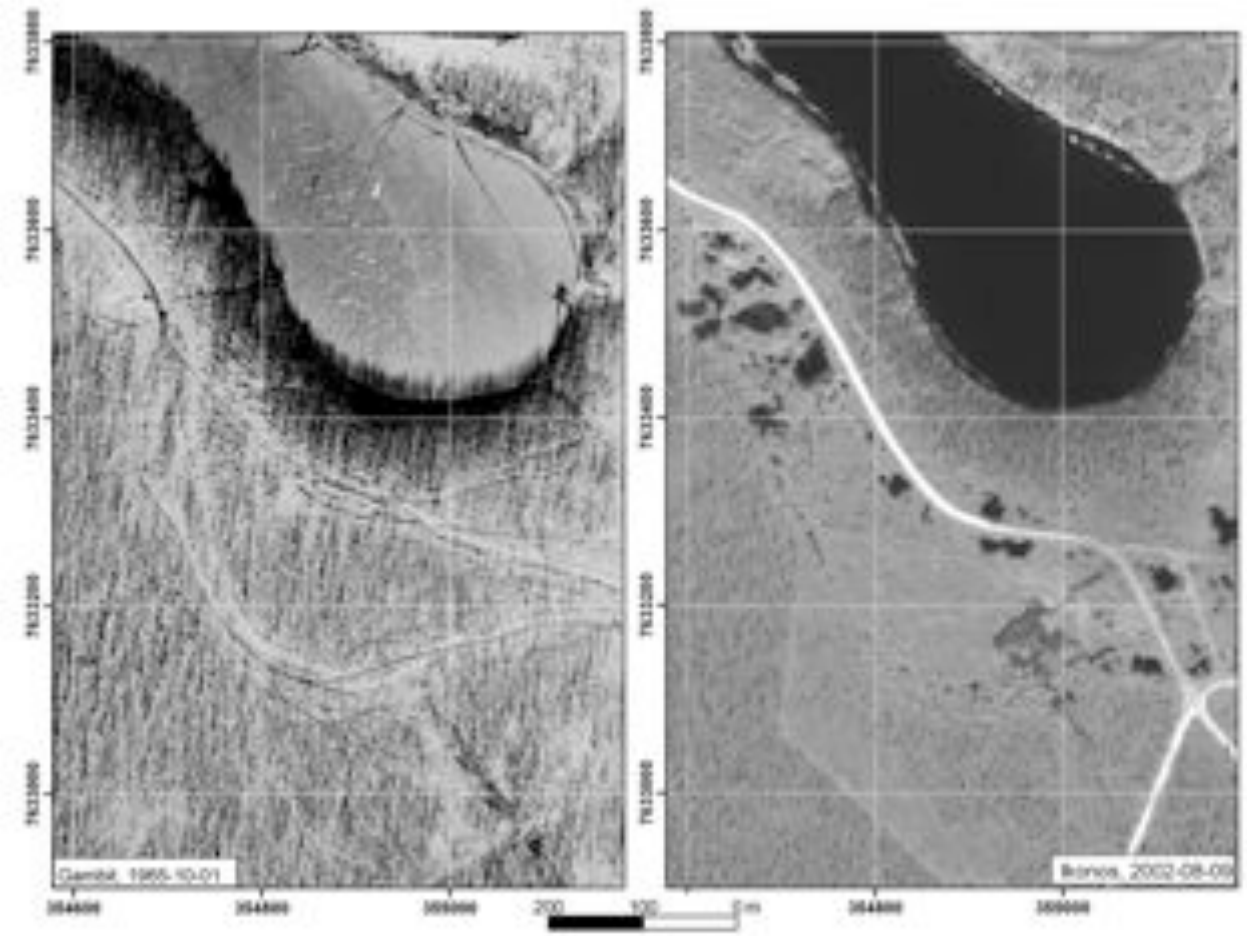
G. Grosse, V. Romanovsky, K. Walter, A. Morgenstern, H. Lantuit, S. Zimov

Thermo-erosion along shore bluffs of thermokarst lakes
(Gambit 1965 vs. Ikonos-2 2002) (1 m ground resolution)



Human impact on permafrost

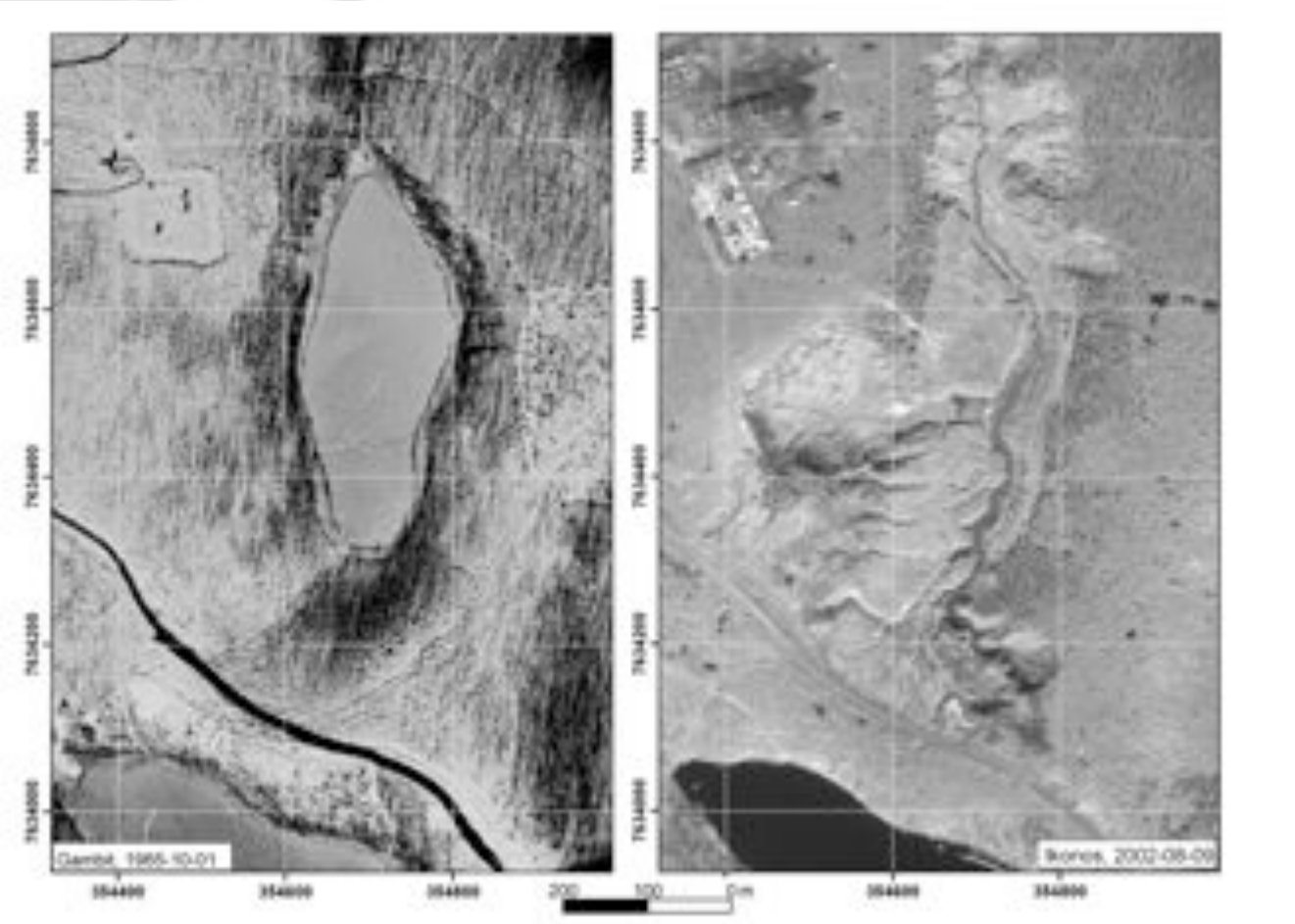
Massive thermokarst pond formation along former dirt roads, Cherskii (Russia)



(Gambit 1965 vs. Ikonos-2 2002) (1.0 m ground resolution)

Human impact on permafrost

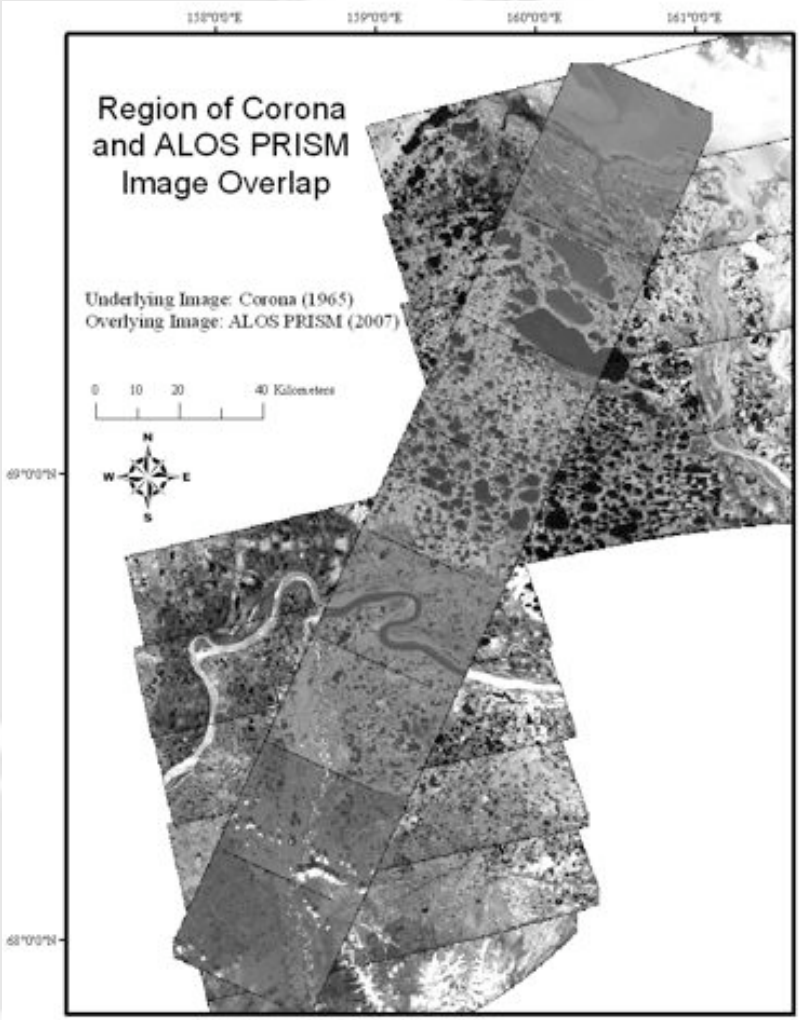
Artificial drainage of a thermokarst lake,
followed by the formation of retrogressive thaw slumps, Cherskii (Russia)

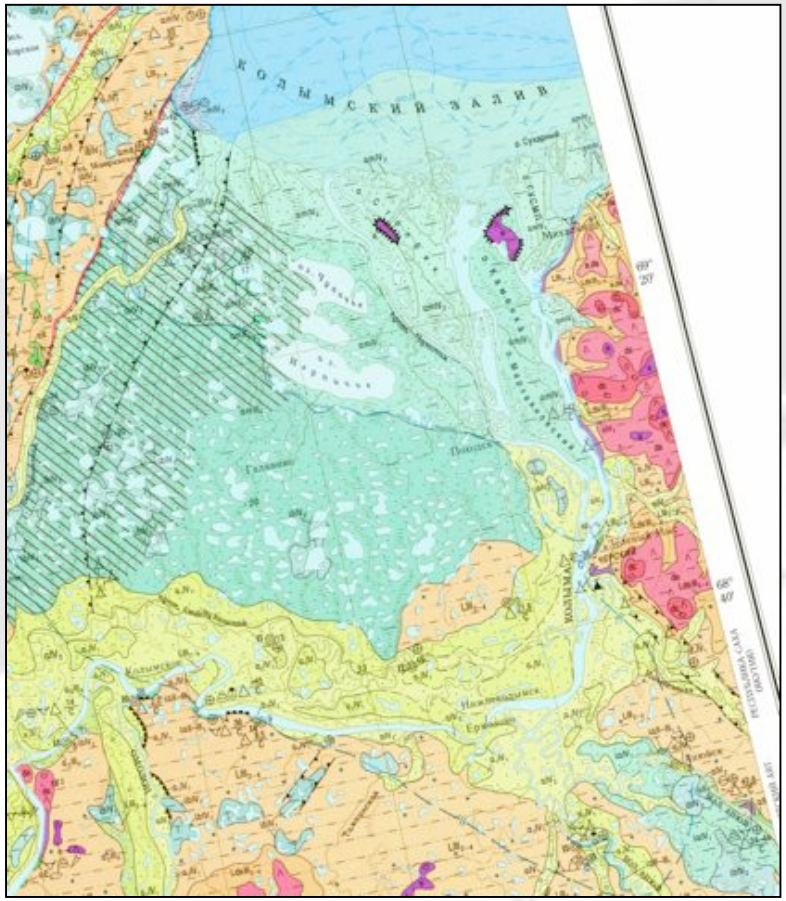


(Gambit 1965 vs. Ikonos-2 2002) (1.0 m ground resolution)

Modern Thermokarst Dynamics in Northeast Siberia: The Kolyma Lowland Transect

- Land surface record is 42 years long (1965-2007)
- Covers >10,000 km^2 in 2.5 m ground resolution
- Crosses a broad variety of hydrological, geological and permafrost conditions
- Largest lake has surface area of 230 km^2





Geological map 1:1,000,000

Drained Lakes

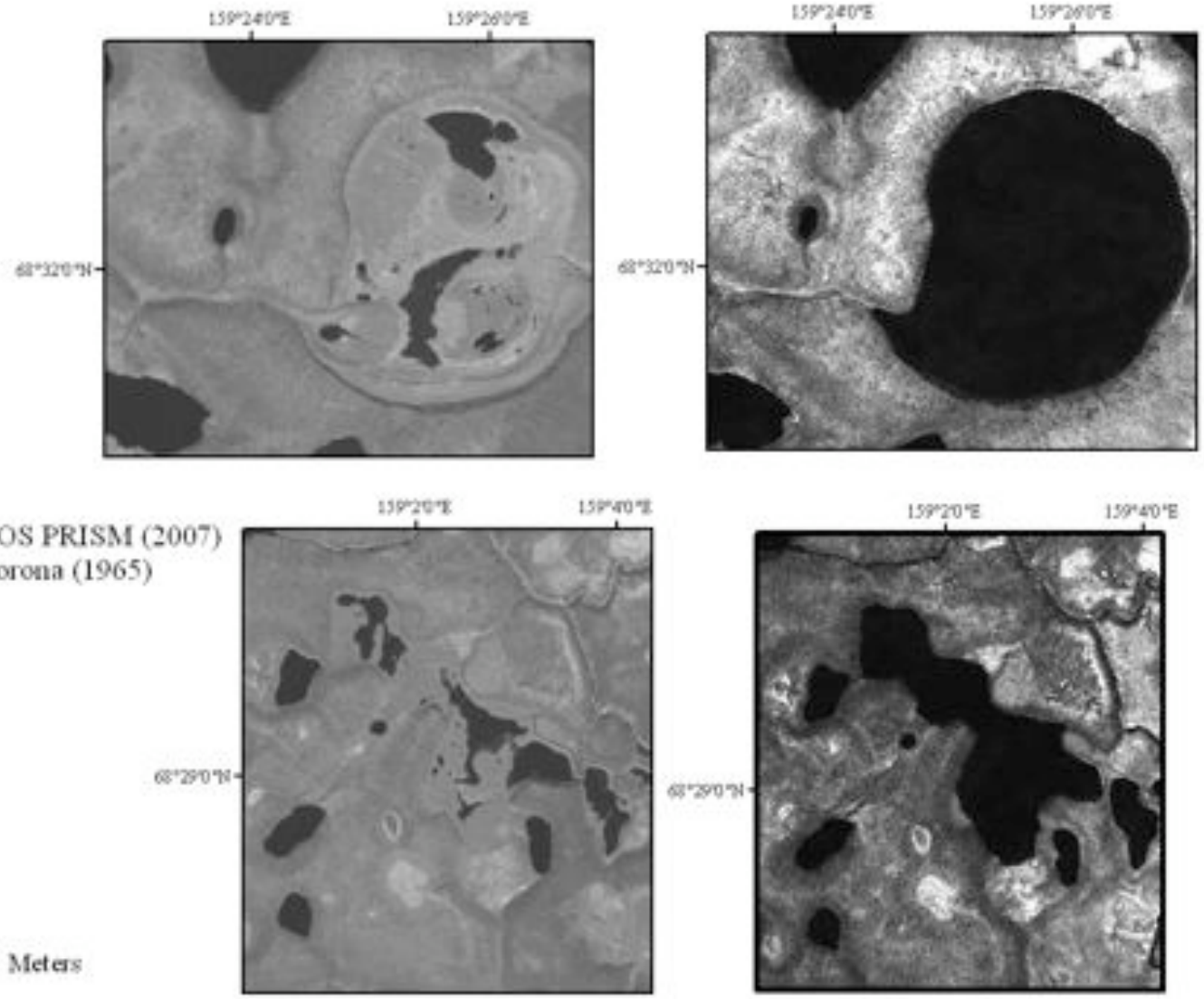


Image on Left: ALOS PRISM (2007)
Image on Right: Corona (1965)

N
W
E
S

0 250 500 1,000 Meters

Summary of First Results

Seward Peninsula

- All lakes visually inspected show signs of rapid expansion up to 1 m/yr
- Extensive permafrost collapse areas on lake margins are camouflaged by floating vegetation mats (FVM); collapse zones expand with more than 1 m/yr
- Low shorelines towards old basins appear to erode more rapid than high bluffs → impact of ice content and sediment volume that has to be removed
- Some considerably large lakes drained partially or completely
- Very few new lakes formed
- Direct impact of long-term precipitation fluctuations on water level appears to be negligible compared to thermokarst and erosion dynamics; however, short-term precipitation events might be a cause for activating or speeding up both erosion and drainage processes

Kolyma Lowland

- Only lakes in Yedoma deposits around Cherskii were assessed so far
- Human disturbance results in massive thermokarst
- Erosion rates are similar to Seward Peninsula

Conclusions

- A wide range of high-resolution remote sensing platforms are available today for Arctic Research
- Remote sensing is highly valuable to assess the spatial dimensions of environmental change in the Arctic
- Using remote sensing we can cover 42 years of land surface changes in the Kolyma lowland and 56 years on the Seward Peninsula
- Thermokarst is highly dynamic and active today in Siberia and Alaska – probably we will see surprising results and feedbacks in the coming years
- Thermokarst lakes behave nonlinear in their spatial dynamics; driven by cryolithological ground conditions and external forcing, slow lake forming processes are accompanied by phases of rapid expansion or sudden drainage