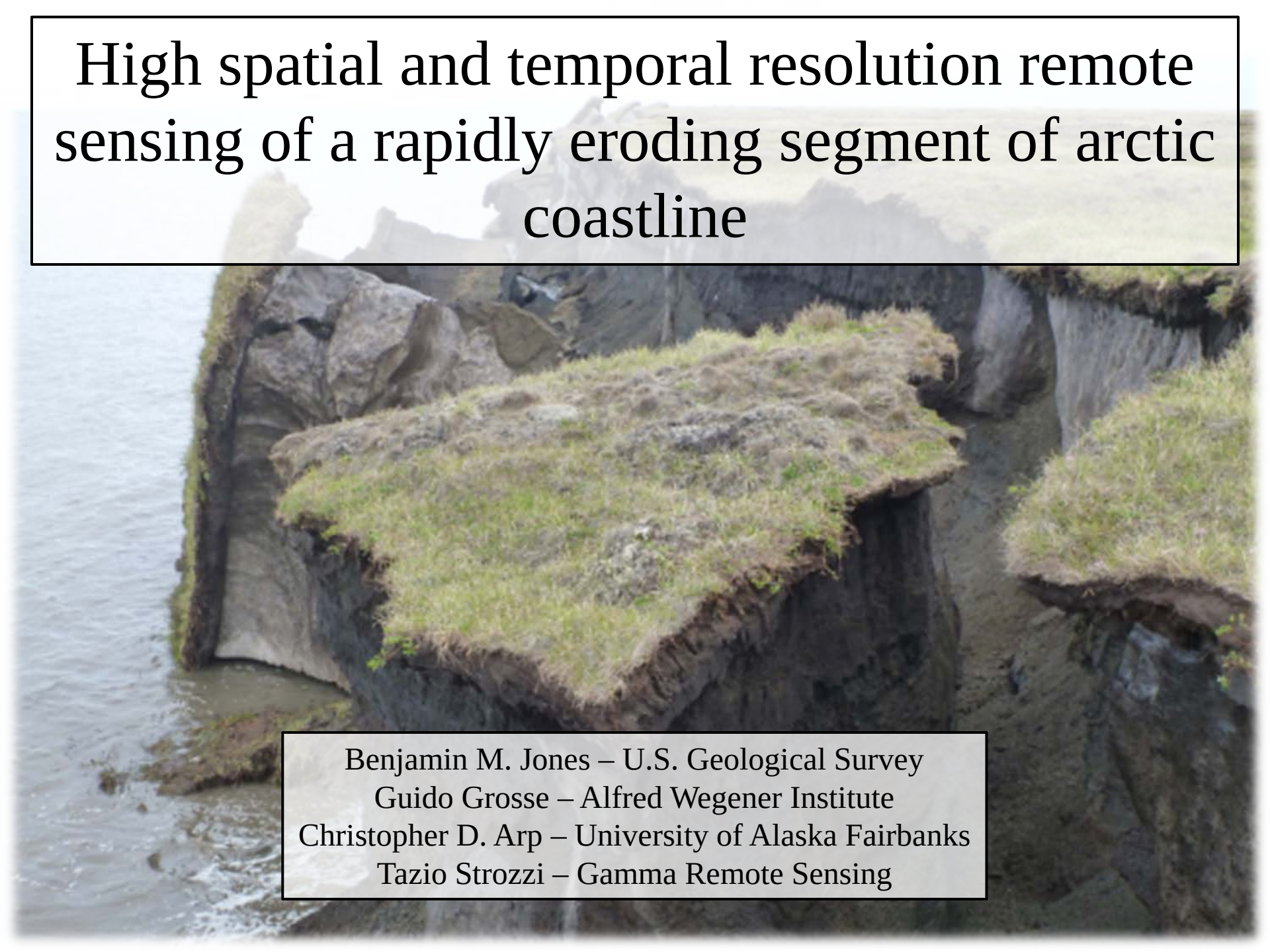
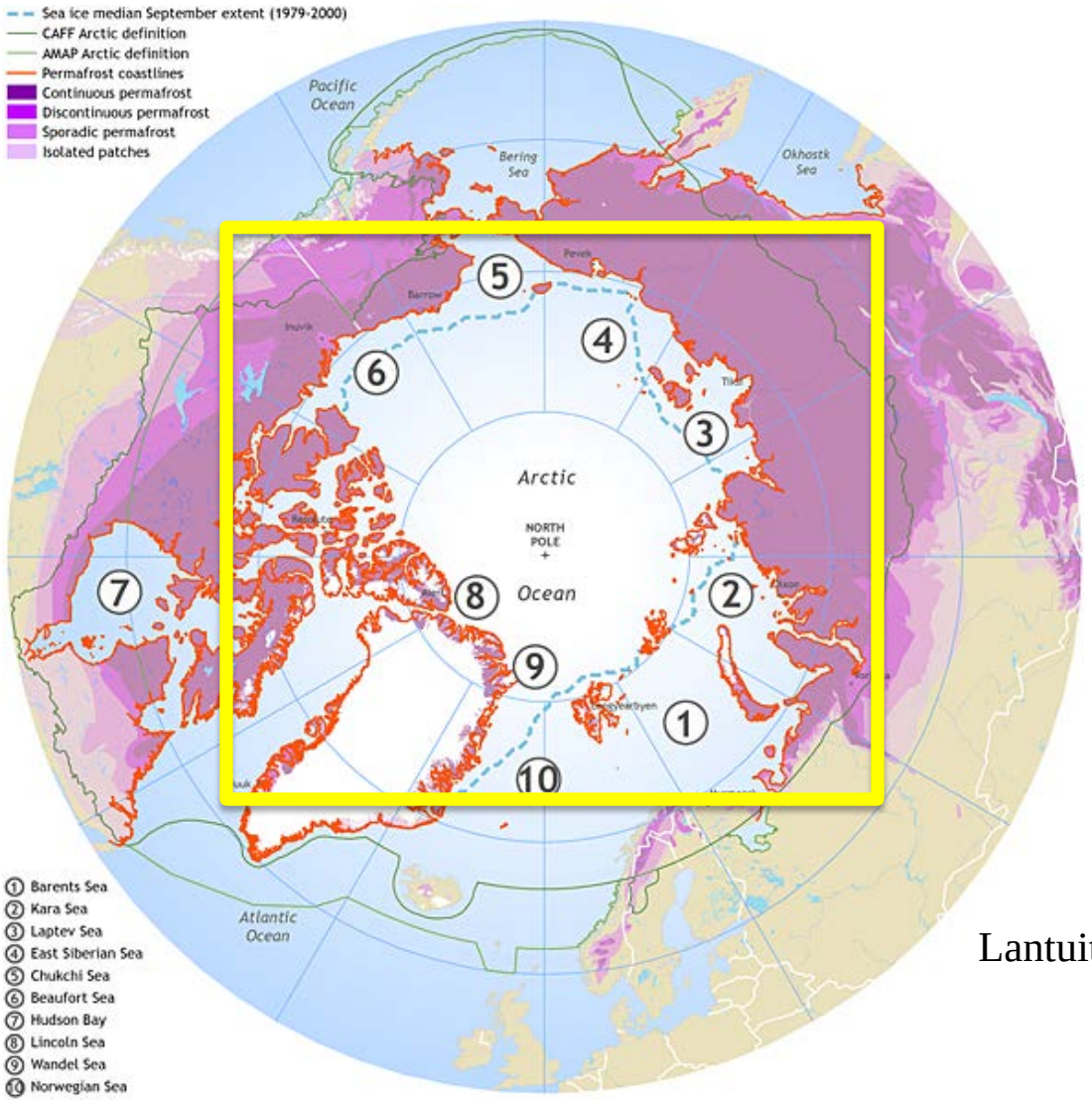
High spatial and temporal resolution remote sensing of a rapidly eroding segment of arctic coastline



Benjamin M. Jones – U.S. Geological Survey
Guido Grosse – Alfred Wegener Institute
Christopher D. Arp – University of Alaska Fairbanks
Tazio Strozzi – Gamma Remote Sensing

Permafrost Coasts of the Northern Hemisphere



Lantuit et al., 2013

~30% of Earth's coastlines

Historic Patterns of Permafrost Coastal Erosion

Lantuit et al., 2012

Influence of Ground-Ice Content on Erosion

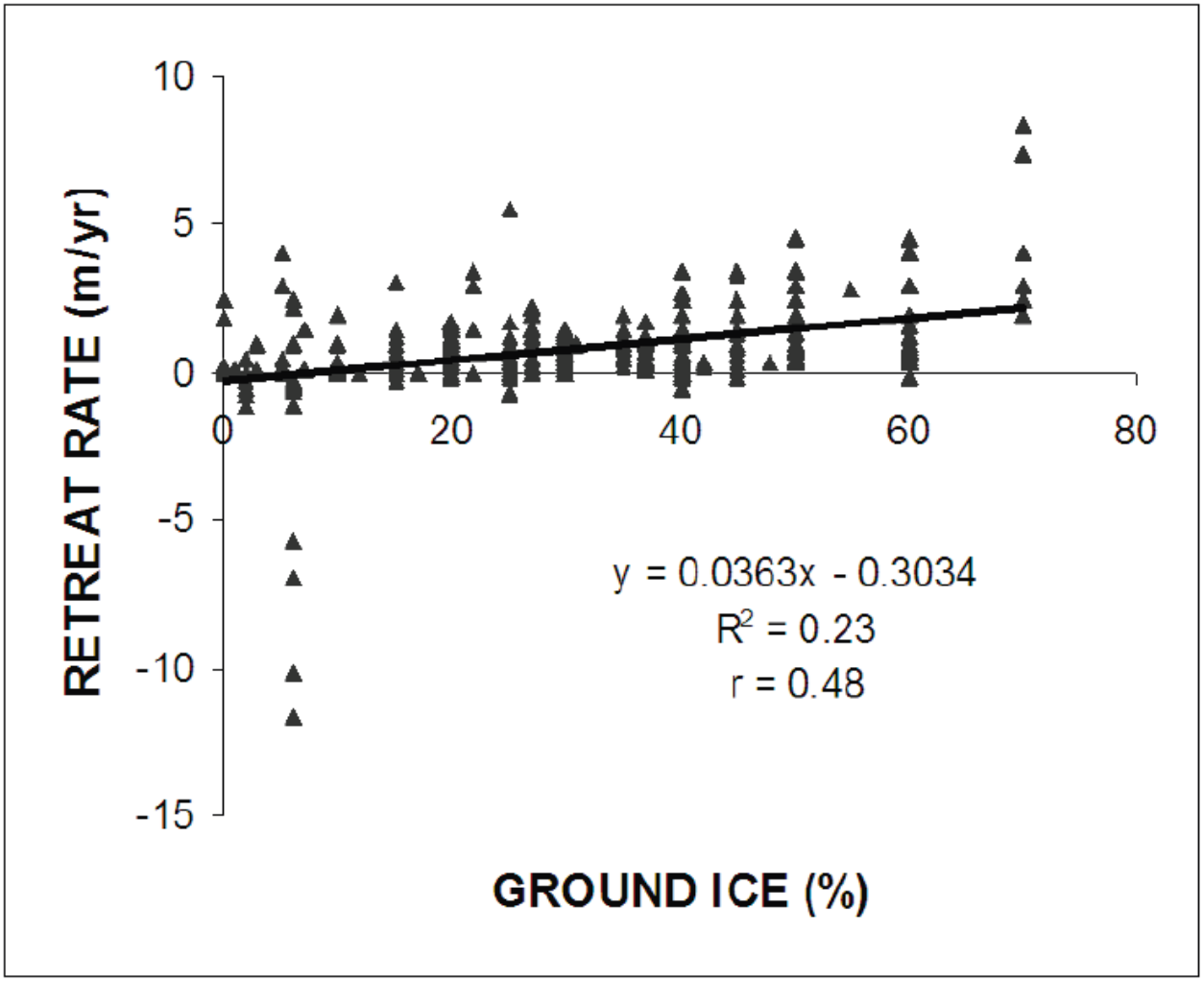


Figure 3. Retreat rate as a function of volumetric ground ice contents.

Lantuit et al. 2008

Primary Mechanisms of Permafrost Coast Erosion

Thermo-denudation
(Thaw Slumps)

Thermo-abrasion
(Erosional niches
and block collapse)

Tend to result in higher, long-term, mean annual retreat rates

Couture et al. 2008

Thermo-abrasion and Block-collapse

Time-lapse Images Showing Erosional Process

Time-lapse Images Showing Erosional Process

Time-lapse Images Showing Erosional Process

Time-lapse Images Showing Erosional Process

Time-lapse Images Showing Erosional Process

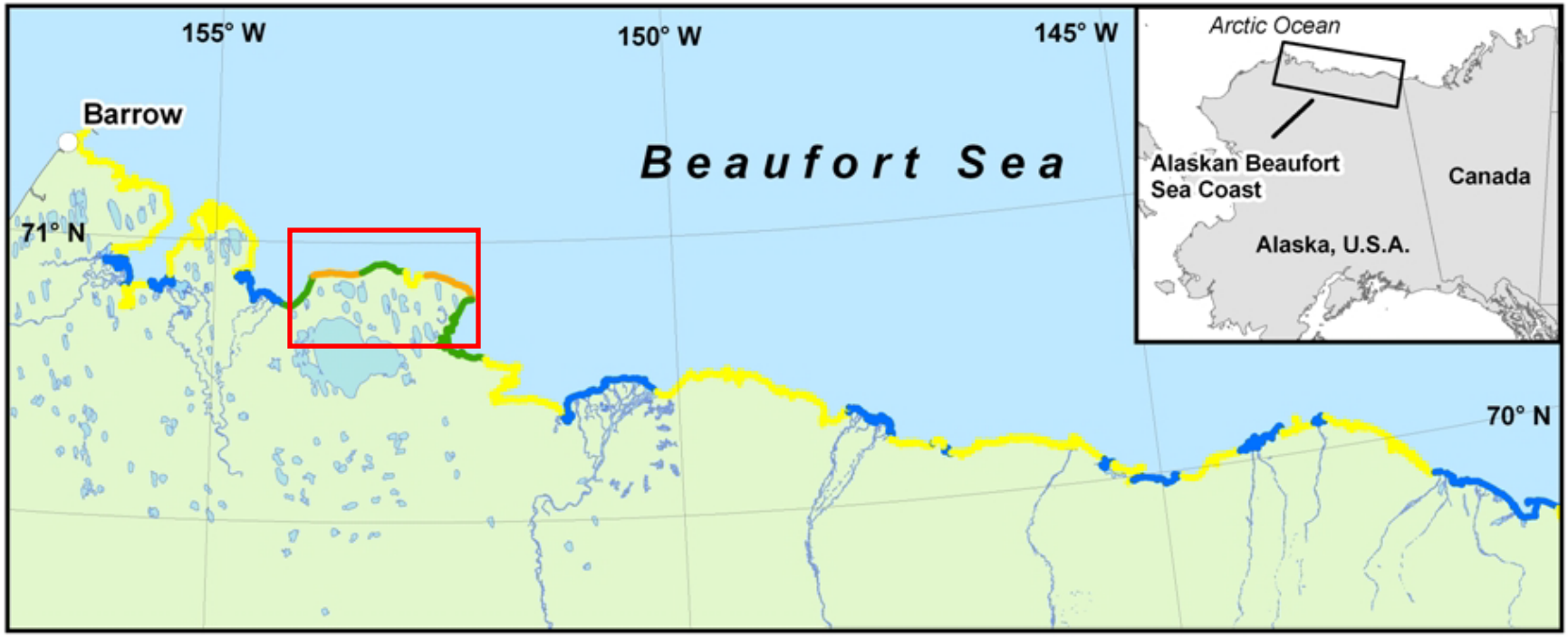
Time-lapse Images Showing Erosional Process

Time-lapse Images Showing Erosional Process

Time-lapse Images Showing Erosional Process

Time-lapse Images Showing Erosional Process

Historic Erosion along Beaufort Sea Coast



Erosion Rate (m a^{-1})

- 5 to 8
- 0 to 2
- 2 to 5
- Progradation

(Jorgenson and Brown, 2005; ACD GIS database)

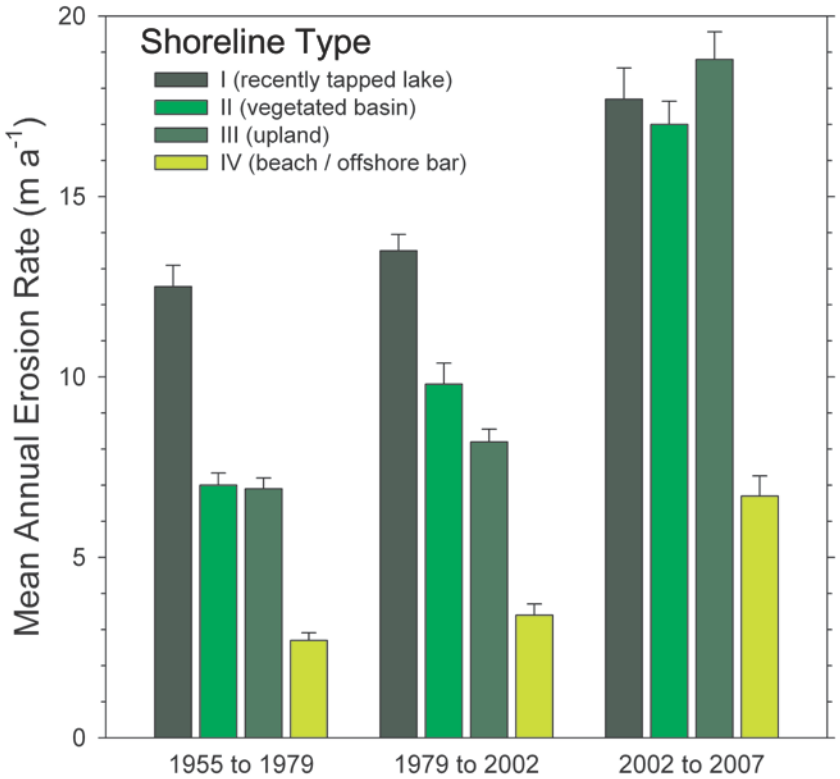
Increase in the Rate and Uniformity of Erosion

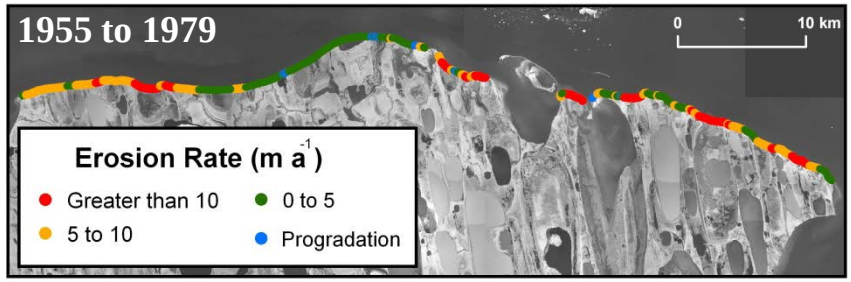
GEOPHYSICAL RESEARCH LETTERS, VOL. 36, L03503, doi:10.1029/2008GL036205, 2009

Click Here for Full Article

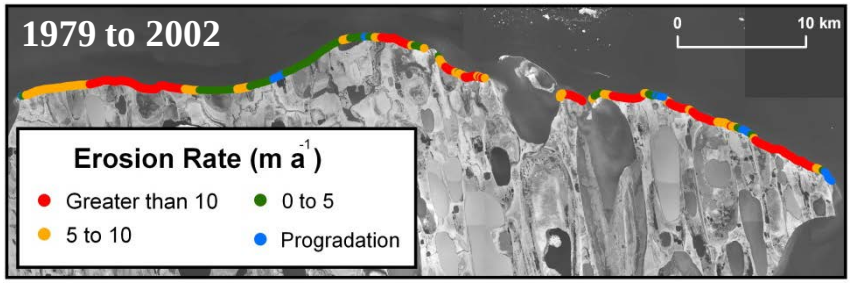
Increase in the rate and uniformity of coastline erosion in Arctic Alaska

B. M. Jones,[1] C. D. Arp,[1] M. T. Jorgenson,[2] K. M. Hinkel,[3] J. A. Schmutz,[1] and P. L. Flint[1]

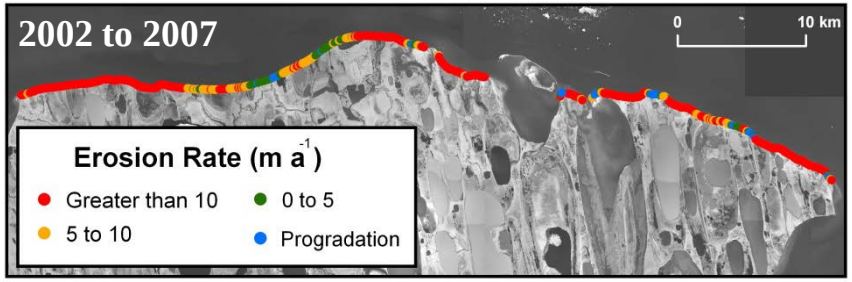




Mean = 6.8 m/yr



Mean = 8.7 m/yr



Mean = 13.6 m/yr

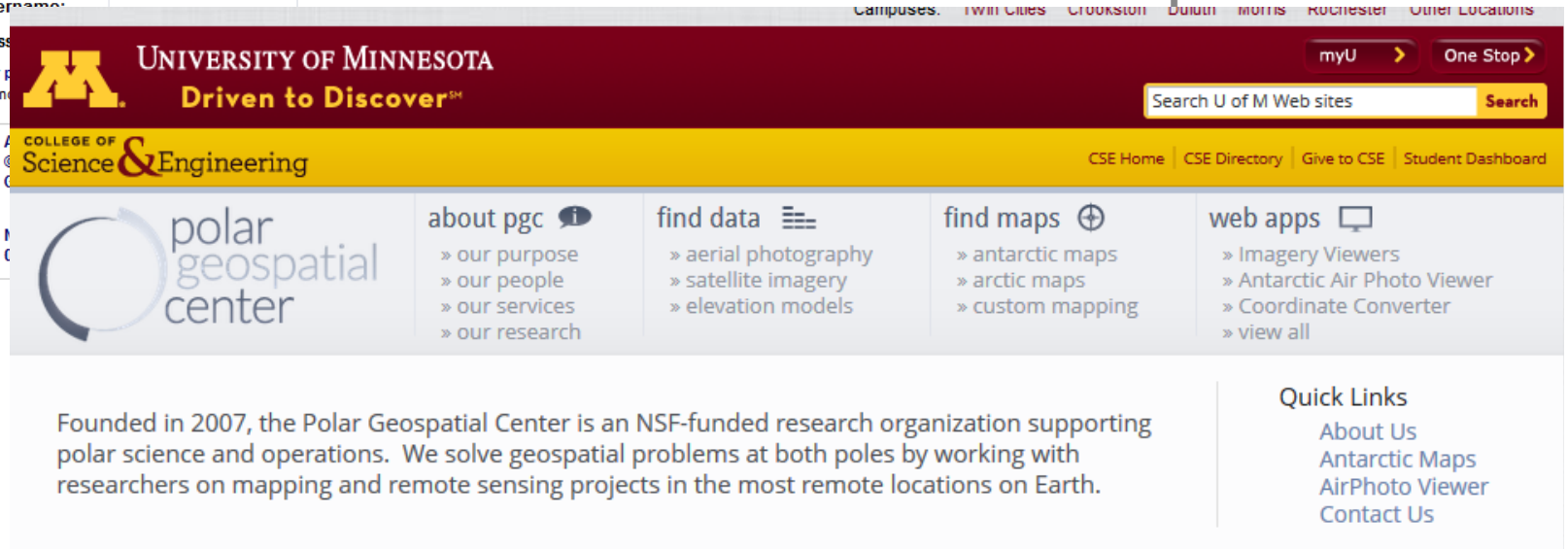
Time-series of erosion along block-failure coastal bluffs

*also note increase in pit formation

But what has happened since 2007?

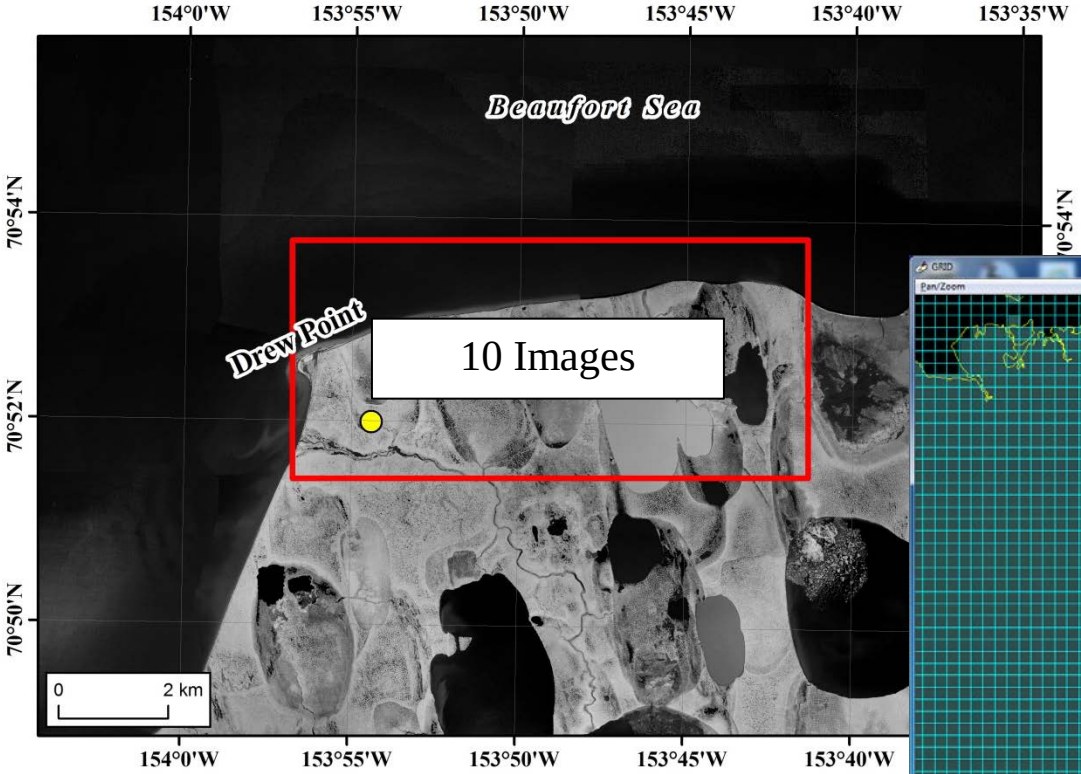
- Have the heightened erosion rates continued since 2007?
- Does the short term mean from 2002 to 2007 represent a new decadal-scale trend?
- Can repeat high-resolution optical and radar satellite imagery be used to assess annual erosion patterns?
- What is causing the reported increase in erosion at this site?

Acquisition of High-Resolution Optical Images

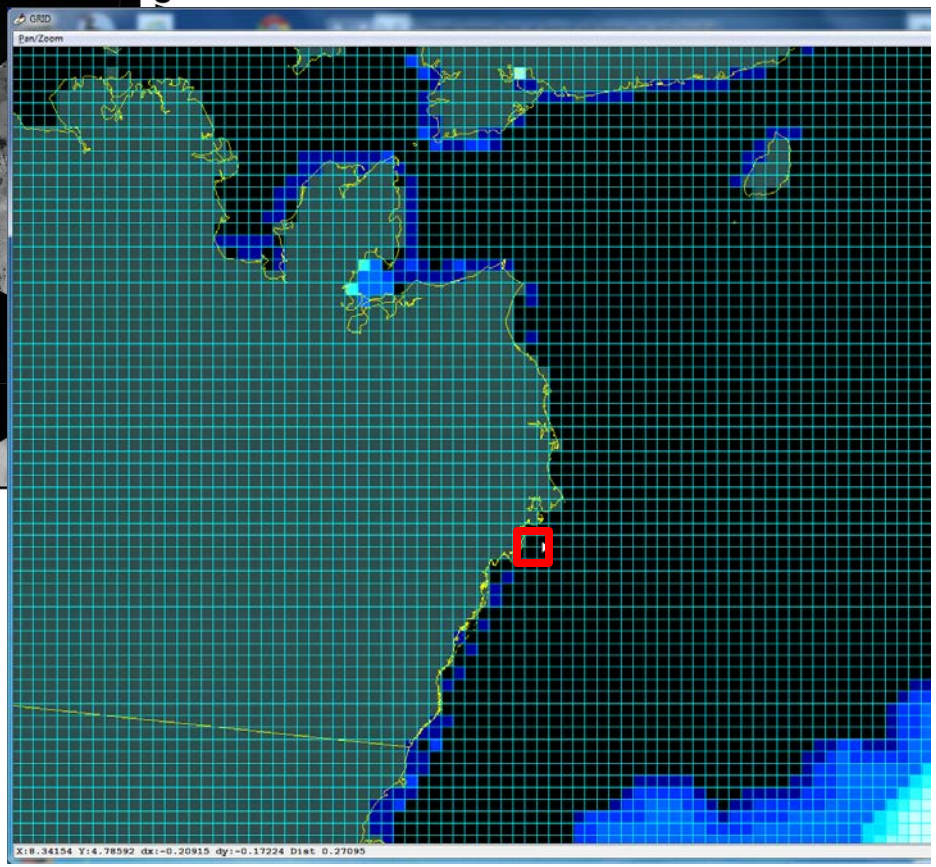


Data Acquisitions between 2008 and 2013

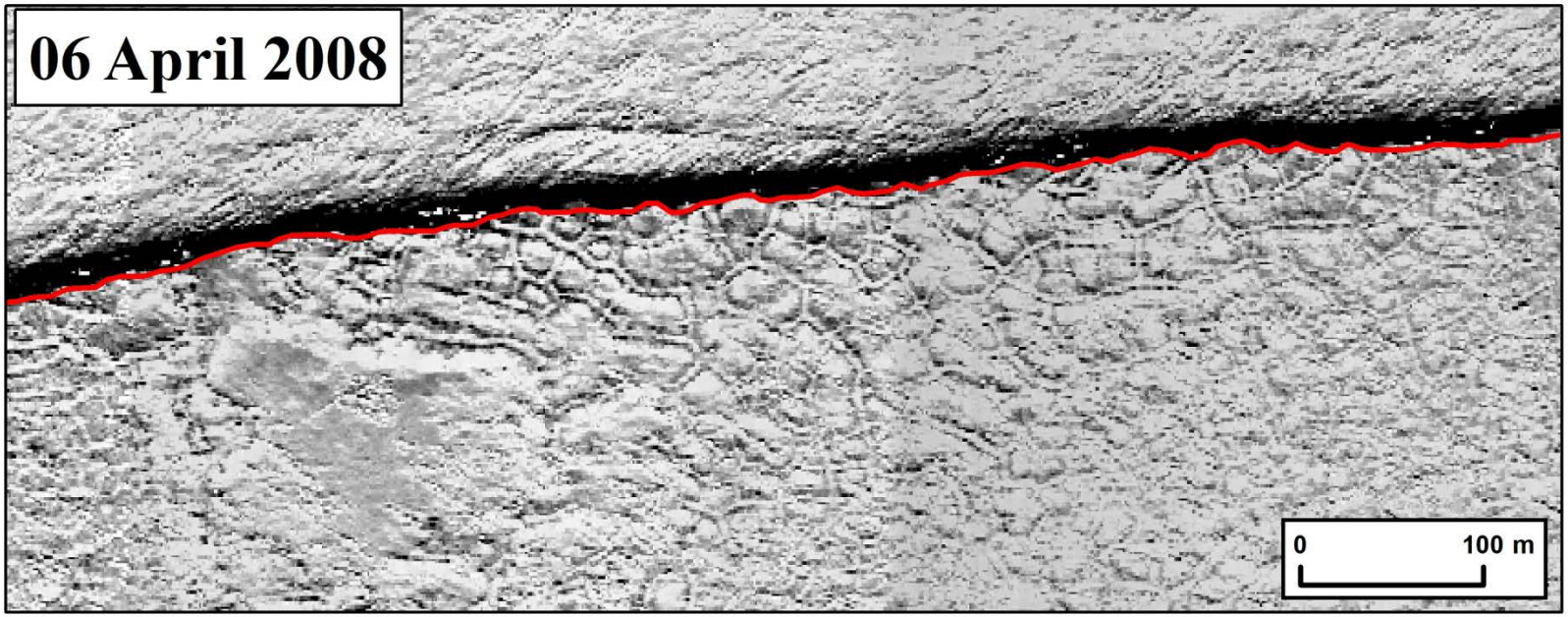
Optical Remote Sensing and Weather Data



SSM/I Sea Ice Extent Data

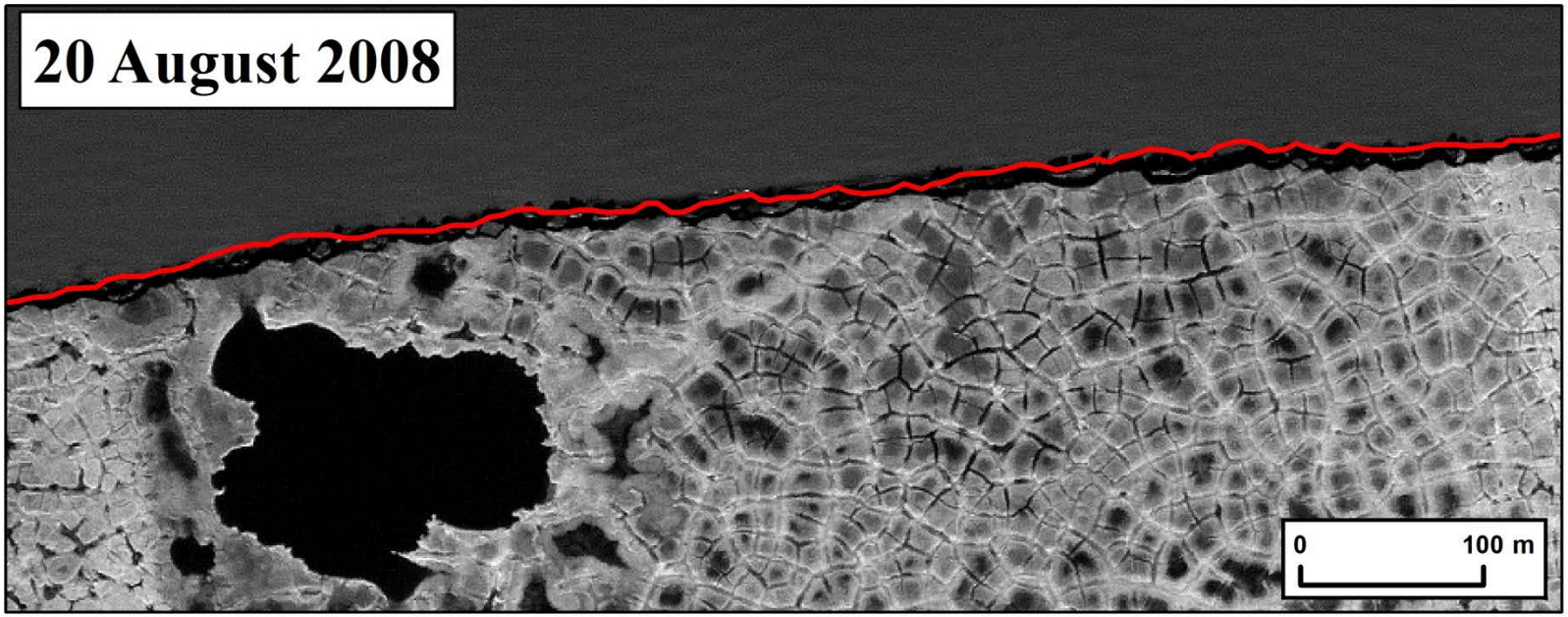


High-Resolution Imagery Time Series



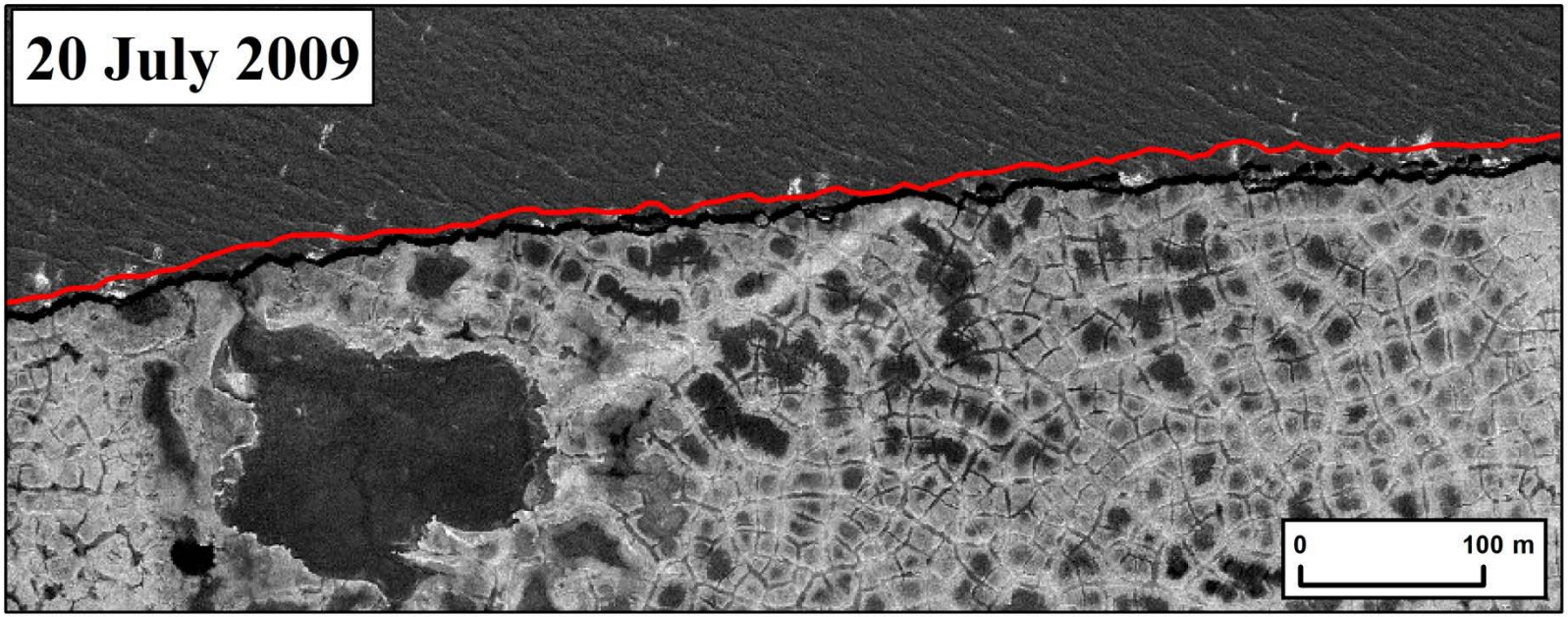
Quickbird

High-Resolution Imagery Time Series



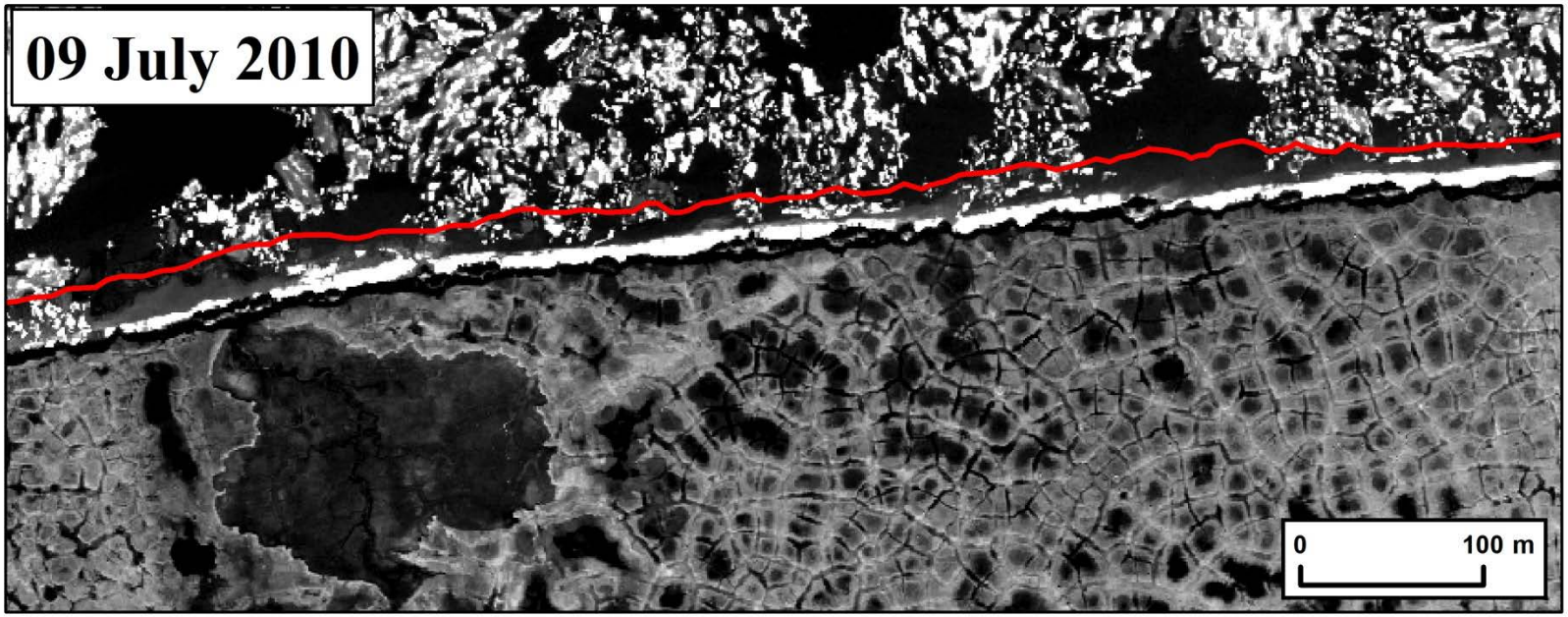
IKONOS

High-Resolution Imagery Time Series



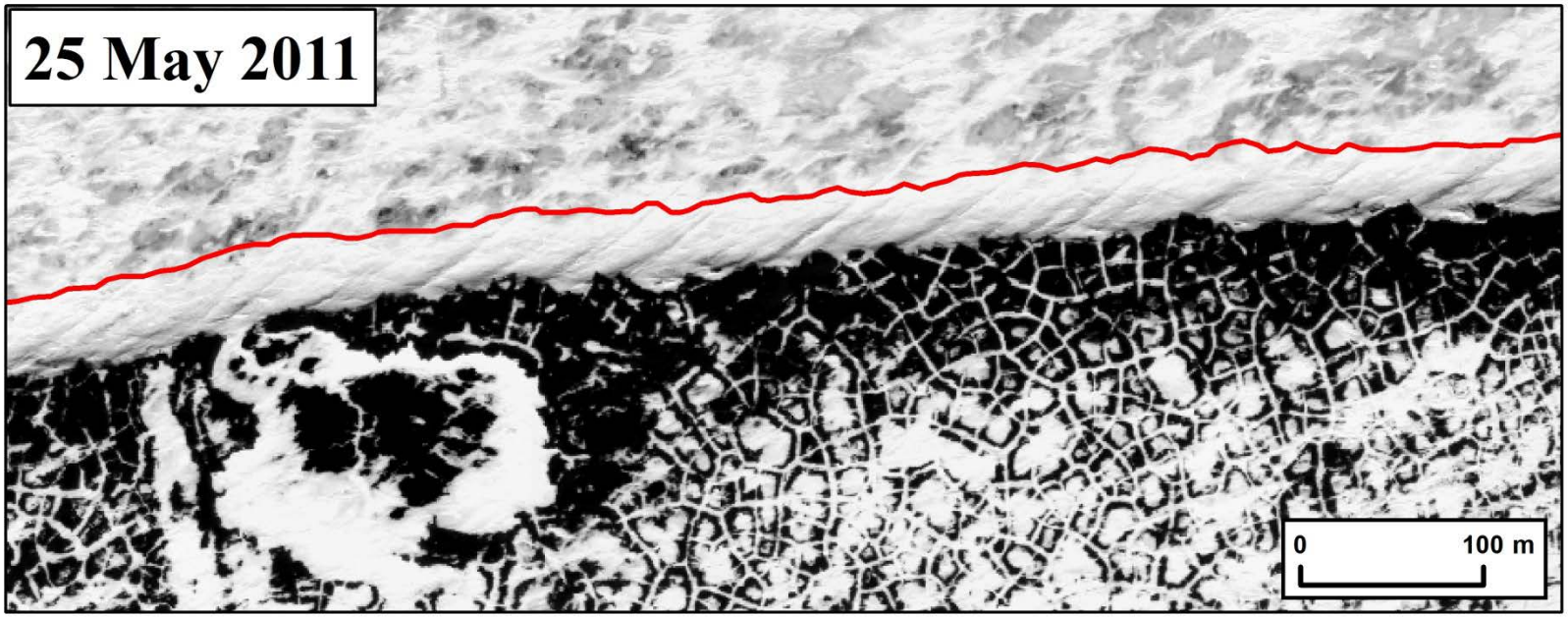
GEOEYE

High-Resolution Imagery Time Series



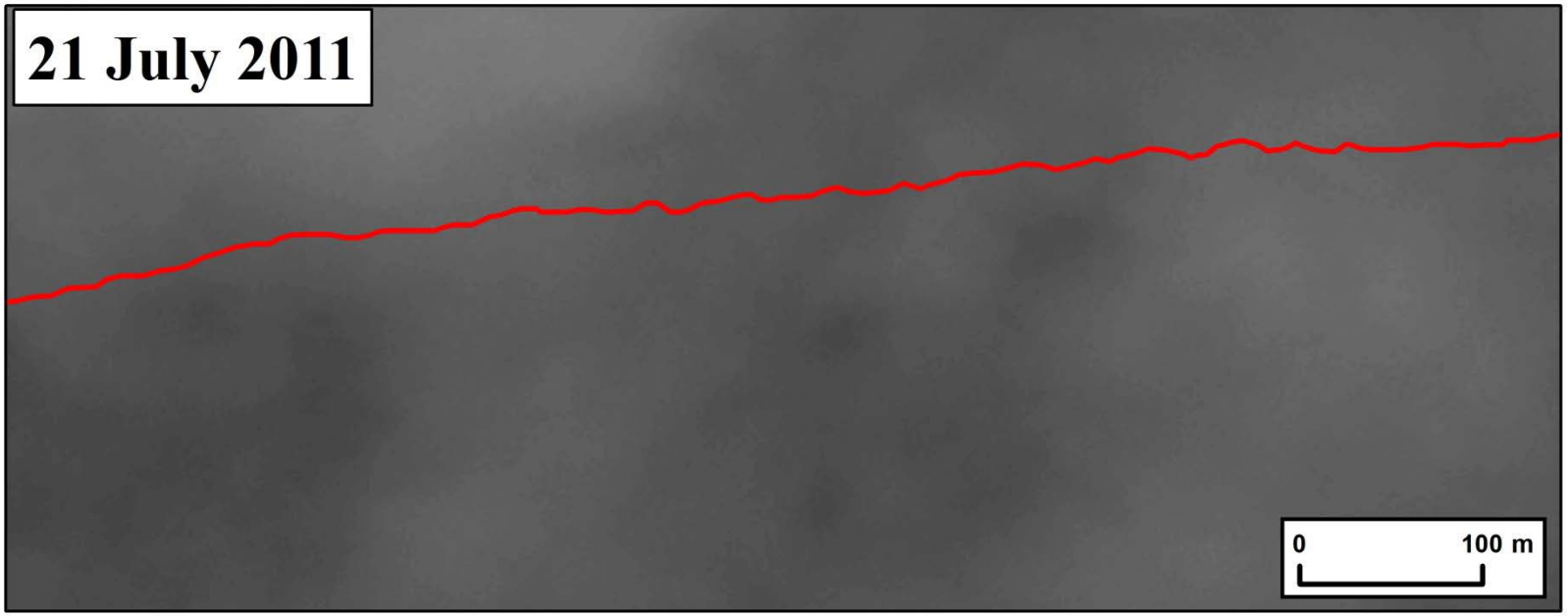
Worldview-1

High-Resolution Imagery Time Series



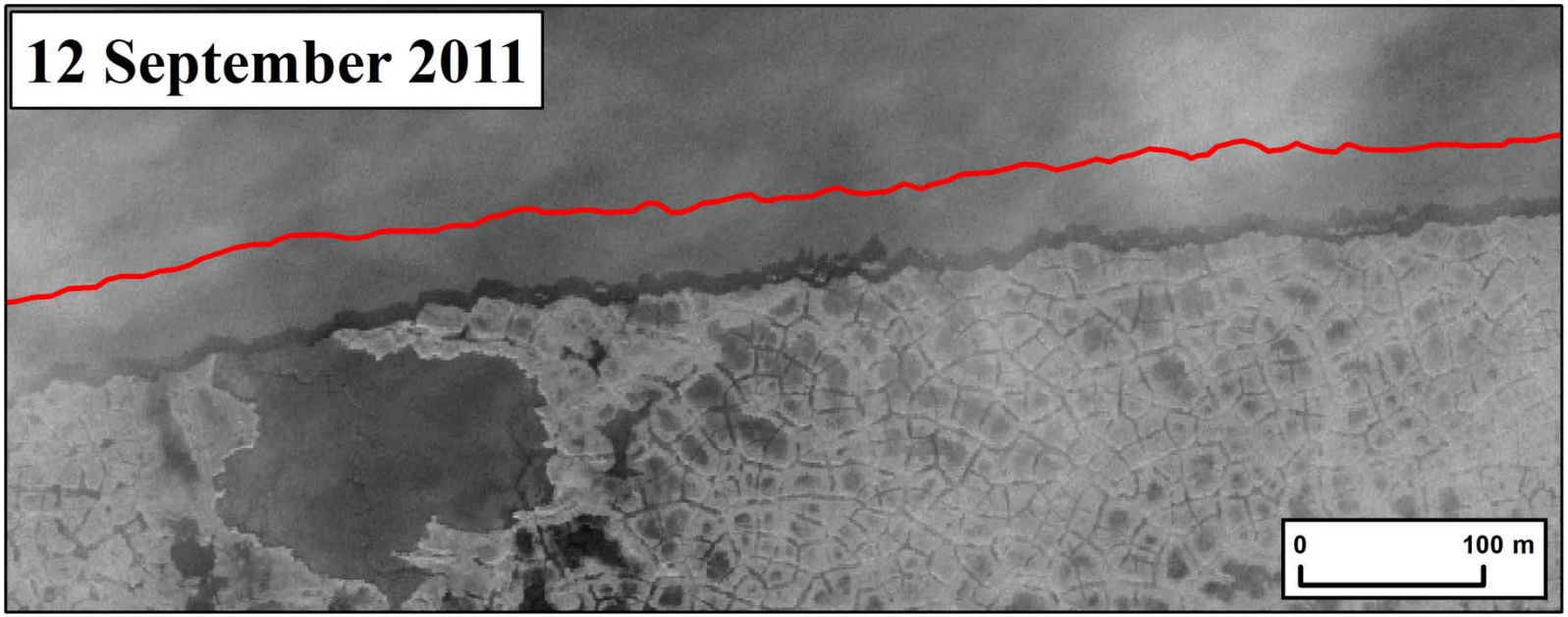
Worldview-2

High-Resolution Imagery Time Series



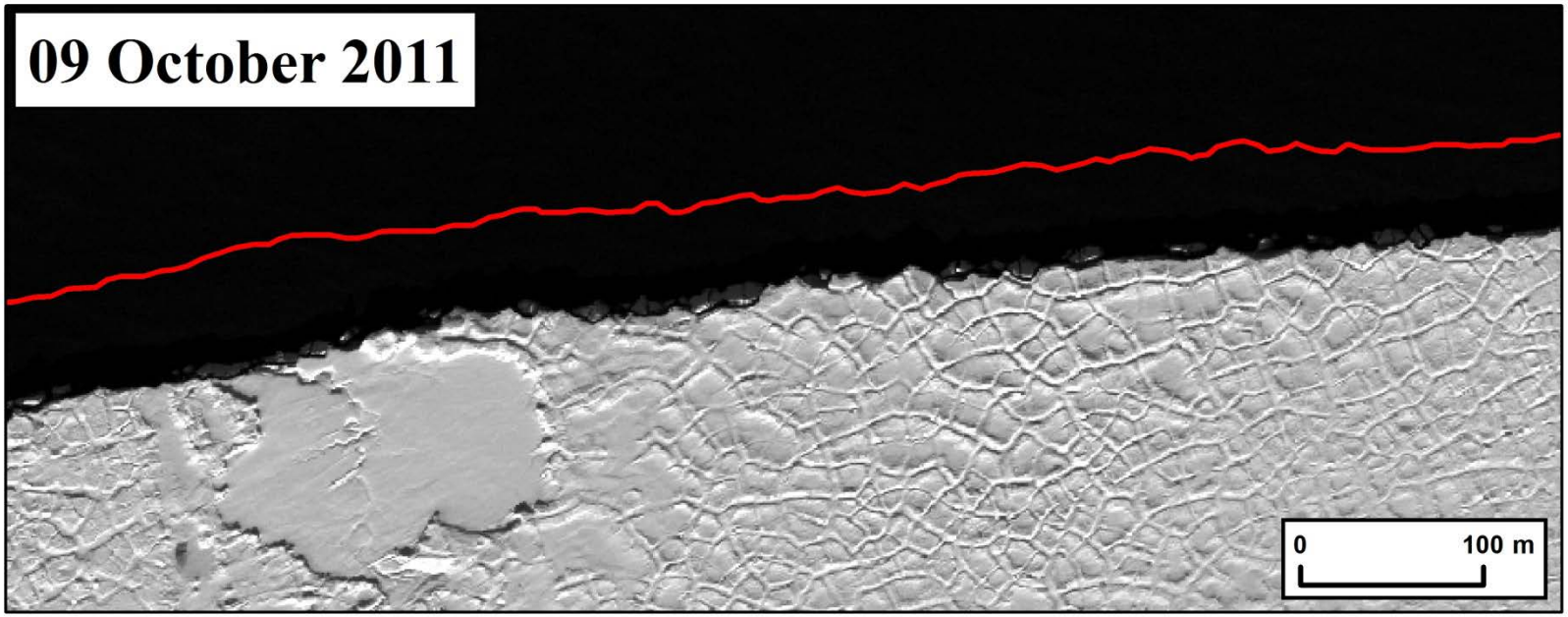
Worldview-2

High-Resolution Imagery Time Series



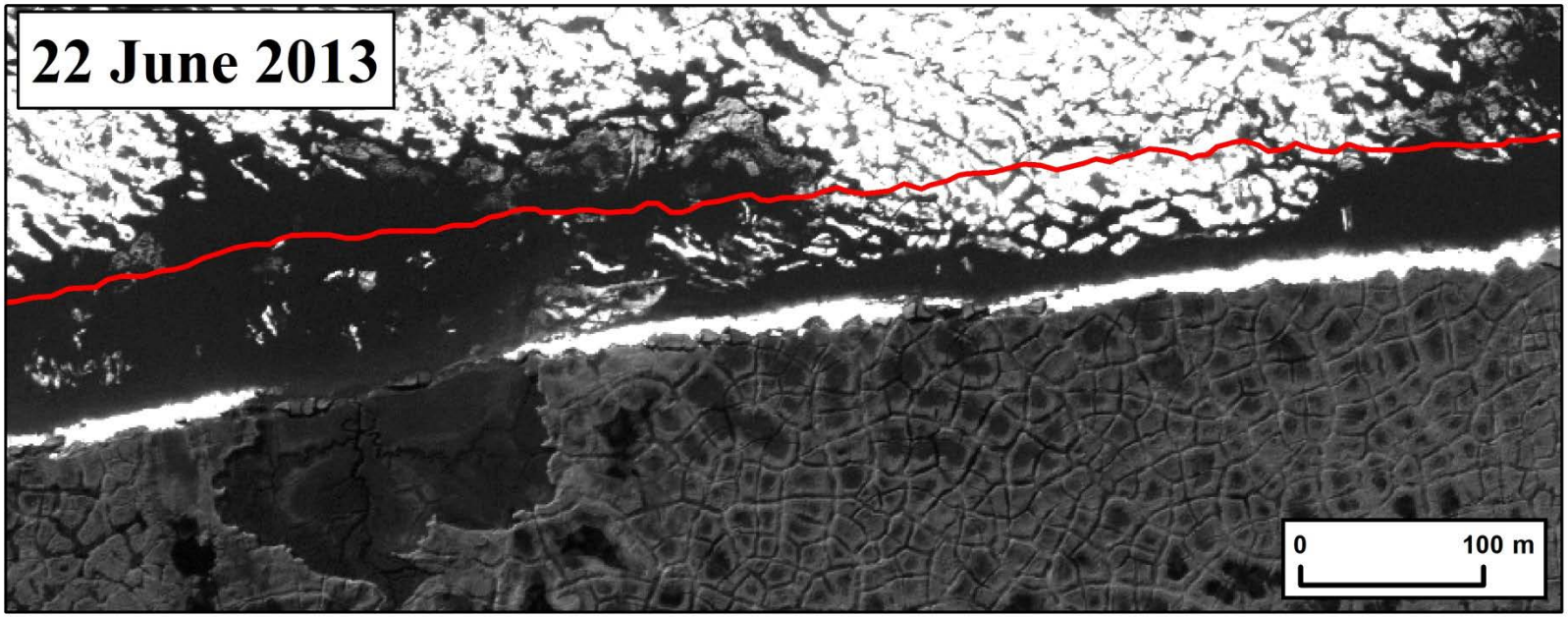
Worldview-1

High-Resolution Imagery Time Series



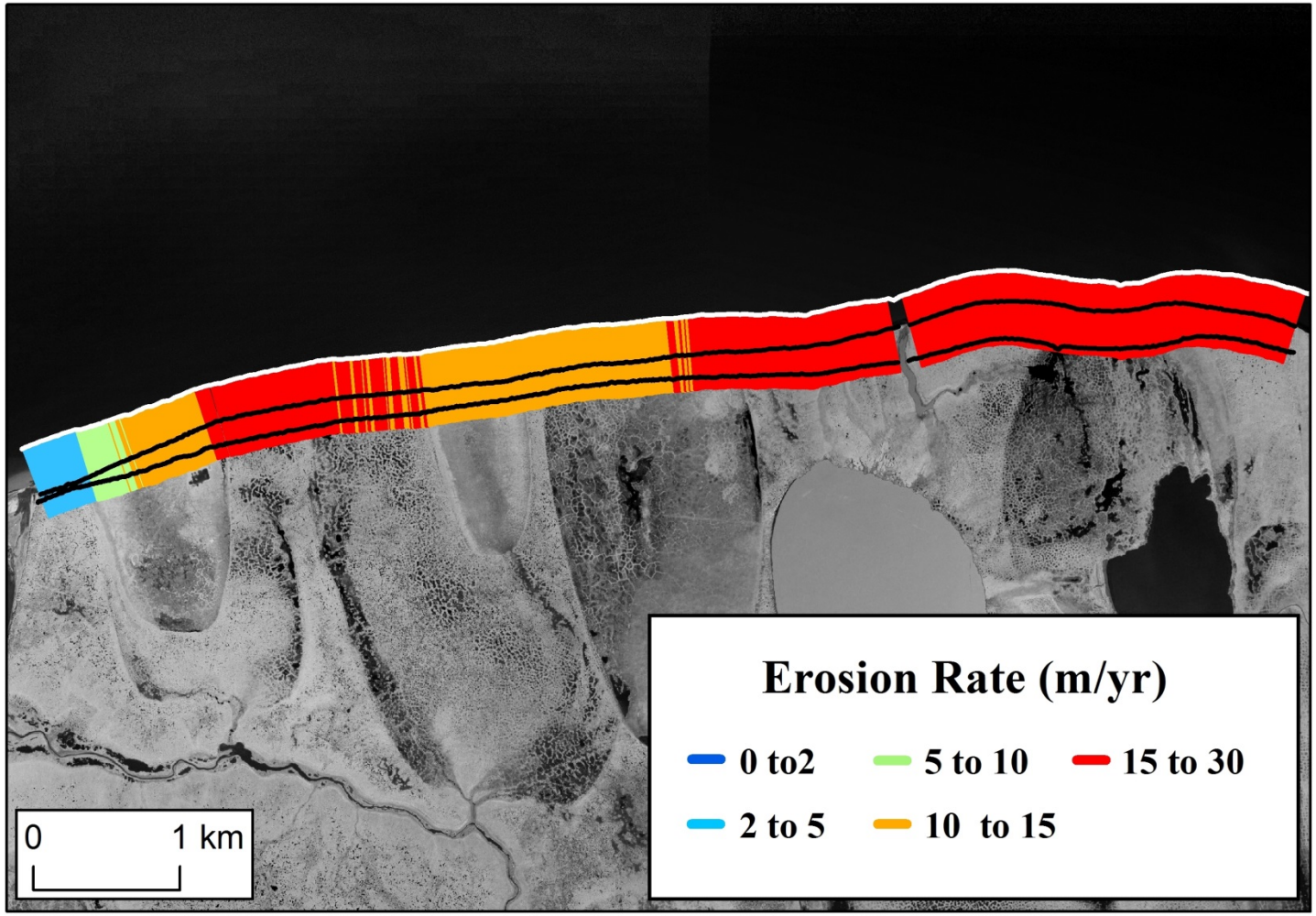
Worldview-1

High-Resolution Imagery Time Series



Worldview-2

Example of Coastal Change Rate Extraction



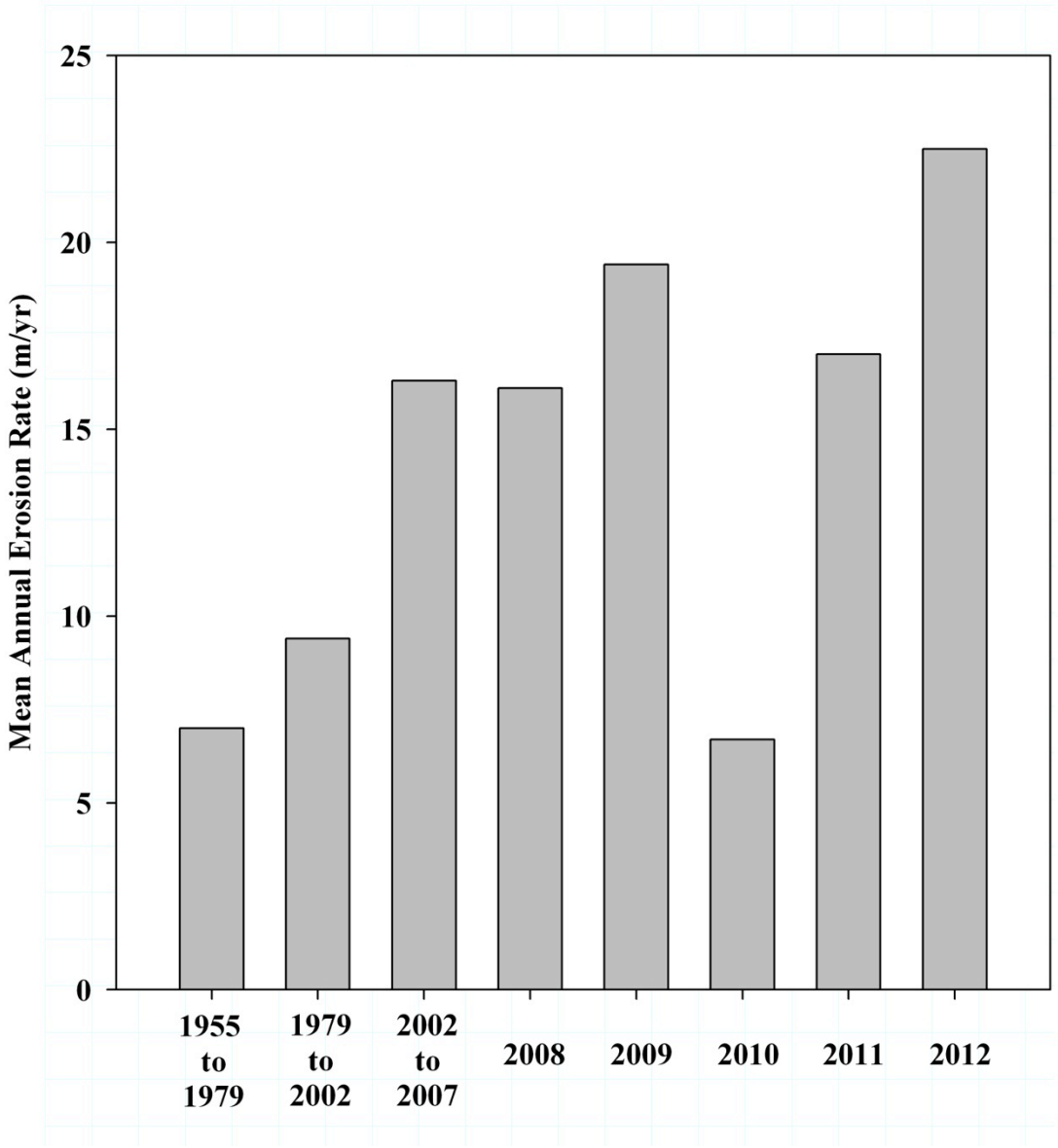
U.S. Geological Survey, Digital Shoreline Analysis System, ArcGIS extension
(http://woodshole.er.usgs.gov/project-pages/DSAS/)

Imagery, Dates, Resolution, Error, and Erosion

Image Source	Date	Spatial Resolution (m)	Mean RMS Error (m)	Digitization Error (m)	Dilution of Accuracy (m)	Mean Erosion (m)
Quickbird	6-Apr-08	0.6	0.78	0.14	1.48	10.9
Ikonos	20-Aug-08	1.0	0.44	0.14		
Ikonos	20-Aug-08	1.0	0.44	0.14	1.36	5.2
Geoeye 1	20-Jul-09	0.5	0.61	0.14		
Geoeye 1	20-Jul-09	0.5	0.61	0.14	1.14	19.4
Worldview 1	9-Jul-10	0.5	0.63	0.14		
Worldview 1	9-Jul-10	0.5	0.63	0.14	1.18	6.7
Worldview 2	25-May-11	0.5	0.67	0.14		
Worldview 2	25-May-11	0.5	0.67	0.14	1.16	11.3
Worldview 1	12-Sep-11	0.5	0.60	0.14		
Worldview 1	12-Sep-11	0.5	0.60	0.14	1.27	5.7
Worldview 1	9-Oct-11	0.5	0.85	0.14		
Worldview 1	9-Oct-11	0.5	0.85	0.14	1.28	22.5
Worldview 2	22-Jun-13	0.5	0.61	0.14		

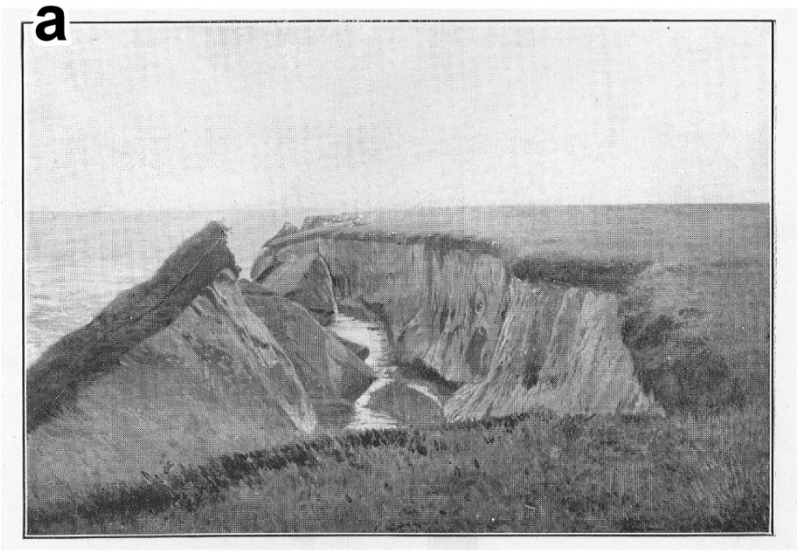
$$DOA(m) = \sqrt{(SR_1)^2 + (SR_2)^2 + (RMSE_1)^2 + (RMSE_2)^2 + (DE_1)^2 + (DE_2)^2}$$

Update on Mean Annual Erosion at Drew Point



Has the Erosion Mechanism Changed Here?

Photo from 1901

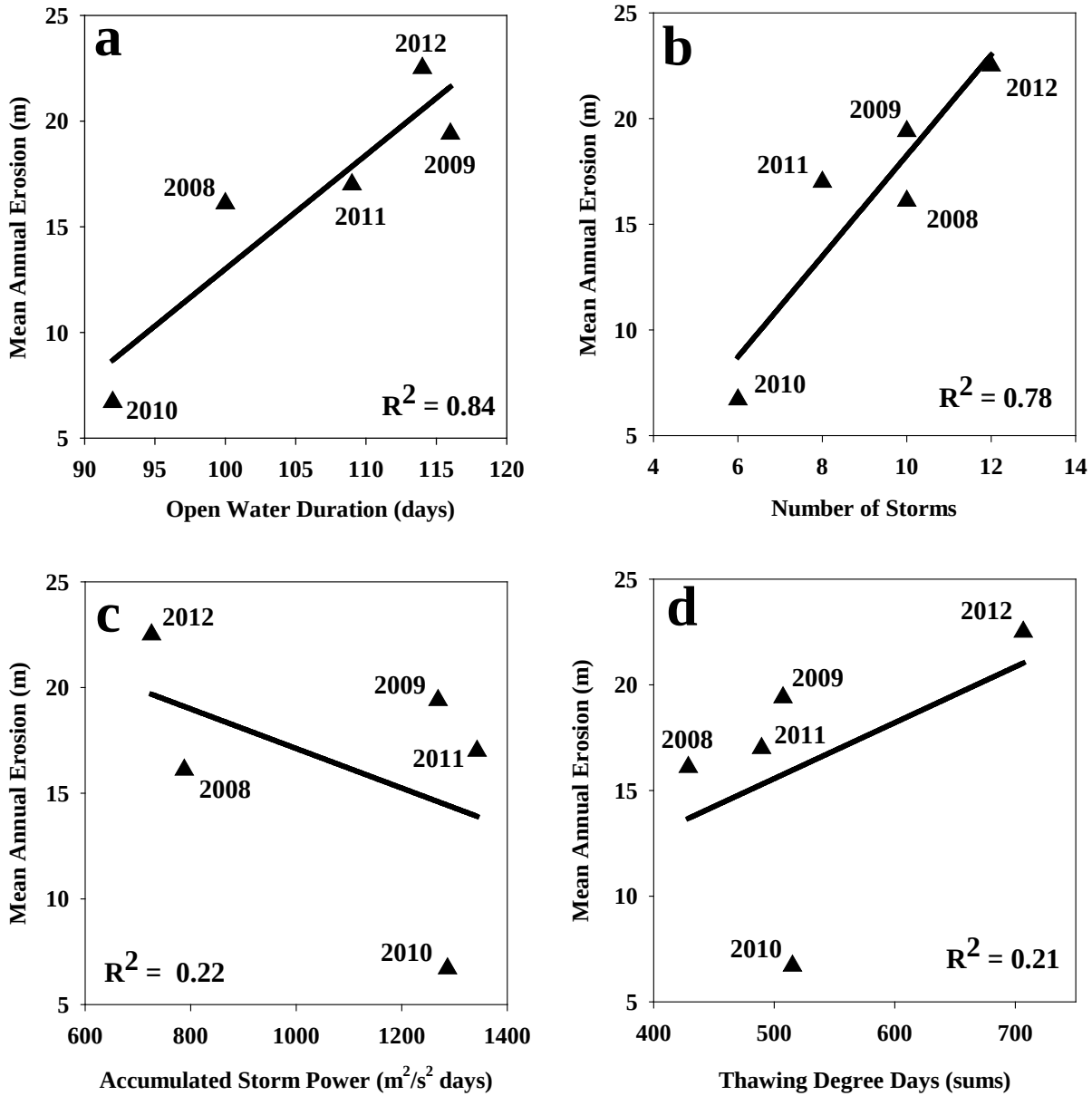


Schrader, 1904

Photo from 2011

- This mechanism has likely been acting upon this coast for quite some time
- Recent increase in erosion is likely a result of an increase in the number of block-collapse episodes per year

Annual Erosion vs. Environmental Conditions



Recent Patterns of Erosion at Drew Point

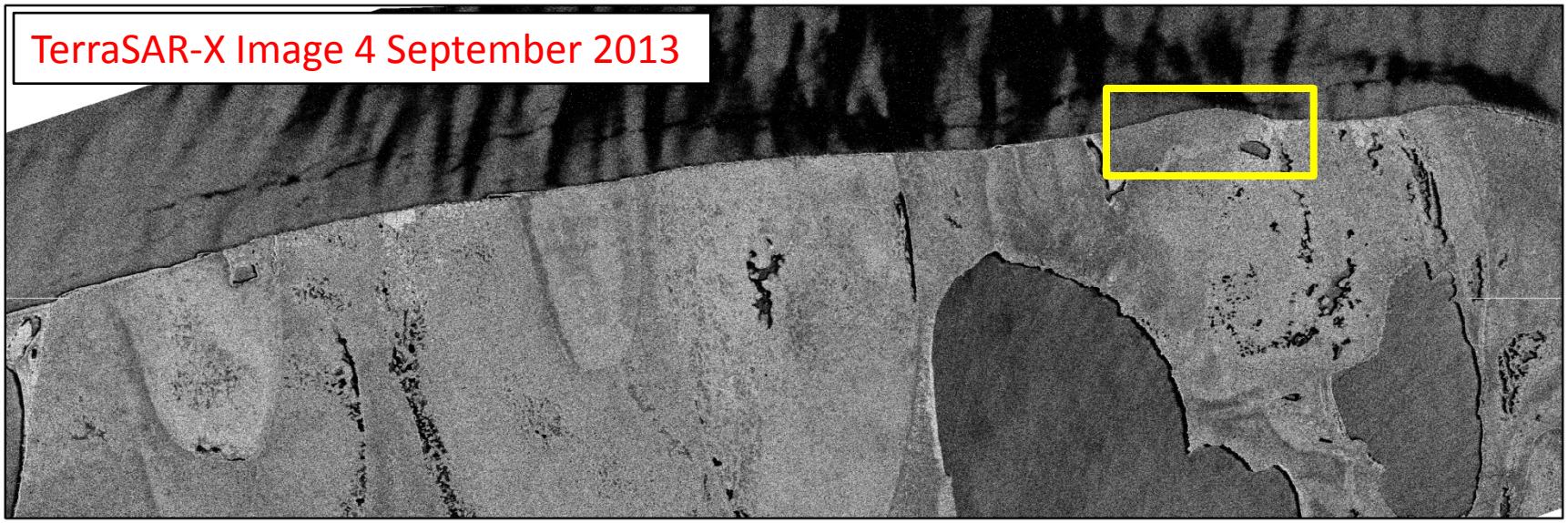
- The erosion rate between 2002 and 2012 was 16.3 m/yr but ranged from 6.7 m to 22.5 m between 2008 and 2012

- Erosion at this site appears to respond directly to the number of ice free days and the number and magnitude of storms

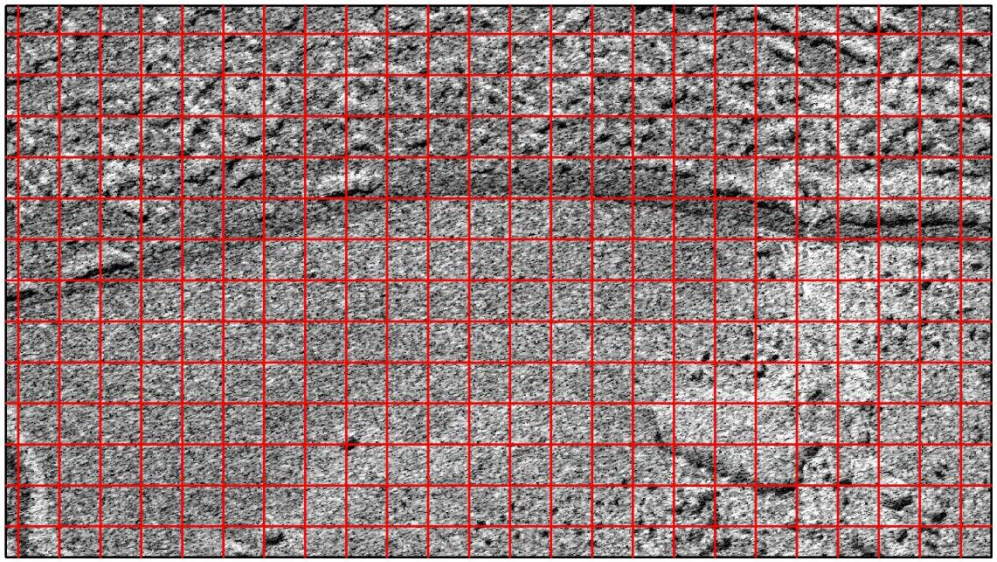
- While this seems like an obvious connection…It's the first site in the Arctic that directly links the decline in sea ice with an increase in erosion

- High spatial resolution optical imagery acquired at high temporal resolution provides a great tool for conducting Arctic coastal studies - however, the frequency of image acquisition will be limited in most areas…so other image sources may be needed to paint a fuller picture….

Future Analyses…Incorporation of TerraSAR-X Imagery



15 June 2010



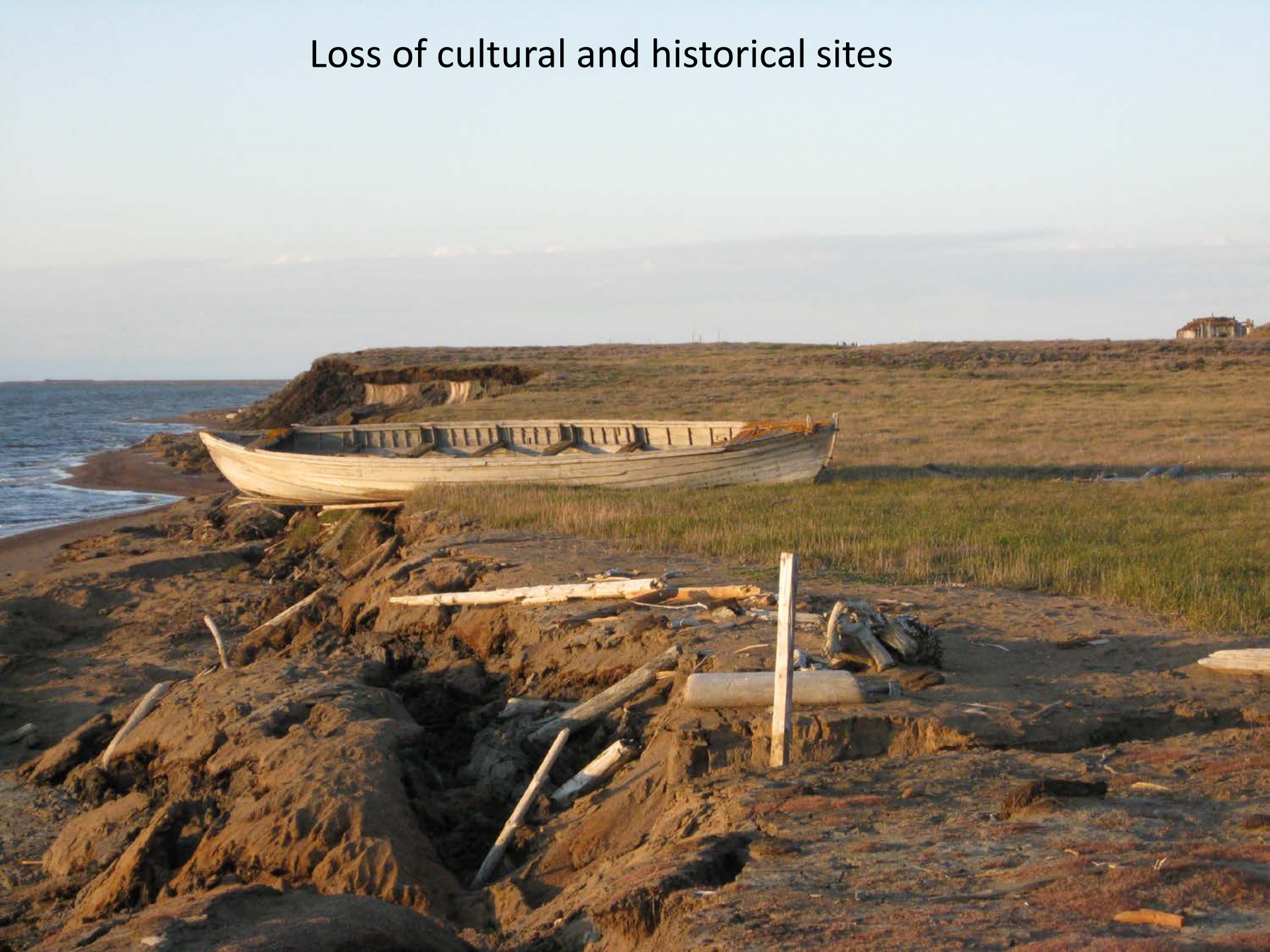
- Acquisition of 8 images between 2010 and 2013
- Ability to distinguish bluffline influenced by wind direction/waves and snow drifts
- 50 to 75 m of erosion here between 2010 and 2013 which is on par with optical dataset measurements
- TSX data can be used to target specific events…

Thanks and Questions…

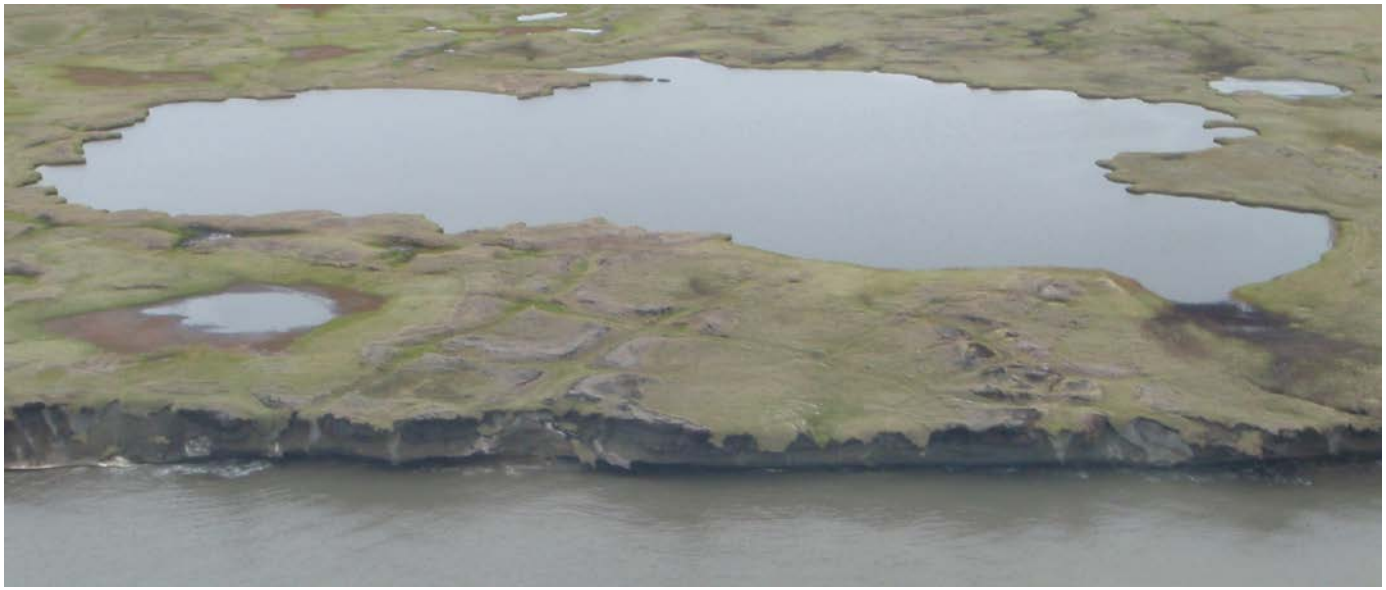
So who cares?

Loss of fishing and hunting camps located near the coast

Loss of cultural and historical sites

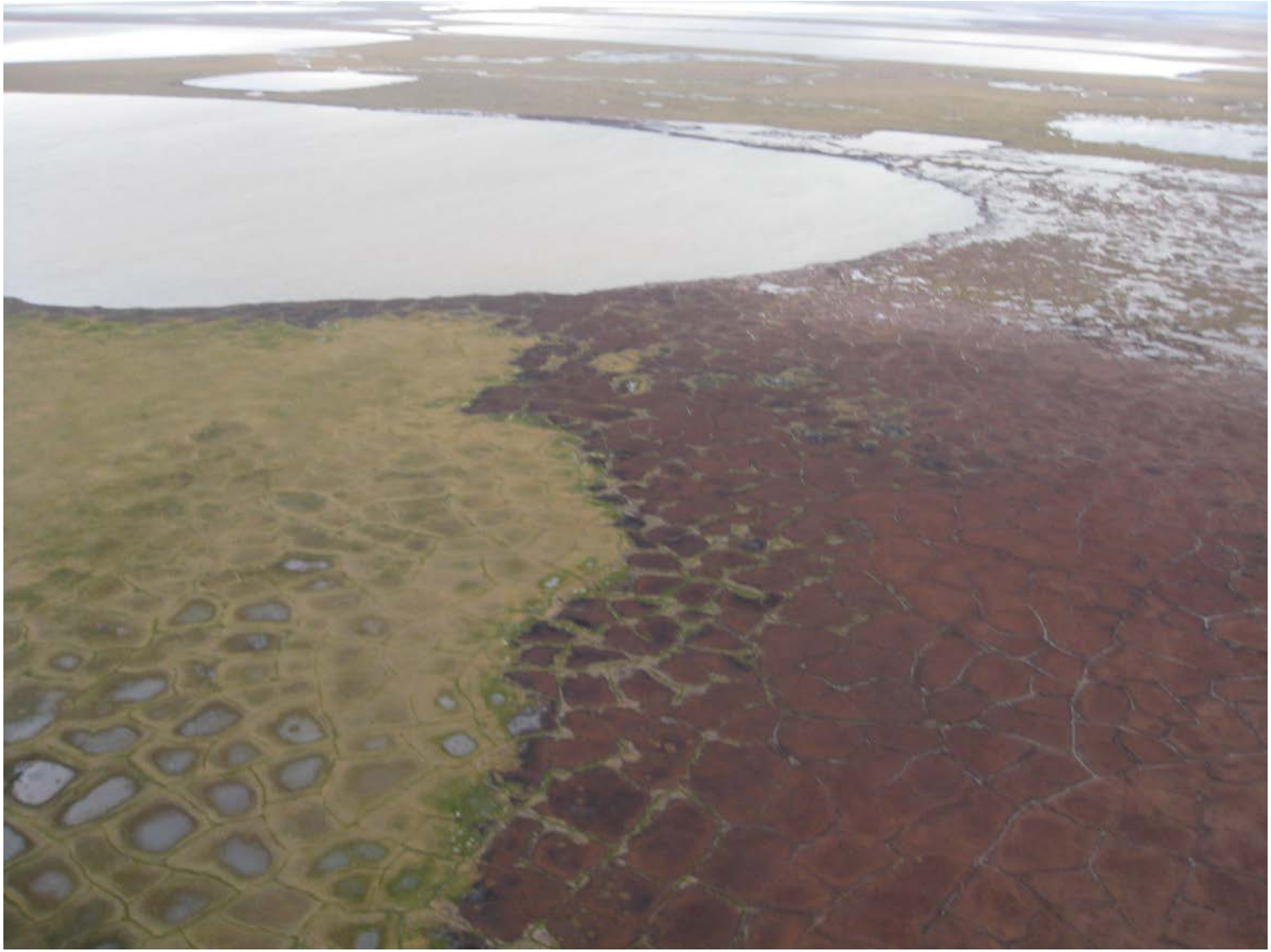


Tapping of thermokarst lakes and ponds



Arp et al., 2010, Polar Biology

Storm-surge flooding, salt-burned tundra, and lake salinization



Arp et al., 2010, Polar Biology

Dalton wellhead clean-up operations in 2004 and 2005

Figure 3 – J.W. Dalton wellhead during the summer of 2004.

Dalton wellhead clean-up operations in 2004 and 2005

Figure 4 – Sleigh Camp used for J.W. Dalton operations April 14, 2004

Dalton wellhead clean-up operations in 2004 and 2005

Figure 5 – Excavation of the well cellar

Dalton wellhead clean-up operations in 2004 and 2005

Figure 7 – Setup for diesel displacement operations

Dalton wellhead clean-up operations in 2004 and 2005

Figure 9 – Excavation of well casing prior to removal