Extensive mapping of coastal change in Alaska by Landsat time-series analysis, 1972-2013

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Western Alaska LCC

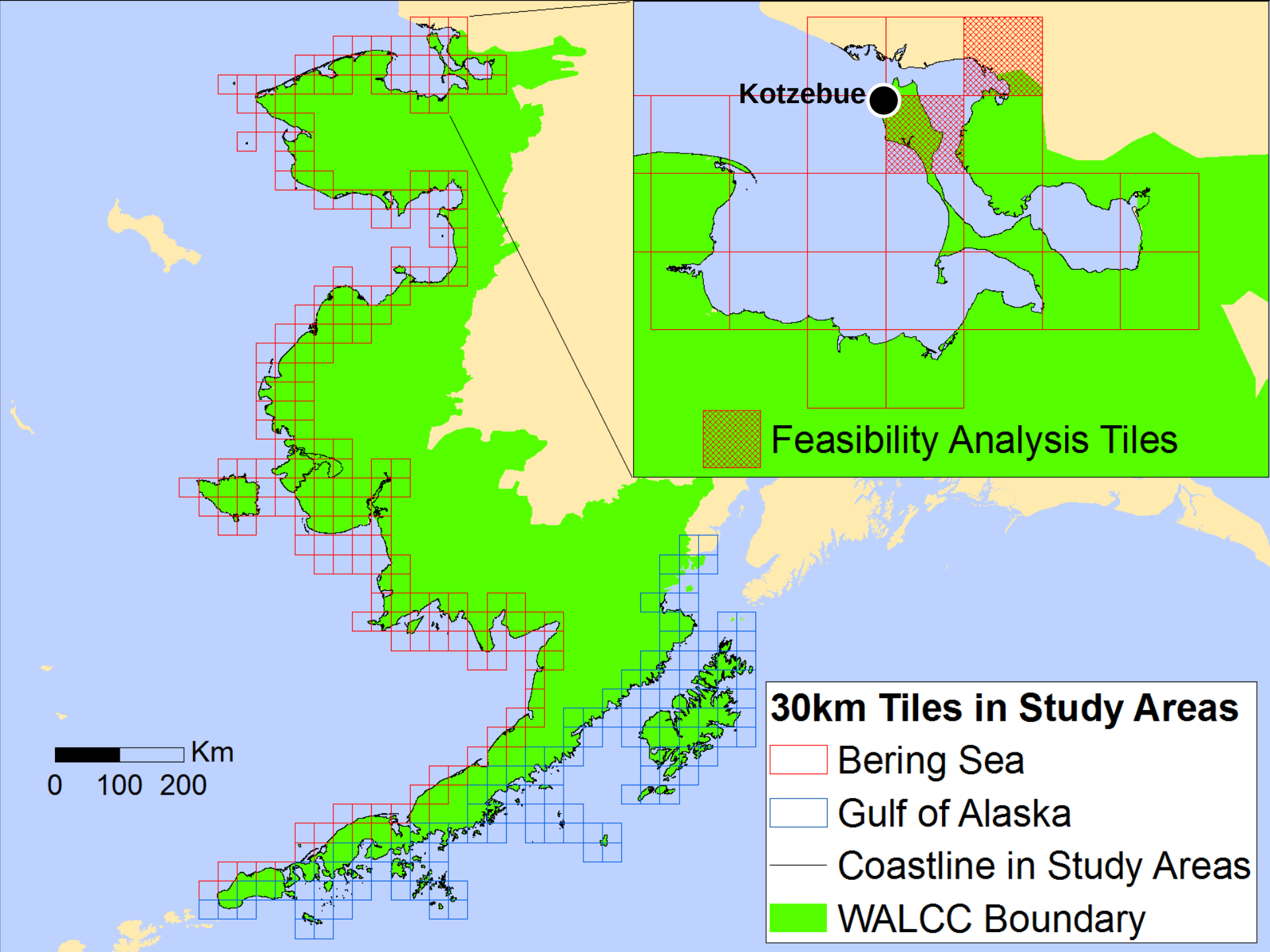
ABR inc.
environmental research & services

WALCC

- Western Alaska Landscape Conservation Cooperative (WALCC).
- In 2012, initiated a two-year pilot program focused on addressing science needs related to changes in coastal storms and their impacts.

Mapping Coastal Change

- Hotspots of coastal erosion well-mapped by intensive methods for several local areas, including Bering Land Bridge NPP and portions of the Yukon Delta.
- To characterize the entire WALCC an extensive approach is needed.

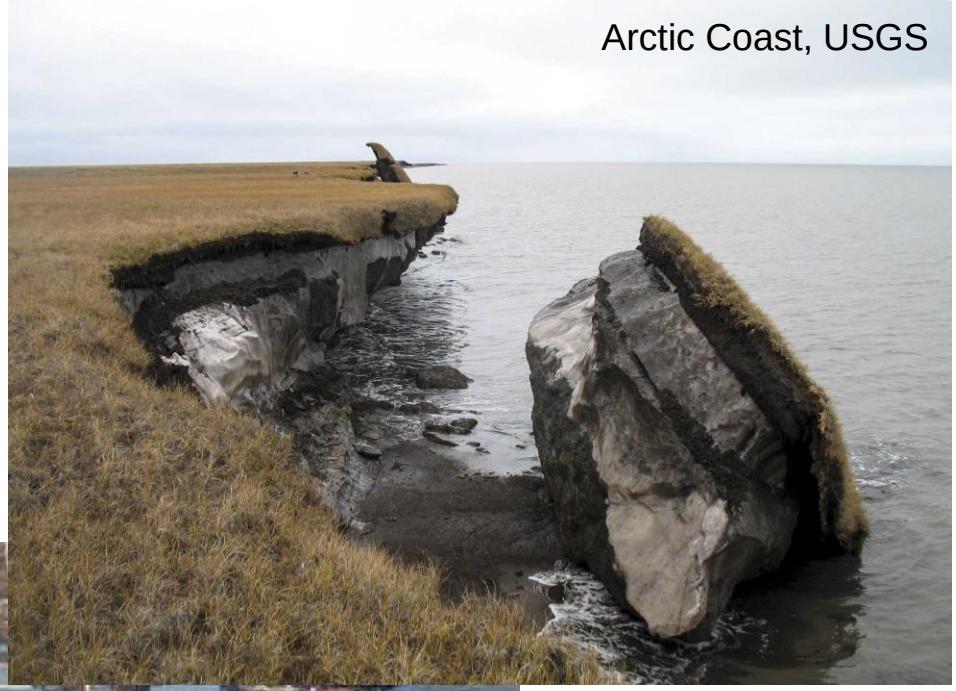

Kotzebue
Feasibility Analysis Tiles
Km
0 100 200
30km Tiles in Study Areas
Bering Sea
Gulf of Alaska
Coastline in Study Areas
WALCC Boundary

Storms and Coastal Change

- Landscape-scale effects on ecosystems, communities, and infrastructure.
  - Coastal erosion
  - Flooding of communities
  - Migration of spits and barrier islands
  - Breaching of coastal lakes and lagoons
  - Inundation and salt-kill of vegetation

Coastal Erosion

Shishmaref, 2006



Arctic Coast, USGS

Kivalina, 2005 (Millie Hawley)

Storms and Coastal Change

Summer Storms

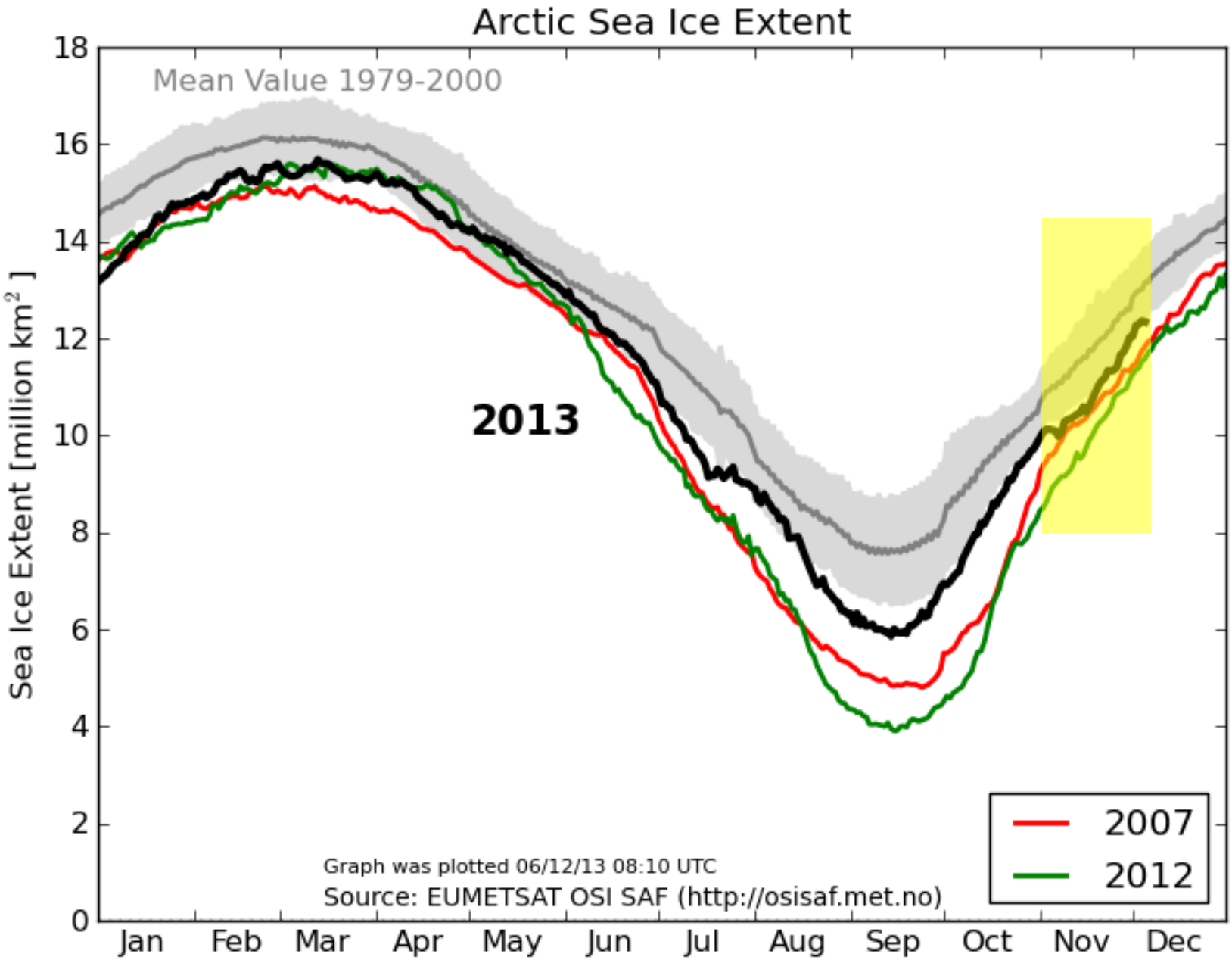
Tend to be weaker.

Fall Storms

Winter storm strength but can occur prior to freeze-up. Reduced sea-ice extent and duration increases the length of time when the coast is exposed to severe fall storms.

Winter Storms

Can be severe but the coast is protected by sea ice and shorefast ice.

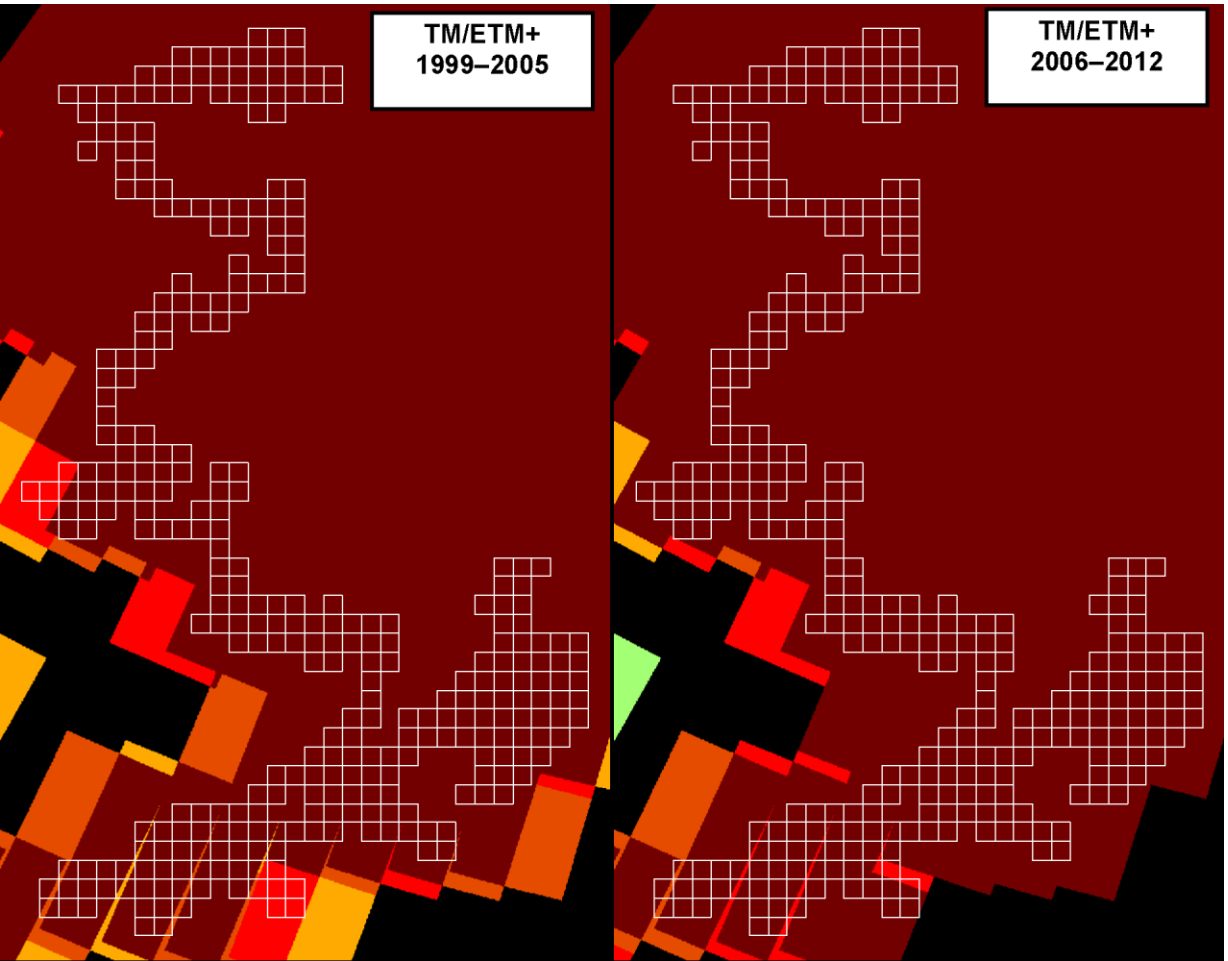

Arctic Sea Ice Extent
Mean Value 1979-2000
2013
2007
2012
Graph was plotted 06/12/13 08:10 UTC
Source: EUMETSAT OSI SAF (http://osisaf.met.no)
Sea Ice Extent [million km^2]
0
2
4
6
8
10
12
14
16
18
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

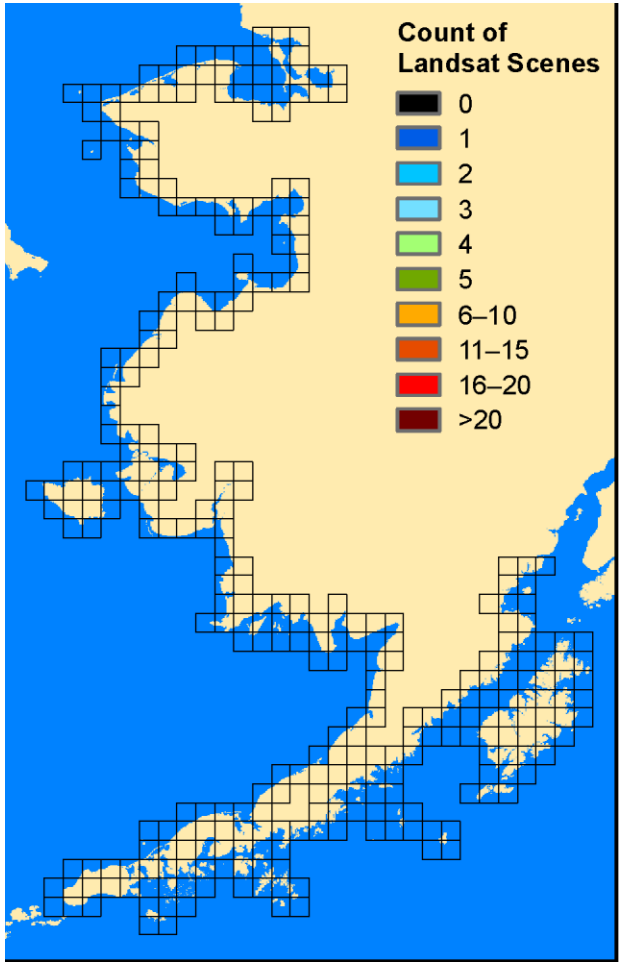
Landsat Time-Series

- Landsat TM, ETM+, OLI cover 1985–2013.
- 30-m resolution and 28-year time-series, 1 m/yr change would equal one pixel.

Landsat Time-Series (July-September)

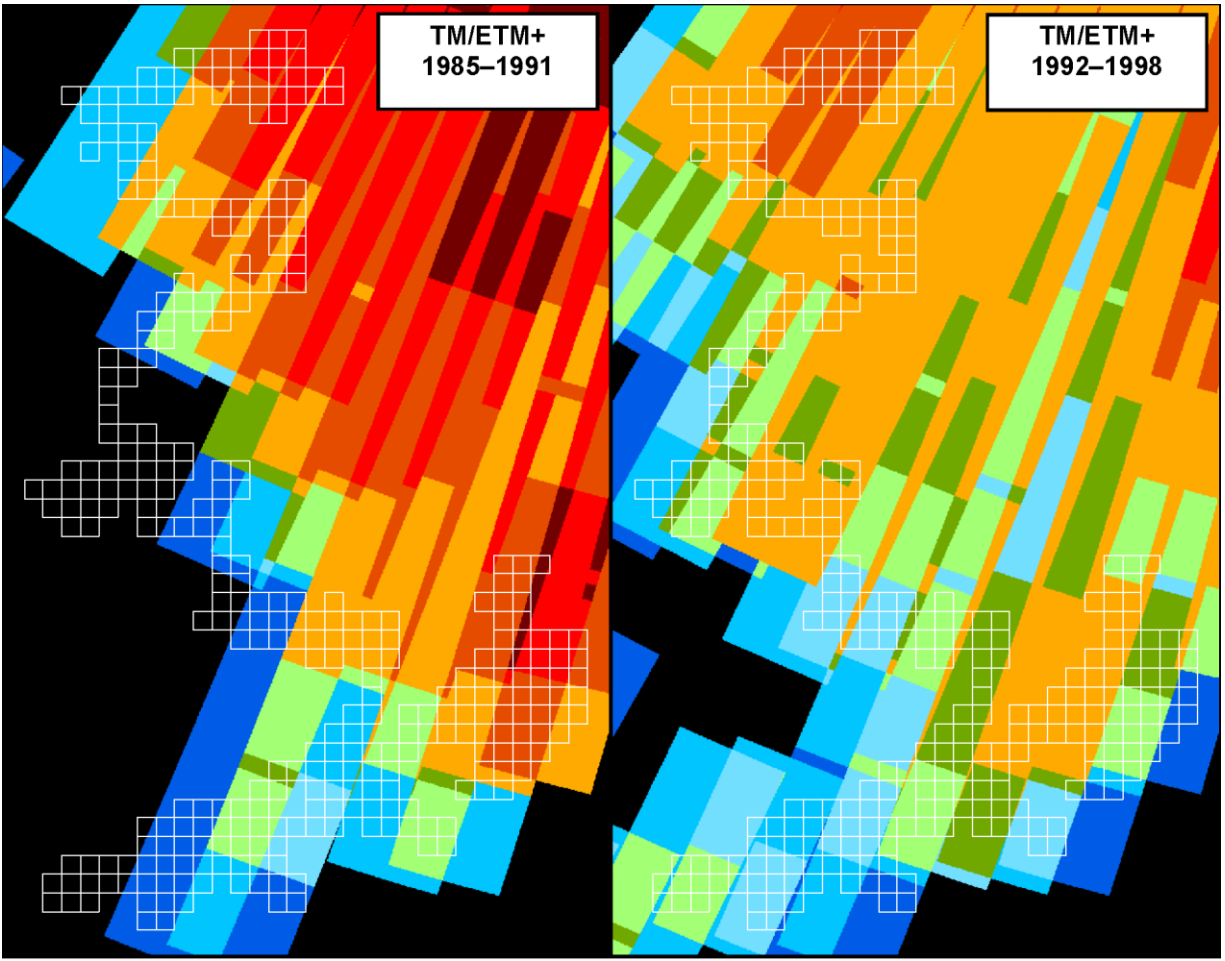
ETM+ era (1999-present)

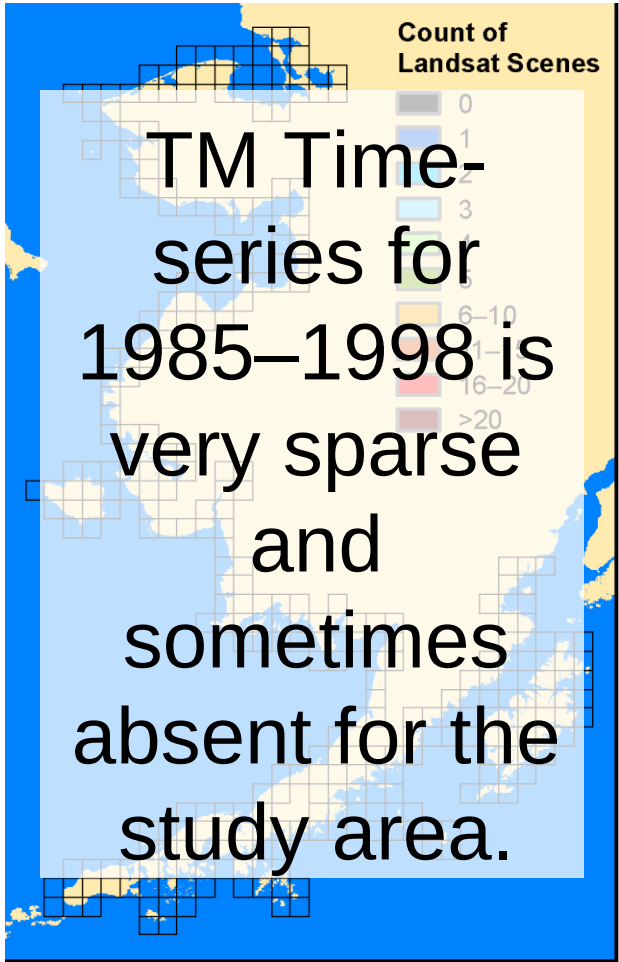




Landsat Time-Series (July-September)

TM era (1985–1998)

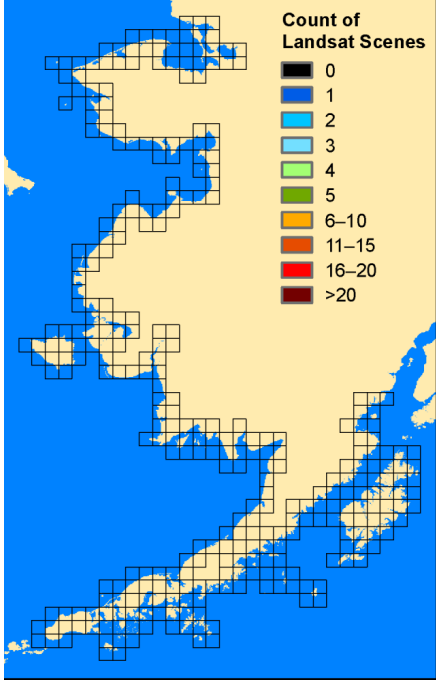


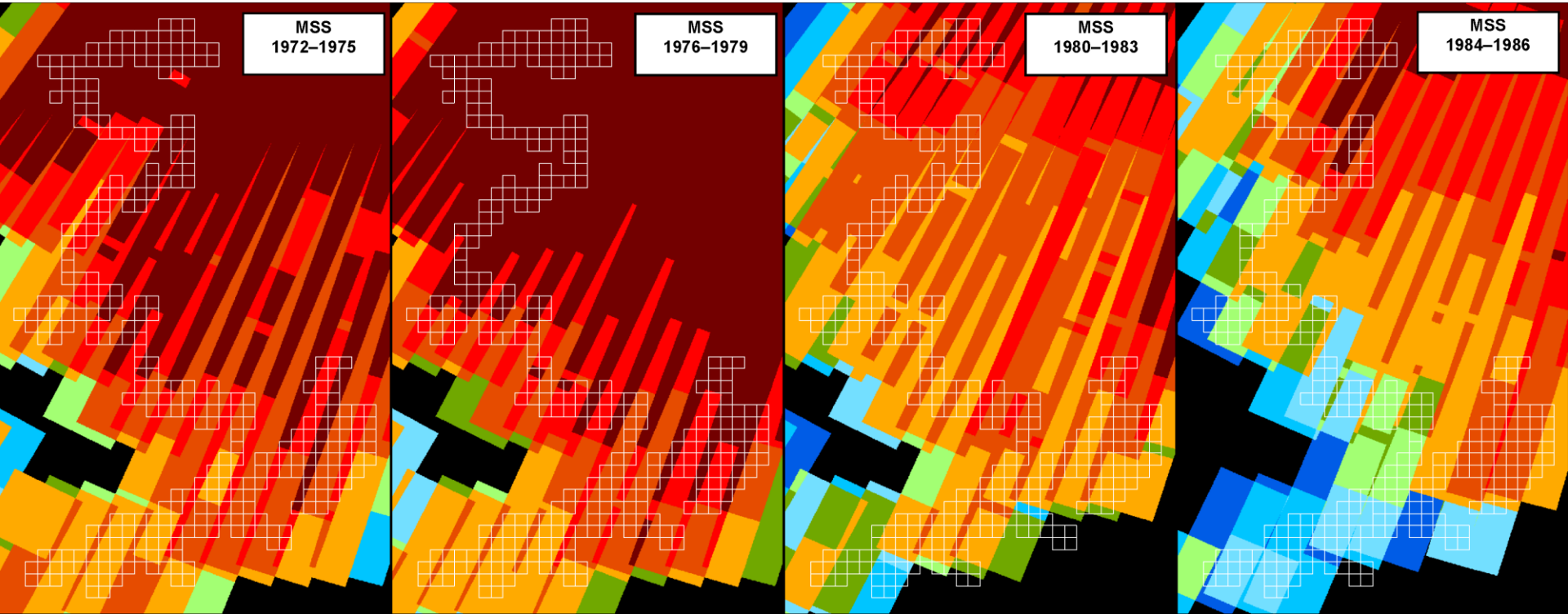


TM Time-series for 1985–1998 is very sparse and sometimes absent for the study area.

Landsat Time-Series (July-September)

MultiSpectral Scanner (MSS) era, 1972–1986



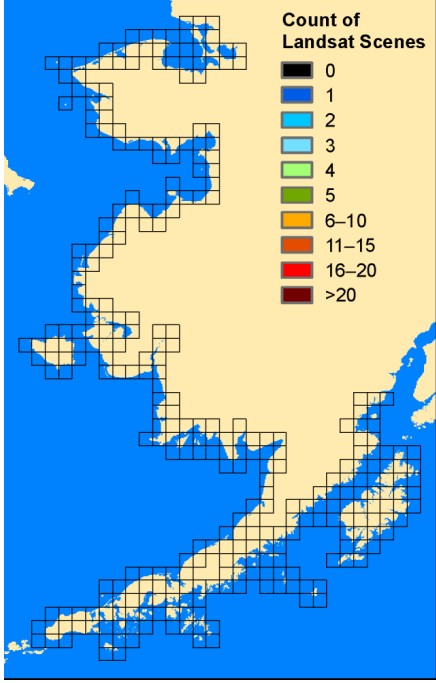


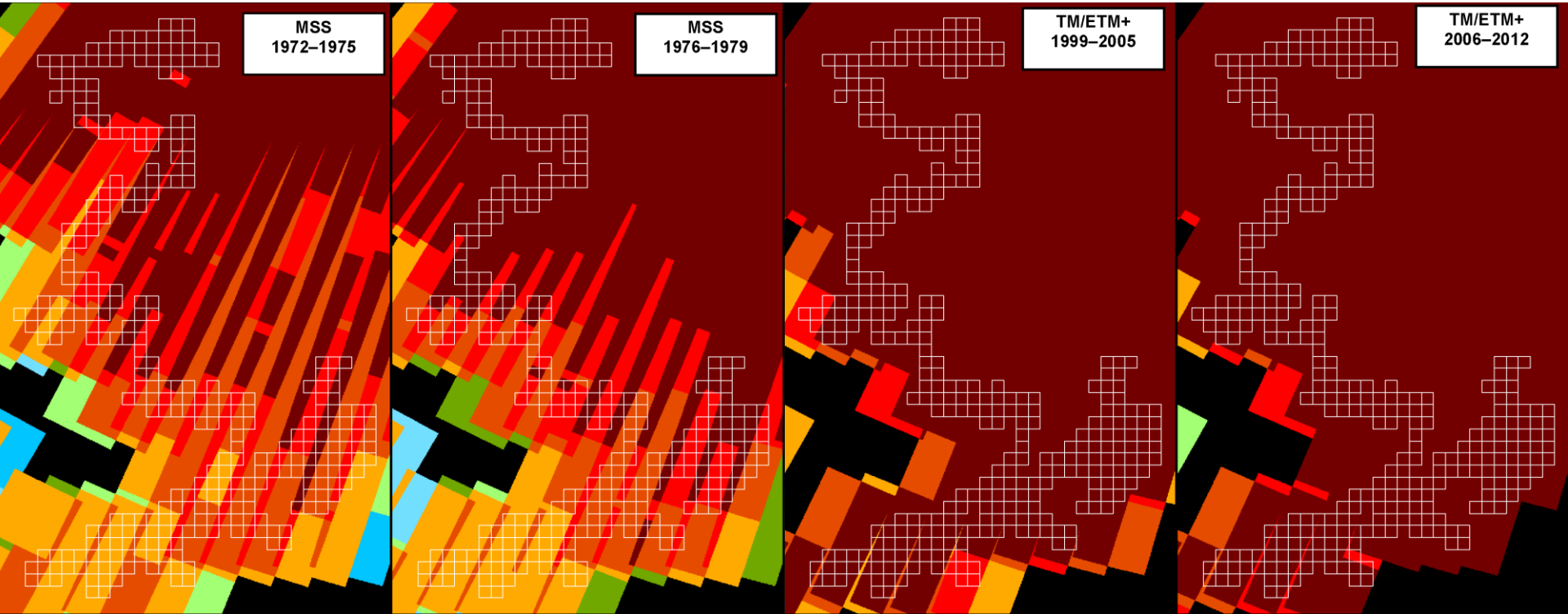
Landsat Time-Series

- Landsat Multispectral Scanner (MSS) extends record back to 1972
  - 60-m resolution
  - Fewer bands with somewhat different bandpasses
  - Noisy
- Aggressive acquisitions 1972–1984

Landsat Time-Series (July-September)

- MSS era combined with Landsat 7 era (1999-present) provides a dense time-series at the start and end of the study period.





Landsat Time-Series

- The middle (1985–1998) may be extremely sparse.
- Multiple years at the end points is critical to reduce effect of annual variability and noise.
- For much of the study area, MSS data effectively adds 27 years to the time-series.

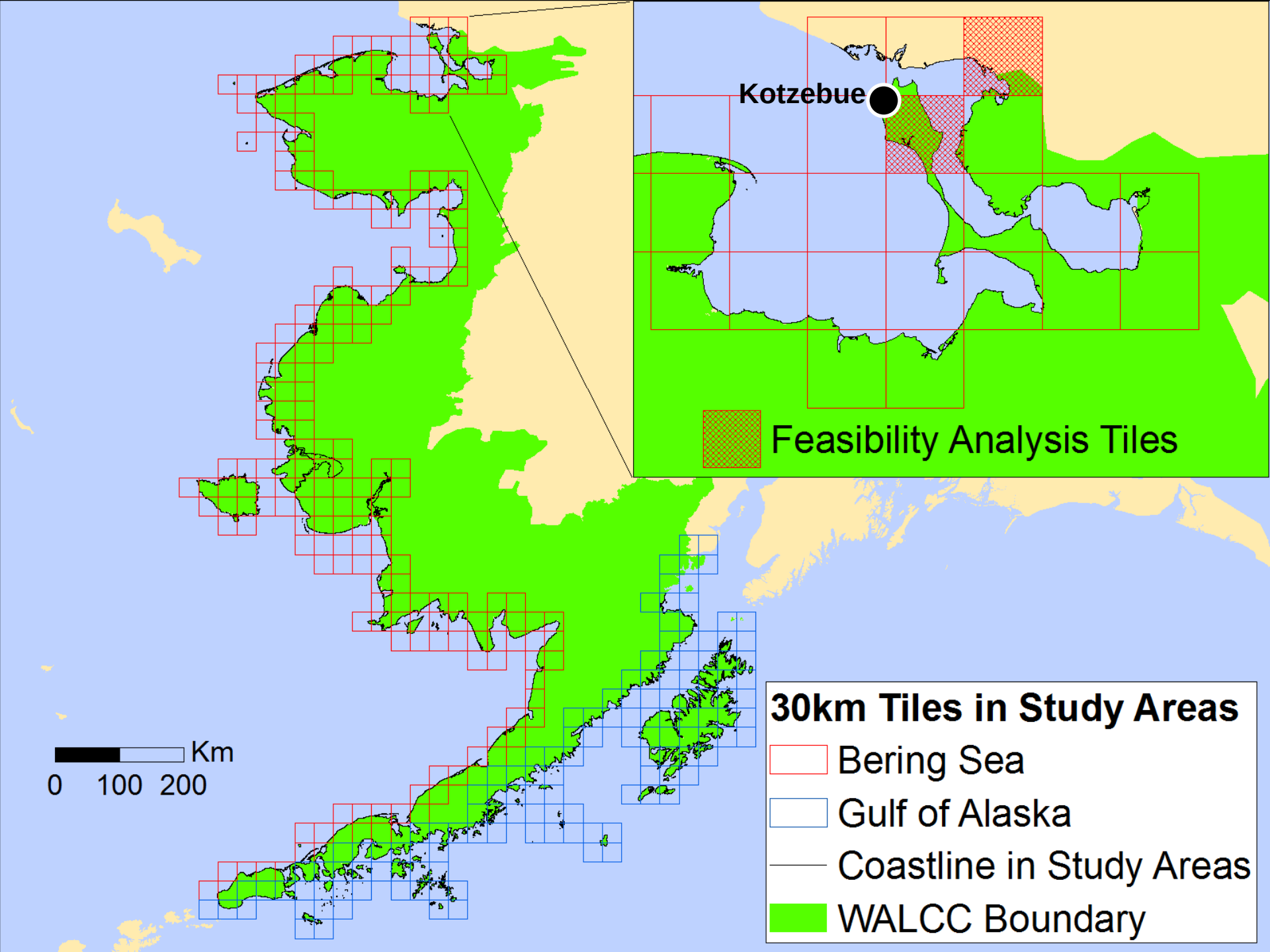

Kotzebue
Feasibility Analysis Tiles
Km
0 100 200
30km Tiles in Study Areas
Bering Sea
Gulf of Alaska
Coastline in Study Areas
WALCC Boundary

Image Acquisition & Preprocessing

- Entire WALCC coastline
  - 22,000 km of coastline
  - ~75 Landsat path/rows
  - 17,000+ Landsat scenes

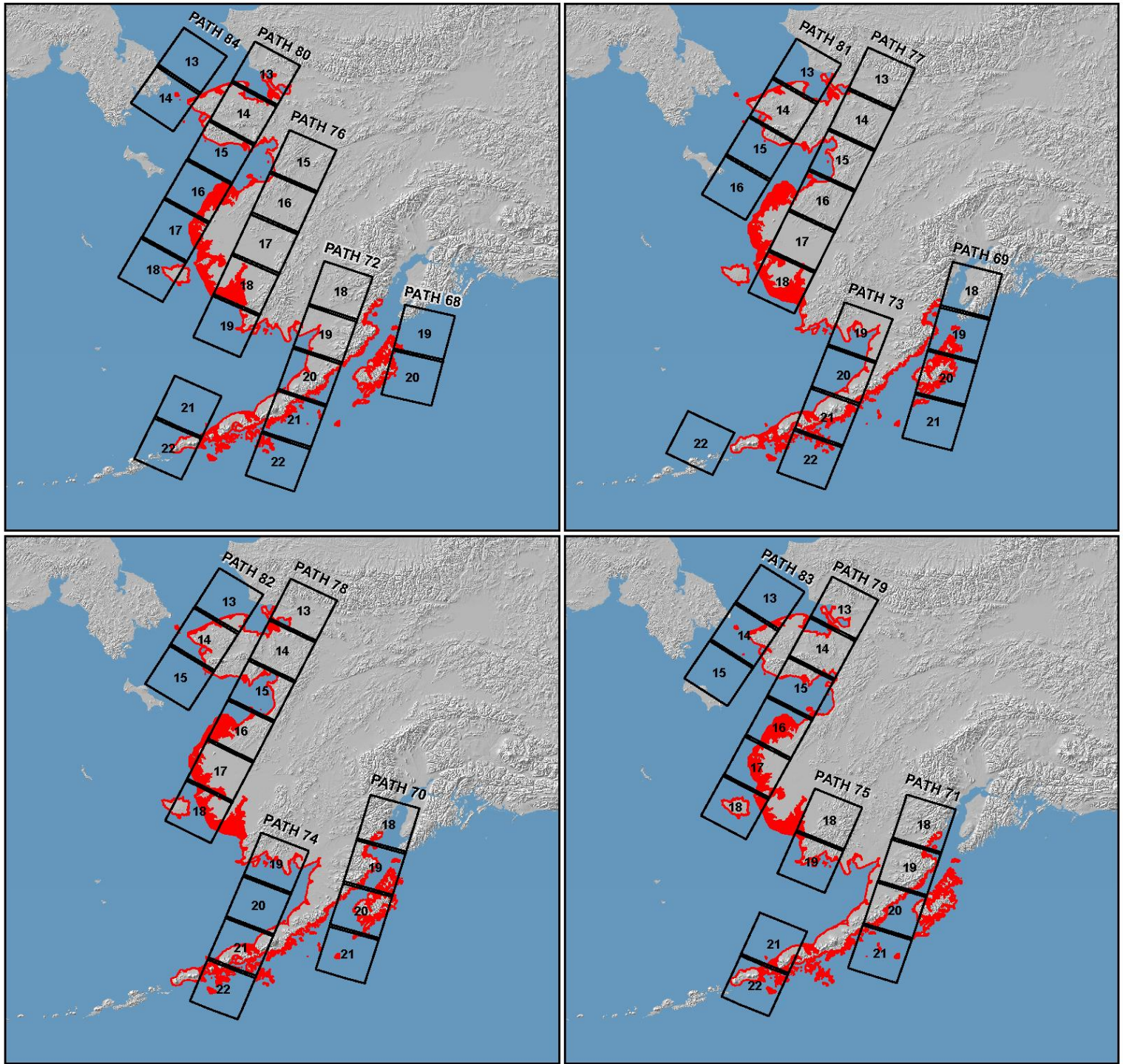

PATH 84
PATH 80
PATH 76
PATH 72
PATH 68
PATH 81
PATH 77
PATH 73
PATH 69
PATH 82
PATH 78
PATH 74
PATH 70
PATH 83
PATH 79
PATH 75
PATH 71

Image Acquisition & Preprocessing

- Calibrated to Top-of-Atmosphere Reflectance
- Reprojected and Tiled to 30km tiles (500 x 500 pixels at 60 m resolution)
  - Cubic convolution resampling
  - 30 m data aggragated to 60 m after reprojection

Image Acquisition & Preprocessing

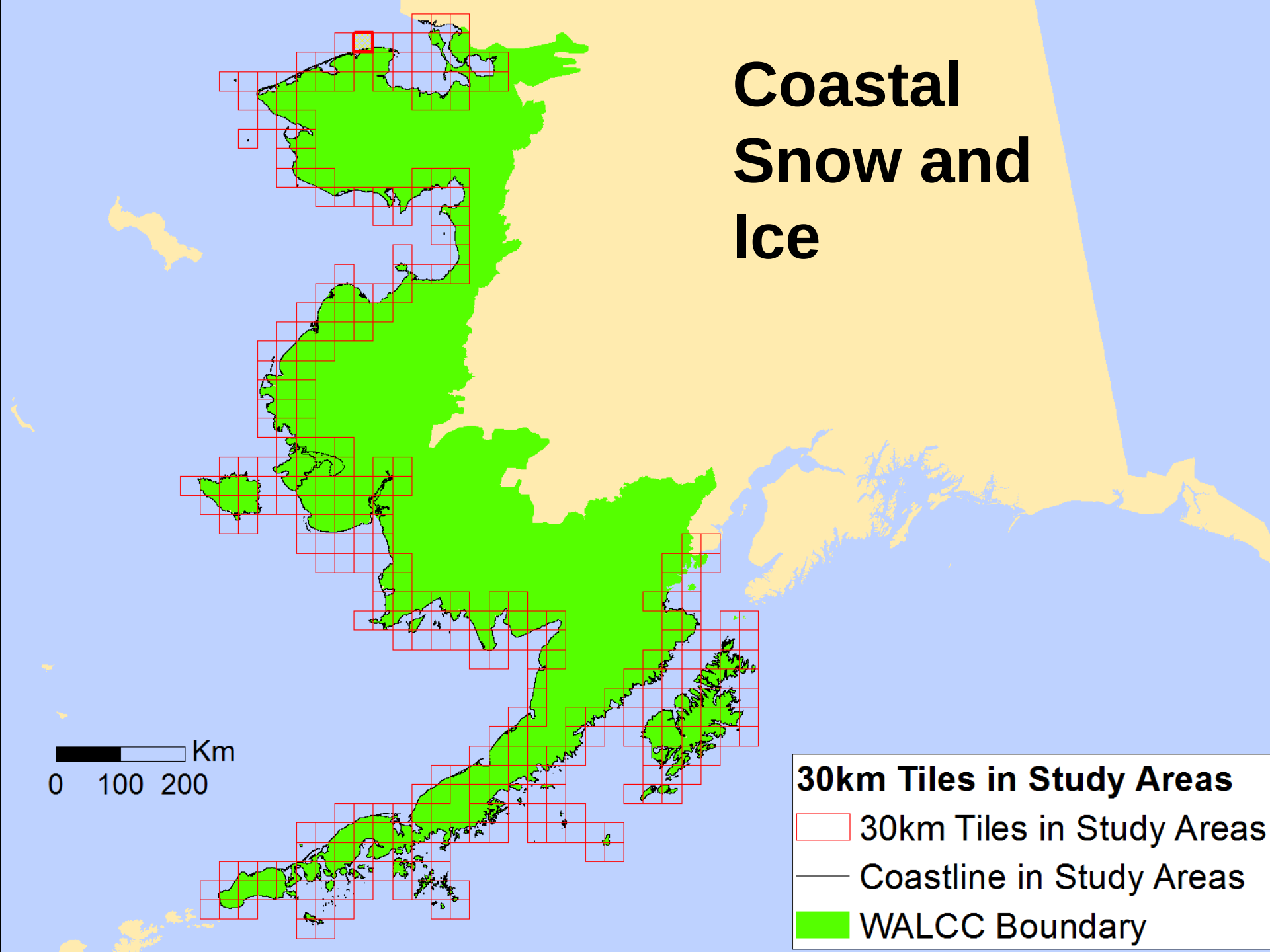
- Review and clean-up of data to exclude bad data:
  - Clouds
  - Cloud Shadows
  - Snow and Ice
  - Sensor artifacts
  - Surf

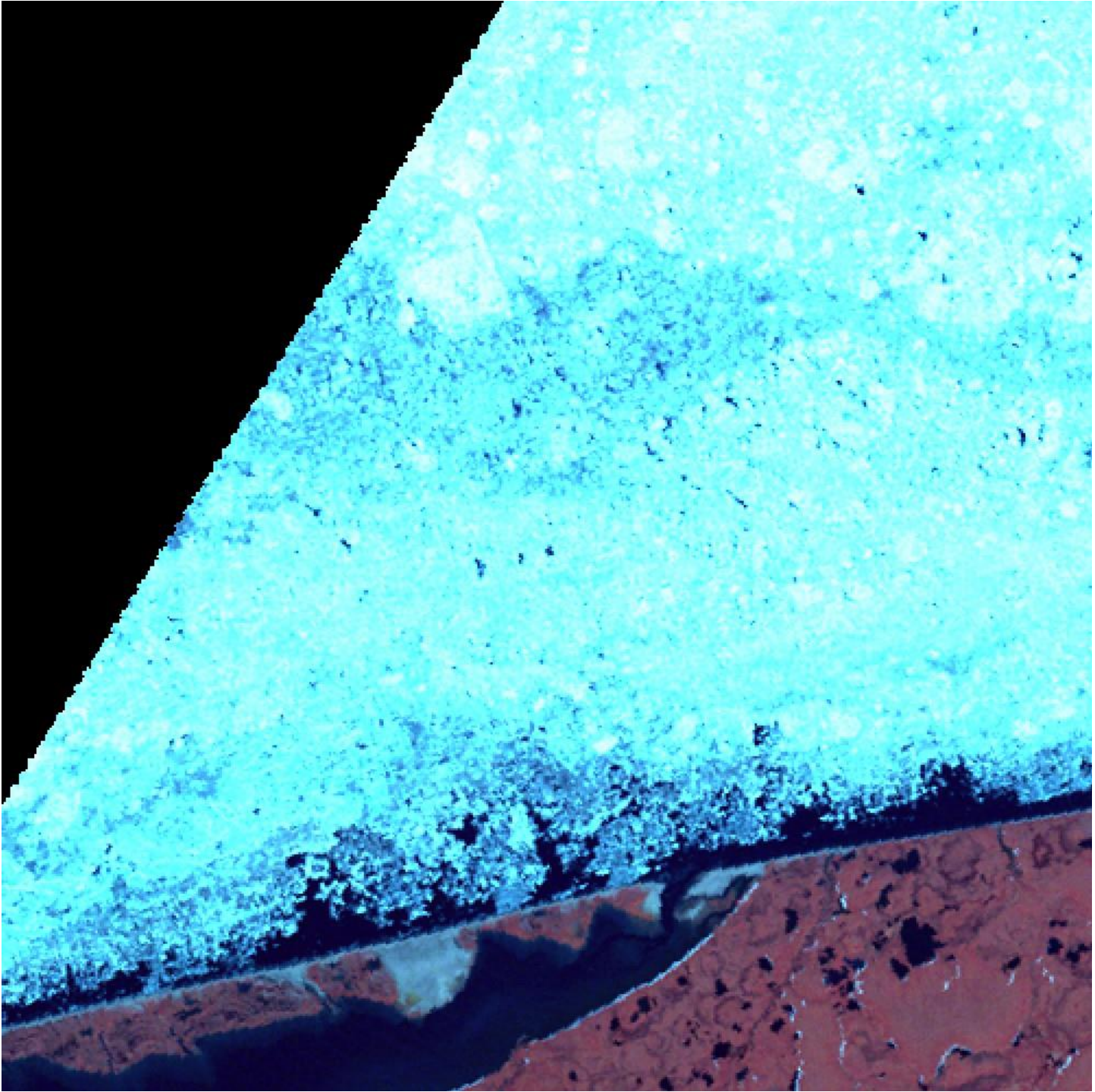
Image Review and Clean-up

- Computer algorithms to identify clouds and cloud shadows almost never identify all “contaminated” data
- Algorithms may perform especially poorly in the Arctic
  - Low sun angle
  - Abundant waterbodies
  - Persistent ice and snow
- Short growing season limits success of automated compositing techniques

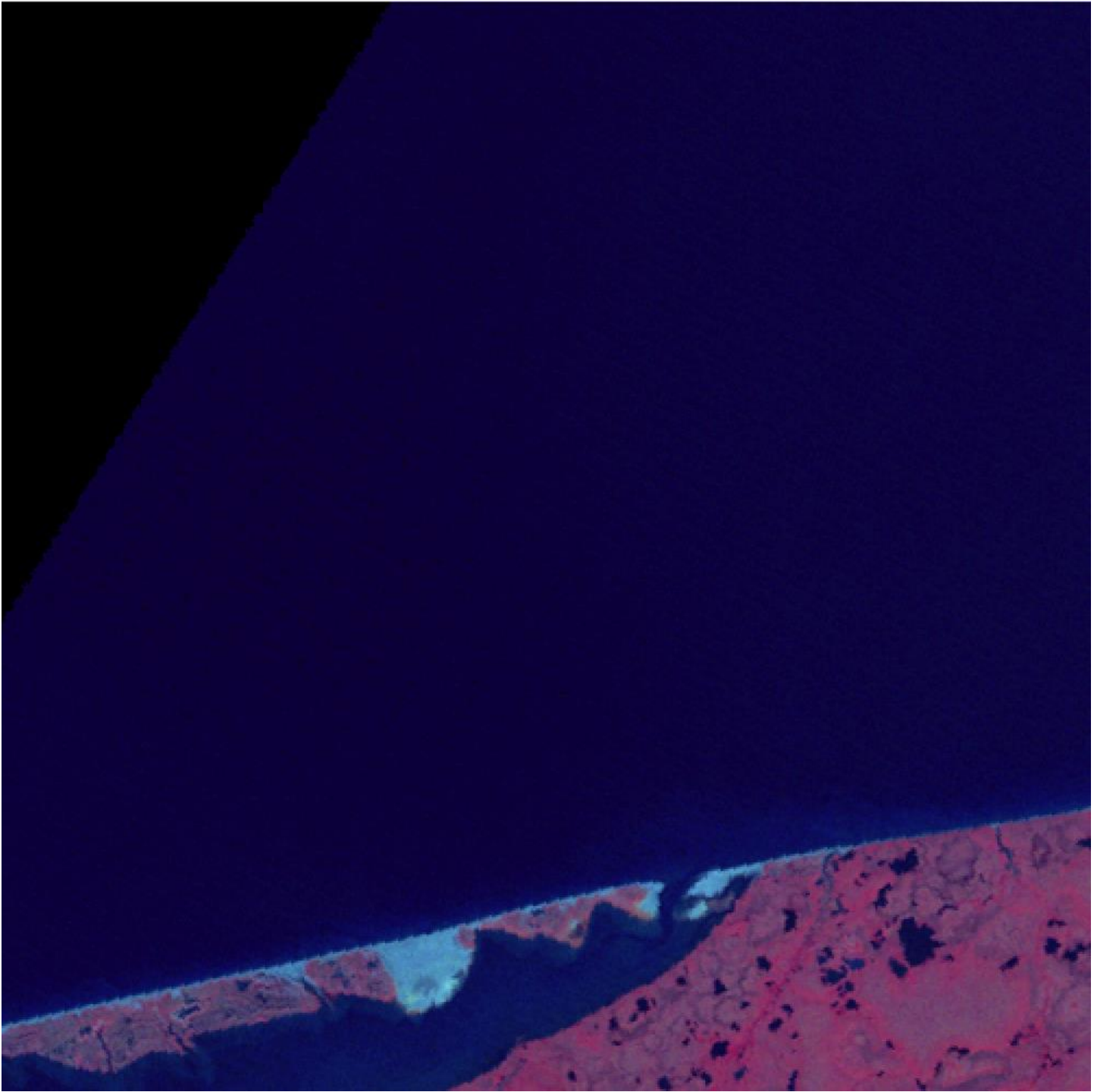
Image Review and Clean-up

- The automated change detection method depends on clean data
  - Susceptible to spurious results if contamination creeps in
- Manual review to identify clean scene “tiles”
- Limited manual digitizing of cloud/shadow/other contamination issues

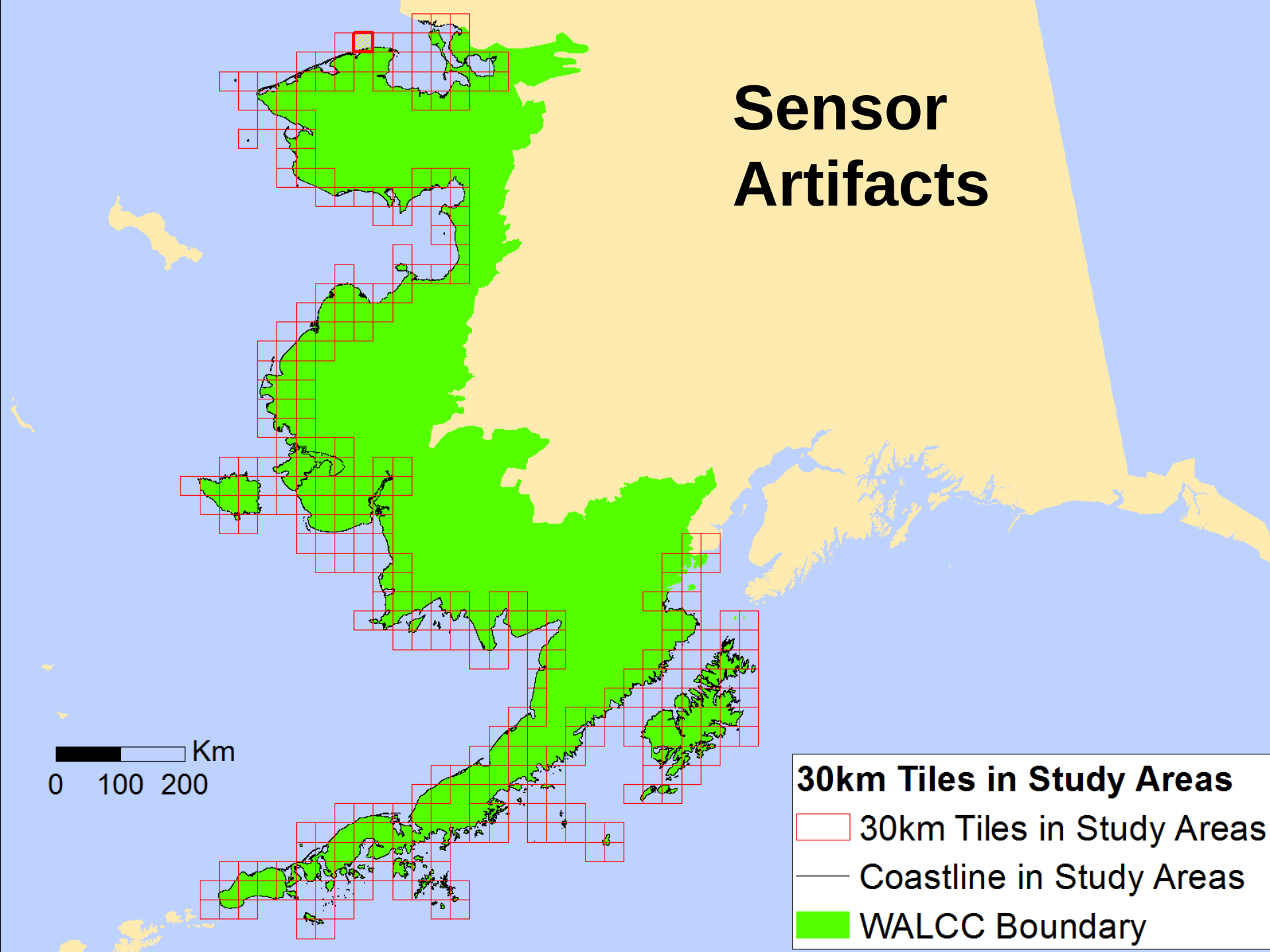

Coastal Snow and Ice
Km
0 100 200
30km Tiles in Study Areas
30km Tiles in Study Areas
Coastline in Study Areas
WALCC Boundary

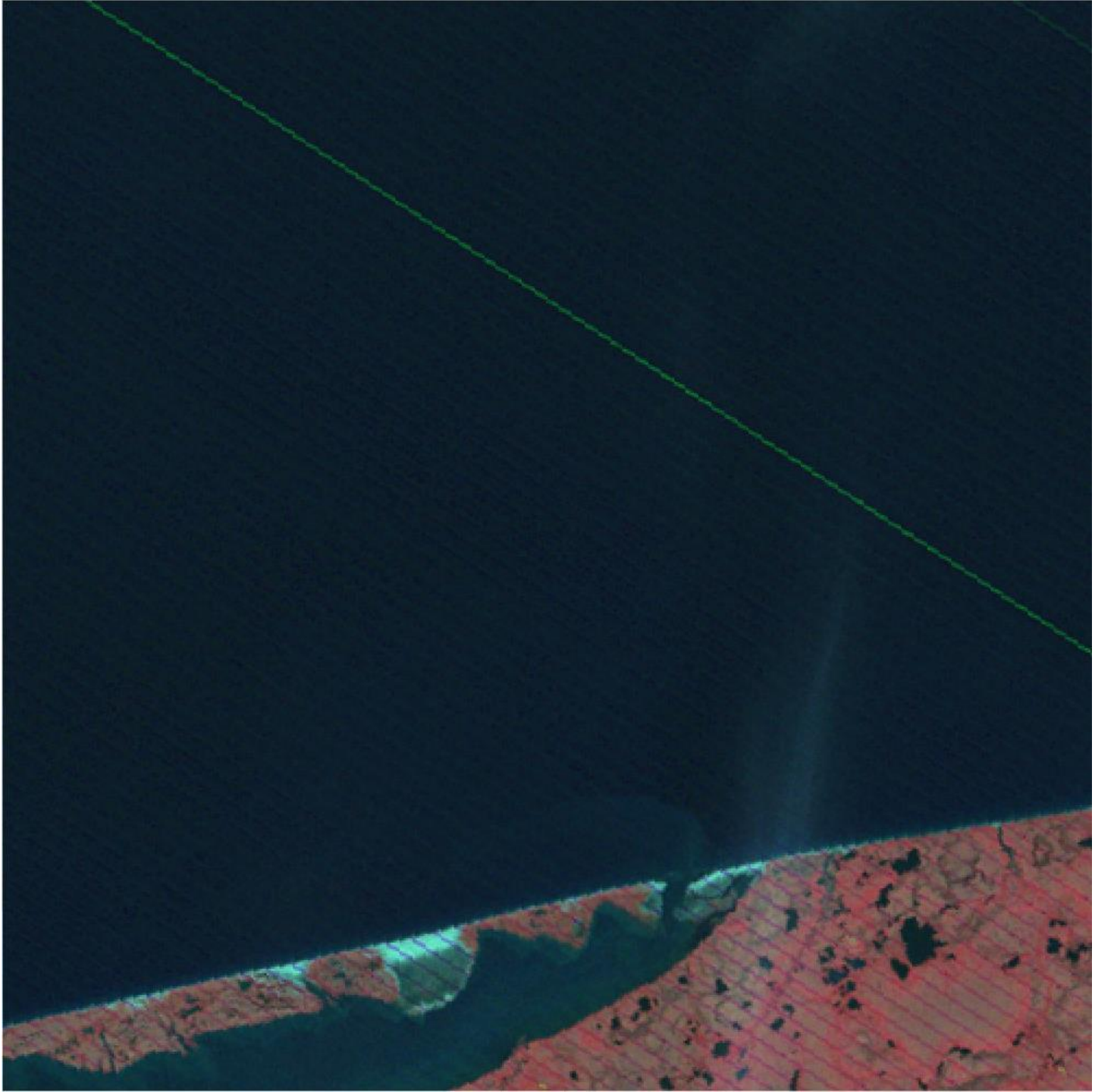


1977-06-25

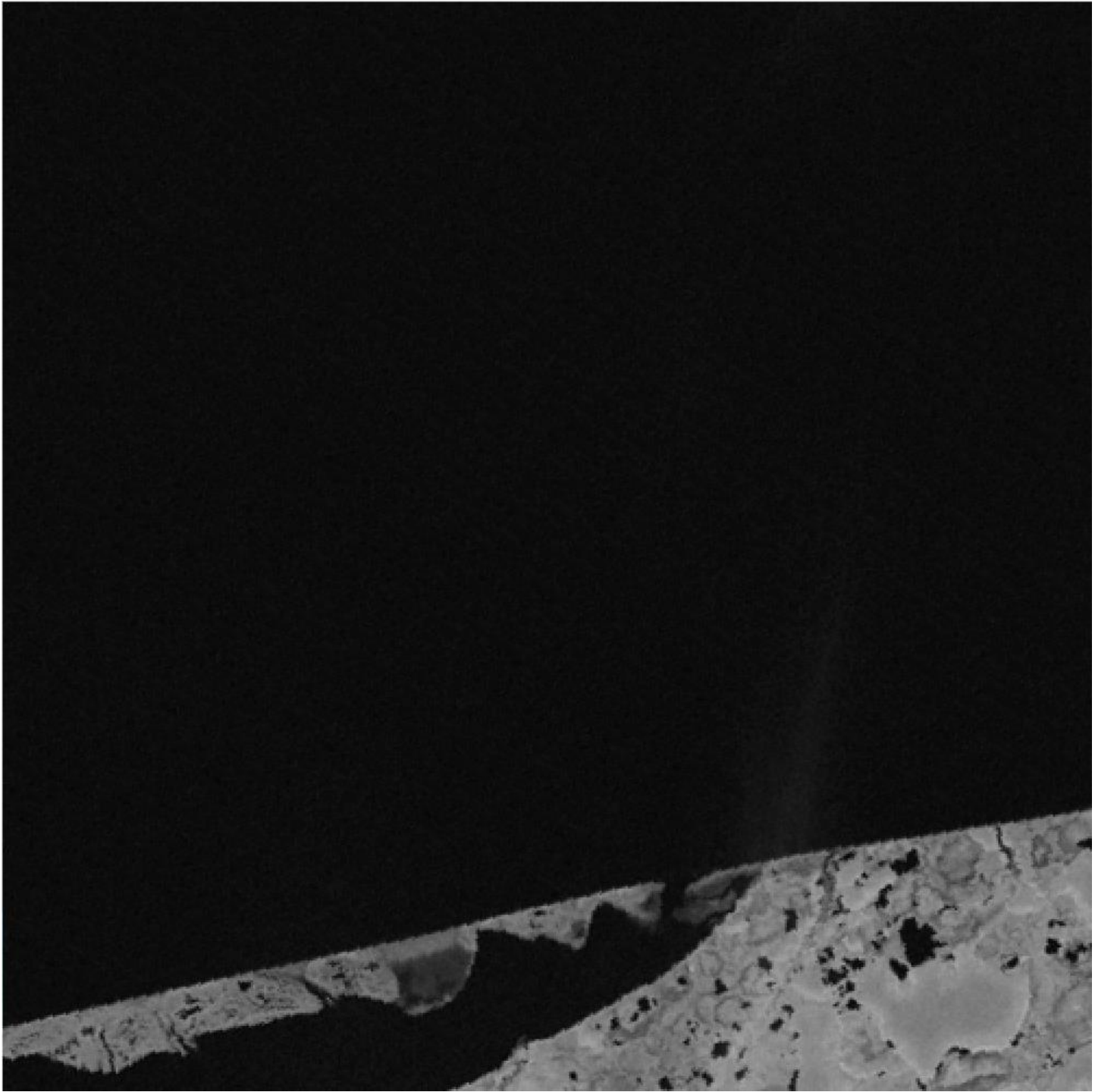


1977-07-31

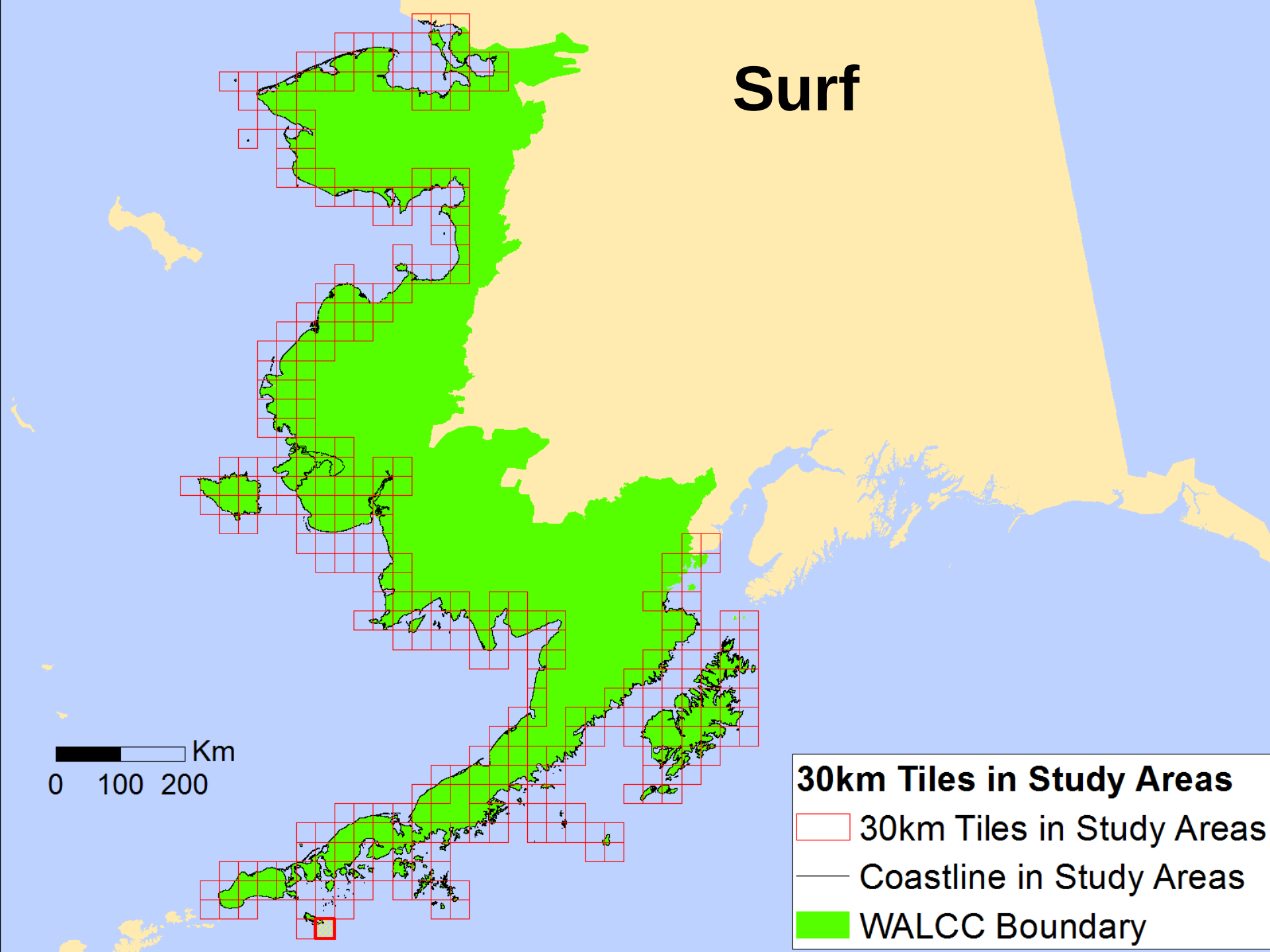

Sensor Artifacts
Km
0 100 200
30km Tiles in Study Areas
30km Tiles in Study Areas
Coastline in Study Areas
WALCC Boundary



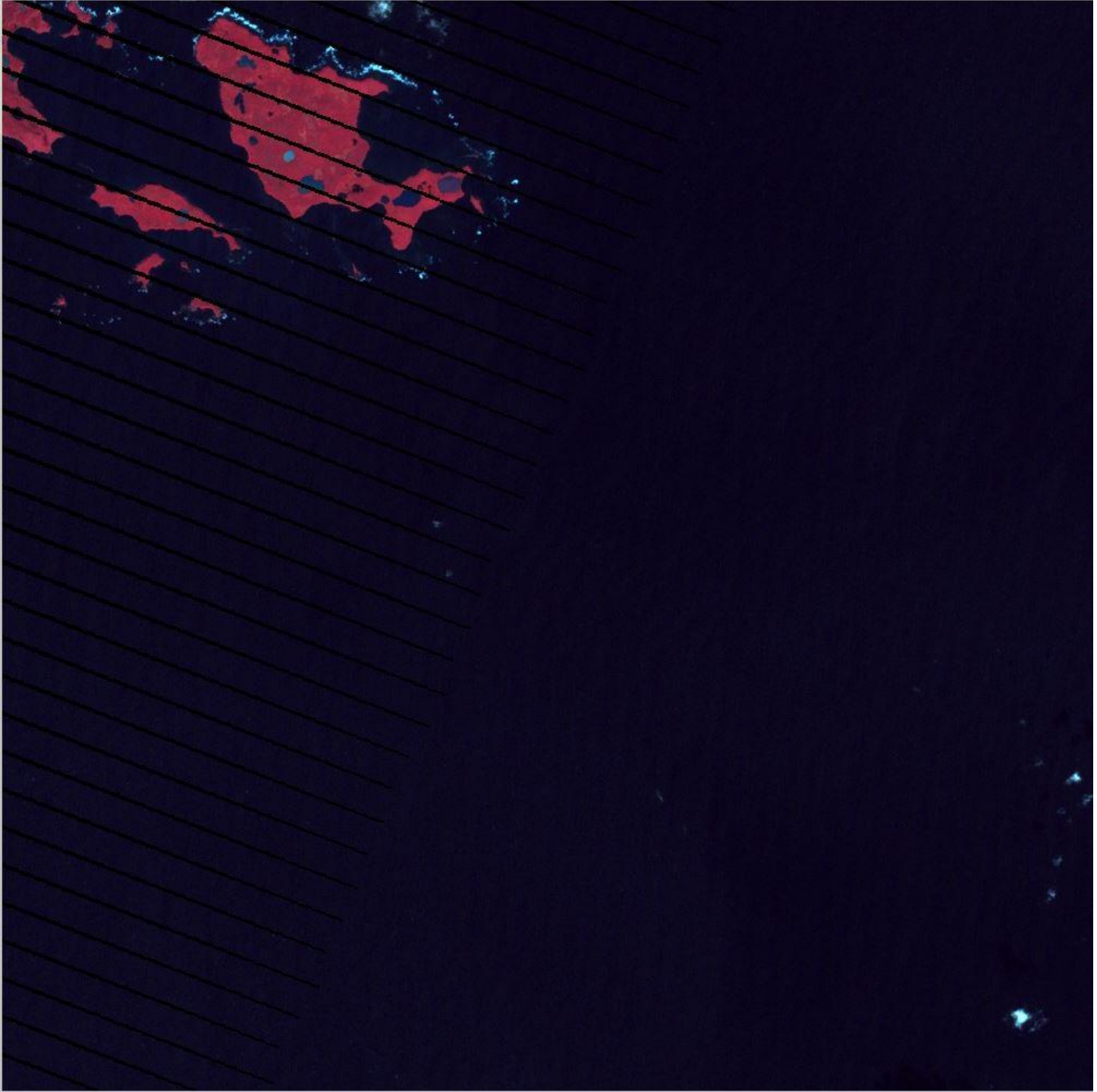
1972-08-01



1972-08-01
MSS Band 4


Surf
Km
0 100 200
30km Tiles in Study Areas
30km Tiles in Study Areas
Coastline in Study Areas
WALCC Boundary

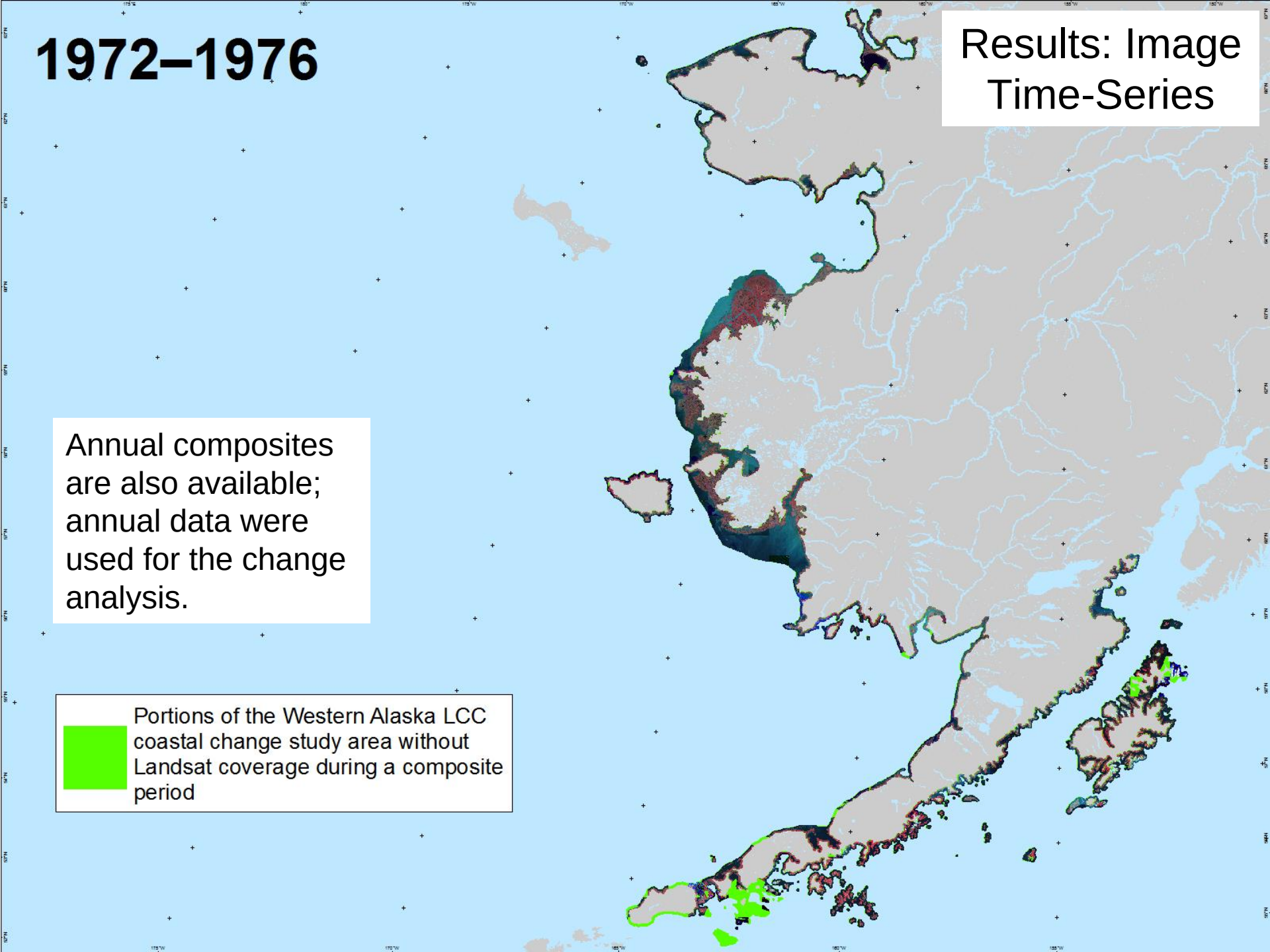
2011-07-02



2010-09-25

1972–1976

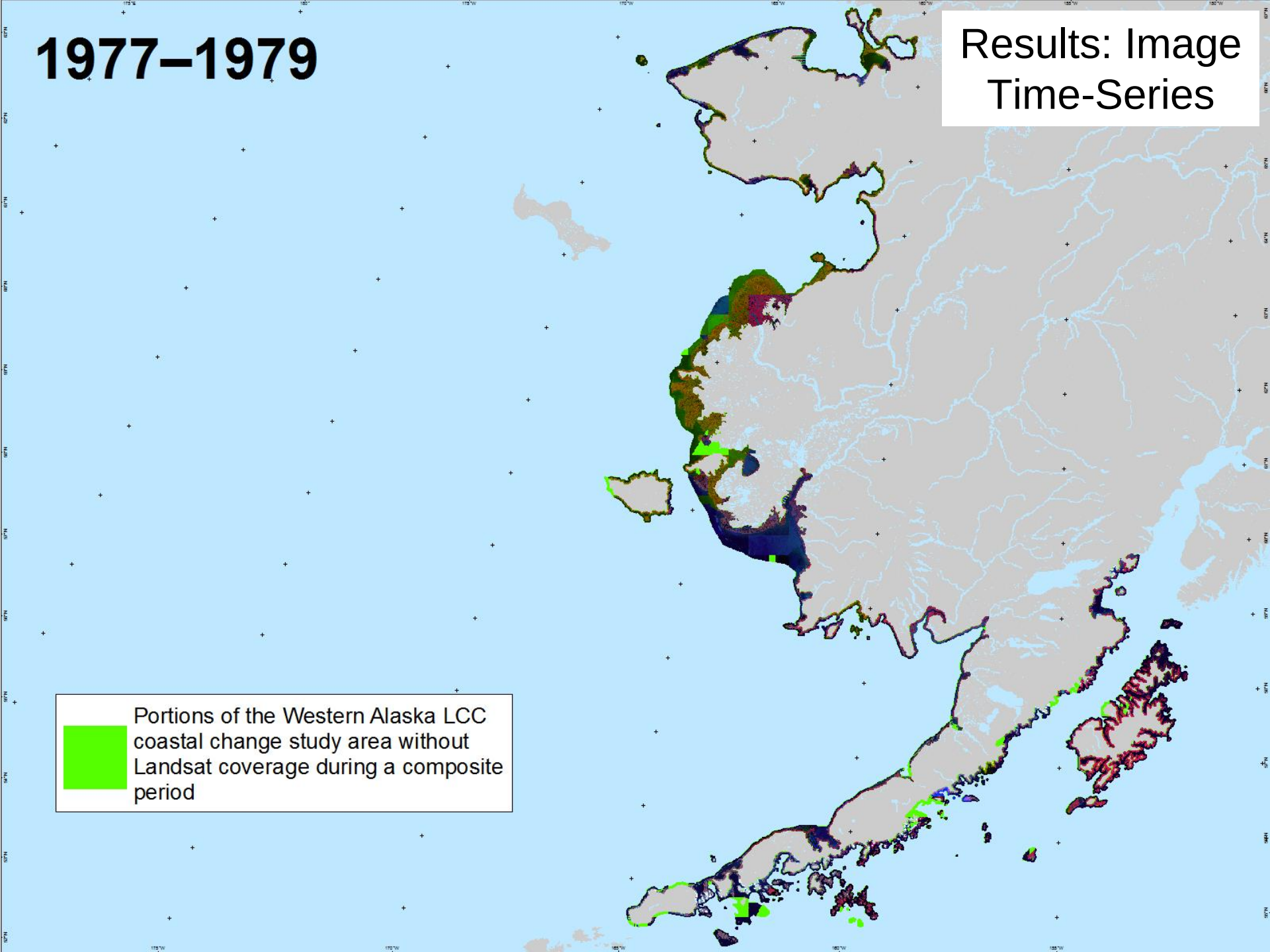
Results: Image Time-Series



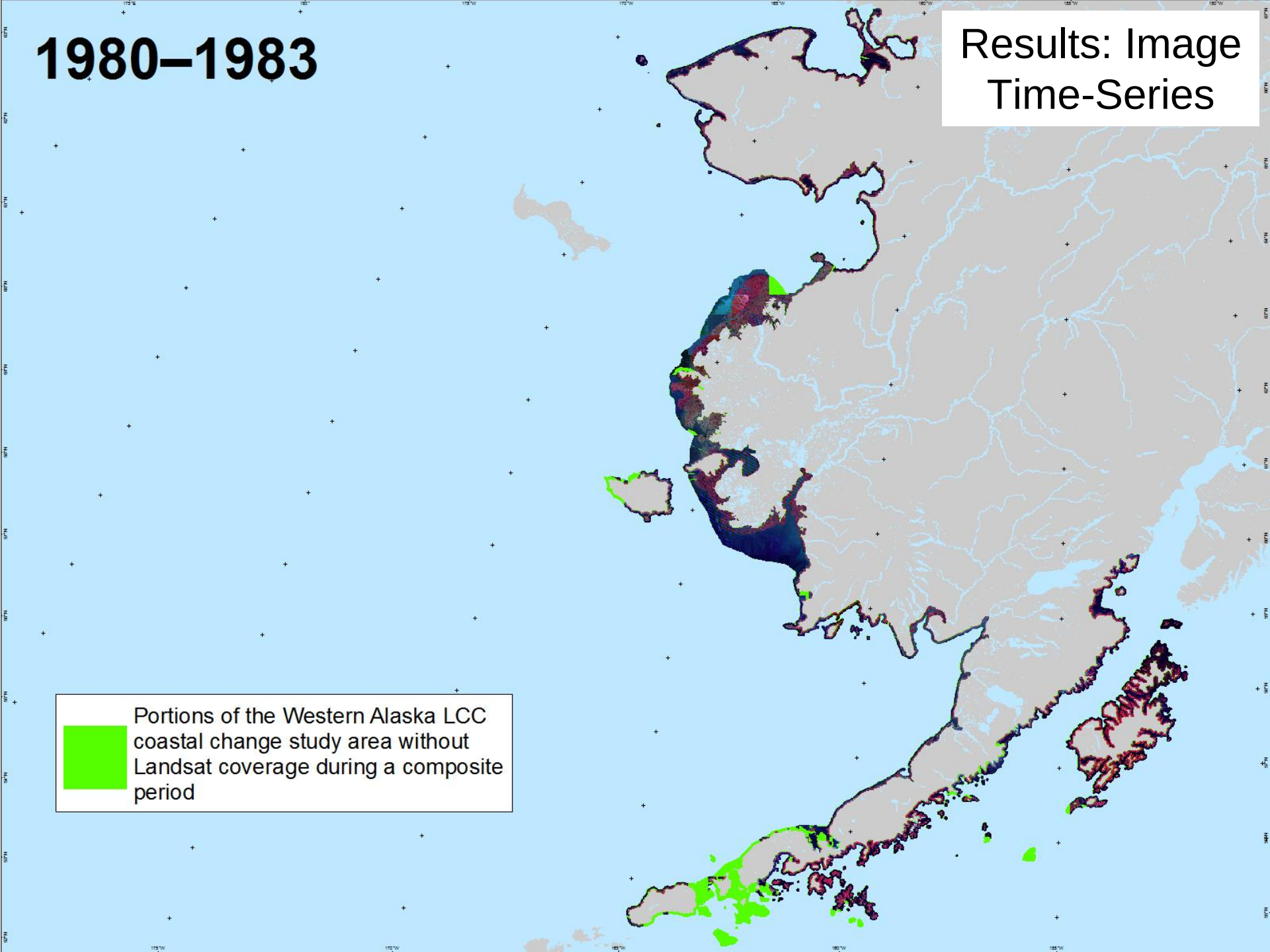
Annual composites are also available; annual data were used for the change analysis.

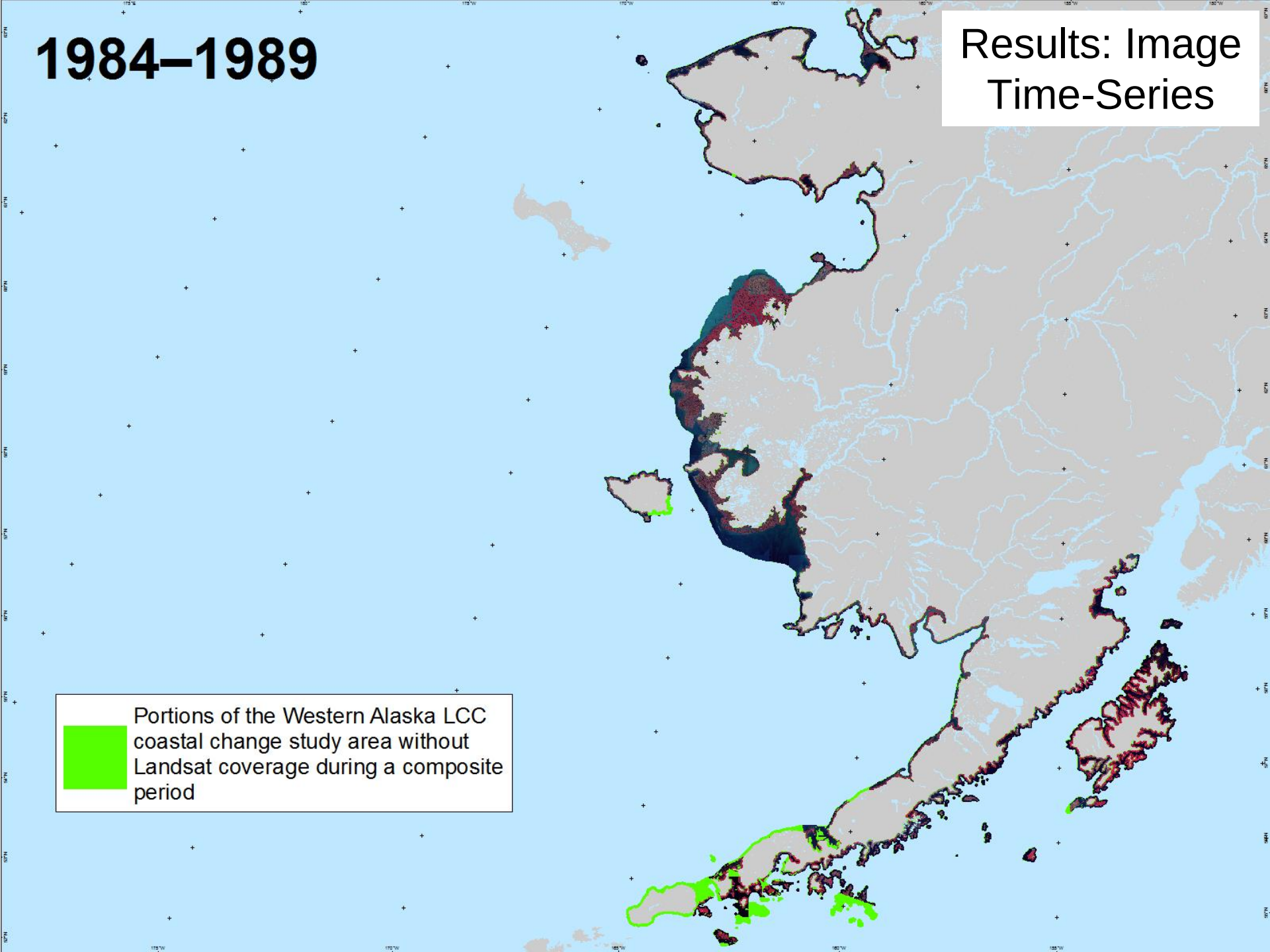
Portions of the Western Alaska LCC coastal change study area without Landsat coverage during a composite period

Results: Image Time-Series



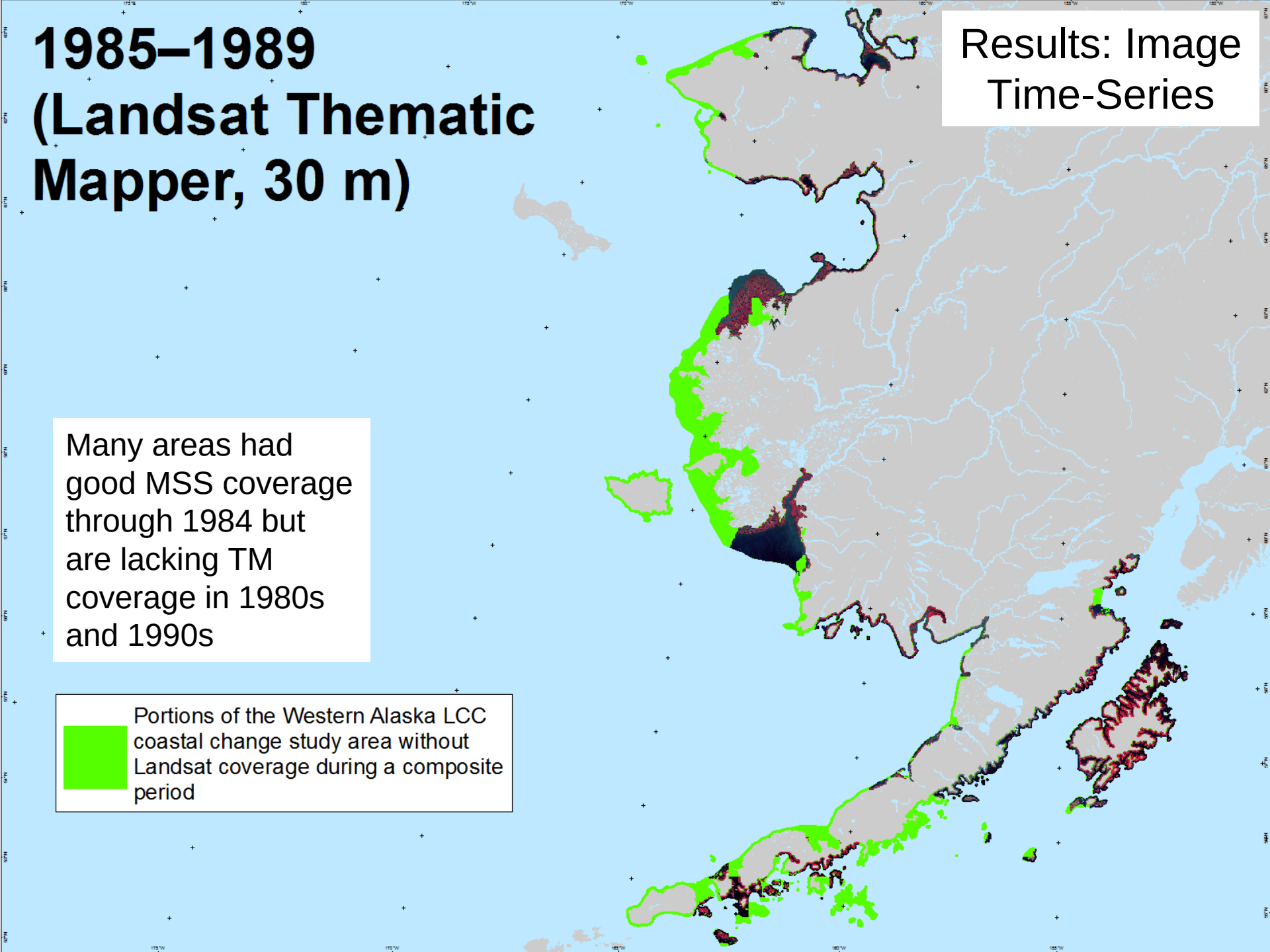
Results: Image Time-Series




1984–1989
Results: Image Time-Series
Portions of the Western Alaska LCC coastal change study area without Landsat coverage during a composite period

1985–1989 (Landsat Thematic Mapper, 30 m)

Results: Image Time-Series



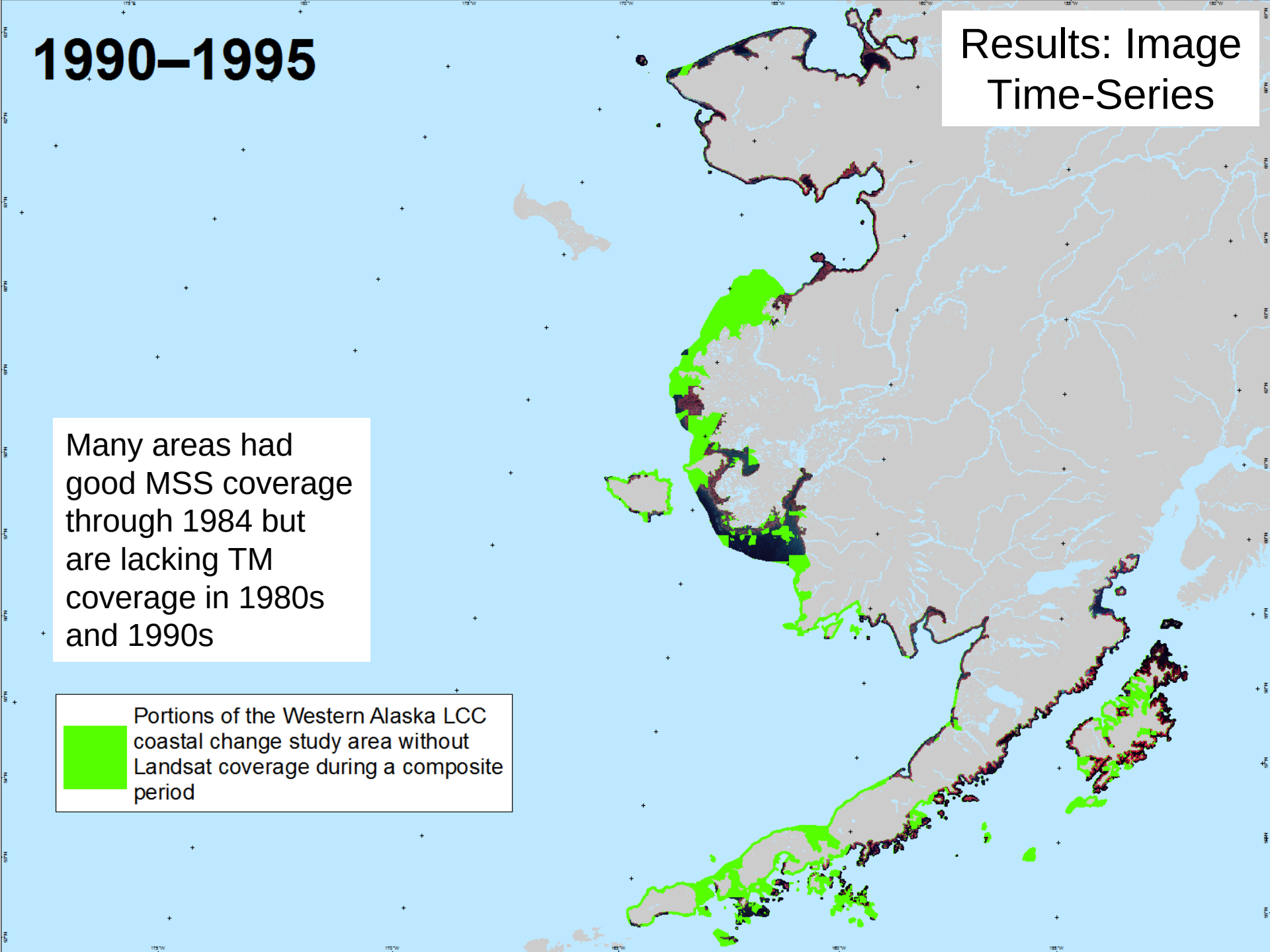
Many areas had good MSS coverage through 1984 but are lacking TM coverage in 1980s and 1990s

Portions of the Western Alaska LCC coastal change study area without Landsat coverage during a composite period

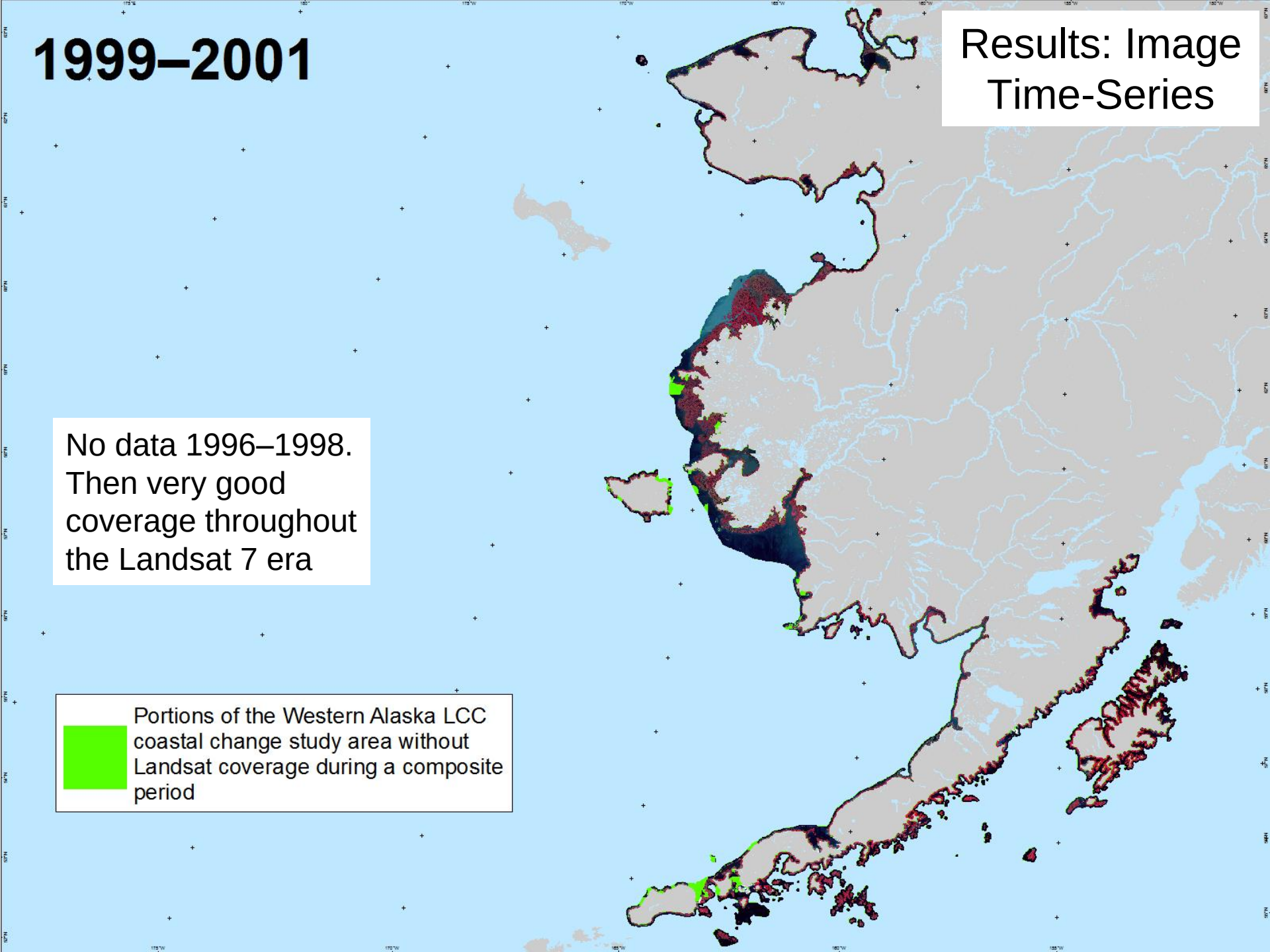
1990–1995

Results: Image Time-Series

Many areas had good MSS coverage through 1984 but are lacking TM coverage in 1980s and 1990s

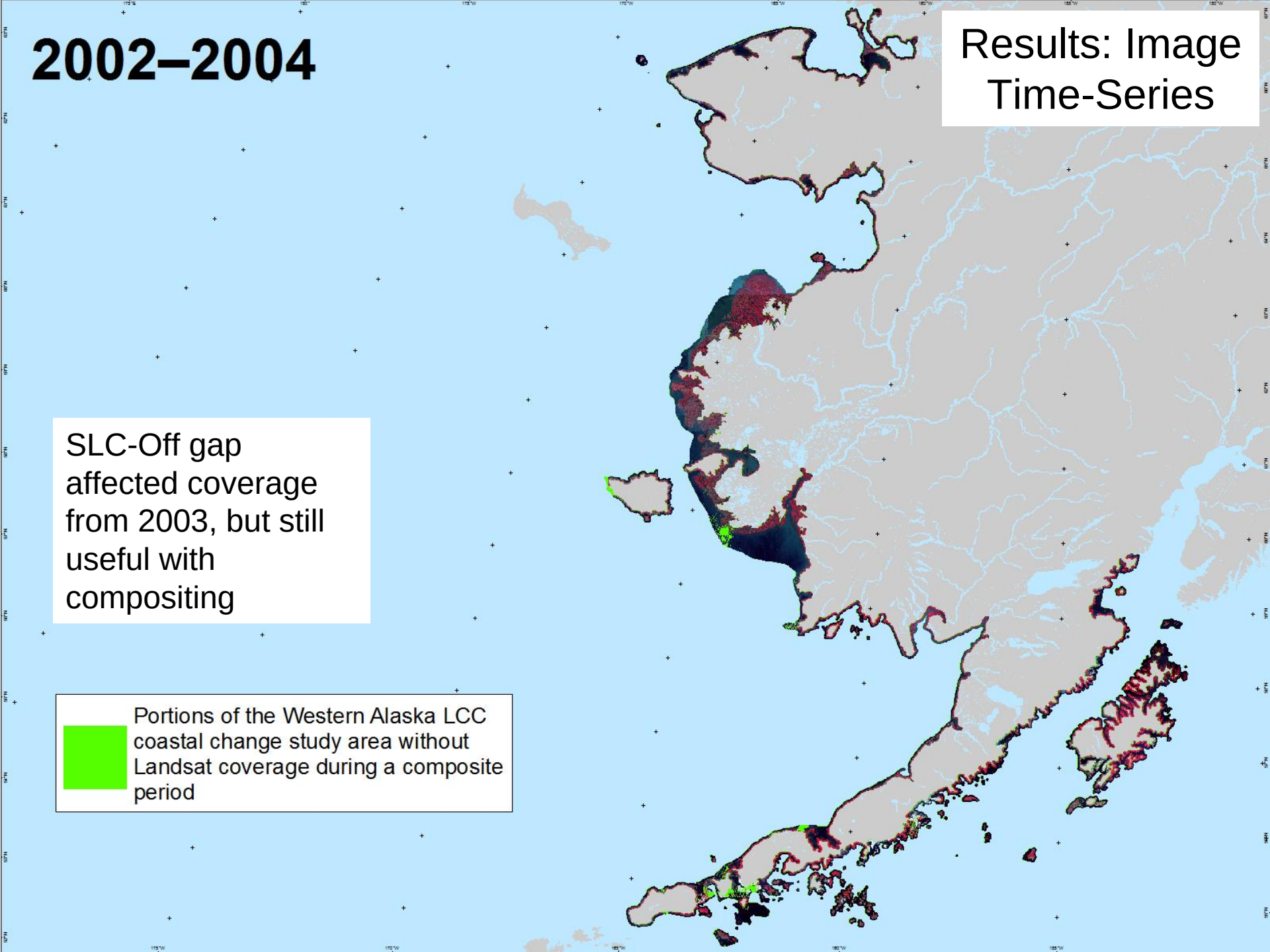


Results: Image Time-Series



2002–2004

Results: Image Time-Series

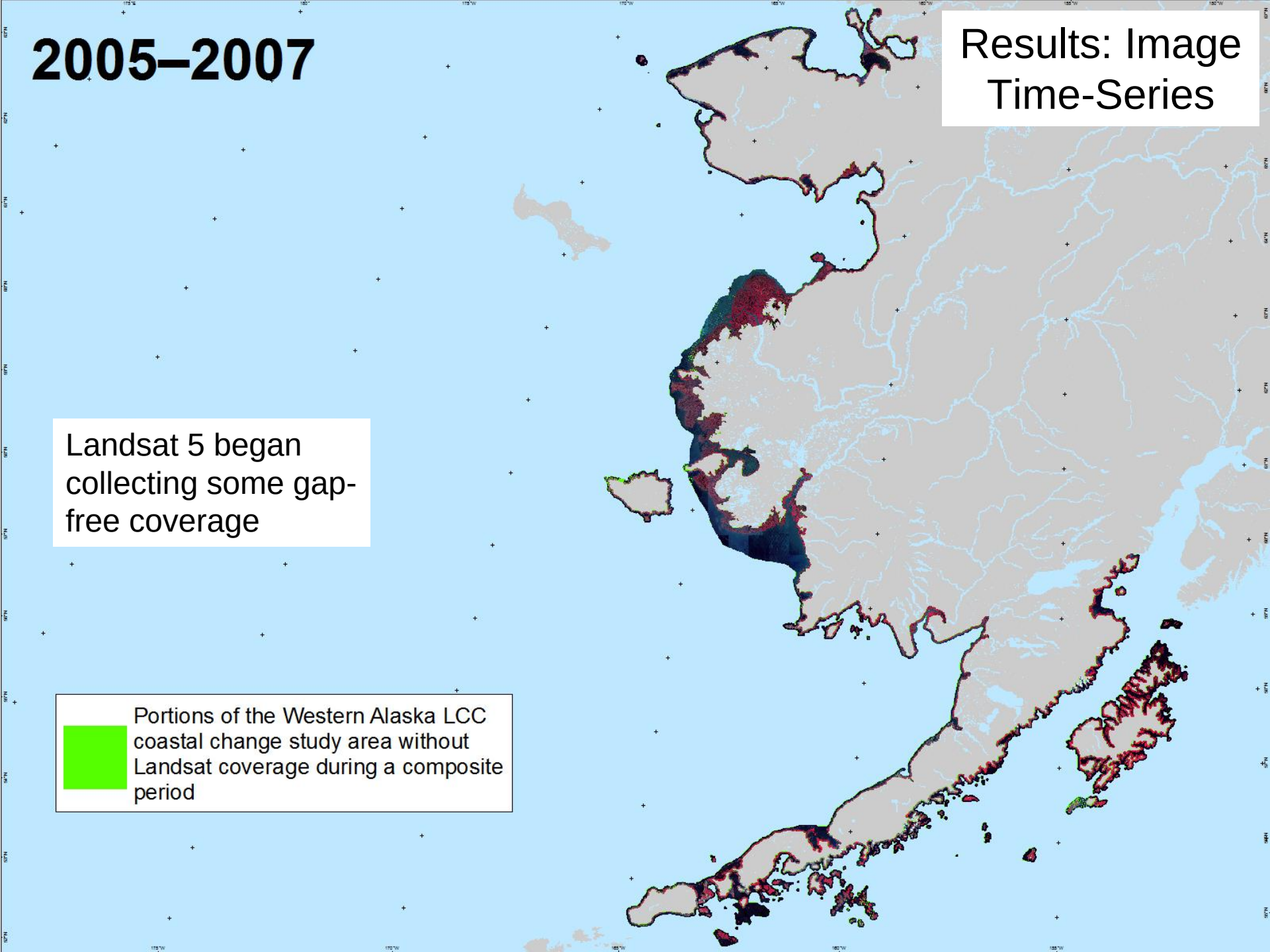


SLC-Off gap affected coverage from 2003, but still useful with compositing

Portions of the Western Alaska LCC coastal change study area without Landsat coverage during a composite period

2005–2007

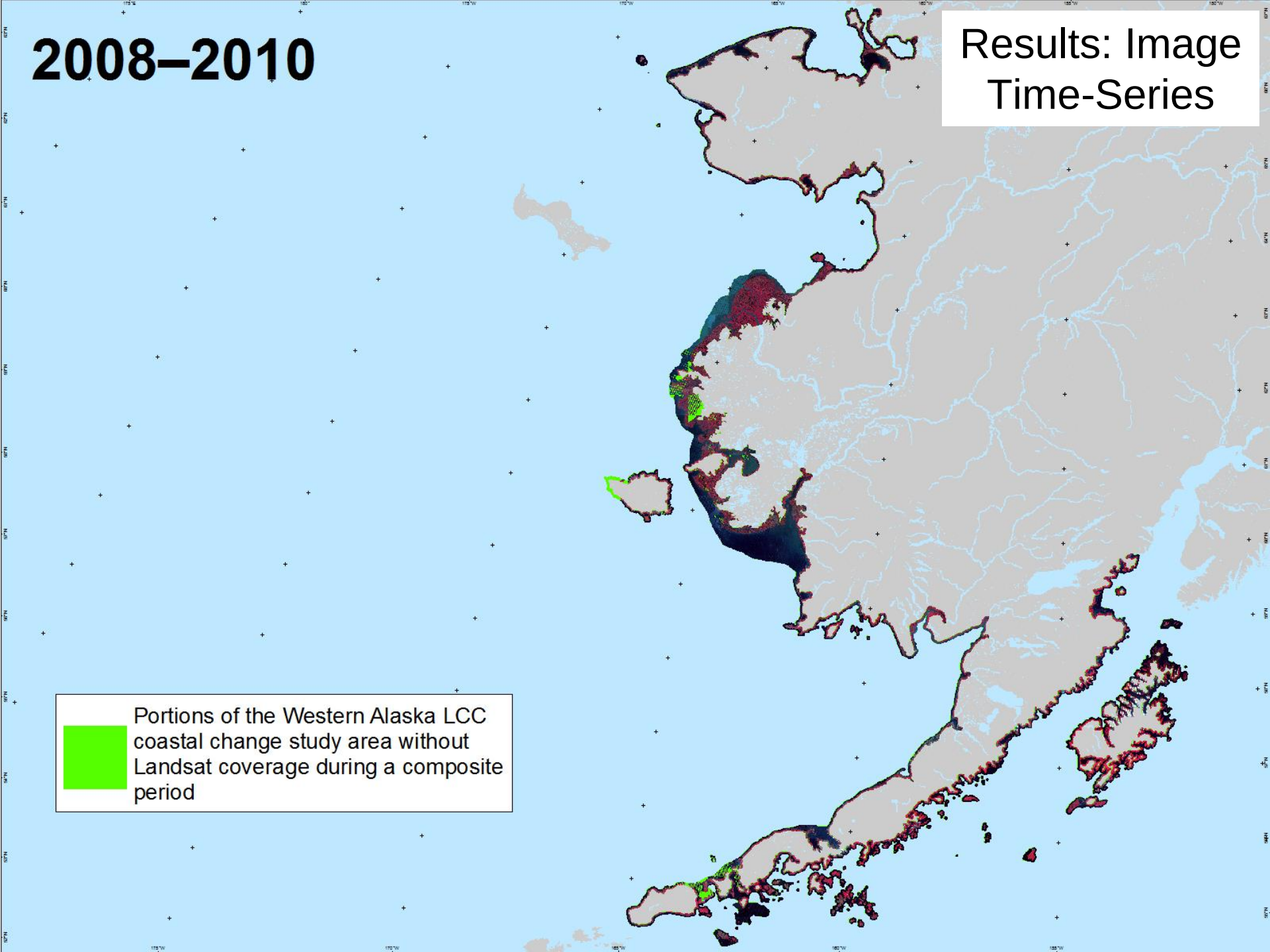
Results: Image Time-Series



Landsat 5 began collecting some gap-free coverage

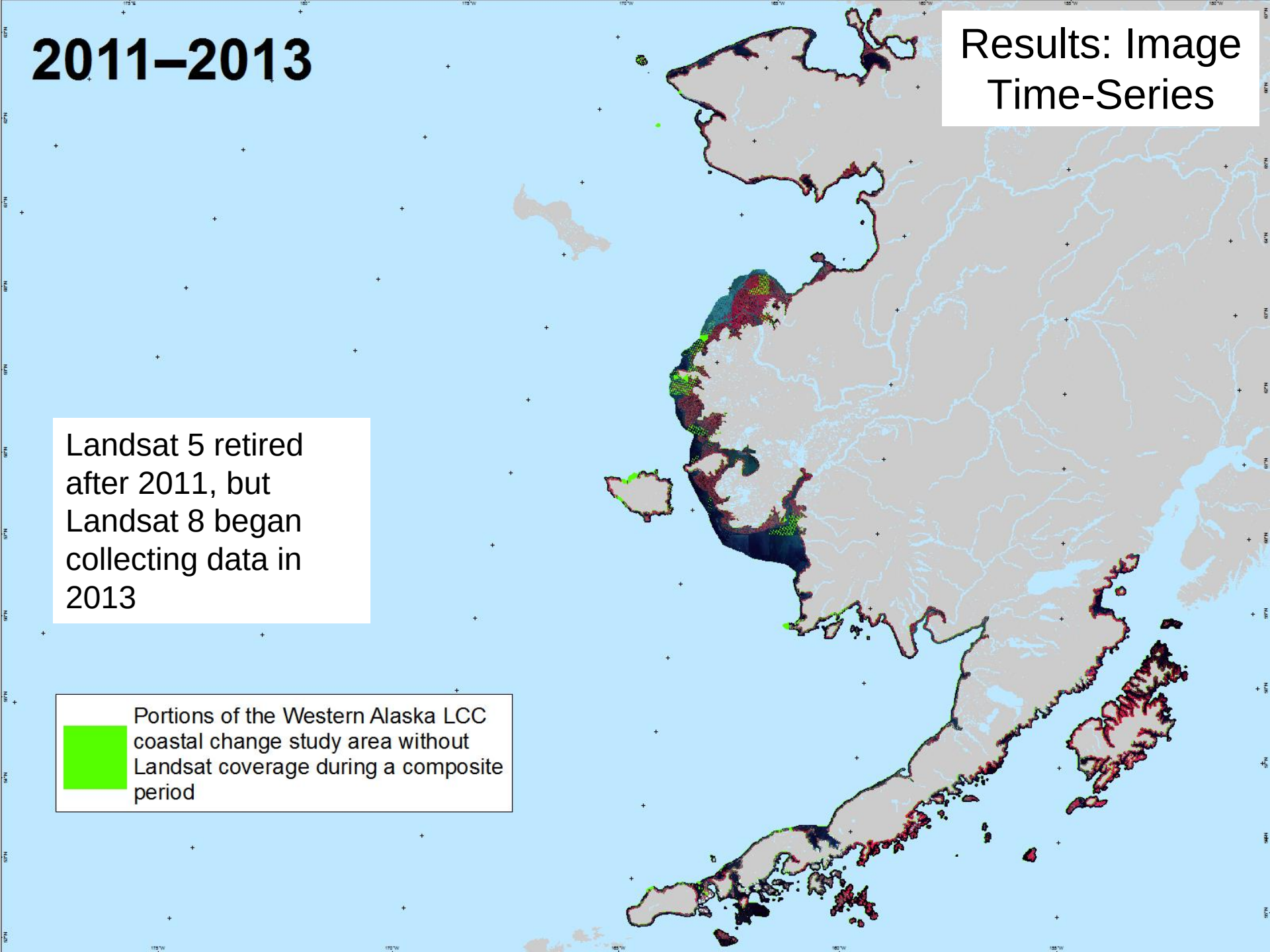
Portions of the Western Alaska LCC coastal change study area without Landsat coverage during a composite period

Results: Image Time-Series



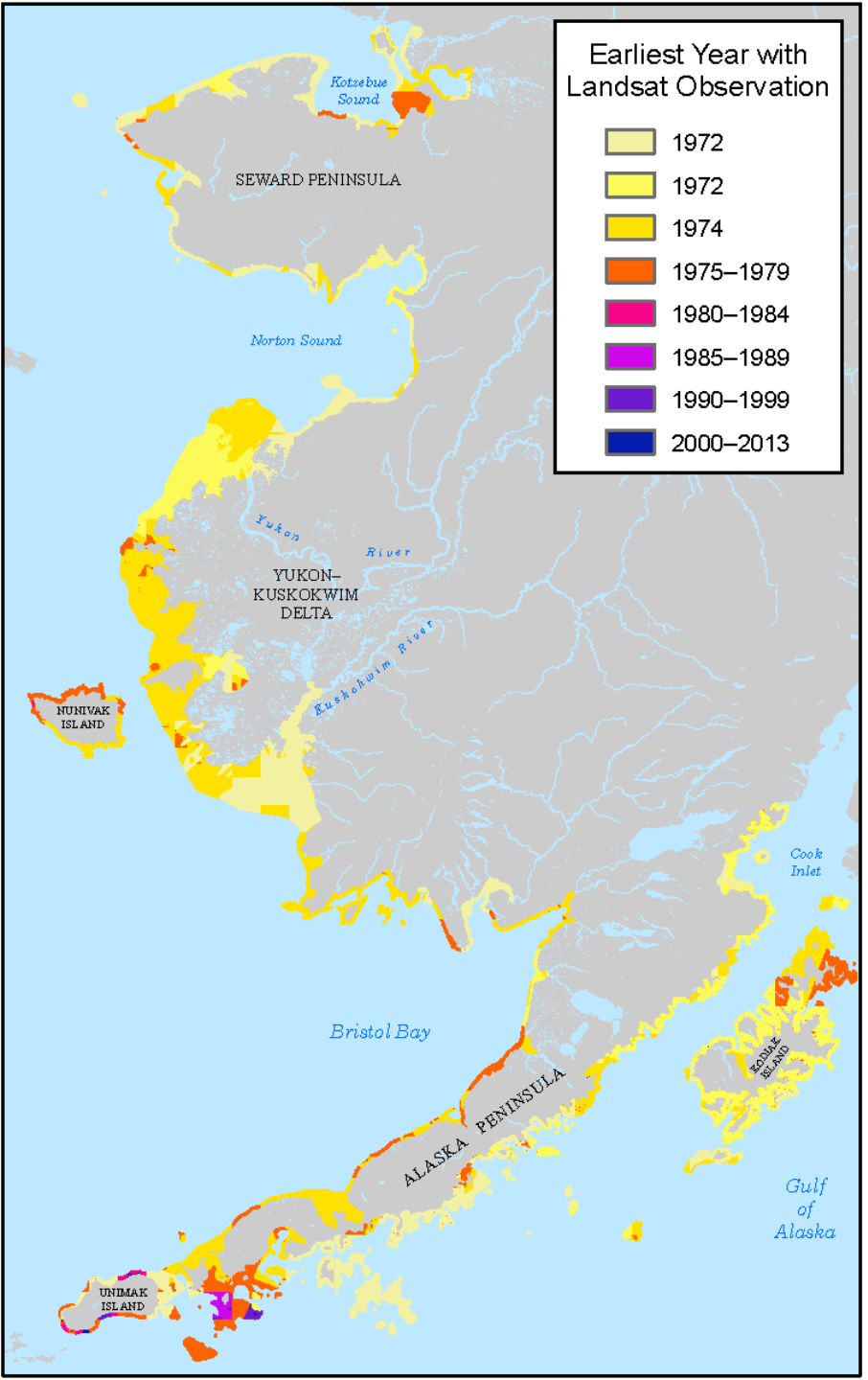
2011–2013

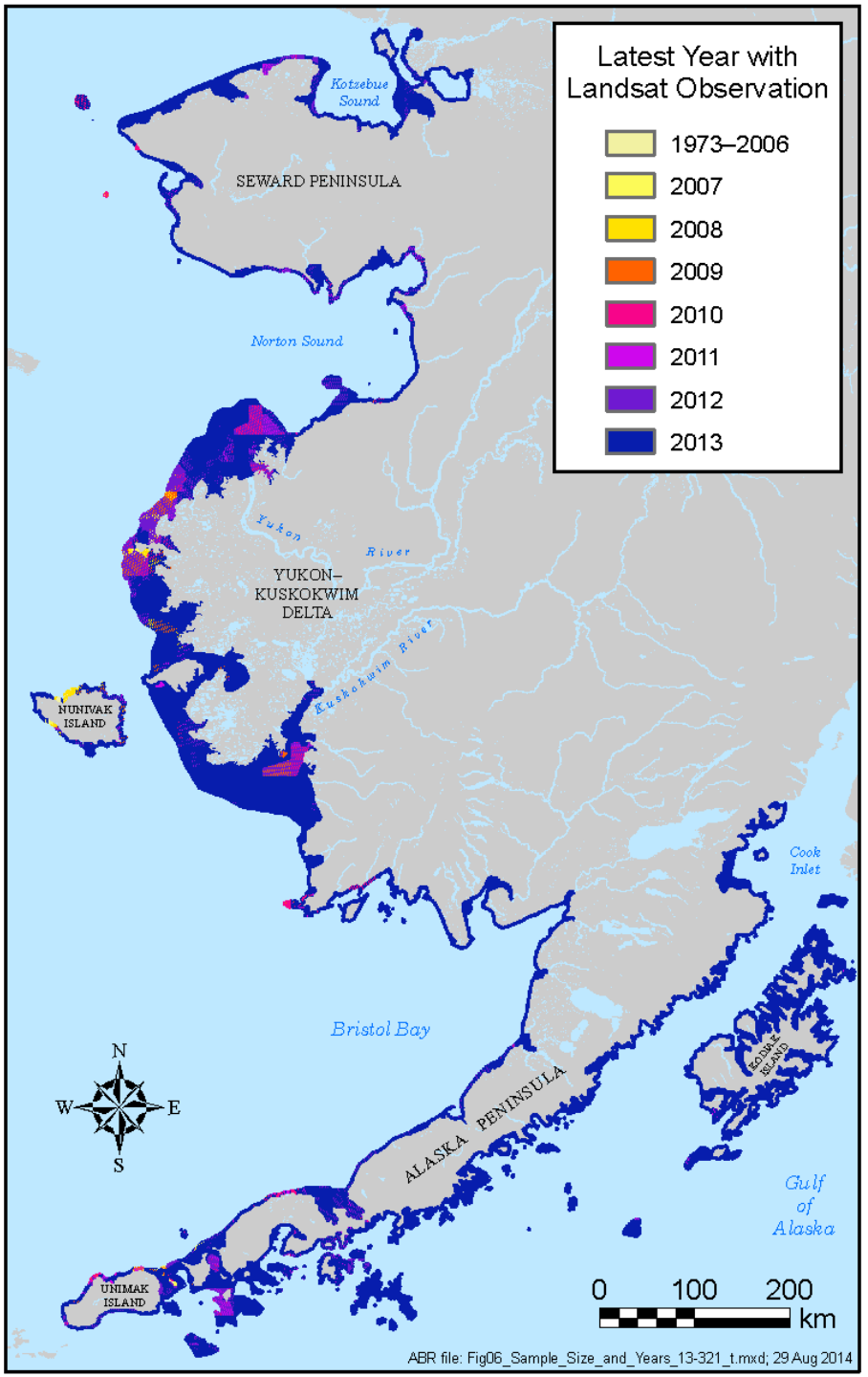
Results: Image Time-Series

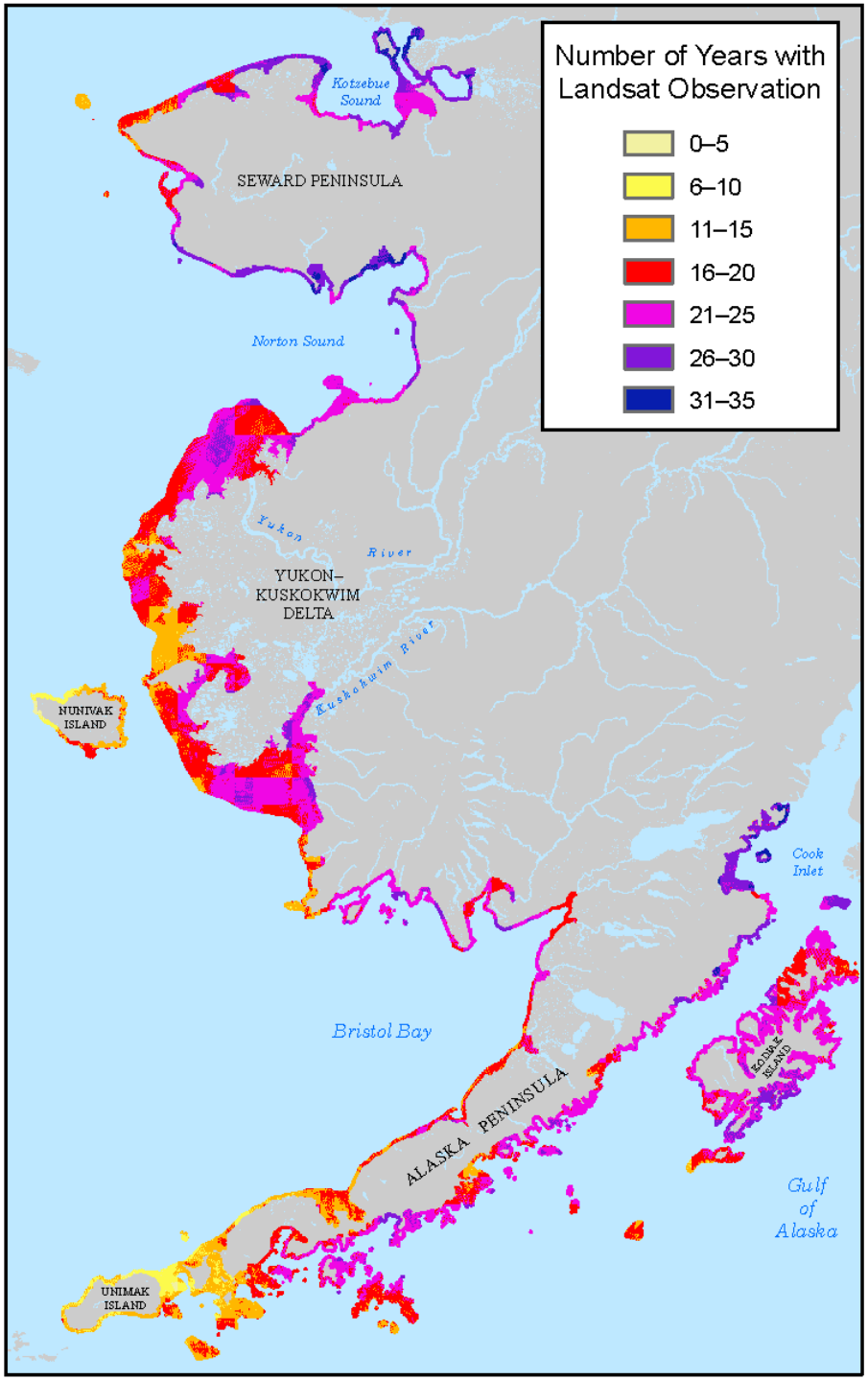


Landsat 5 retired after 2011, but Landsat 8 began collecting data in 2013

Portions of the Western Alaska LCC coastal change study area without Landsat coverage during a composite period


Earliest Year with Landsat Observation
1972
1972
1974
1975–1979
1980–1984
1985–1989
1990–1999
2000–2013
Kotzebue Sound
SEWARD PENINSULA
Norton Sound
Yukon River
YUKON–KUSKOKWIM DELTA
Kuskokwim River
NUNIVAK ISLAND
Cook Inlet
Bristol Bay
KODIAK ISLAND
ALASKA PENINSULA
Gulf of Alaska
UNIMAK ISLAND

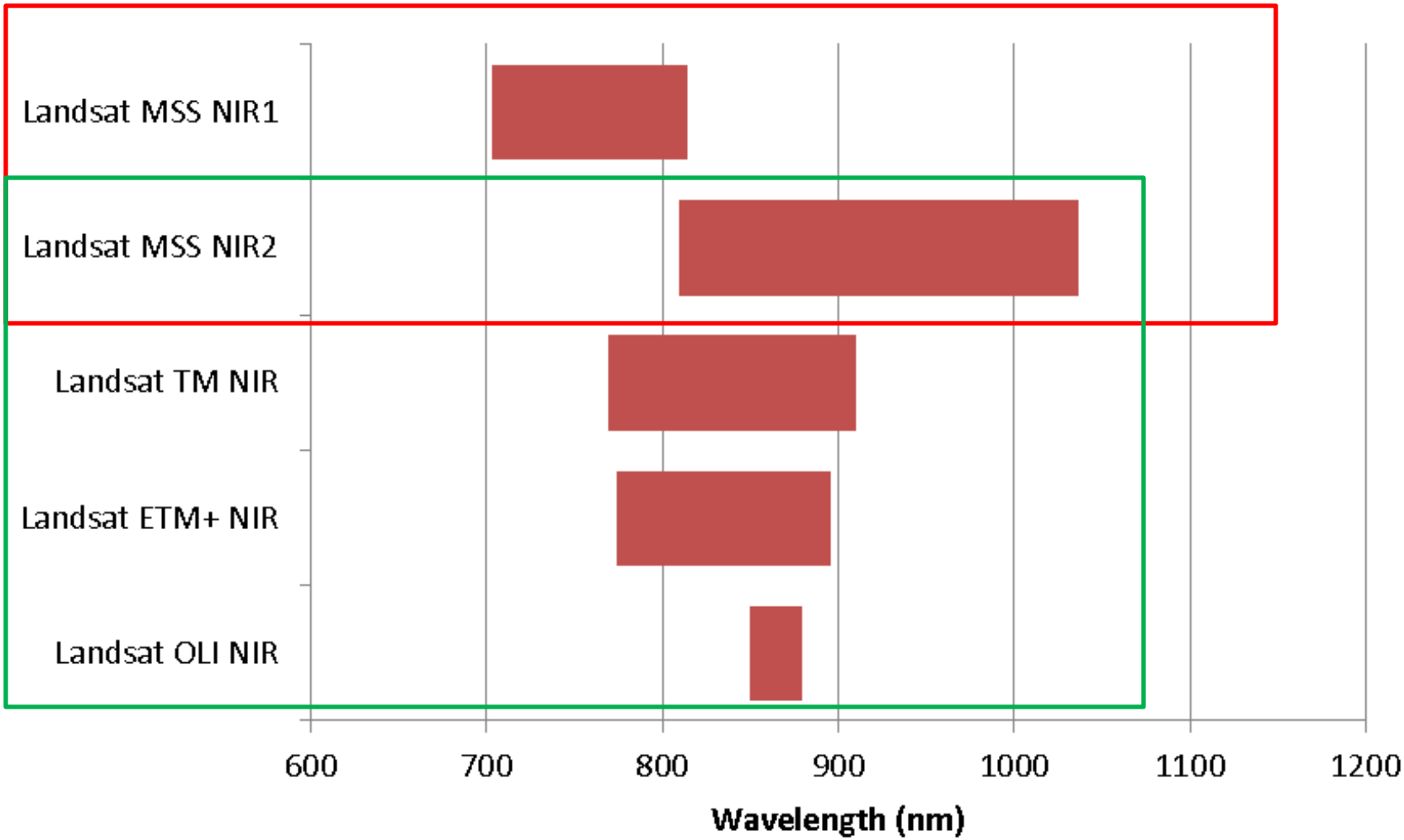

Latest Year with Landsat Observation
1973–2006
2007
2008
2009
2010
2011
2012
2013
Kotzebue Sound
SEWARD PENINSULA
Norton Sound
Yukon River
YUKON–KUSKOKWIM DELTA
Kuskokwim River
NUNIVAK ISLAND
Cook Inlet
Bristol Bay
N
W
E
S
KODIAK ISLAND
ALASKA PENINSULA
Gulf of Alaska
UNIMAK ISLAND
0 100 200
km
ABR file: Fig06_Sample_Size_and_Years_13-321_t.mxd; 29 Aug 2014


Number of Years with Landsat Observation
0–5
6–10
11–15
16–20
21–25
26–30
31–35
Kotzebue Sound
SEWARD PENINSULA
Norton Sound
Yukon River
YUKON–KUSKOKWIM DELTA
Kuskokwim River
NUNIVAK ISLAND
Cook Inlet
Bristol Bay
KODIAK ISLAND
ALASKA PENINSULA
Gulf of Alaska
UNIMAK ISLAND

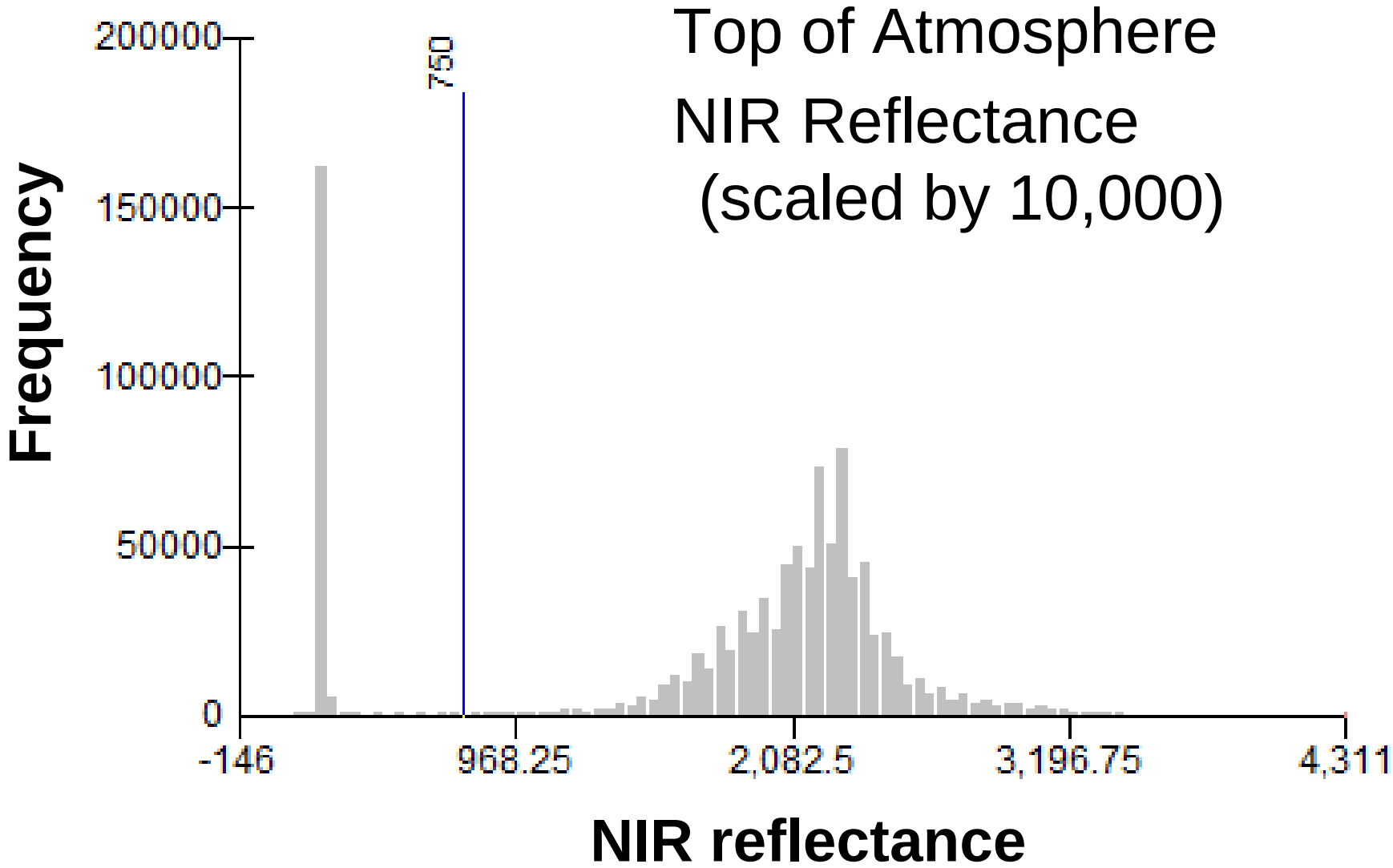
Mapping Land, Water and Transitions

- Inclusion of MSS data limits available bands and metrics
- MSS data also noisier with radiometric artifacts fairly common: more bands = more opportunity for artifacts to affect results
- Near-Infrared Reflectance is very useful for distinguishing (liquid) water from most other cover types

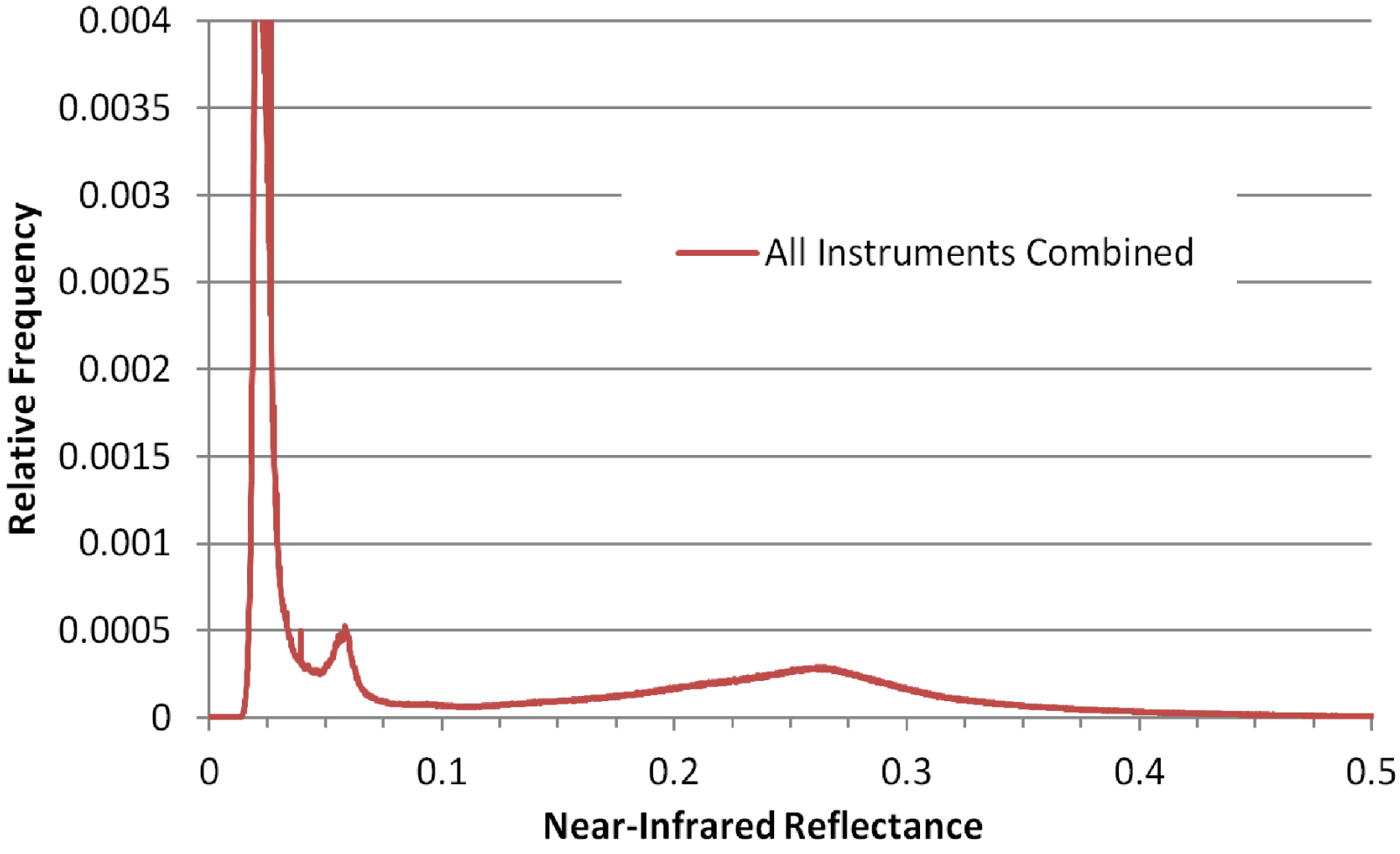
Near-Infrared Bands on Landsat Sensors



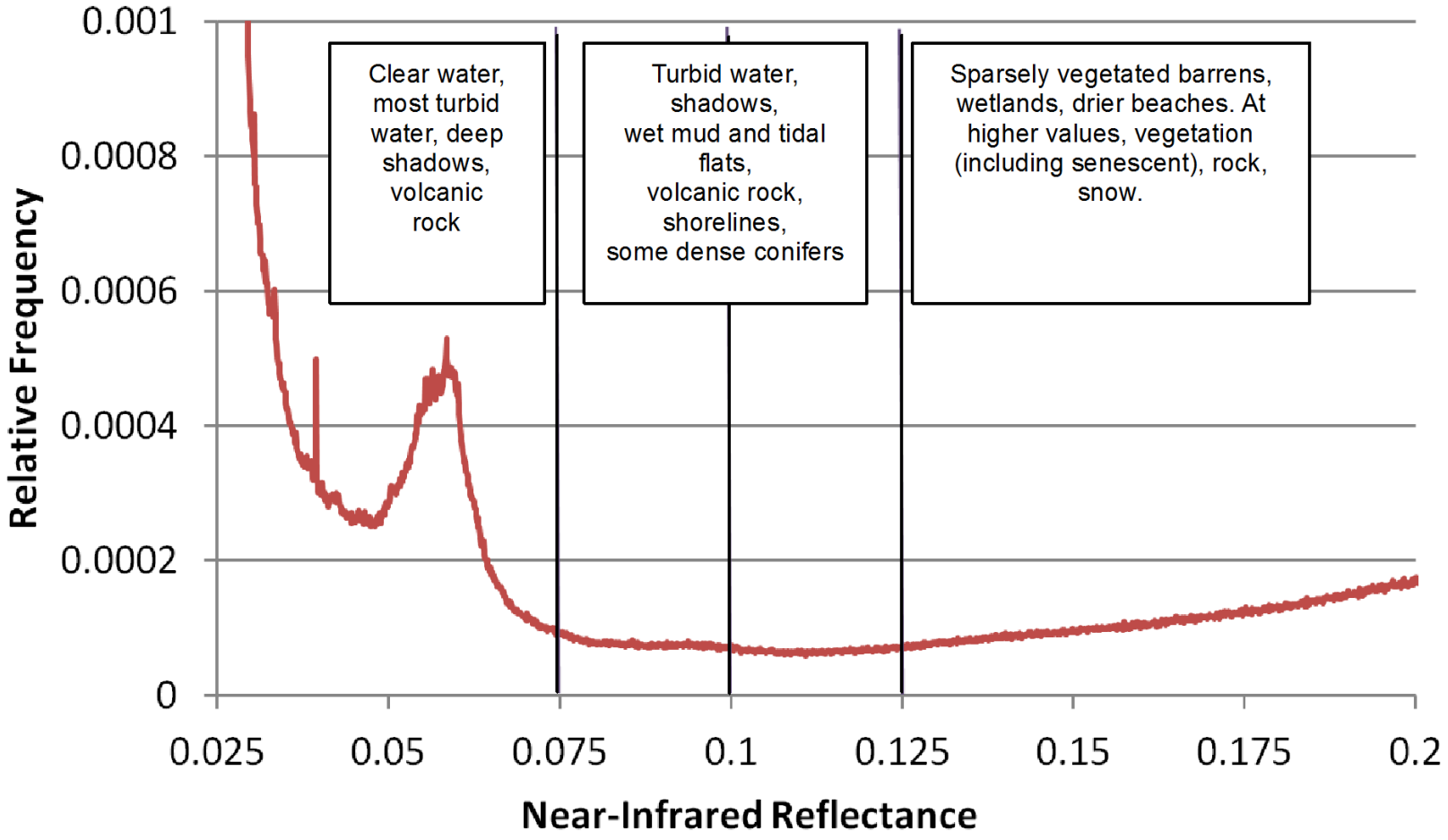
Classifying Land and Water: Feasability Tiles



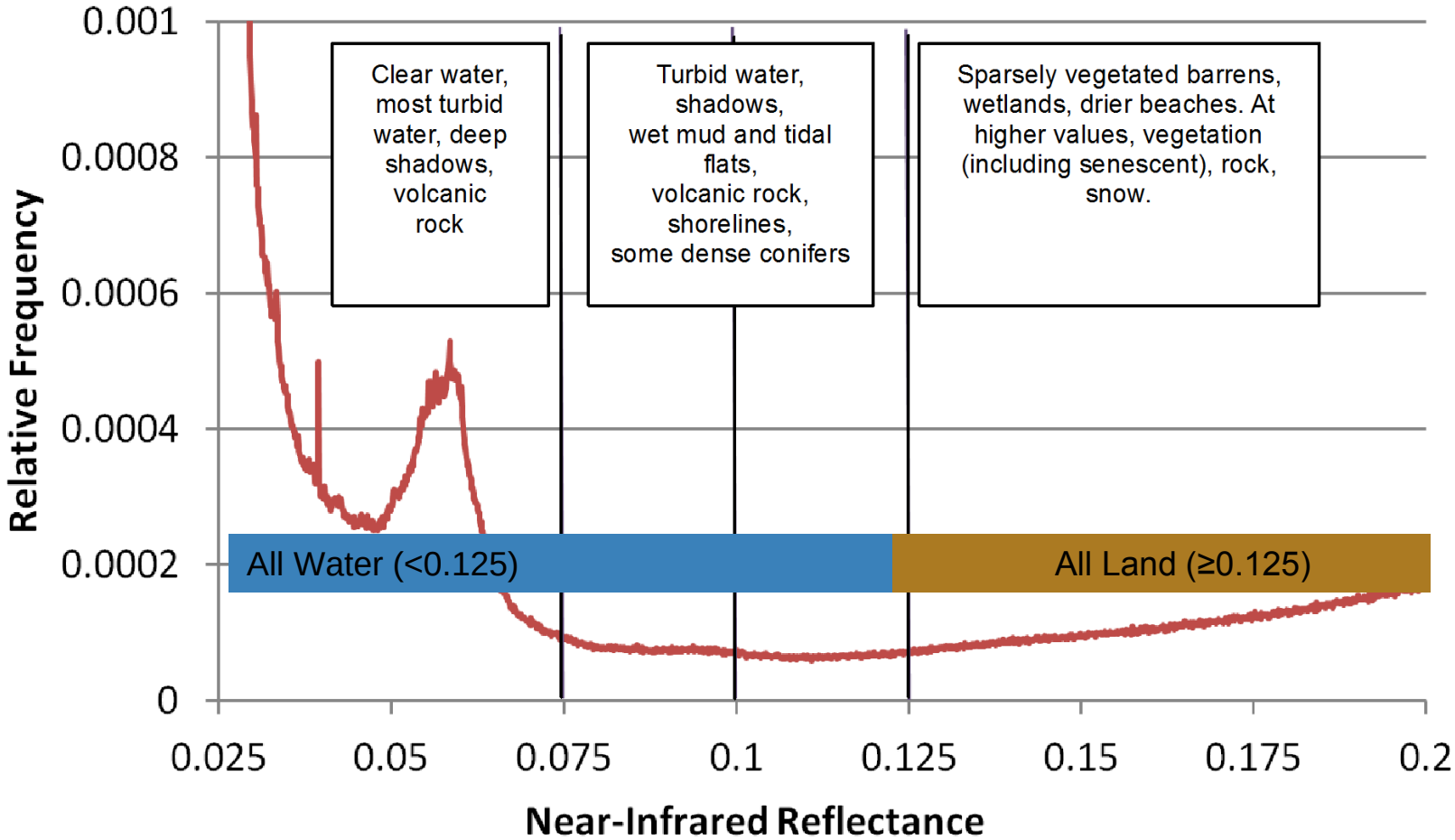
Classifying Land and Water



Classifying Land and Water

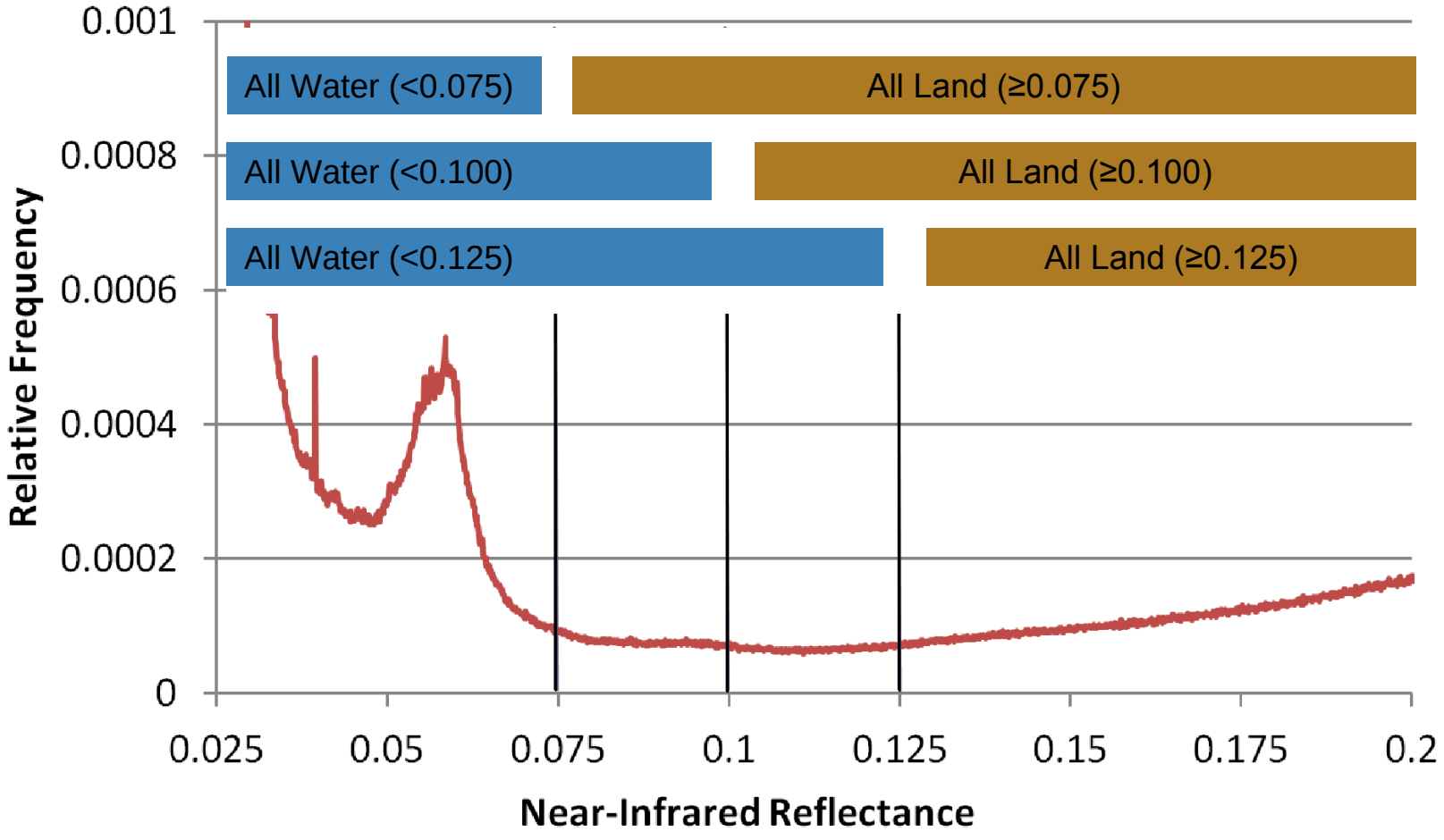


Classifying Land and Water: Adaptive Threshold



First pass selecting only 100% pure, Second pass allowing one outlier (all except one observation water, etc.)

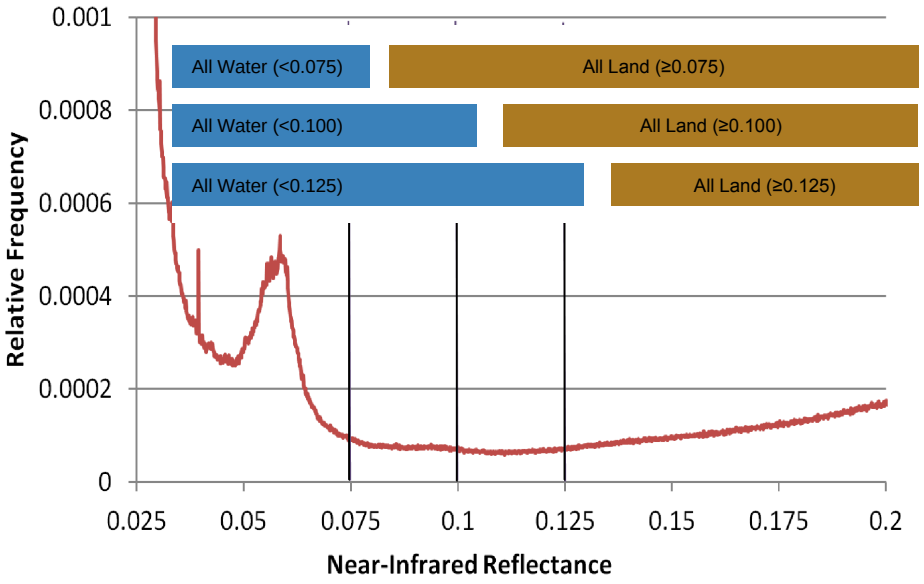
Classifying Land and Water: Adaptive Threshold



First pass selecting only 100% pure, Second pass allowing one outlier

Classifying Land and Water: Adaptive Threshold

- Step through the entire time-series to identify pixels that are always water, or always land
- First pass selecting only 100% pure
- Second pass allowing one outlier
    - Misregistration
    - Sensor noise
    - Missed clouds, shadows, or ice



- Pixels that are not classified to Land or Water at this stage are "**Potential Transition Pixels**" and are the focus of the change analysis

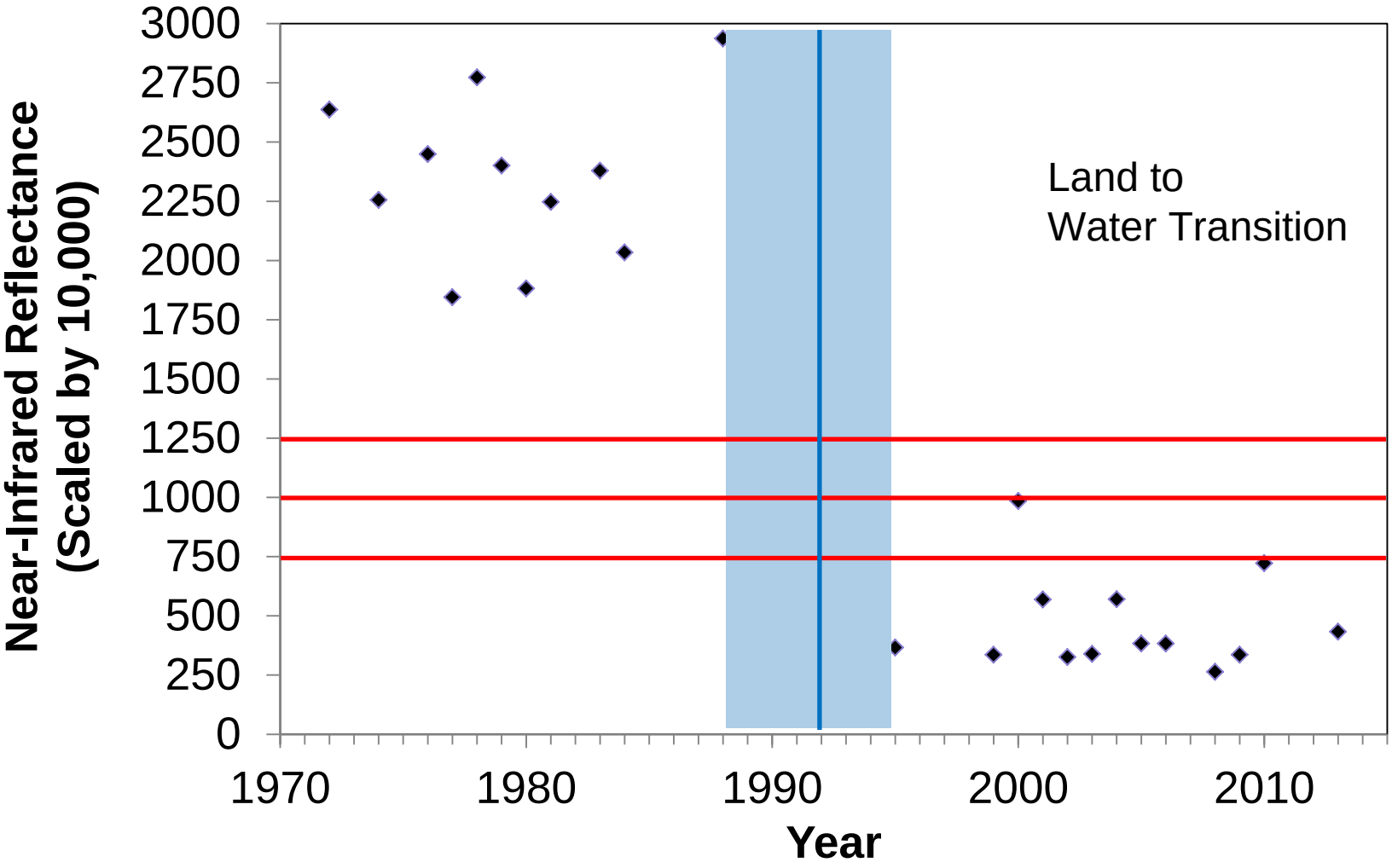
Potential Transition Pixels

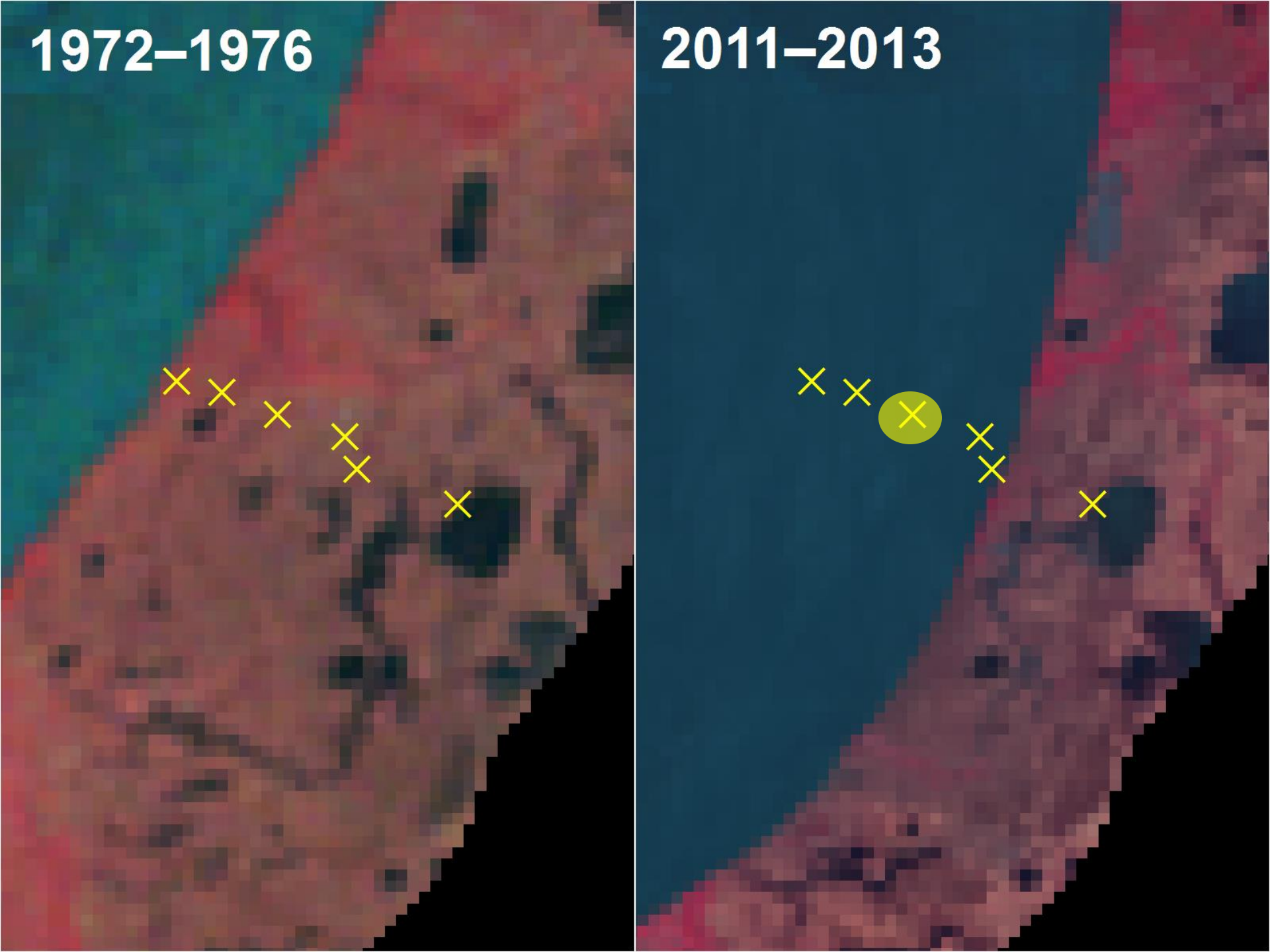
	1972–2013 60 m resolution		1985–2013 30 m resolution	
Class	Area (km²)	Percentage	Area (km²)	Percentage
Water (<2 Land Observations)	45,873.3	55.7%	46,502.2	56.4%
Land (<2 Water Observations)	34,175.9	41.5%	34,662.0	42.1%
Potential Transition (>1 Land Observation and >1 Water Observation)	2,358.0	2.9%	1,244.7	1.5%
Total	82,407.1		82,408.9	

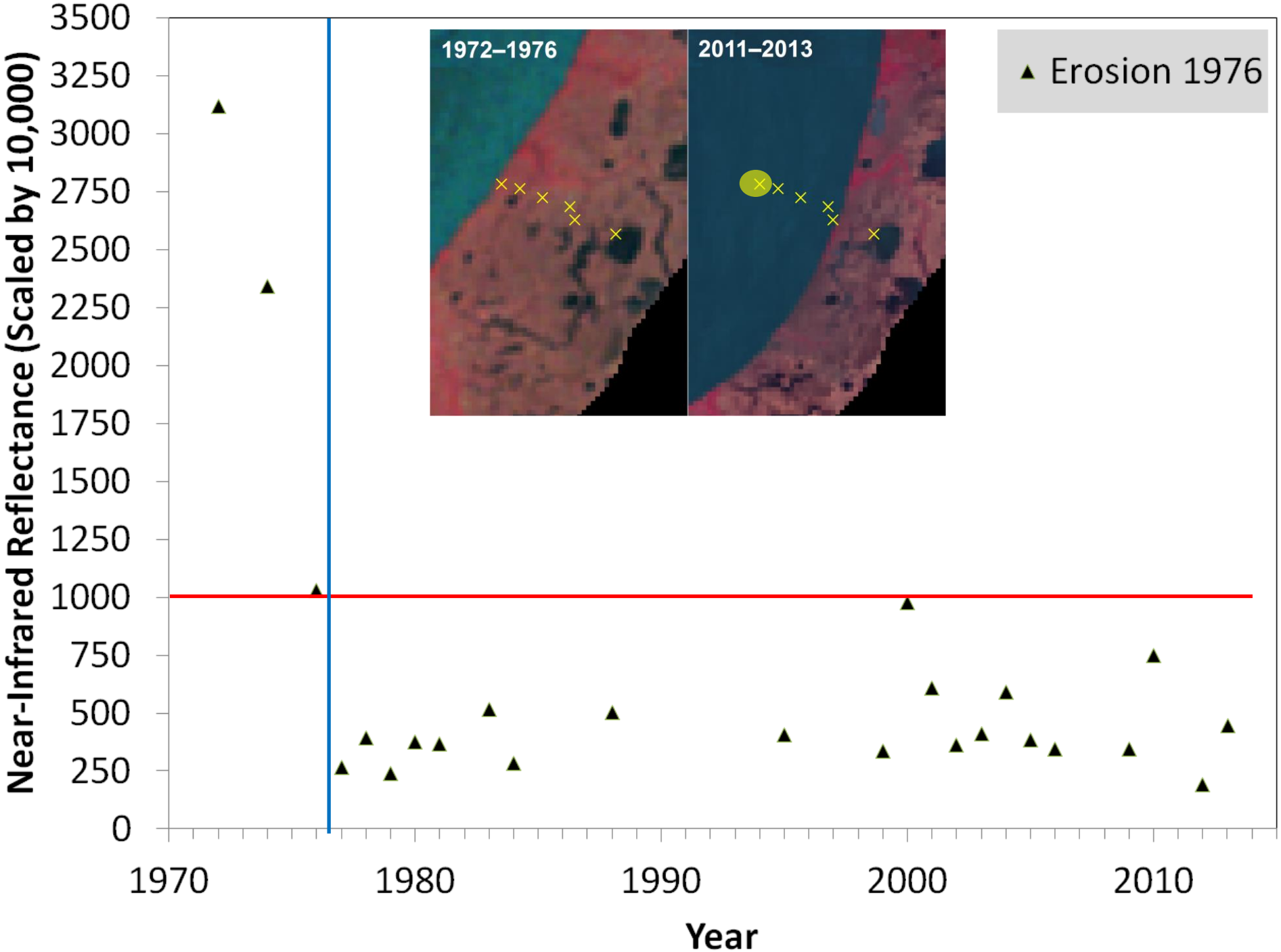
Transition Detection via Binary Classification Tree

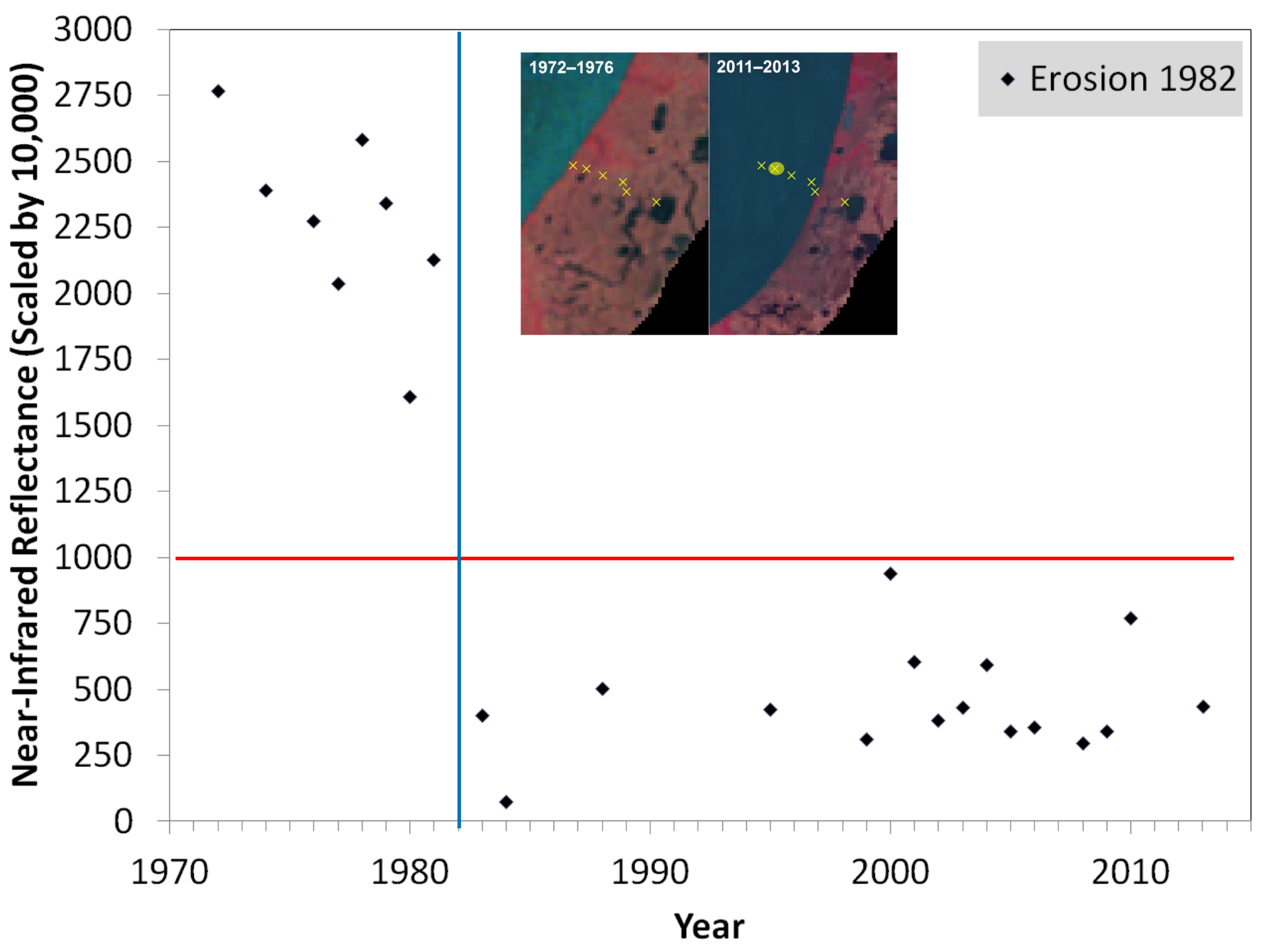
- Reclassify continuous NIR values to Land or Water based on 0.075 threshold
- Predict state of pixel with Binary Classification Tree using Year as predictor
  - Maximum 1 split
  - At least 2 observations required for each segment

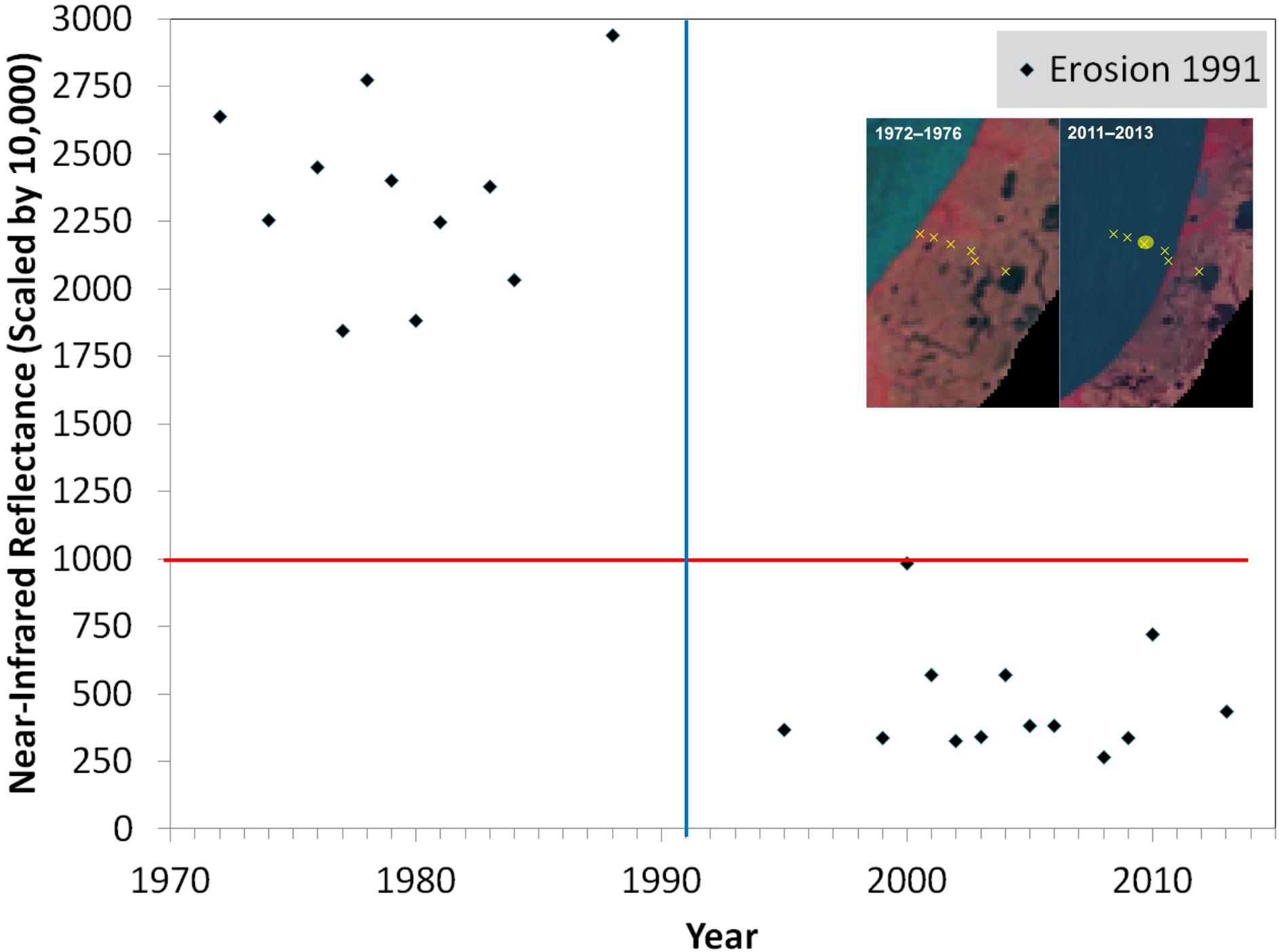
Transition Detection via Binary Classification Tree

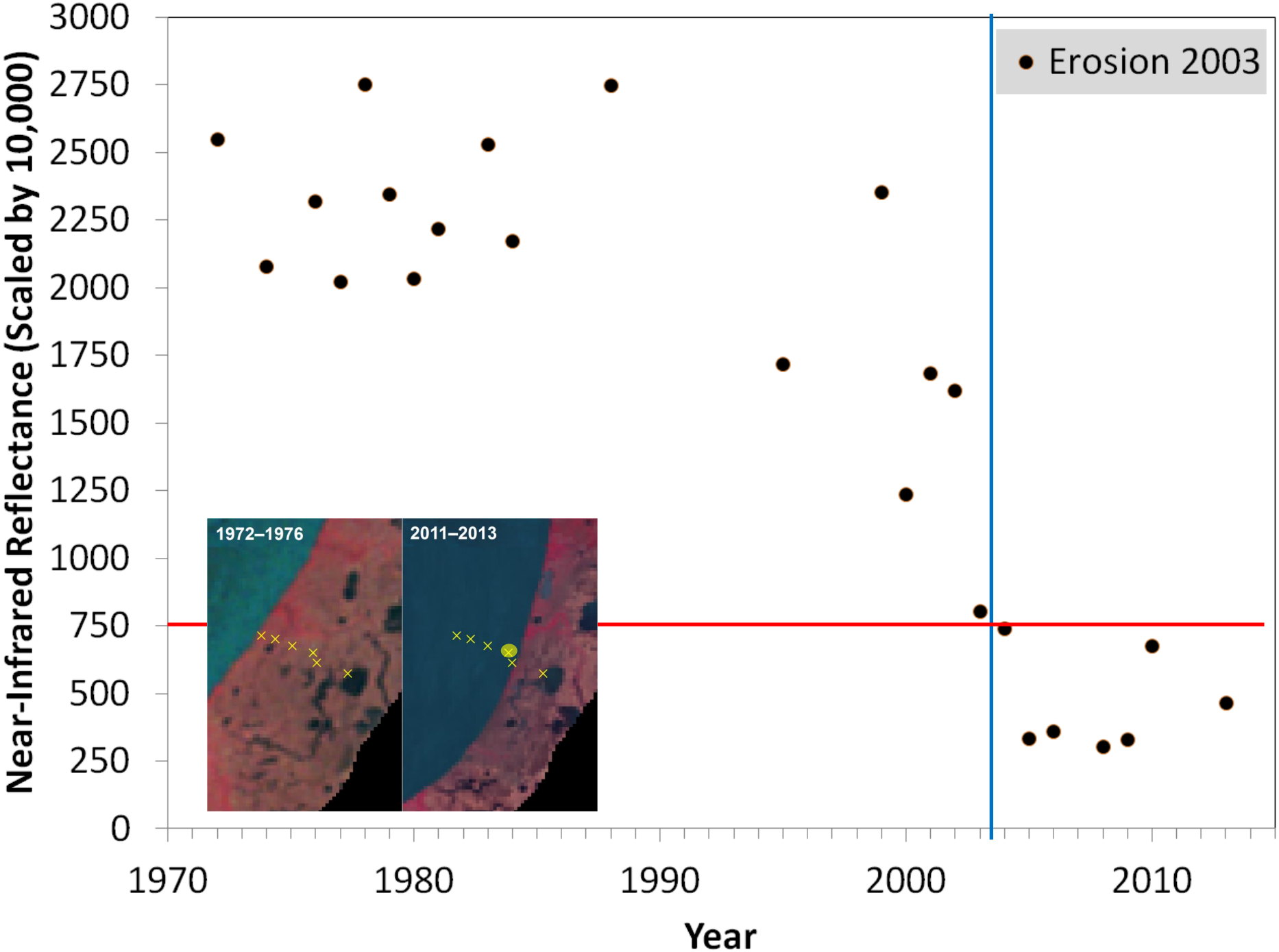


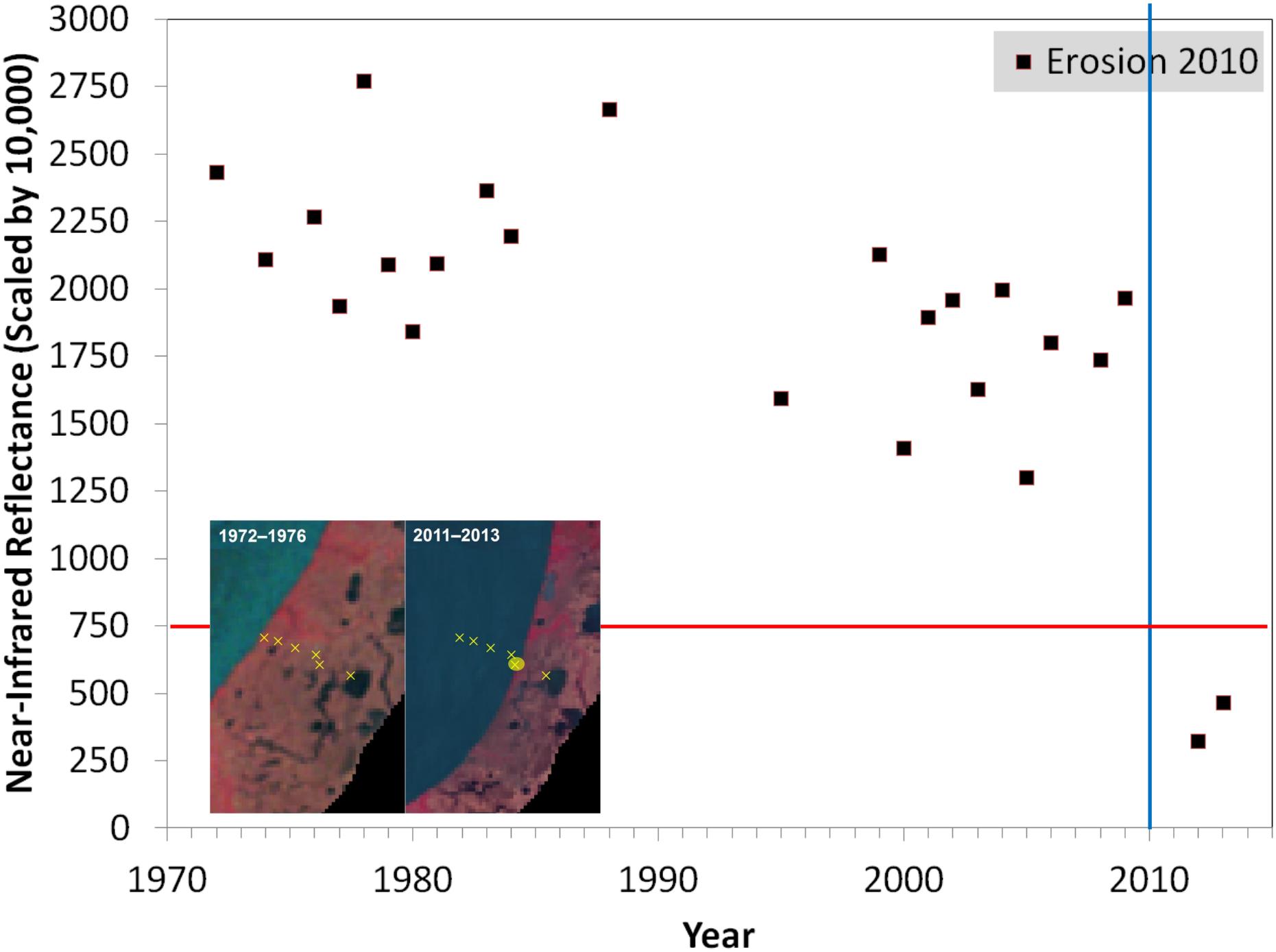

1972–1976
2011–2013

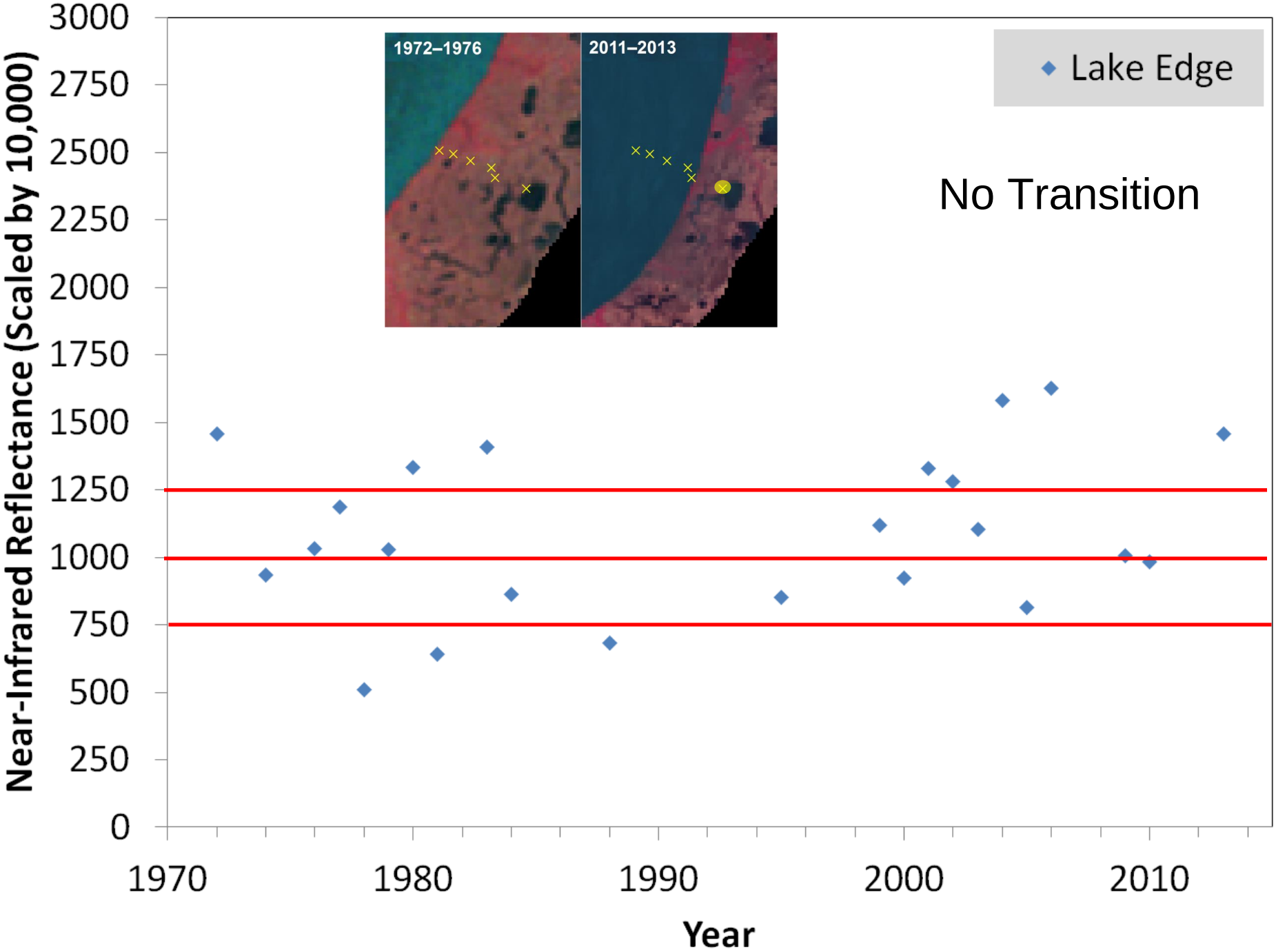

1972–1976
2011–2013
Erosion 1976
Near-Infrared Reflectance (Scaled by 10,000)
3500
3250
3000
2750
2500
2250
2000
1750
1500
1250
1000
750
500
250
0
1970
1980
1990
2000
2010
Year

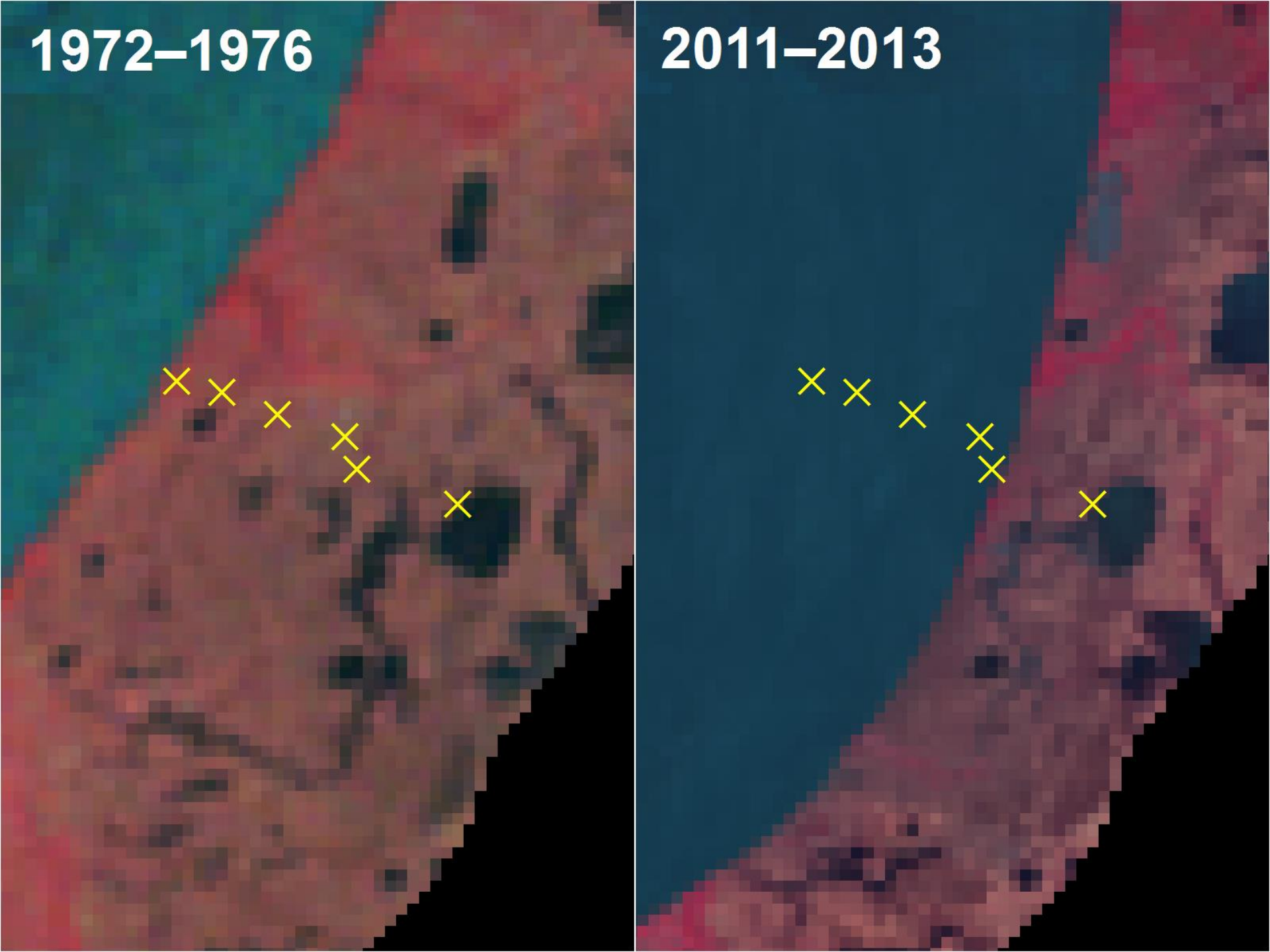

Erosion 1982
1972–1976
2011–2013
Near-Infrared Reflectance (Scaled by 10,000)
3000
2750
2500
2250
2000
1750
1500
1250
1000
750
500
250
0
1970
1980
1990
2000
2010
Year

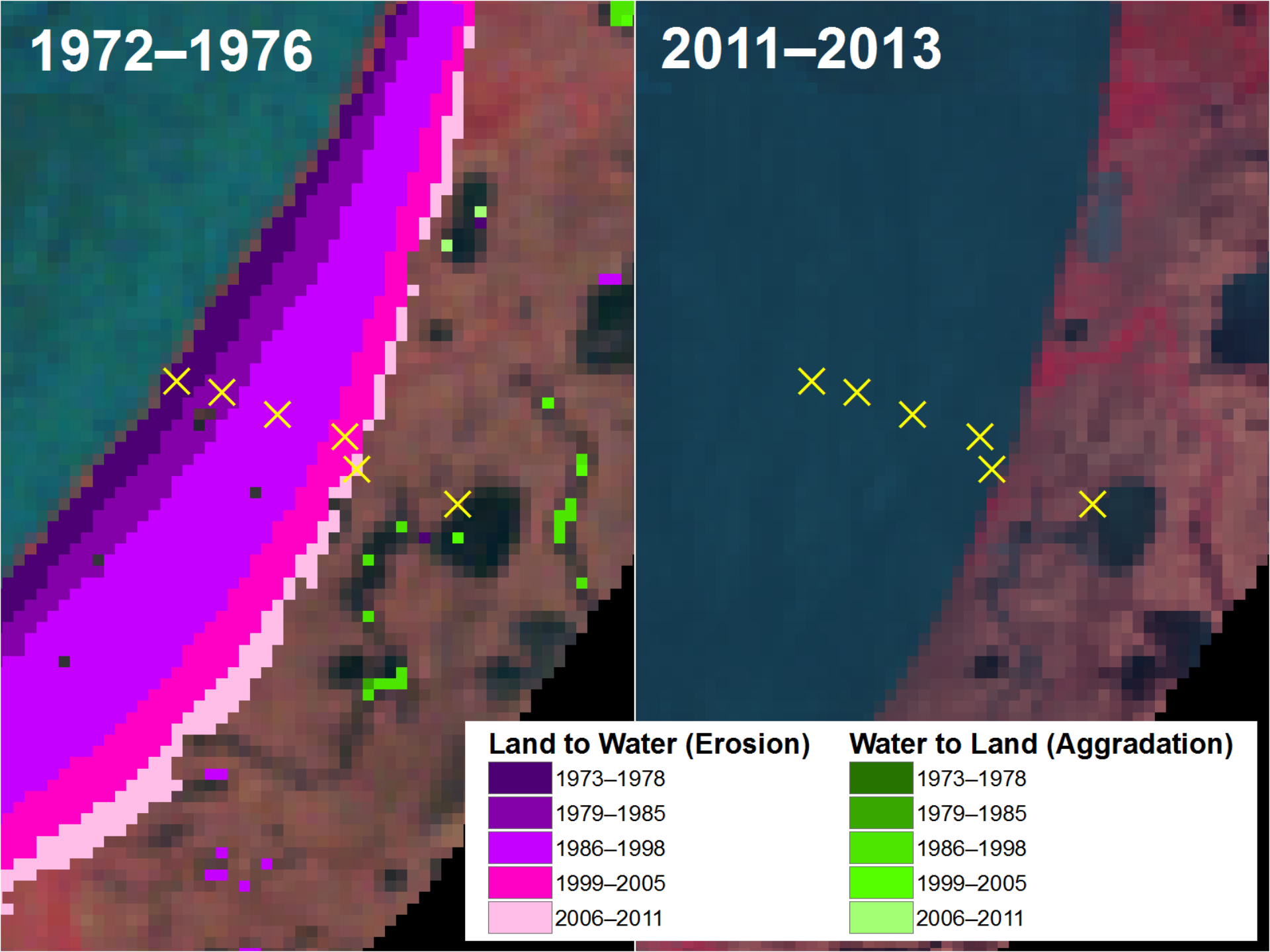

Erosion 1991
1972–1976
2011–2013
Near-Infrared Reflectance (Scaled by 10,000)
3000
2750
2500
2250
2000
1750
1500
1250
1000
750
500
250
0
1970
1980
1990
2000
2010
Year


Erosion 2003
Near-Infrared Reflectance (Scaled by 10,000)
3000
2750
2500
2250
2000
1750
1500
1250
1000
750
500
250
0
1970
1980
1990
2000
2010
Year
1972–1976
2011–2013


Erosion 2010
Near-Infrared Reflectance (Scaled by 10,000)
3000
2750
2500
2250
2000
1750
1500
1250
1000
750
500
250
0
1970
1980
1990
2000
2010
Year
1972–1976
2011–2013


1972–1976
2011–2013
Lake Edge
No Transition
Near-Infrared Reflectance (Scaled by 10,000)
3000
2750
2500
2250
2000
1750
1500
1250
1000
750
500
250
0
1970
1980
1990
2000
2010
Year


1972–1976
2011–2013


1972–1976
2011–2013
Land to Water (Erosion)
1973–1978
1979–1985
1986–1998
1999–2005
2006–2011
Water to Land (Aggradation)
1973–1978
1979–1985
1986–1998
1999–2005
2006–2011

Transition Detection via Binary Classification Tree

	1972–2013 60 m resolution		1985–2013 30 m resolution	
Transition Type	Area (km²)	Percentage	Area (km²)	Percentage
Other	1,310.9	55.6%	670.5	53.9%
Single Transition (total)	1,047.0	44.4%	574.2	46.1%
Land to water (total)	504.3	21.4%	314.2	25.2%
Split accepted	396.3	16.8%	190.7	15.3%
Split rejected, purity index < 85%	107.9	4.6%	123.6	9.9%
Water to land (total)	542.8	23.0%	259.9	20.9%
Split accepted	392.6	16.7%	139.7	11.2%
Split rejected, purity index < 85%	150.1	6.4%	120.2	9.7%
Total	2,358.0		1,244.7	

Change Interpretation: Coastal Physiography

Study area diverse and includes non-coastal features. Interpretation of detected transitions different depending on geographical context.

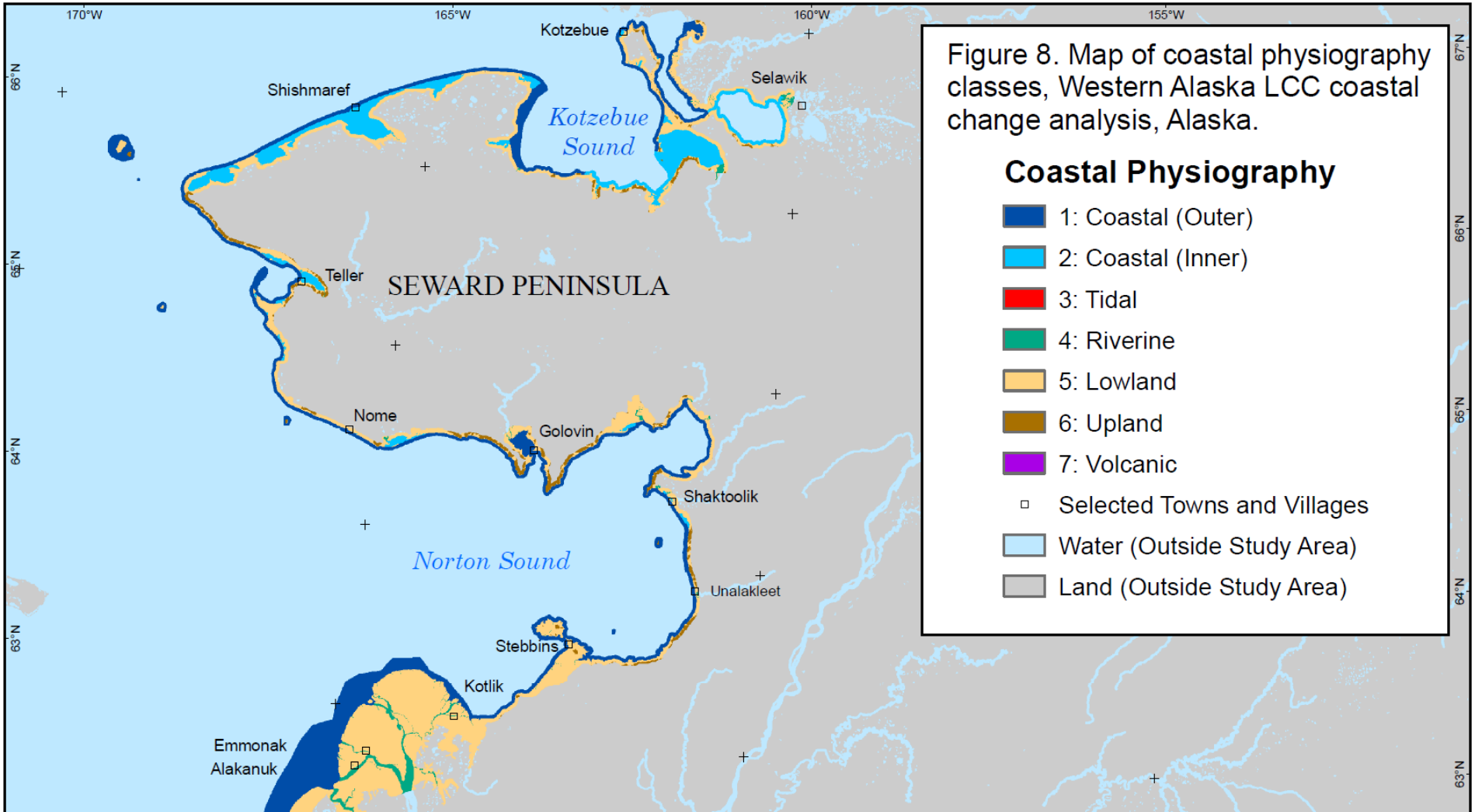


Figure 8. Map of coastal physiography classes, Western Alaska LCC coastal change analysis, Alaska.

Change Interpretation: Coastal Physiography

Coastal Physiography Class	Transition Type	Primary Change Class Interpretation
Coastal (Outer)	Land to water	Coastal erosion
Coastal (Outer)	Water to land	Coastal aggradation
Coastal (Inner)	Land to water	Coastal erosion
Coastal (Inner)	Water to land	Coastal aggradation
Tidal	Land to water	Seaweed reduction or noise
Tidal	Water to land	Seaweed expansion or noise
Riverine	Land to water	Riverine channel migration (erosion)
Riverine	Water to land	Riverine channel migration (aggradation)
Lowland	Land to water	Lake formation/expansion or landscape wetting
Lowland	Water to land	Lake drainage or landscape drying
Upland	Land to water	Mostly mountain shadow noise
Upland	Water to land	Mostly mountain shadow noise
Volcanic	Land to water	Volcanic disturbance
Volcanic	Water to land	Volcanic succession

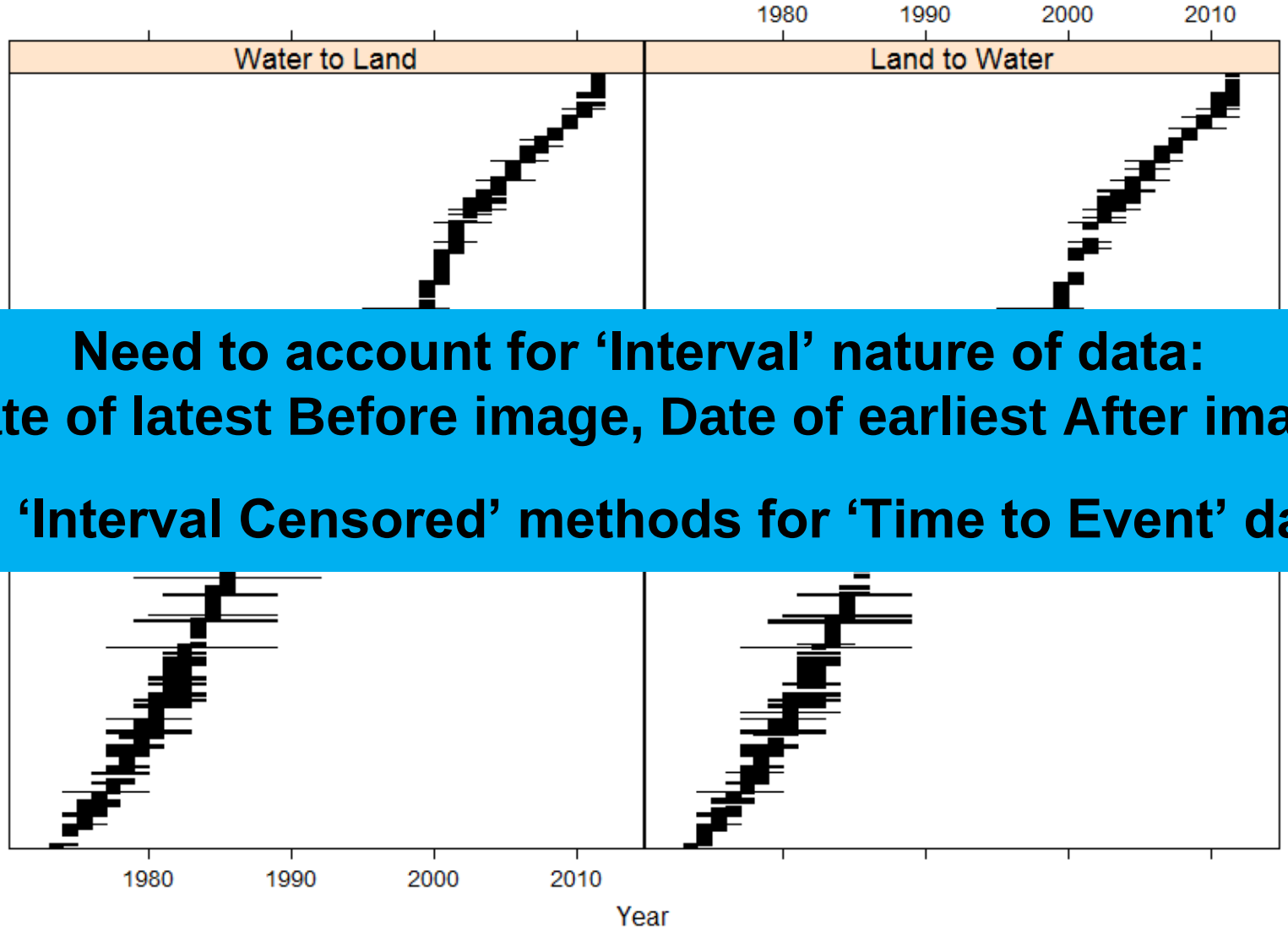
Change Interpretation: Results (1972–2013, 60 m)

Coastal Physiography Class/ Transition Direction/	Total
Coastal (Outer)	
Land to water: Coastal erosion	77.2
Water to land: Coastal aggradation	88.3
Coastal (Inner)	
Land to water: Coastal erosion	22.4
Water to land: Coastal aggradation	24.8
Riverine	
Land to water: Riverine channel migration (erosion)	122.7
Water to land: Riverine channel migration (aggradation)	142.2
Lowland	
Land to water: Lake formation/wetting	170.5
Water to land: Lake drainage or drying	110.1
Tidal	
Land to water: Seaweed reduction or noise	0.7
Water to land: Seaweed expansion or noise	9.9
Upland	
Land to water: Mostly mountain shadow noise	2.3
Water to land: Mostly mountain shadow noise	15.7
Volcanic	
Land to water: Volcanic disturbance	0.6
Water to land: Volcanic succession	1.7
Total	**789.0**

Rates of Change (1972–2013, 60 m)

Year or Years of Transition	Coastal Erosion (Land to Water) 1972–2013 60 m resolution (km^2)	Coastal Aggradation (Water to Land) 1972–2013 60 m resolution (km^2)
Annual Rate		
1973–1978	2.8	1.9
1979–1985	2.4	5.2
1986–1998	2.6	2.8
1999–2005	2.7	2.5
2006–2011	2.1	1.9
Full Time-Series	2.6	2.9

Changes in Temporal Pattern of Transitions?



Need to account for 'Interval' nature of data:
(Date of latest Before image, Date of earliest After image)

=> 'Interval Censored' methods for 'Time to Event' data

Accuracy Assessment (User's)

- Historical high-resolution imagery not available
- Modern high-resolution imagery limited (GINA BDL)
- Focused on patches >5 ha that could usually be interpreted based on Landsat time-series (14 pixels at 60 m resolution)

Accuracy Assessment

Mapped Transition Type: Land to water		
Human-interpreted transition type and confidence	Total	Percentage
Land to water (high confidence)	36	72%
Land to water (medium confidence)	9	18%
Land to water (low confidence)	4	8%
No clear transition	1	2%
Total	50	

Mapped Transition Type: Water to land		
Human-interpreted transition type and confidence	Total	Percentage
Water to land (high confidence)	35	70%
Water to land (medium confidence)	7	14%
Water to land (low confidence)	4	8%
No clear transition	4	8%
Total	50	

Overmapping of "aggradation" in tidal flats. ~15% of sampled coastal aggradation patches appear spurious.

Mapping Change

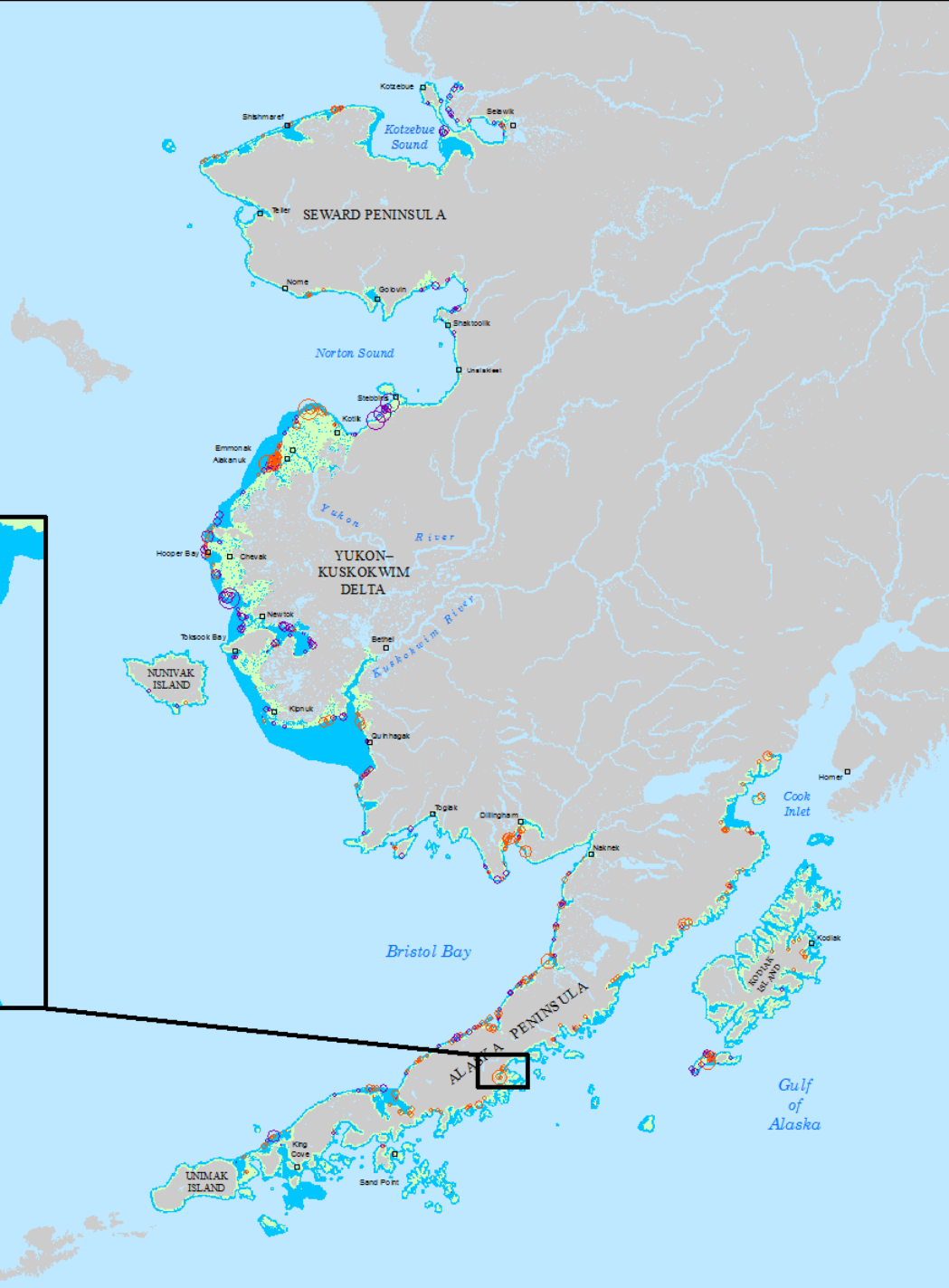
GIS layers will be available, watch the WALCC project page for up to date information:

https://westernalaskalcc.org/projects/SitePages/WA2013_24.aspx

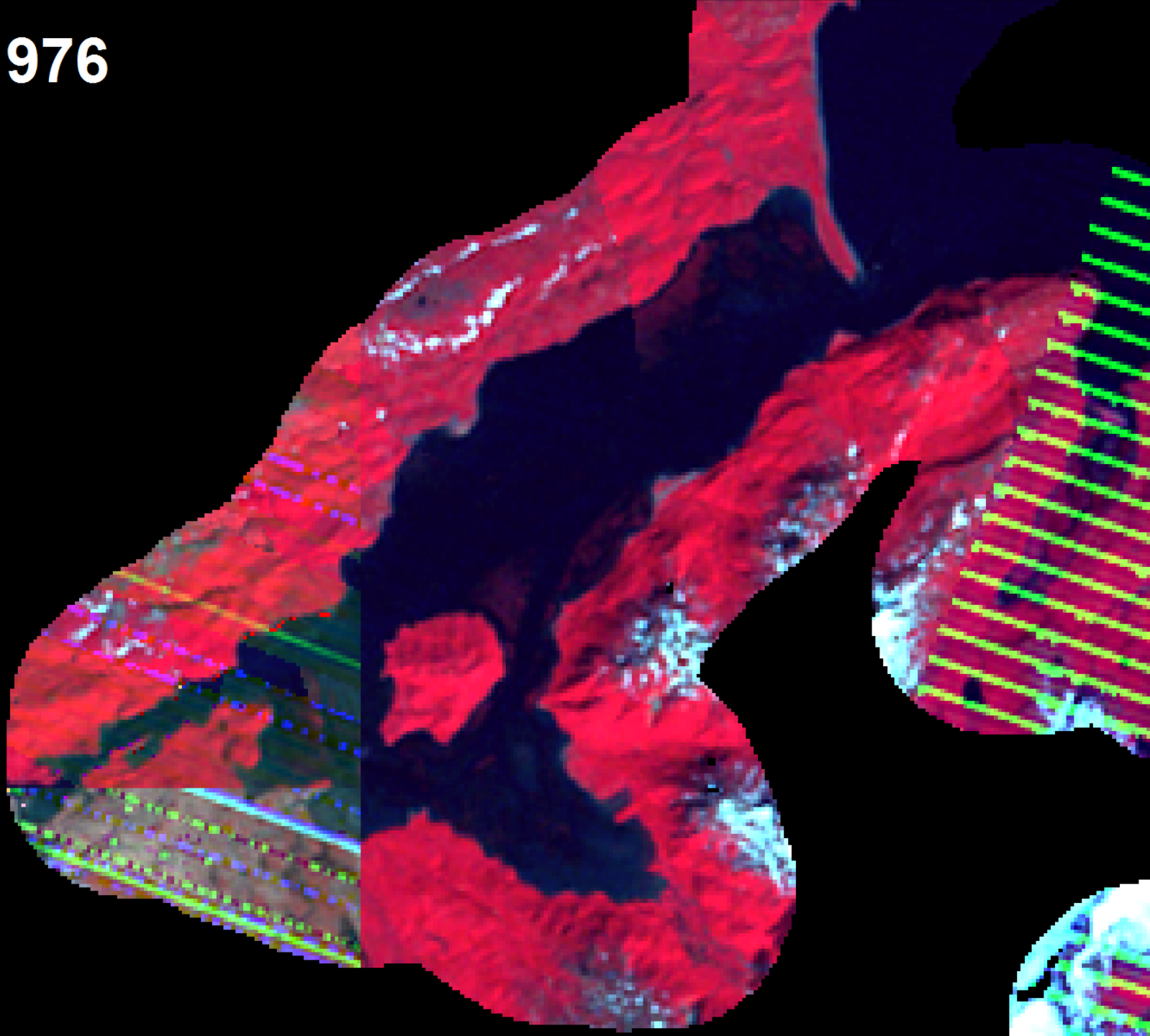
Interactive PDF figure files provided in report

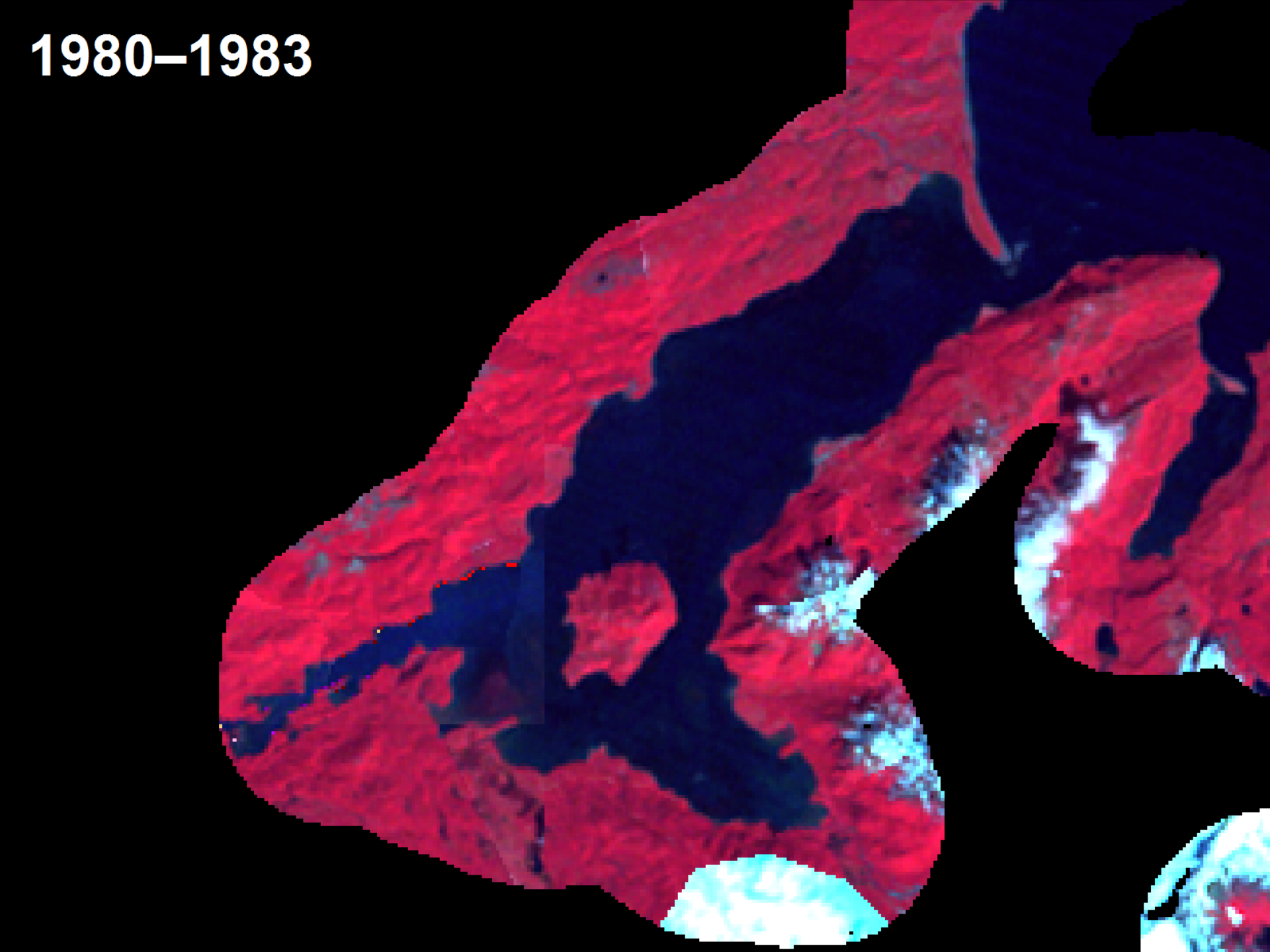
Examples and Hotspots of Change

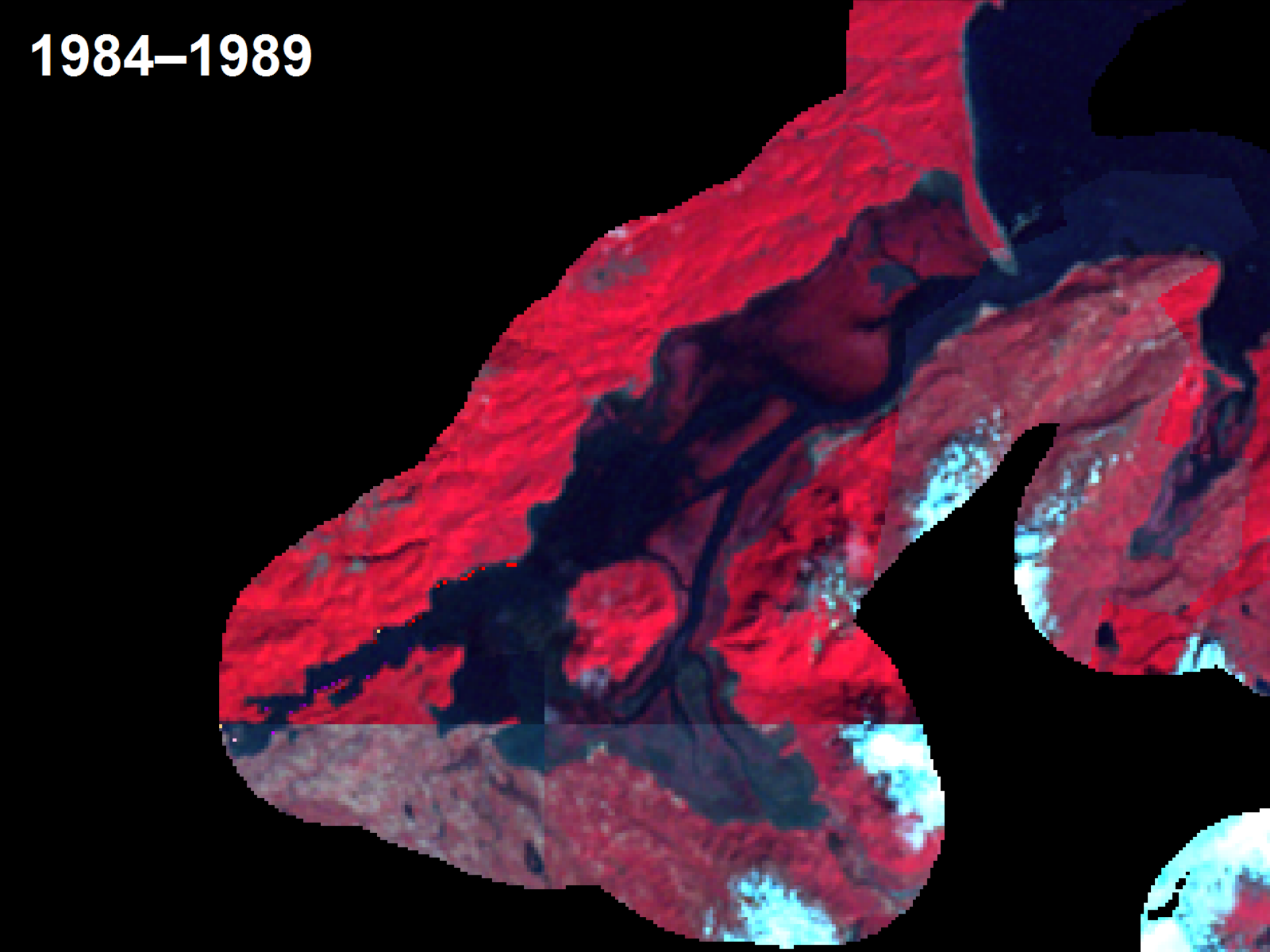
Chignik Lagoon Coastal Aggradation

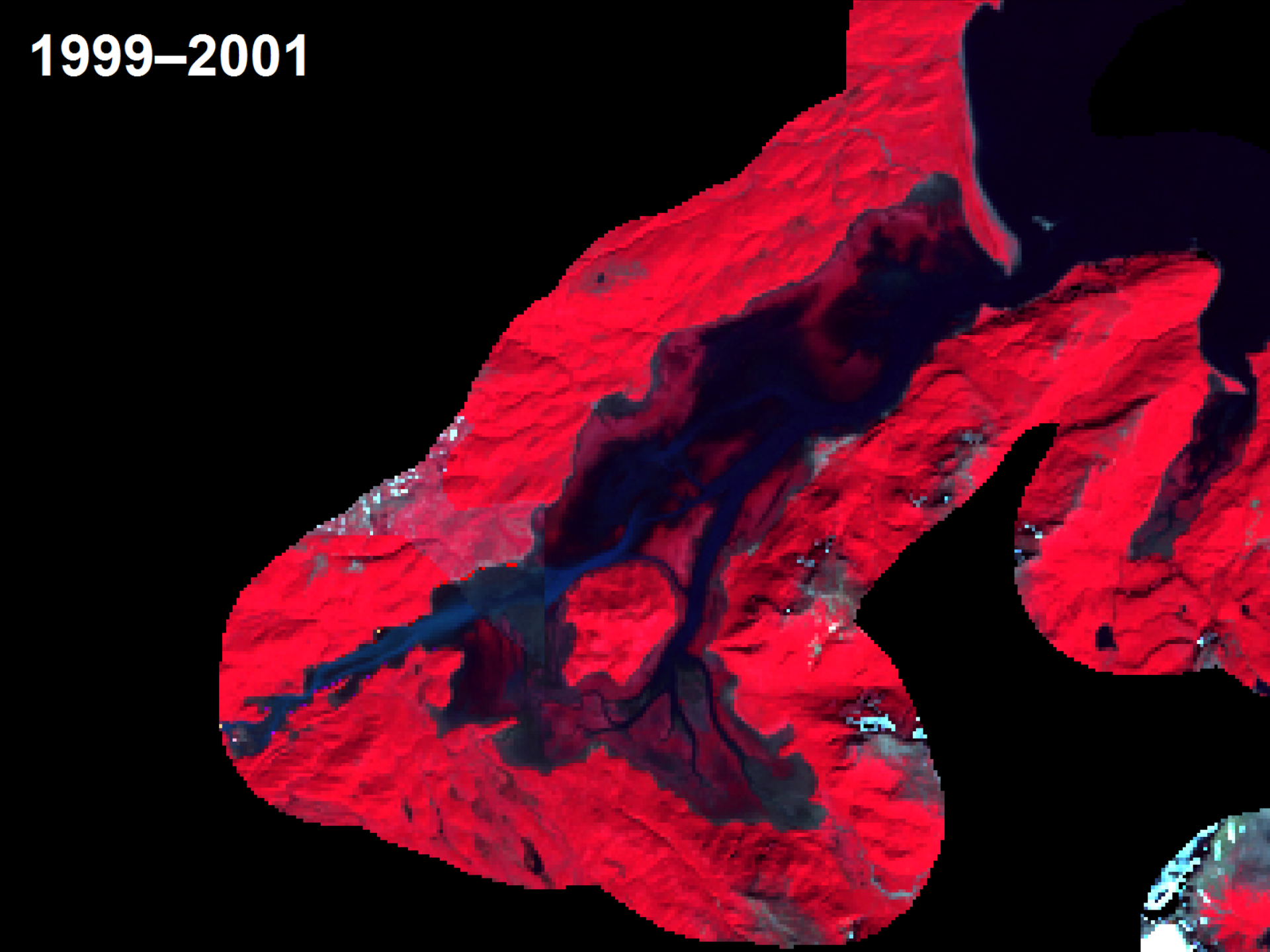


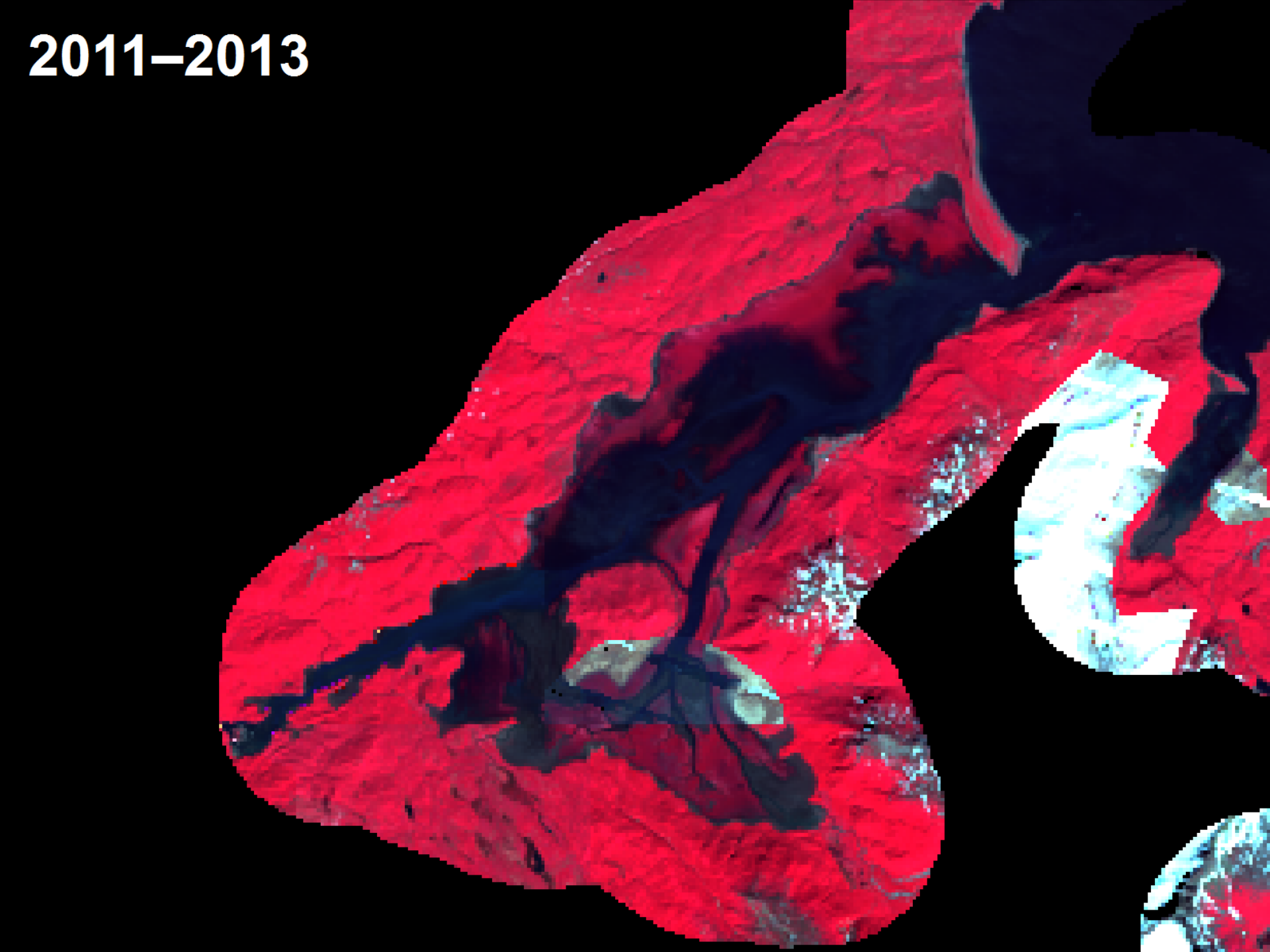
1972–1976



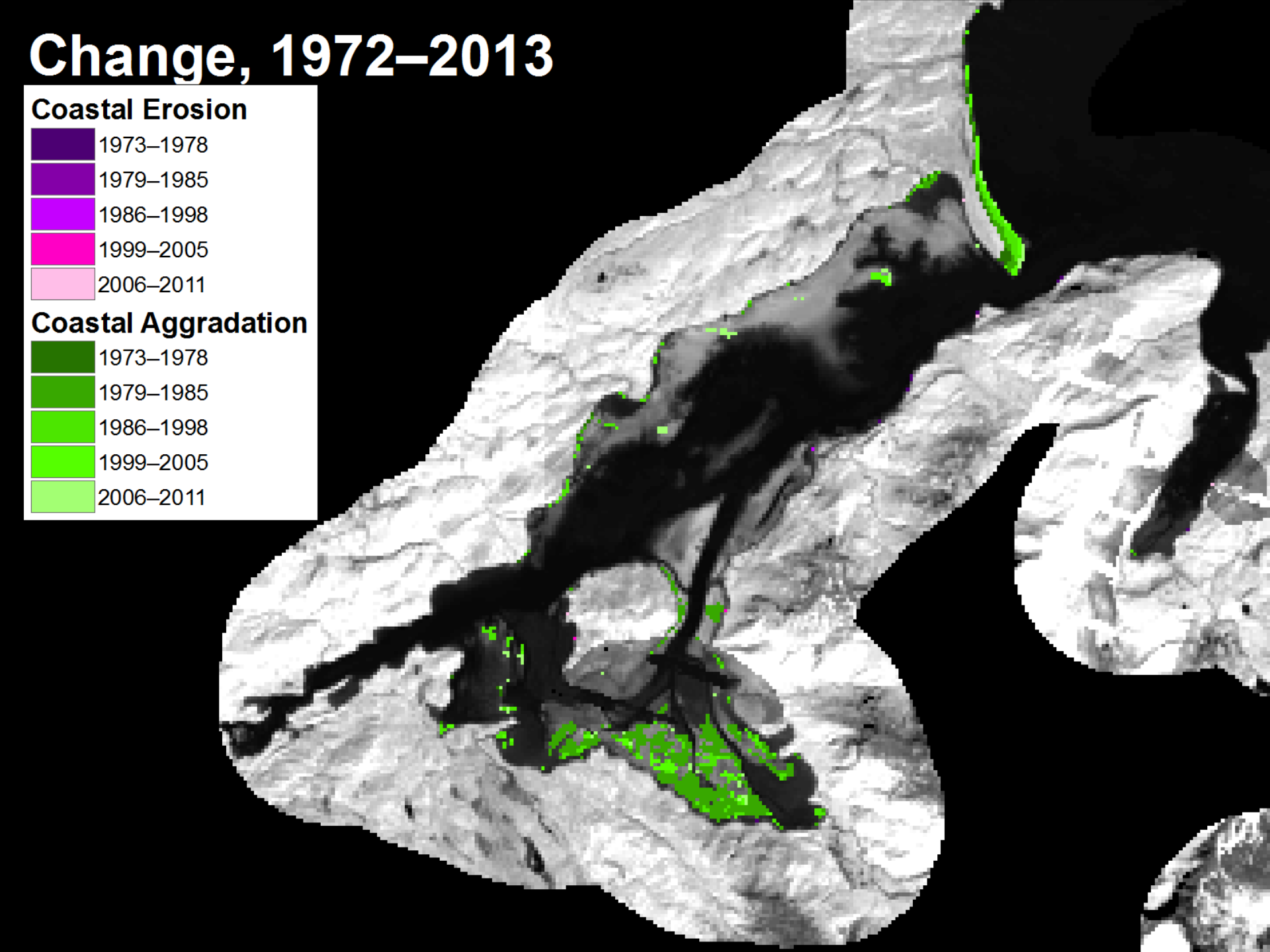

1980–1983


1984–1989

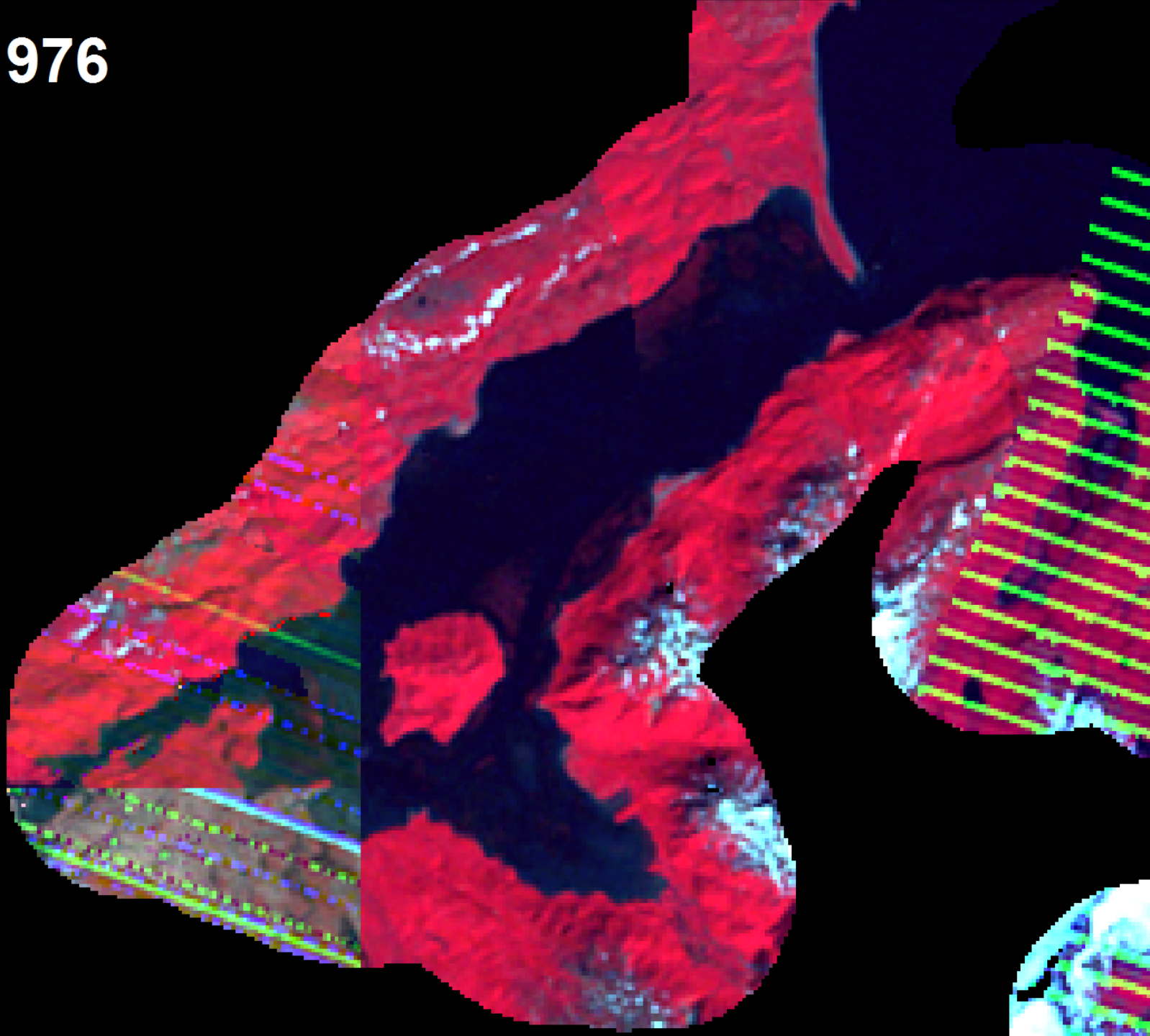

1999–2001

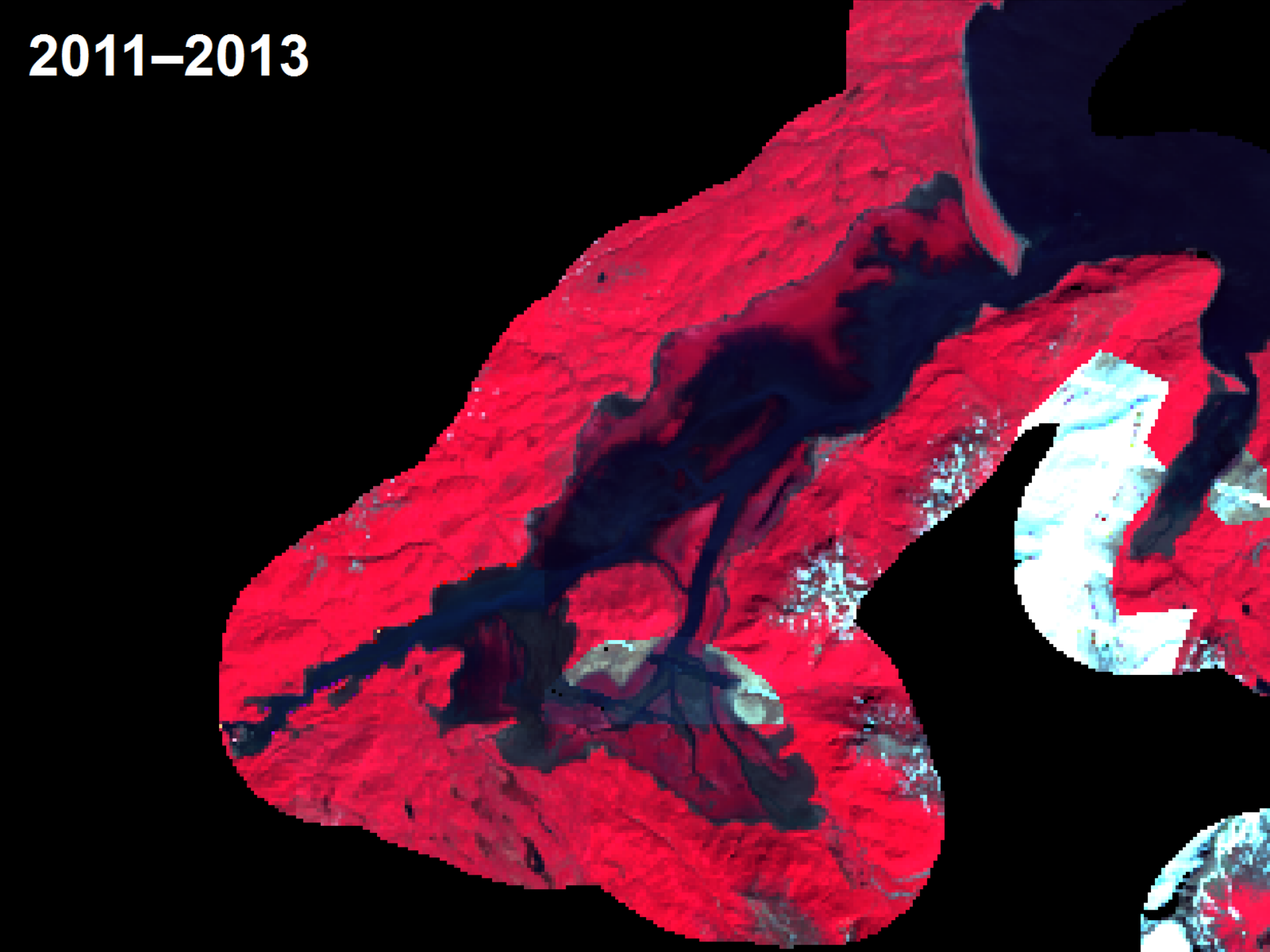

2011–2013

Change, 1972–2013

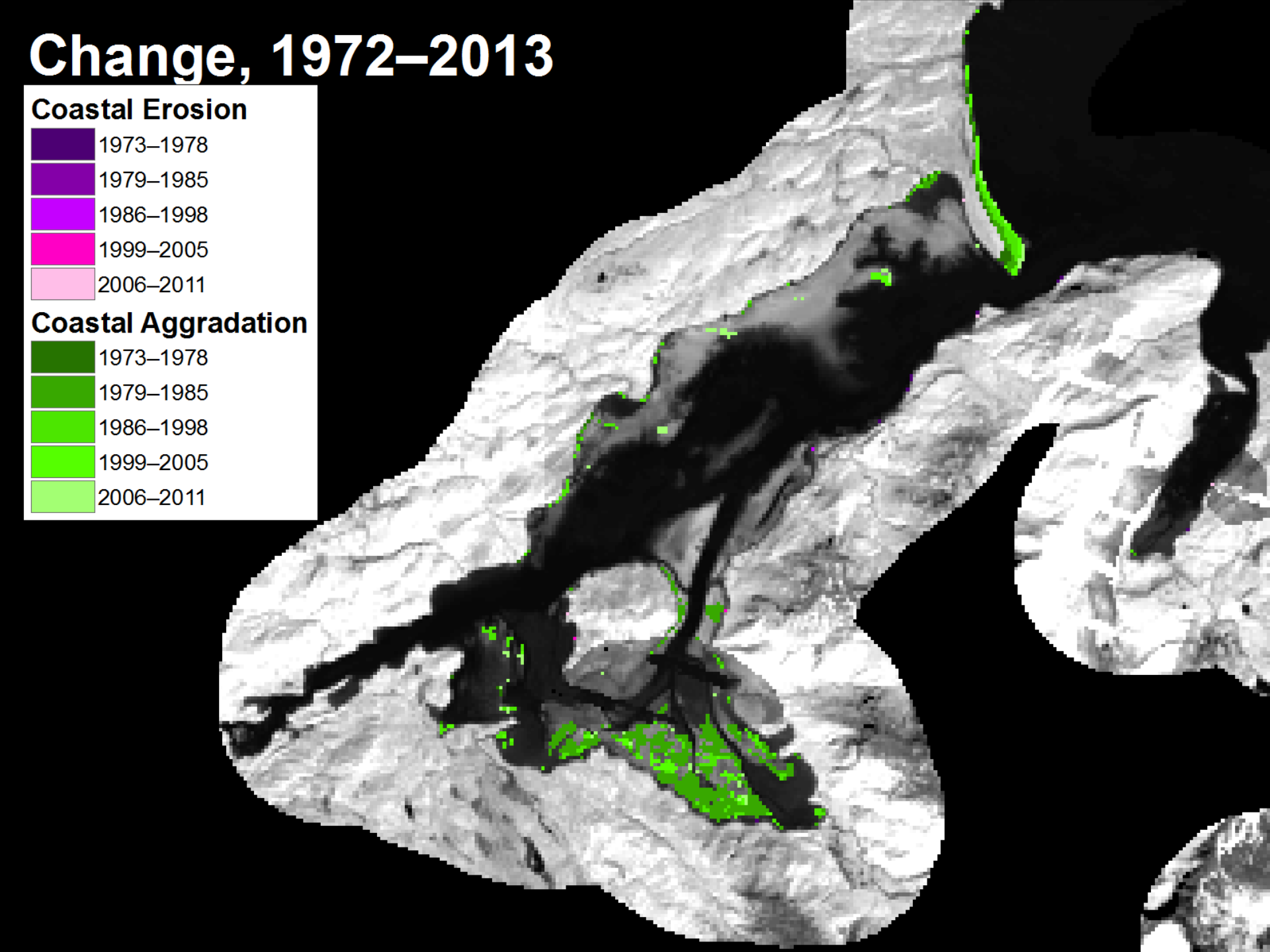


1972–1976

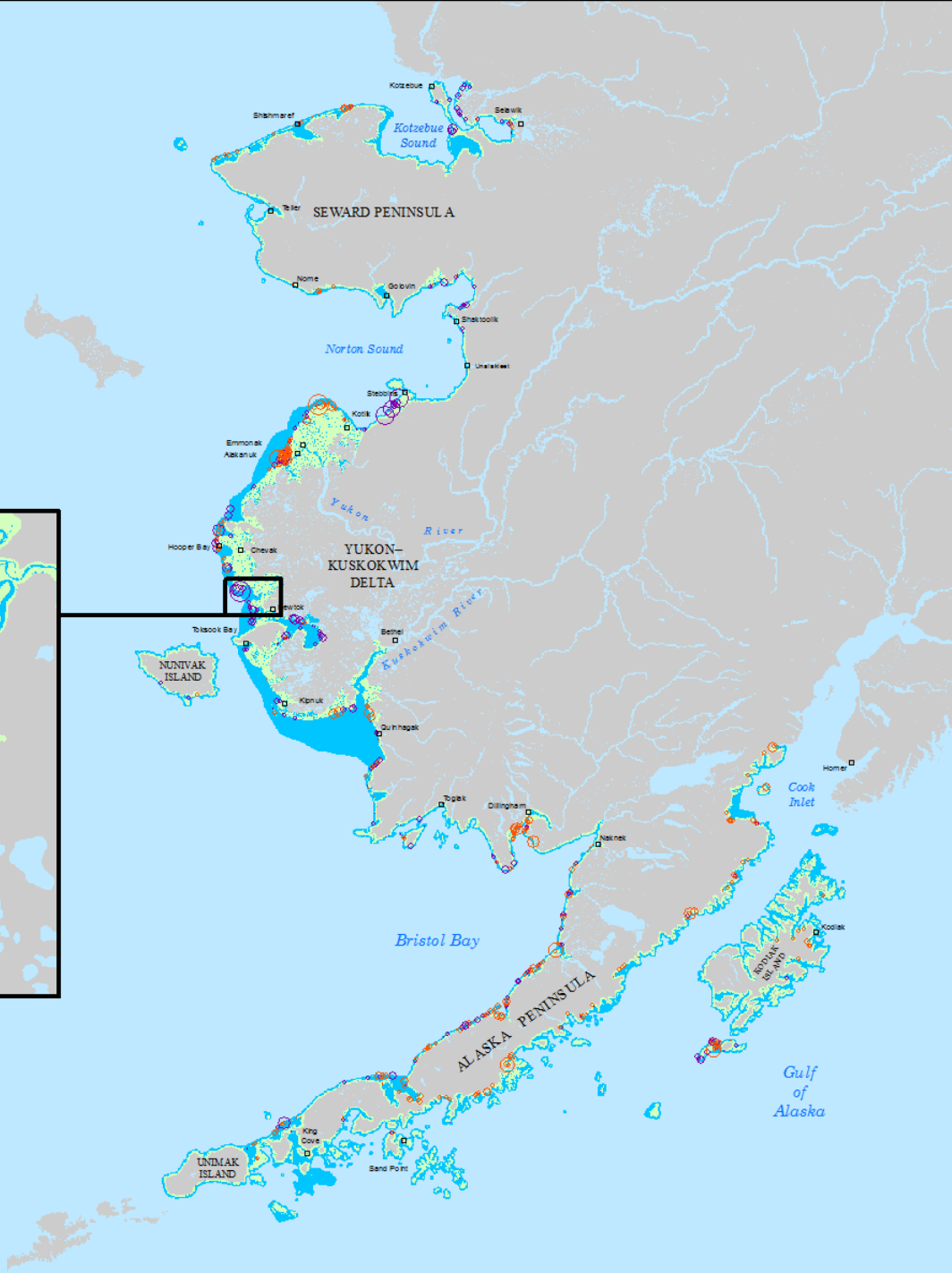



2011–2013

Change, 1972–2013



Hazen Bay Coastal Erosion



1972–1976

1977–1979

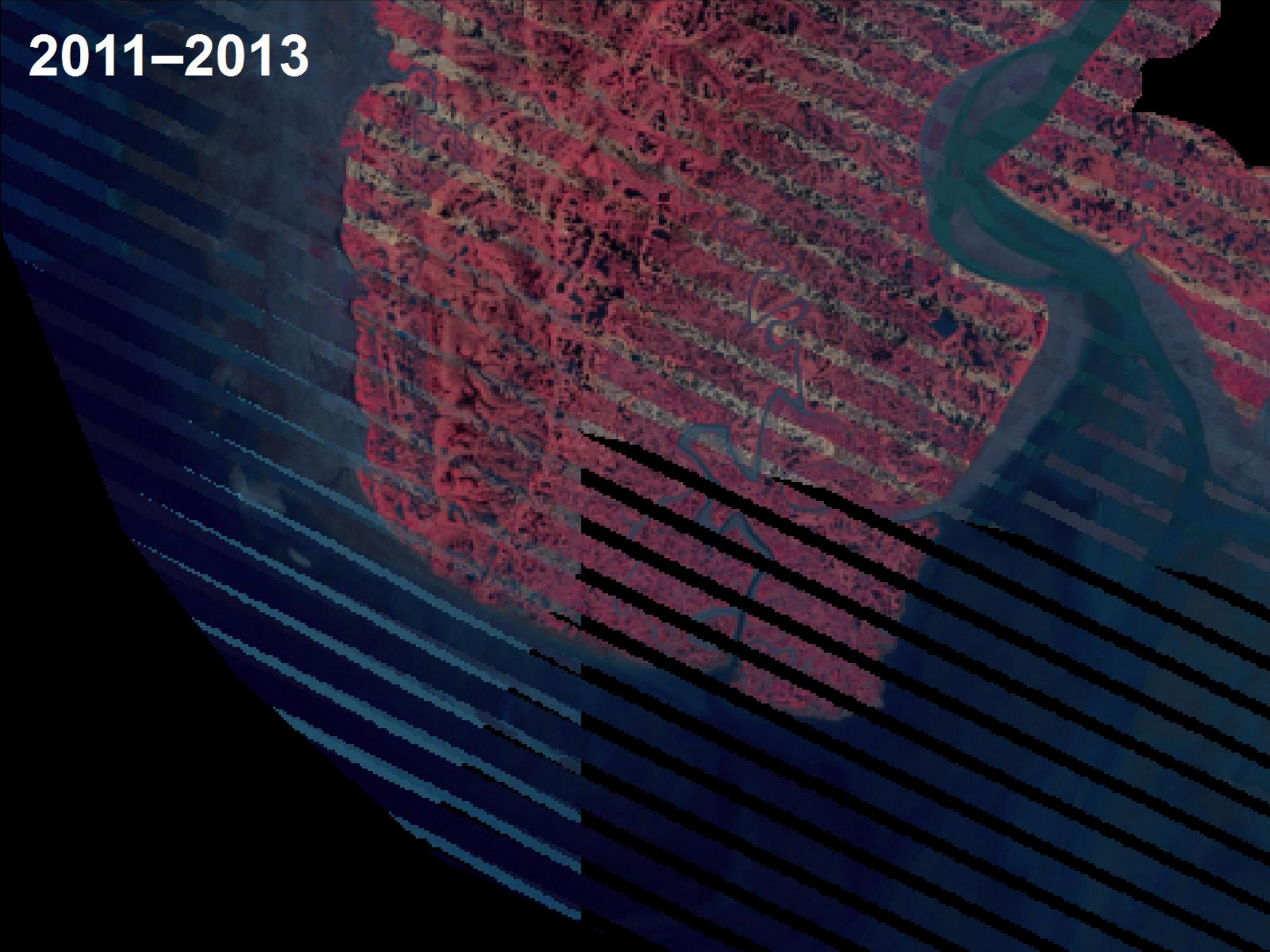
1980–1983

1984–1989

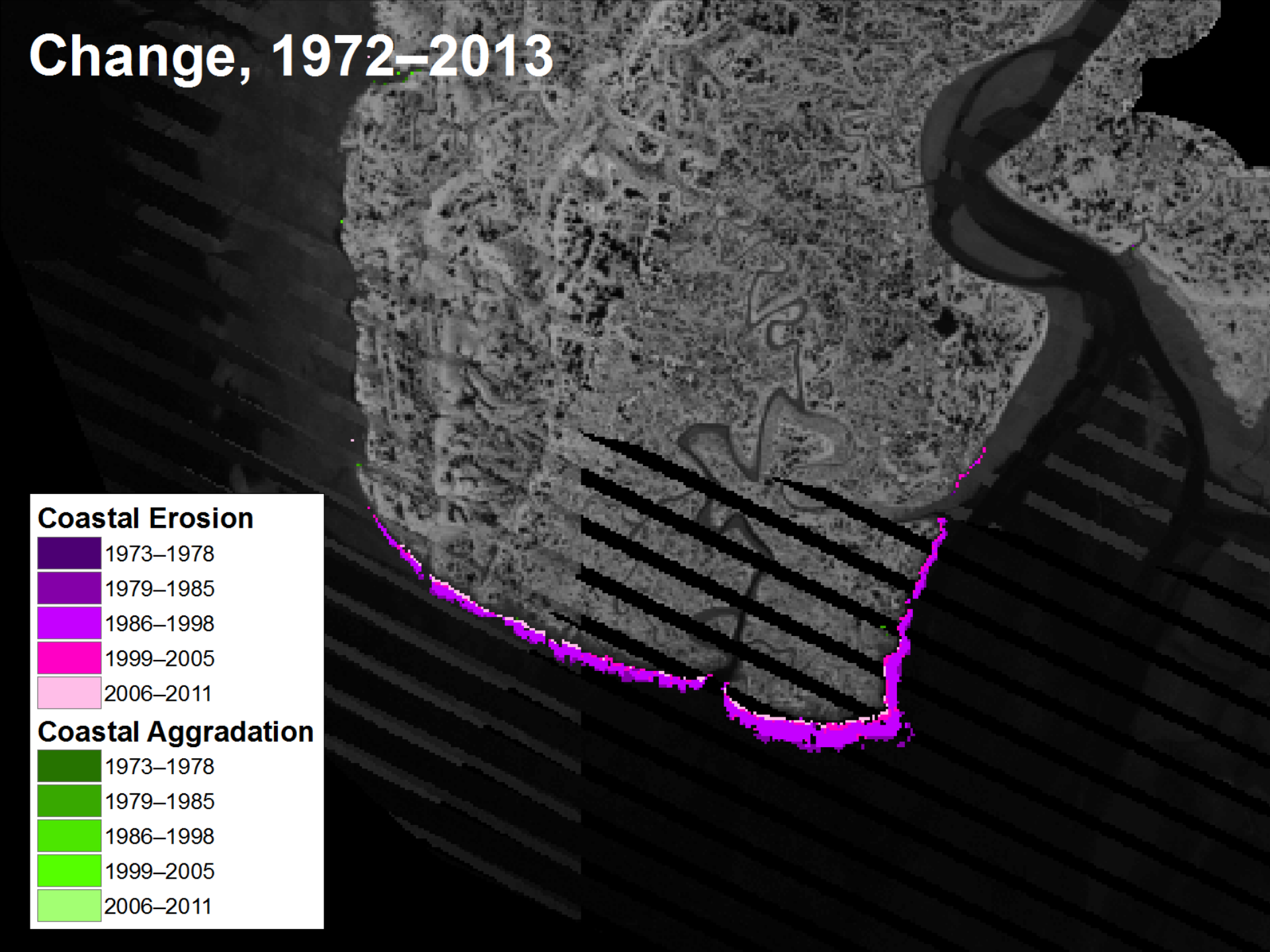
1999–2001

2002–2004

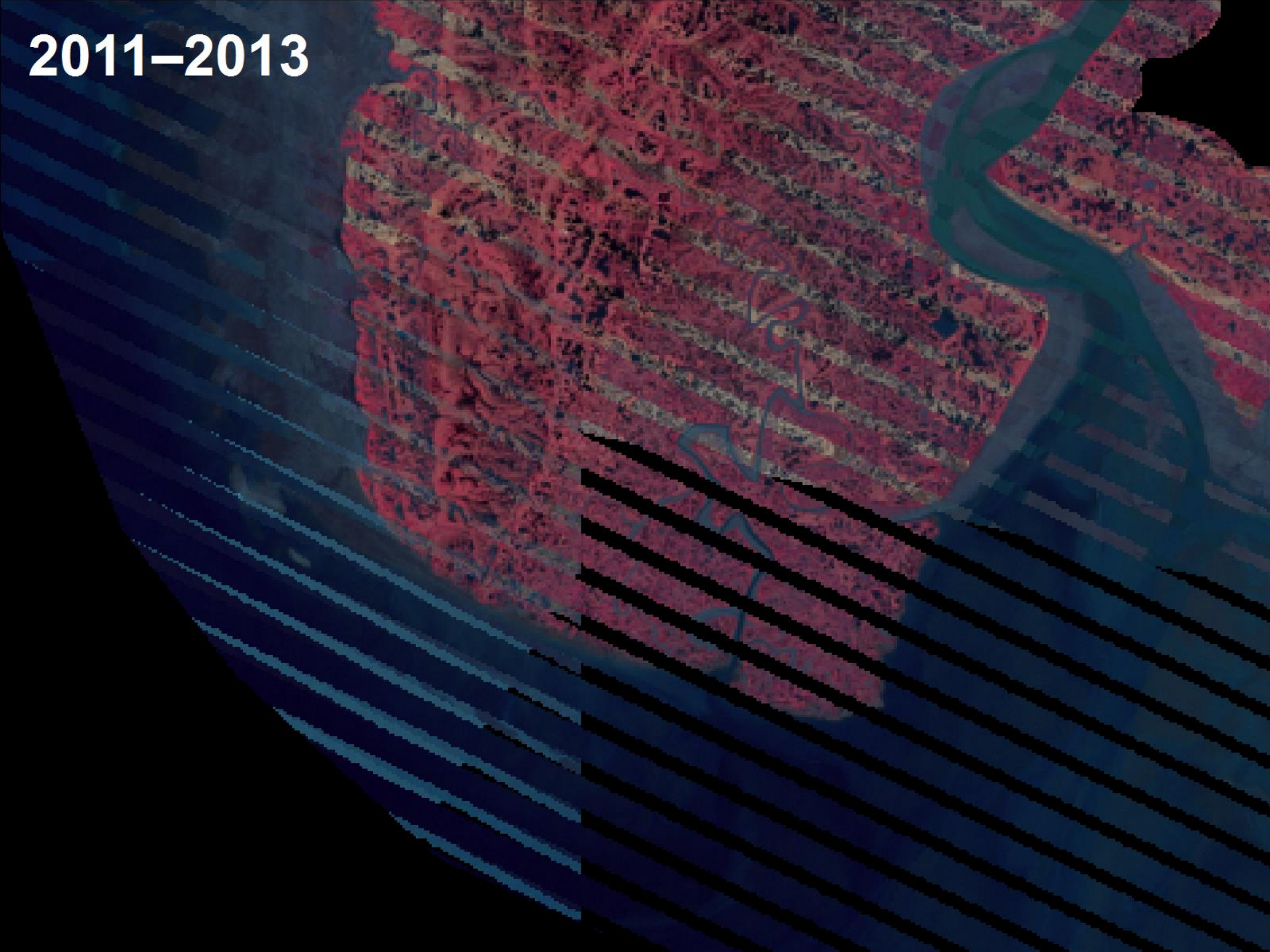
2008–2010


2011–2013

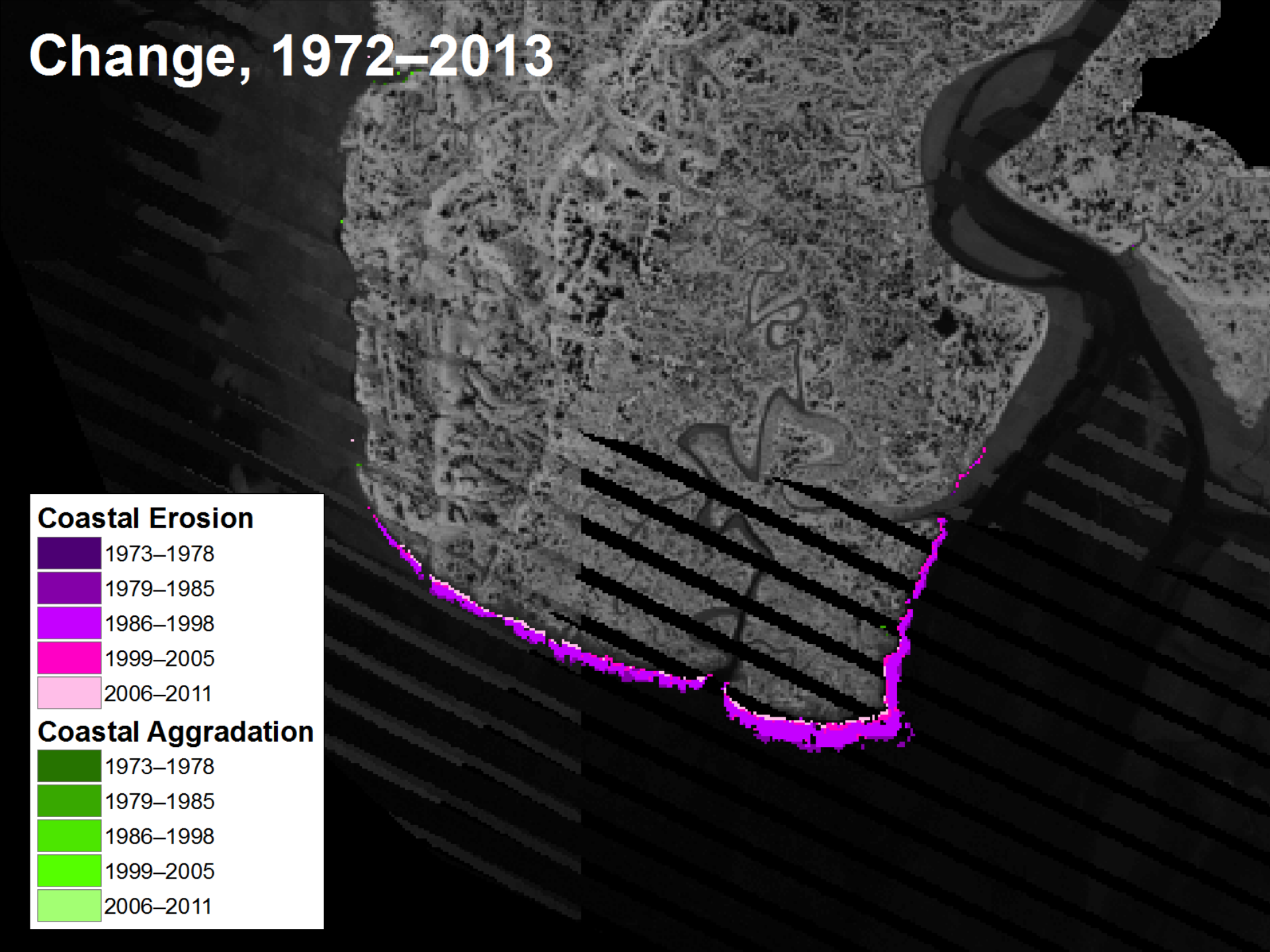
Change, 1972–2013



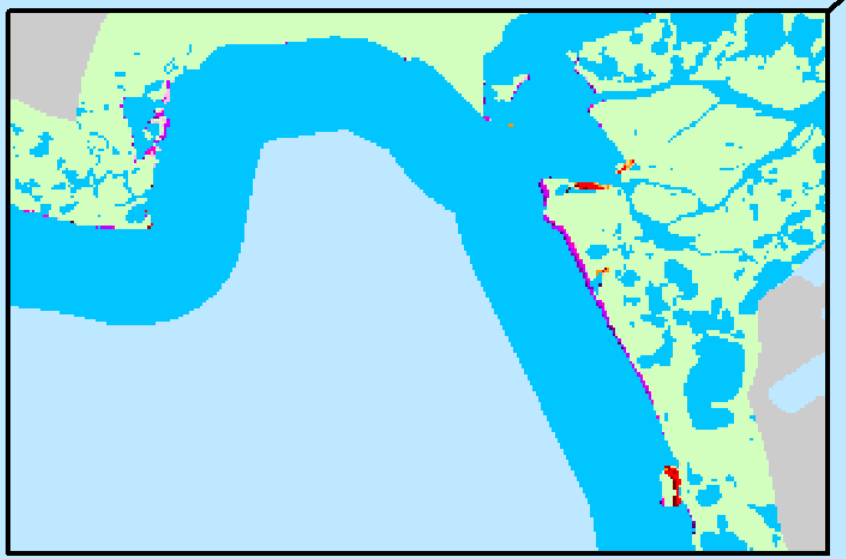
1972–1976

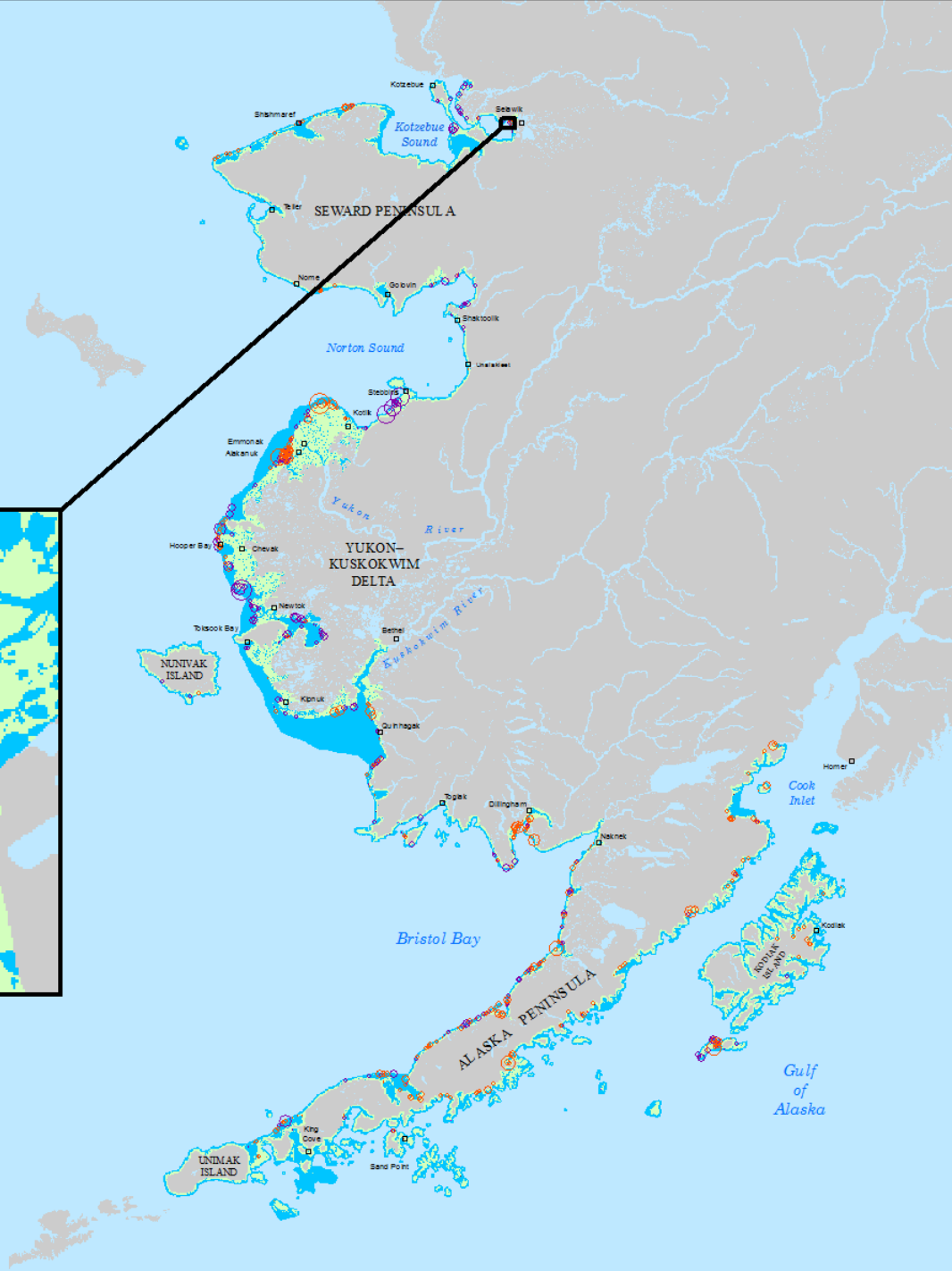

2011–2013

Change, 1972–2013



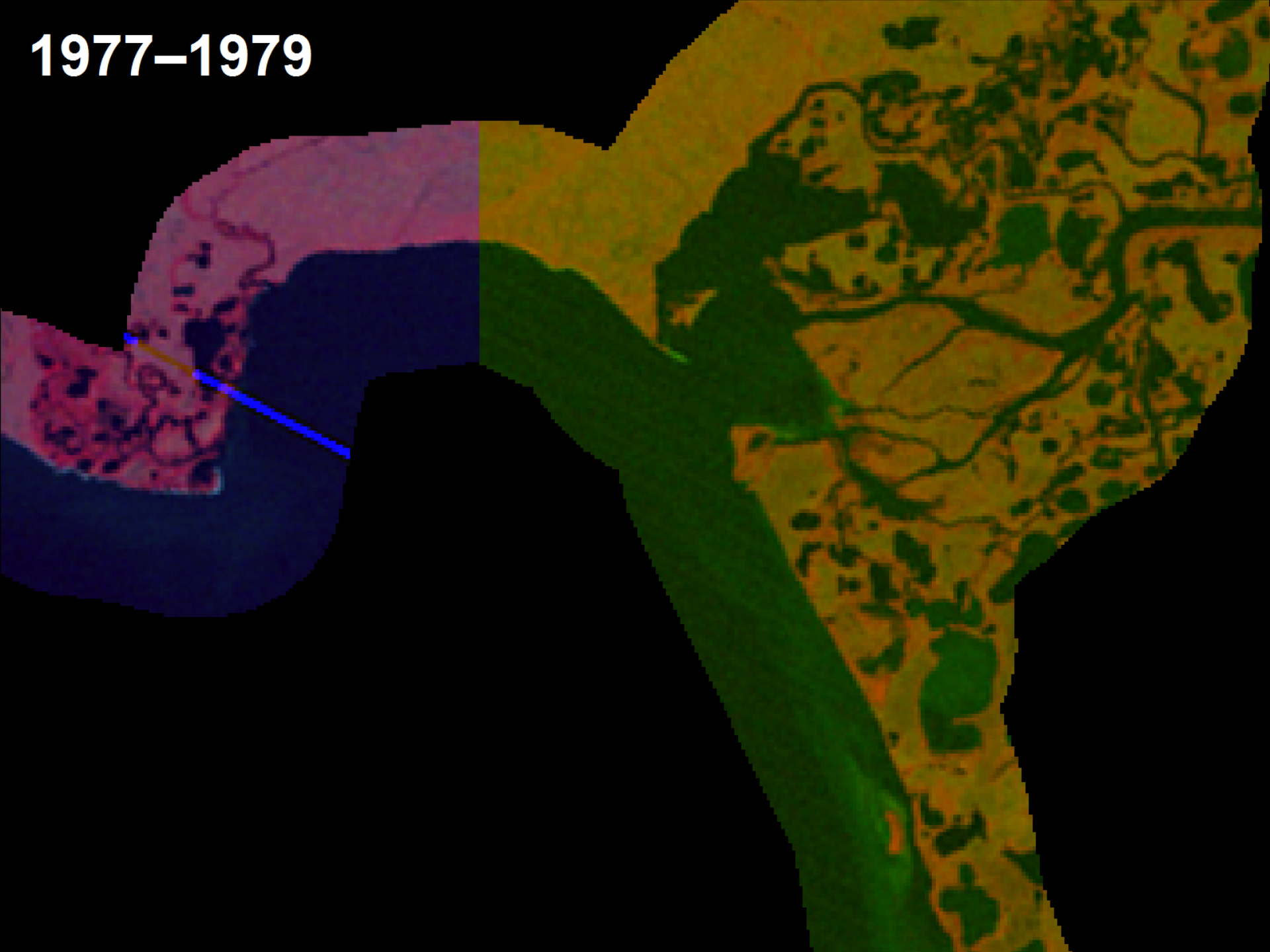
Shoniktok Point, Selawik Lake Coastal Change

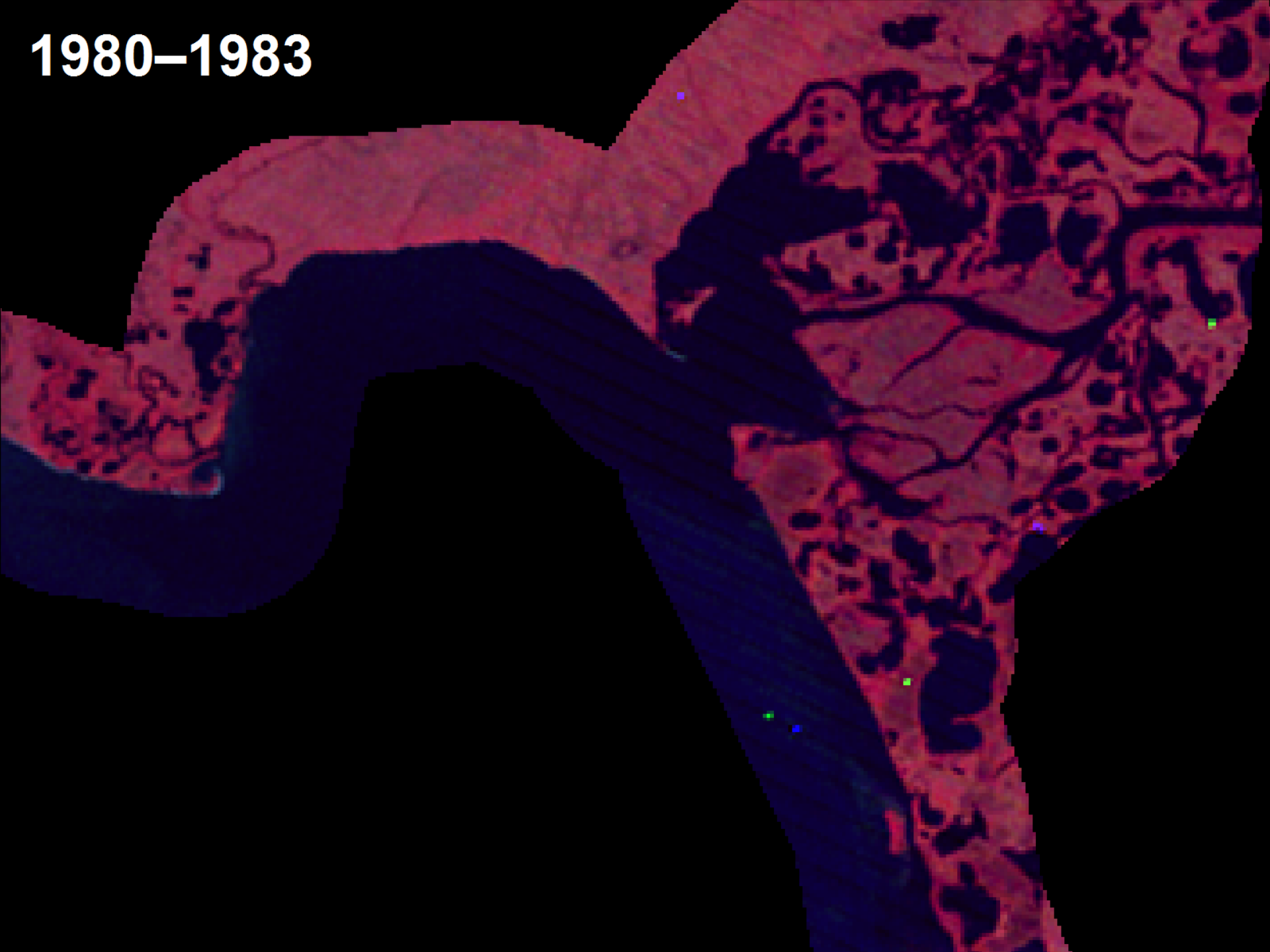




1972–1976

1977–1979




1980–1983

1984–1989

1990–1995

1999–2001

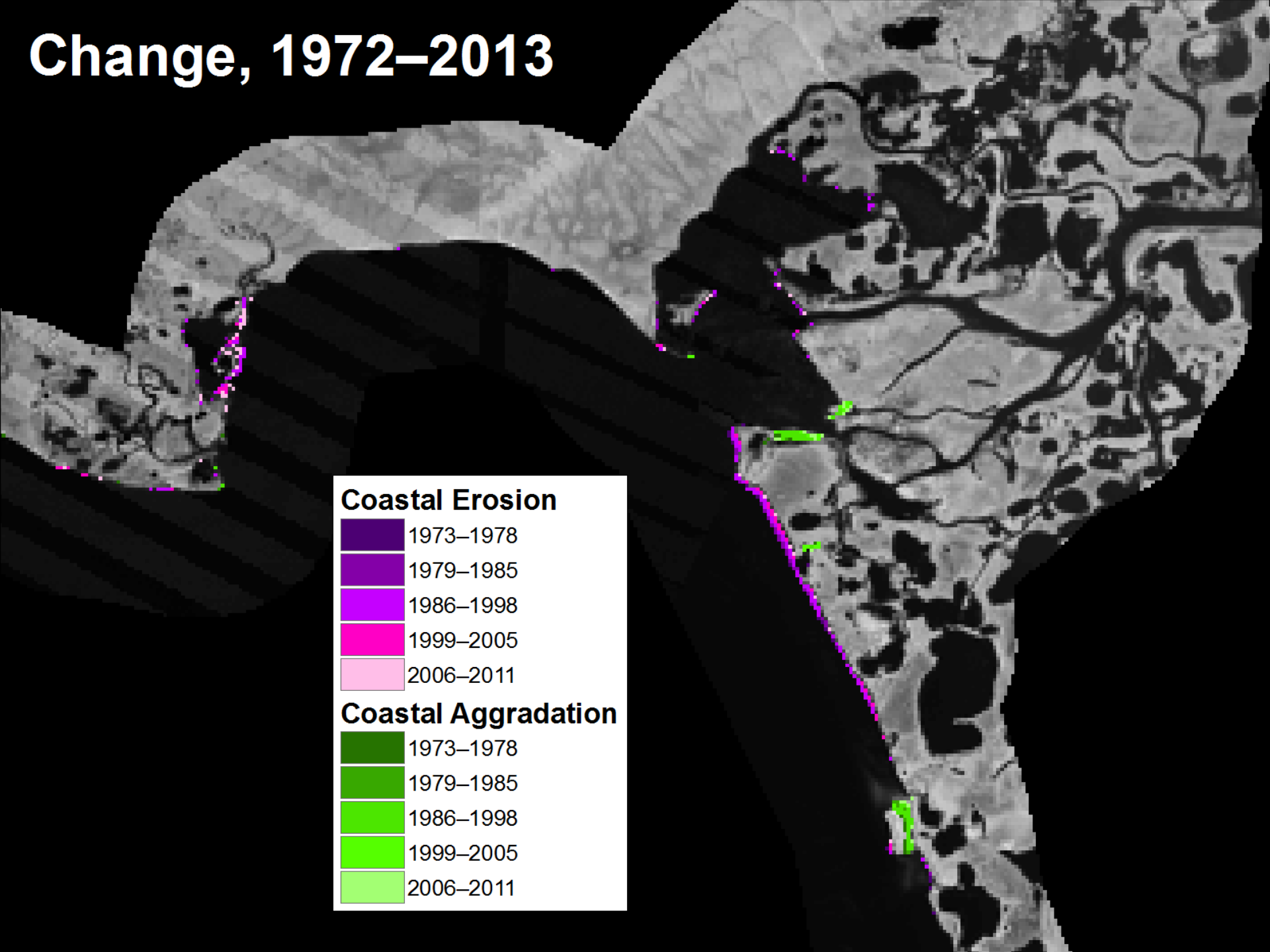
2002–2004

2005–2007

2008–2010

2011–2013

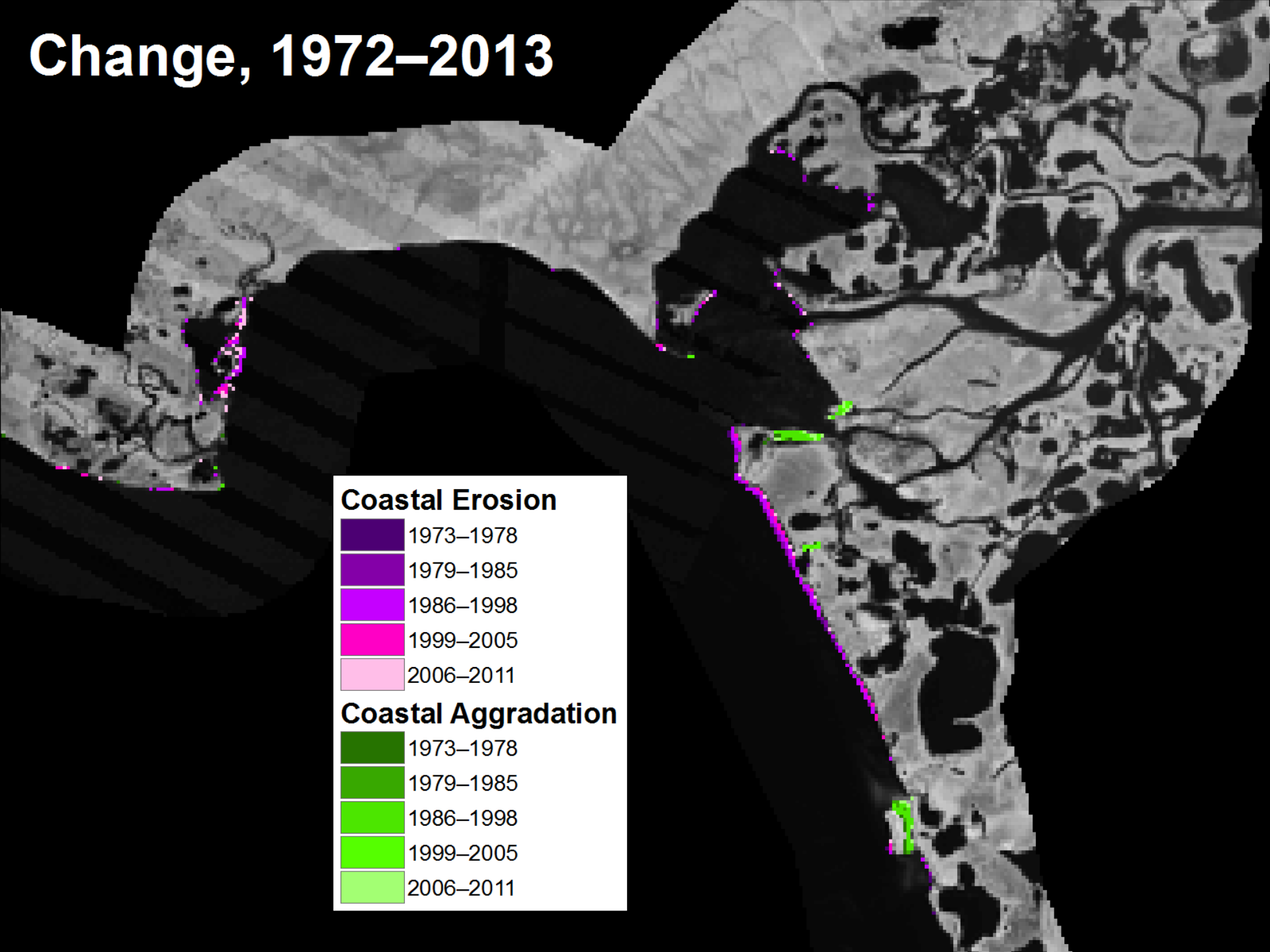
Change, 1972–2013



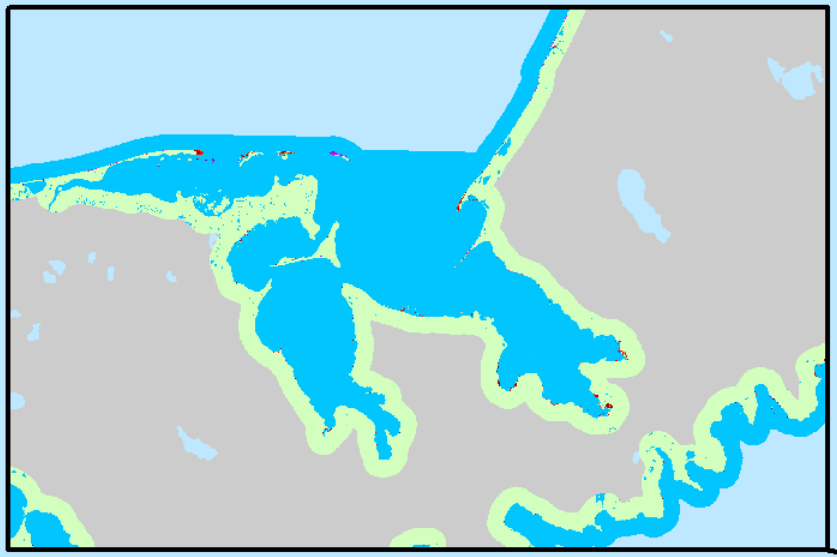
1972–1976

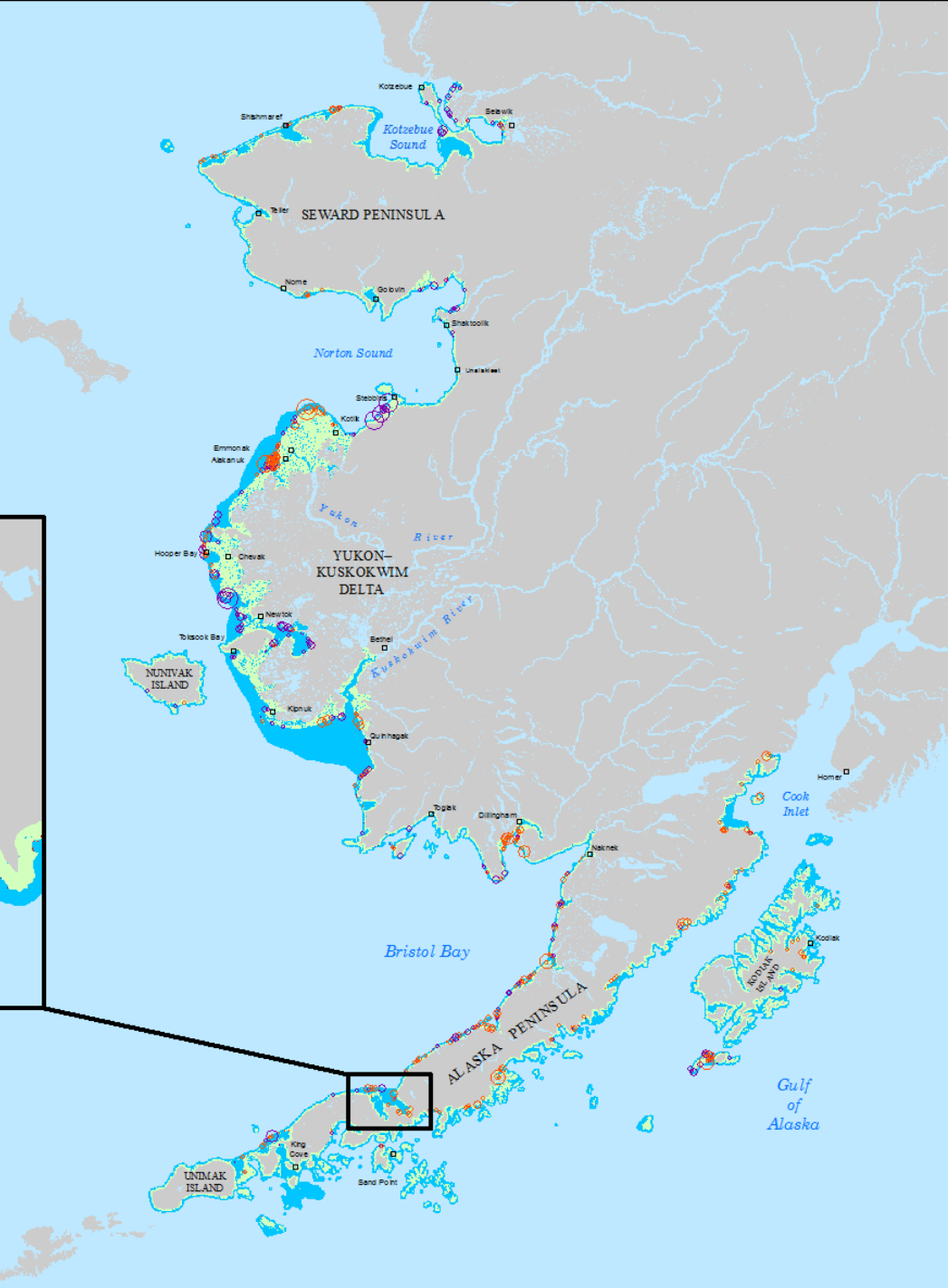
2011–2013

Change, 1972–2013



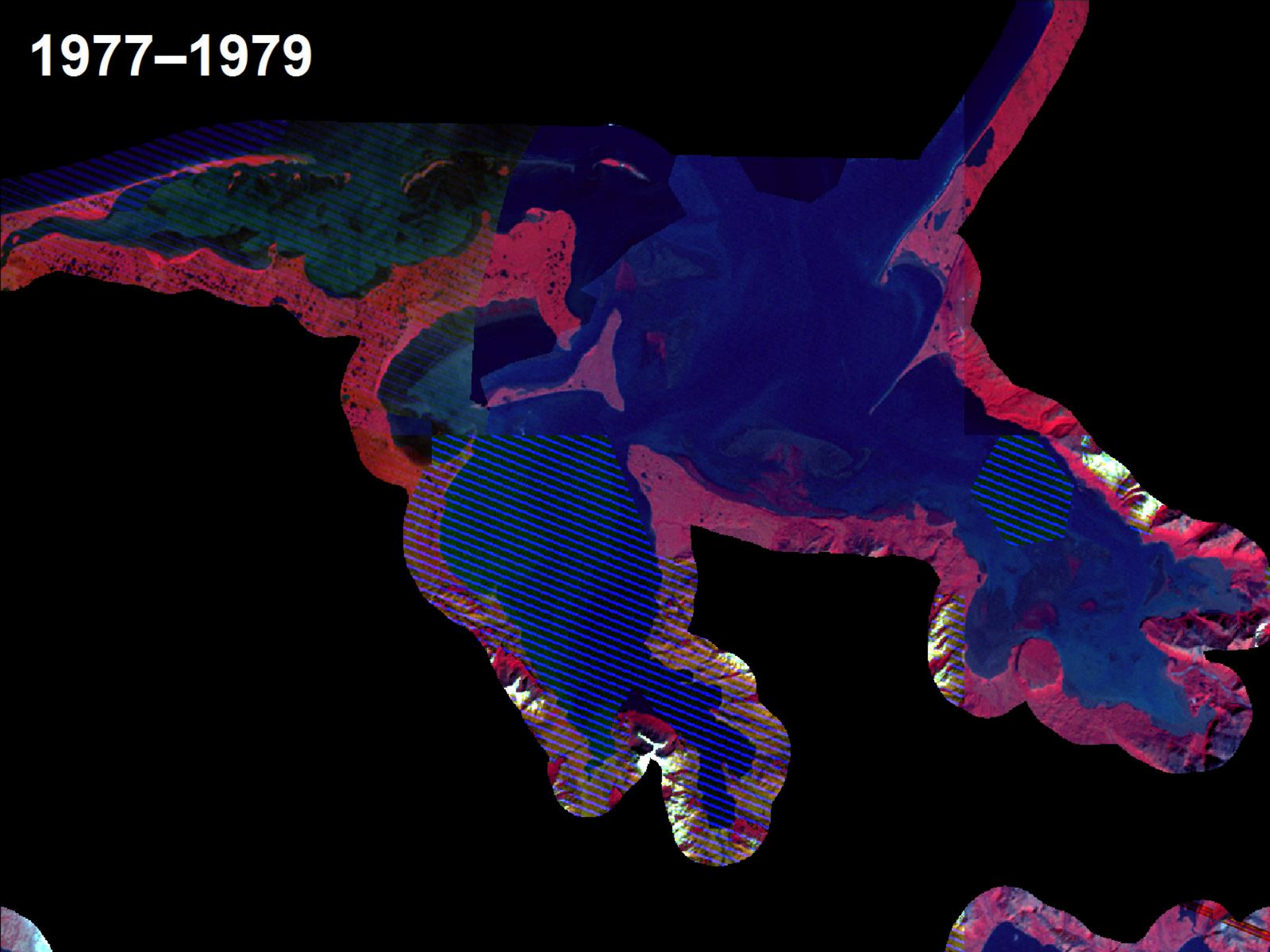
Port Moller and Nelson Lagoon, Coastal Change



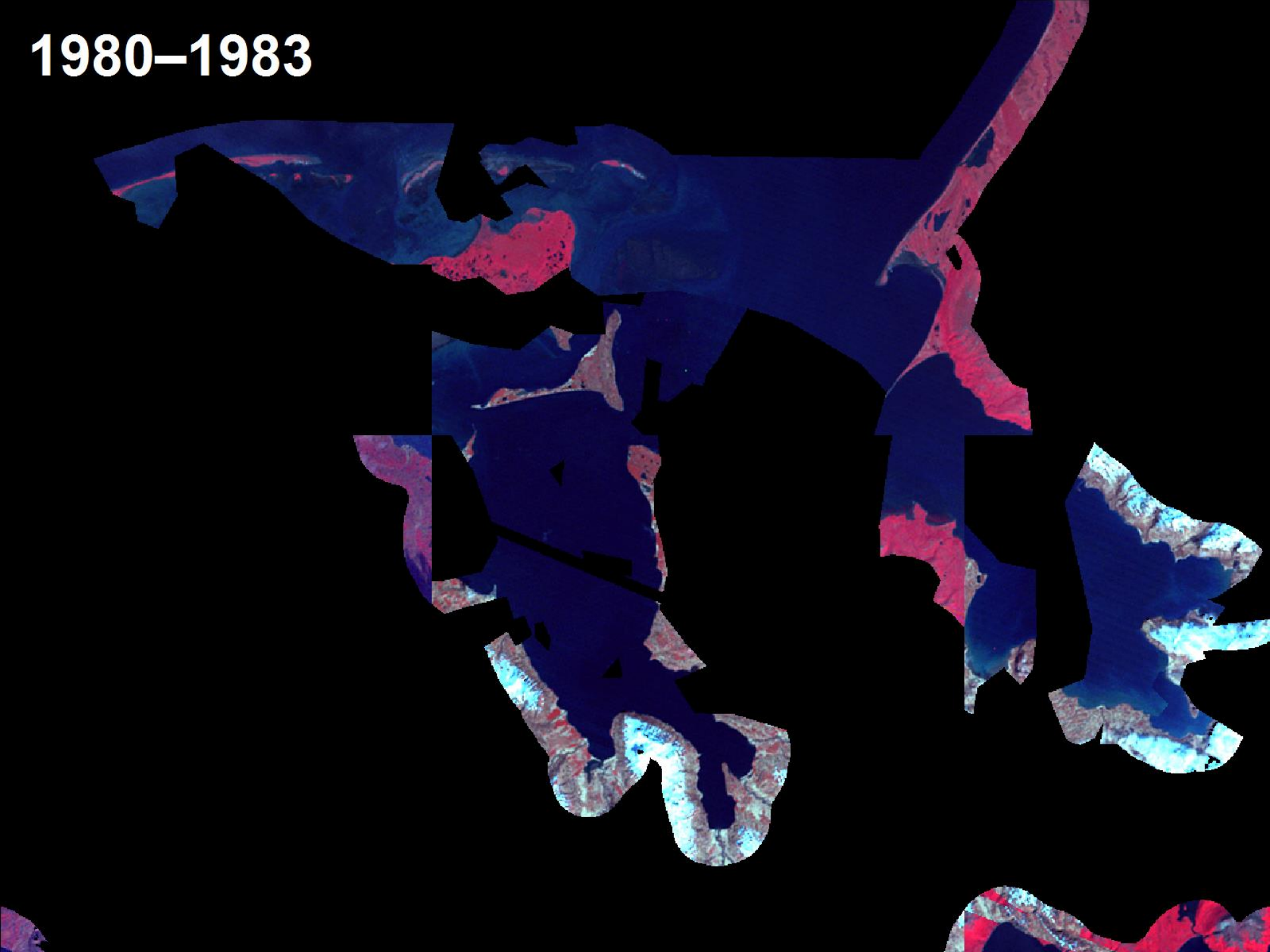


1972–1976

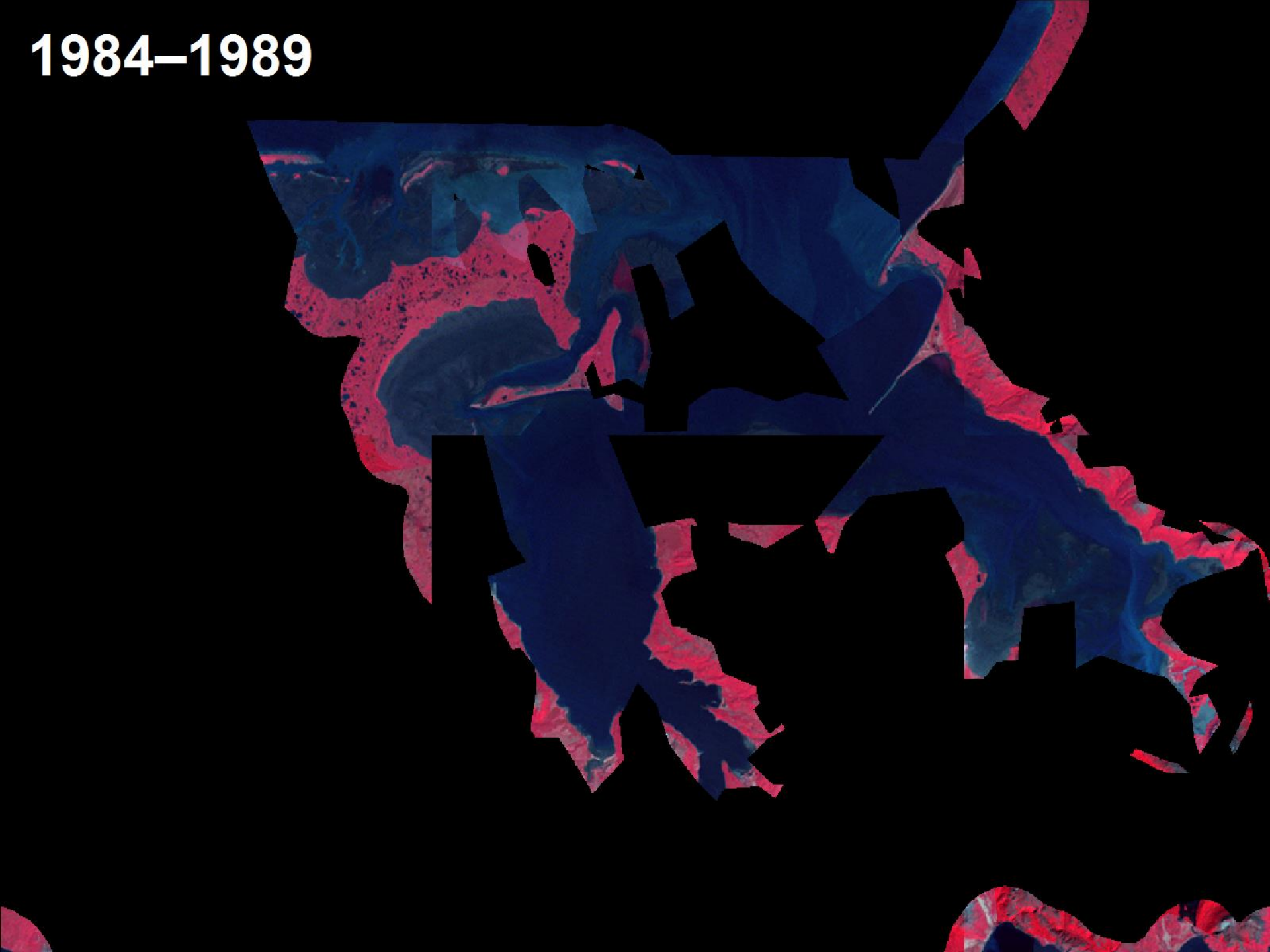
1977–1979

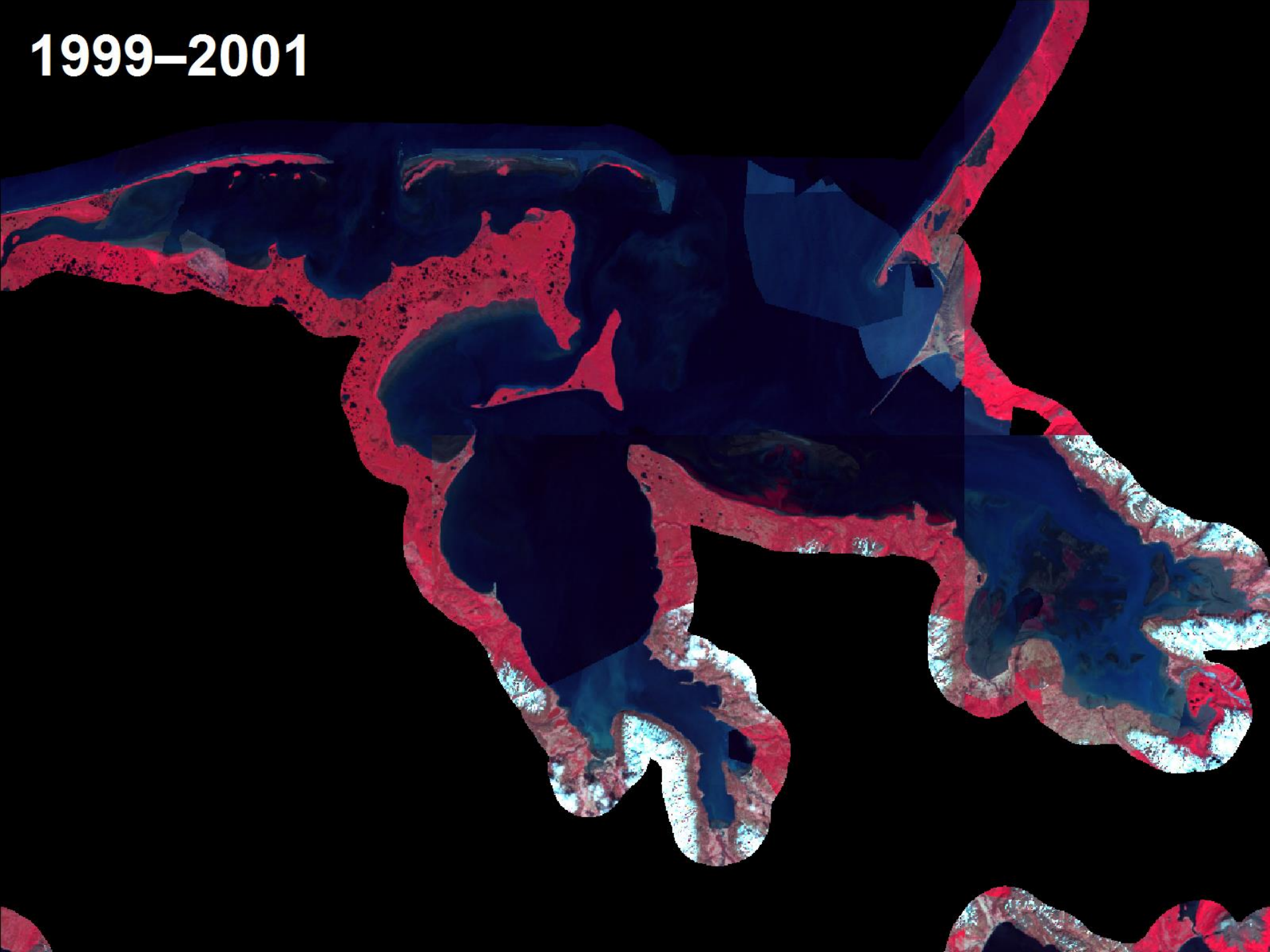


1980–1983



1984–1989

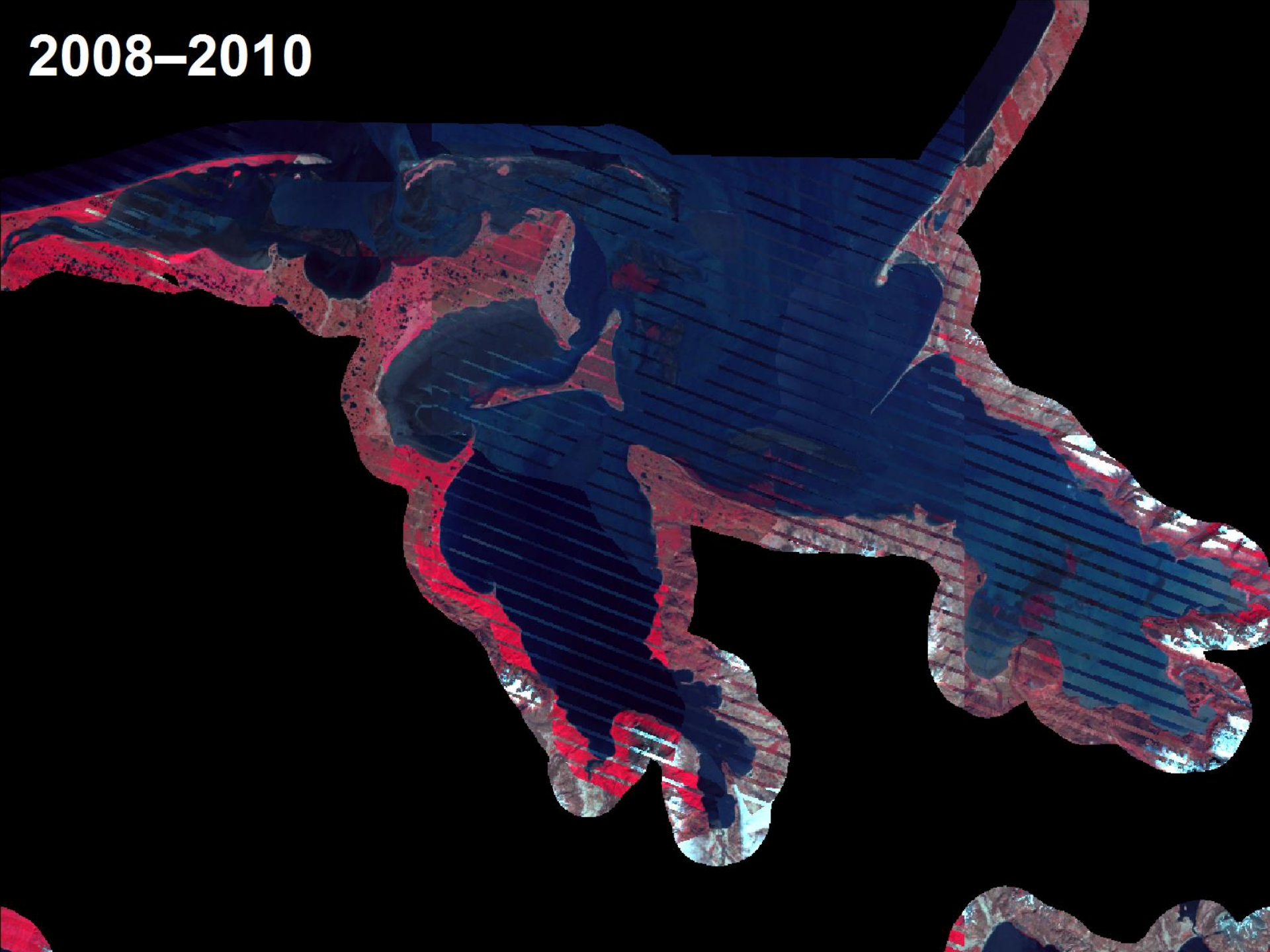



1999–2001

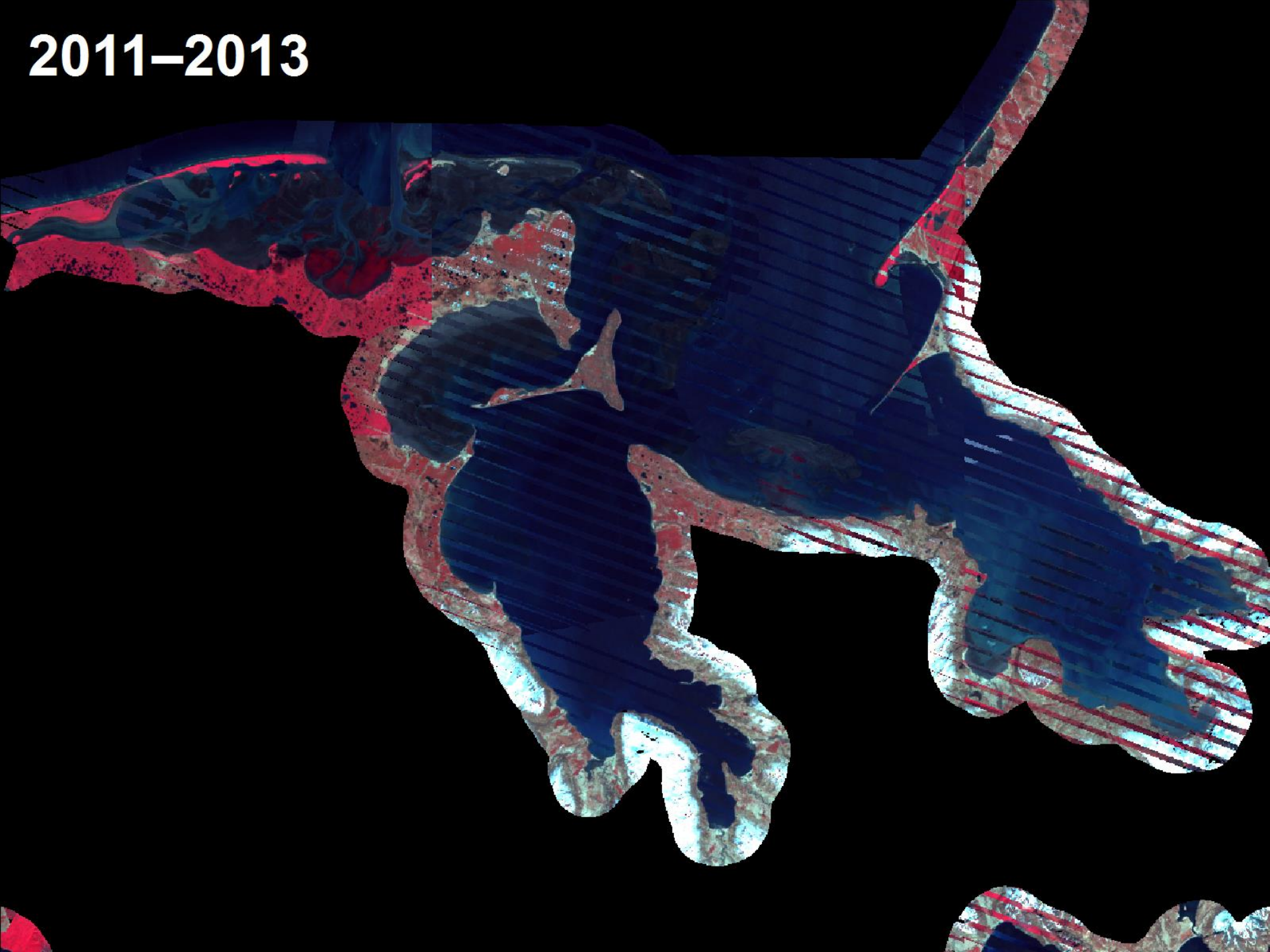
2002–2004

2005–2007

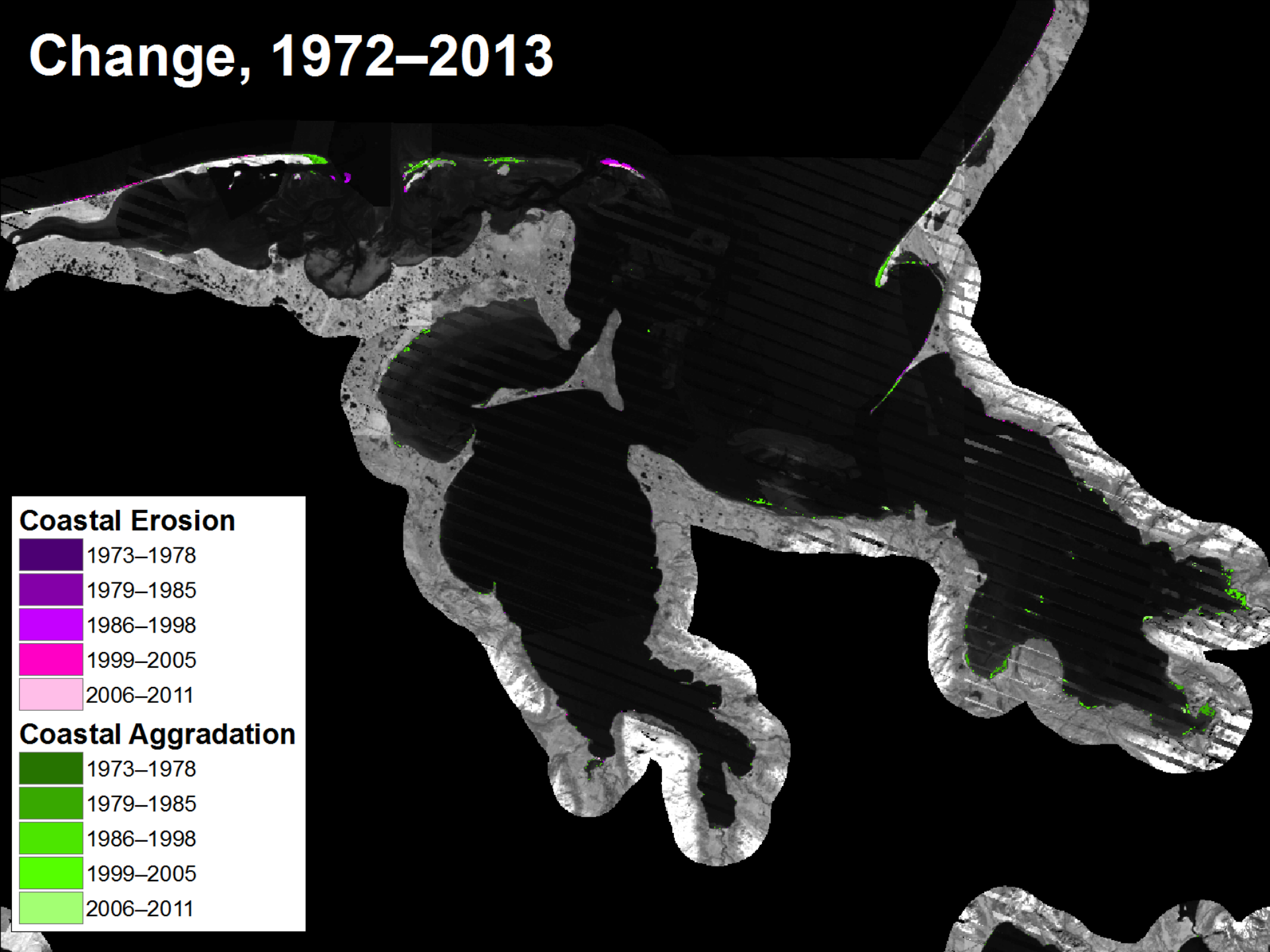
2008–2010



2011–2013

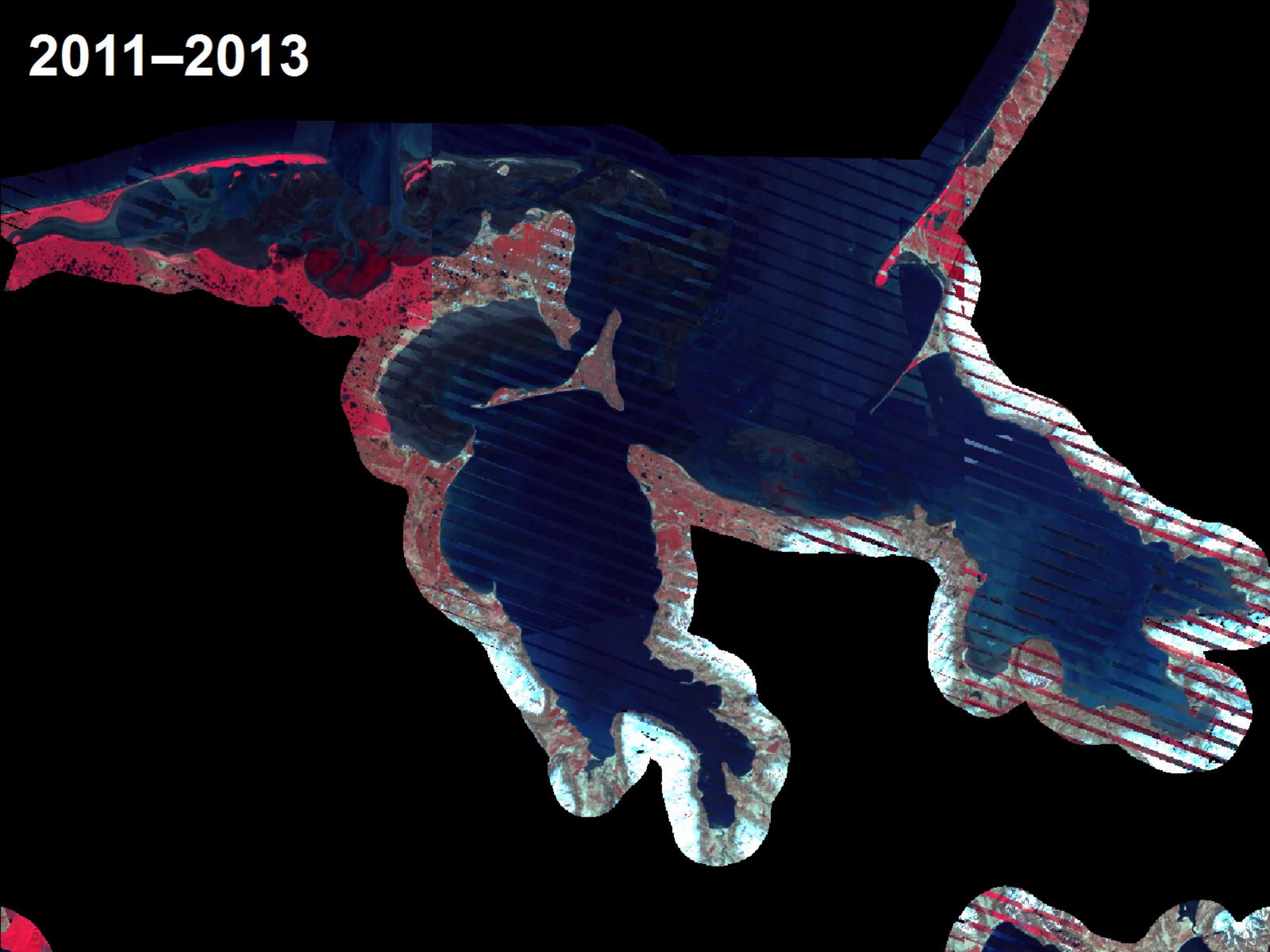


Change, 1972–2013

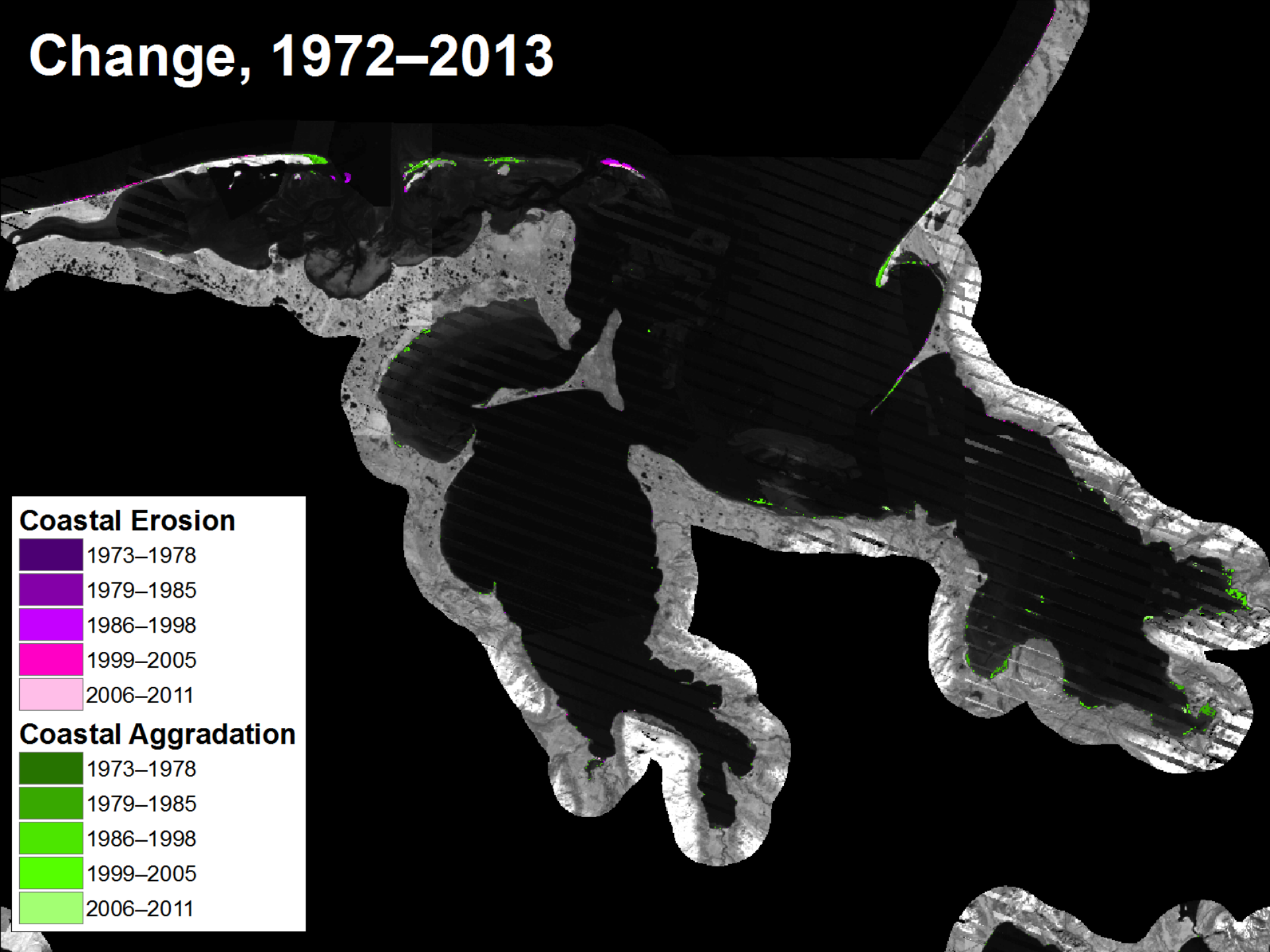


1972–1976

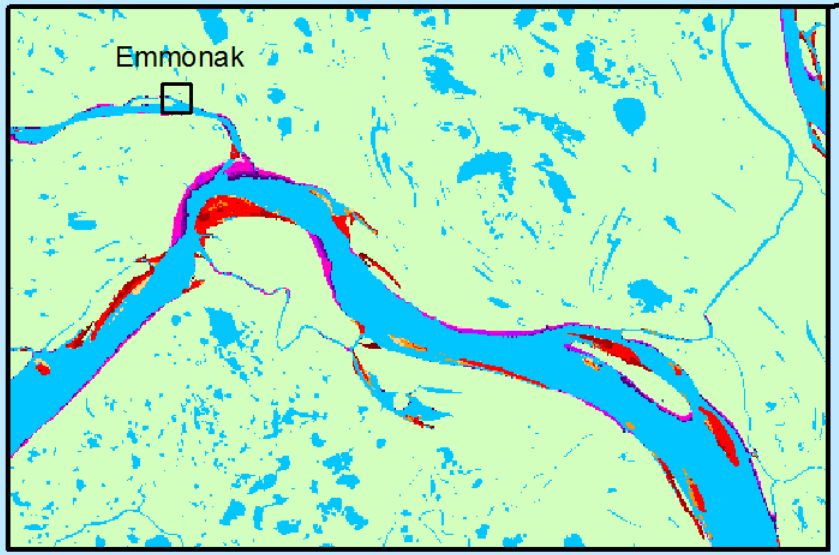
2011–2013

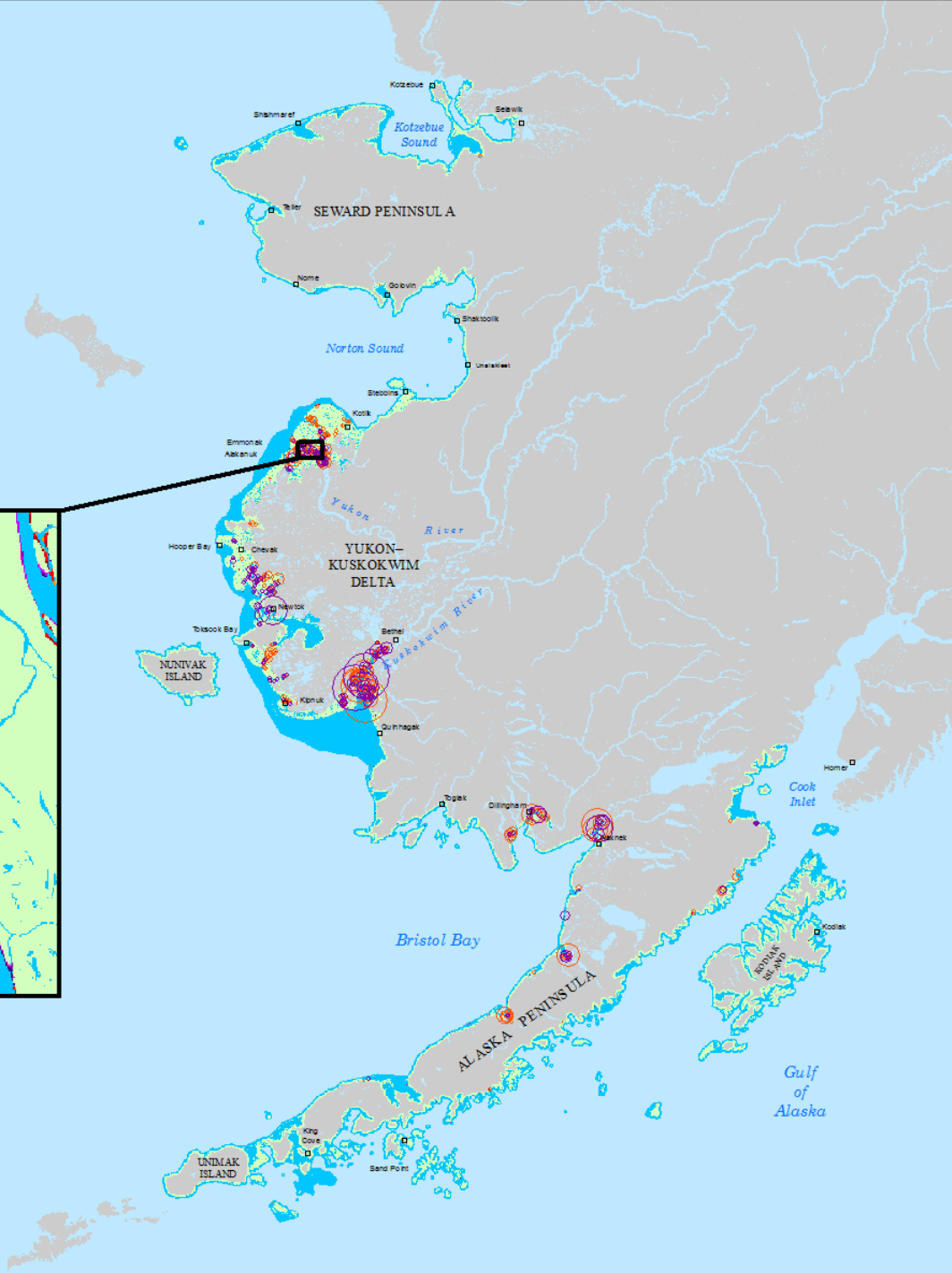


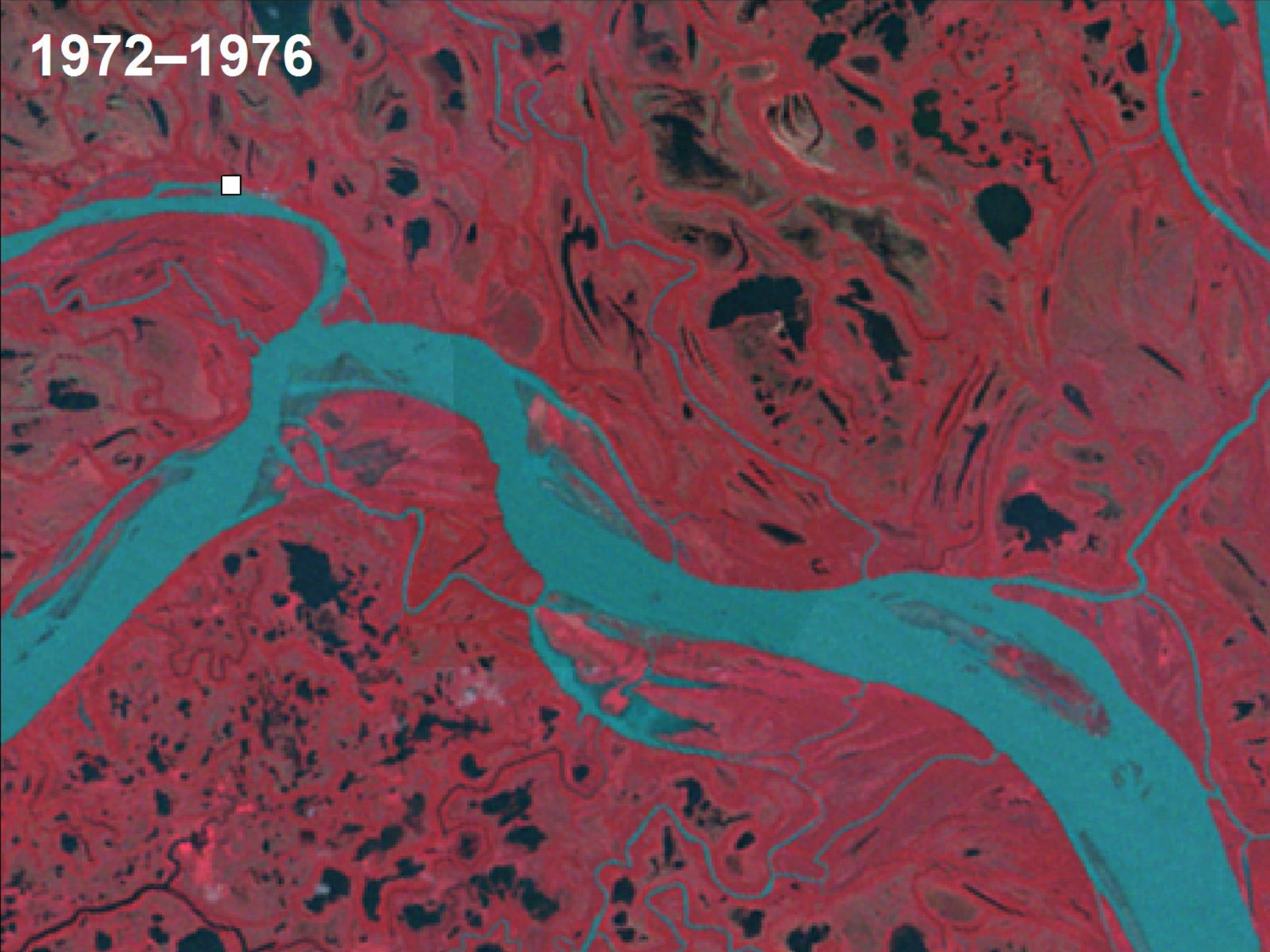
Change, 1972–2013



Emmonak Kwikluak Pass, Yukon River Riverine Change



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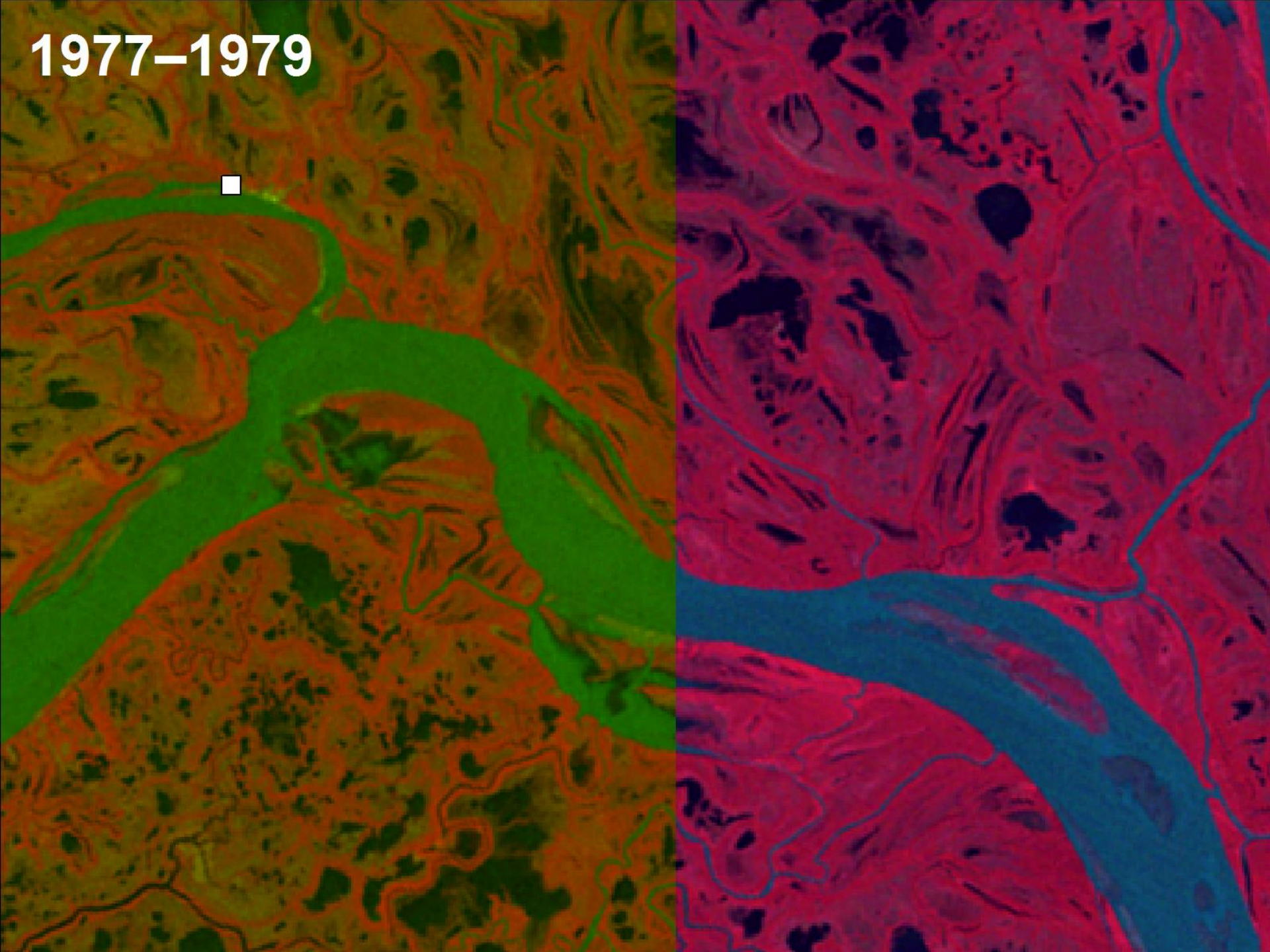
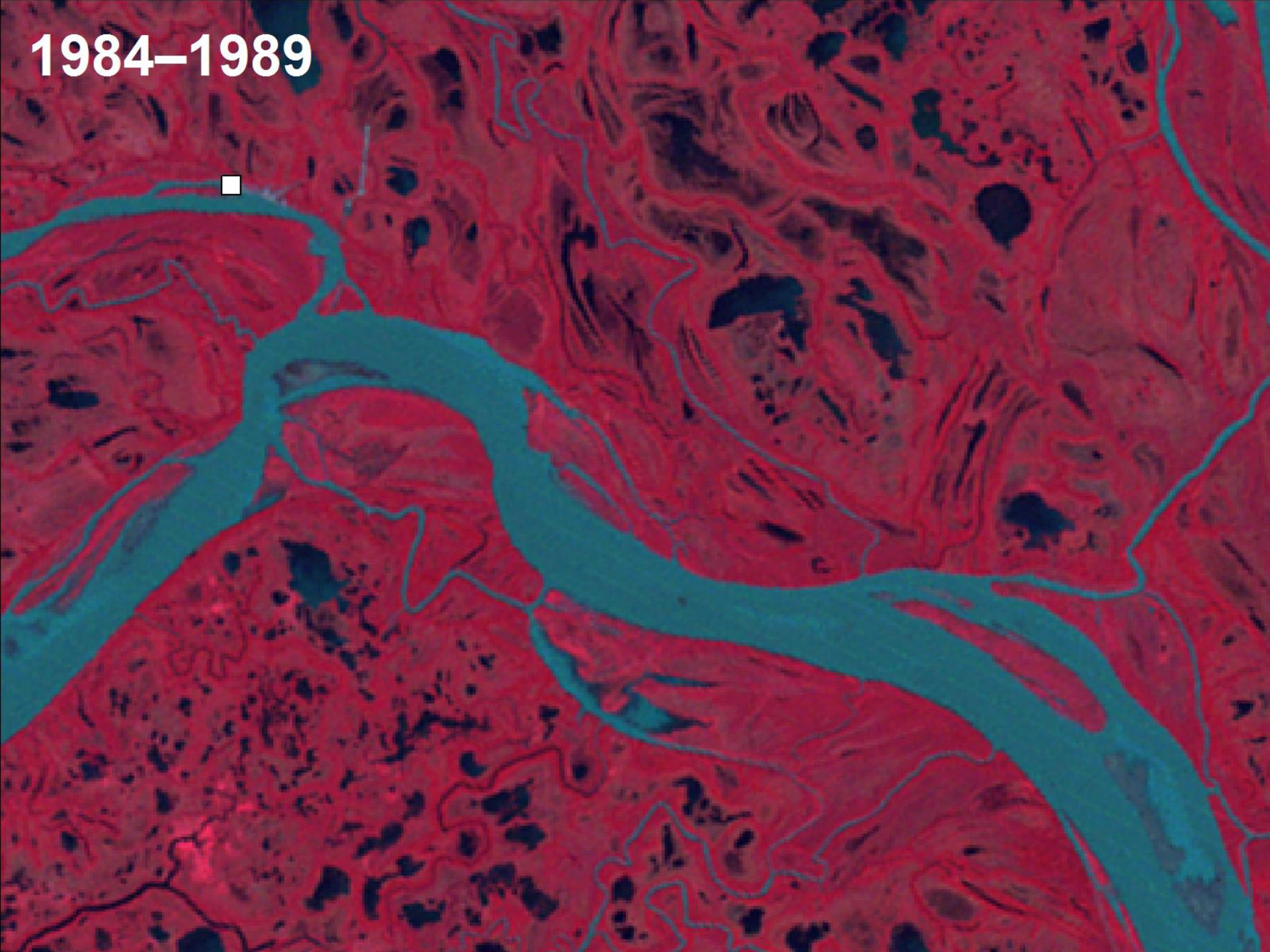

1977–1979

1980–1983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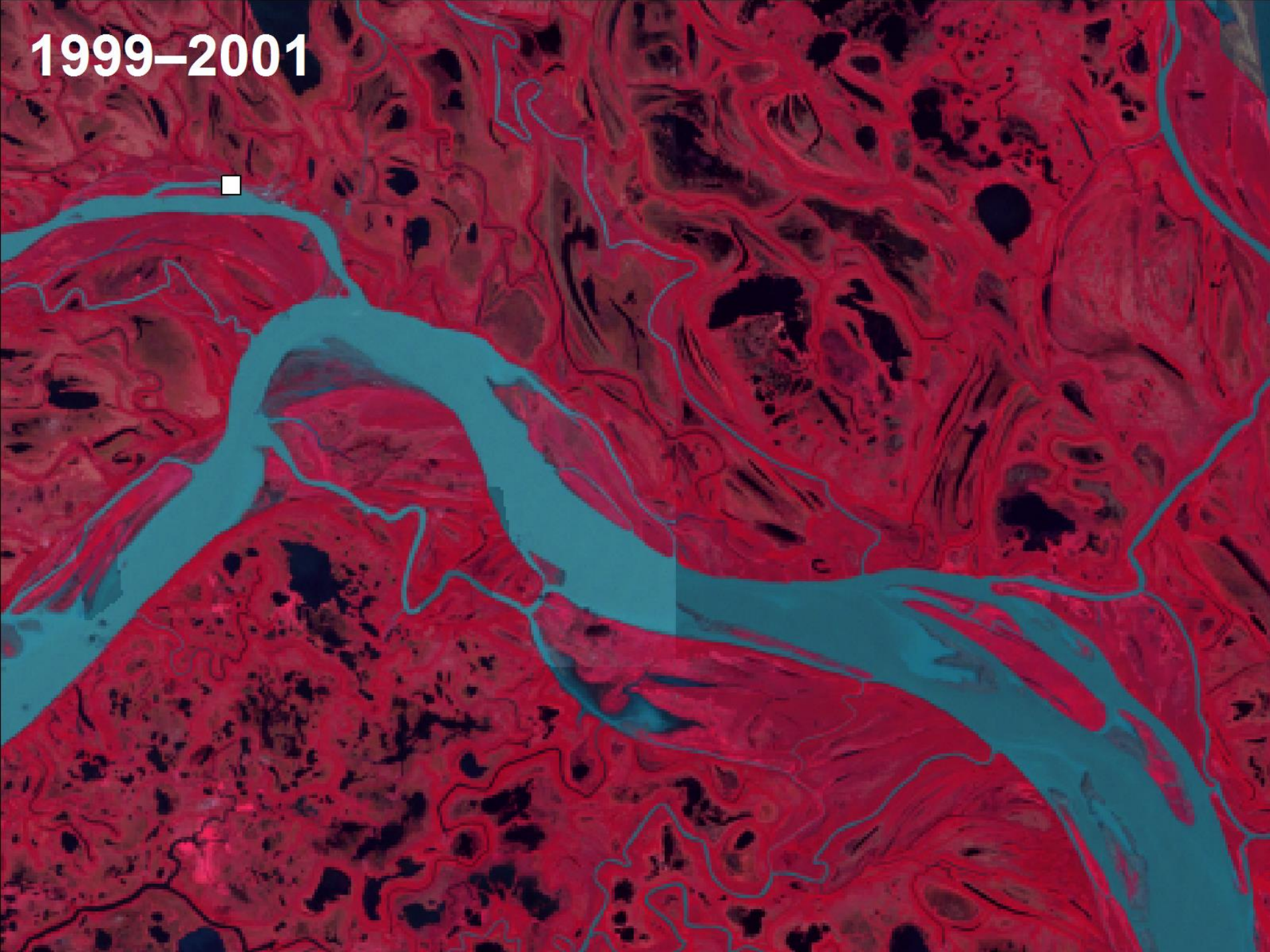
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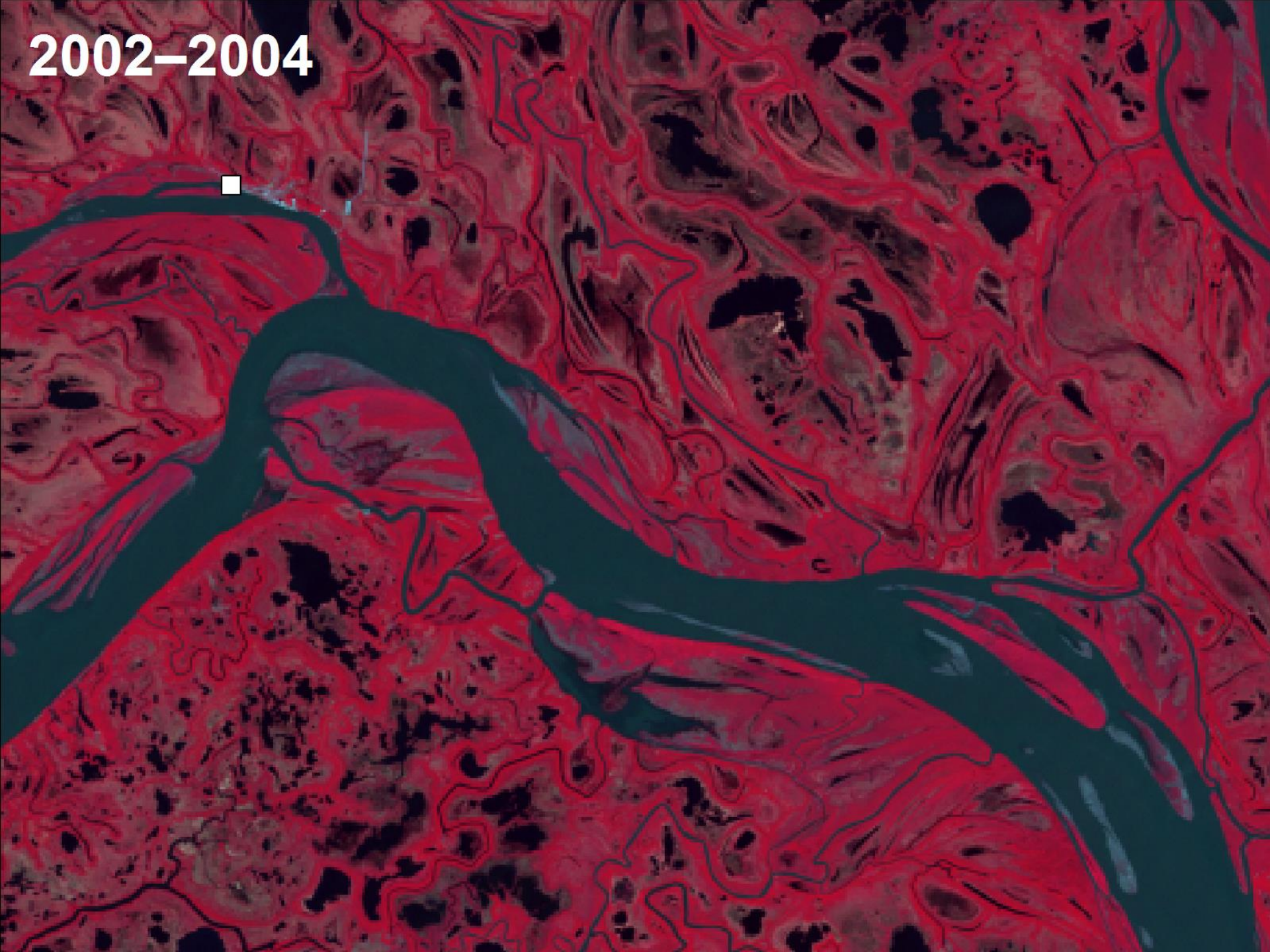
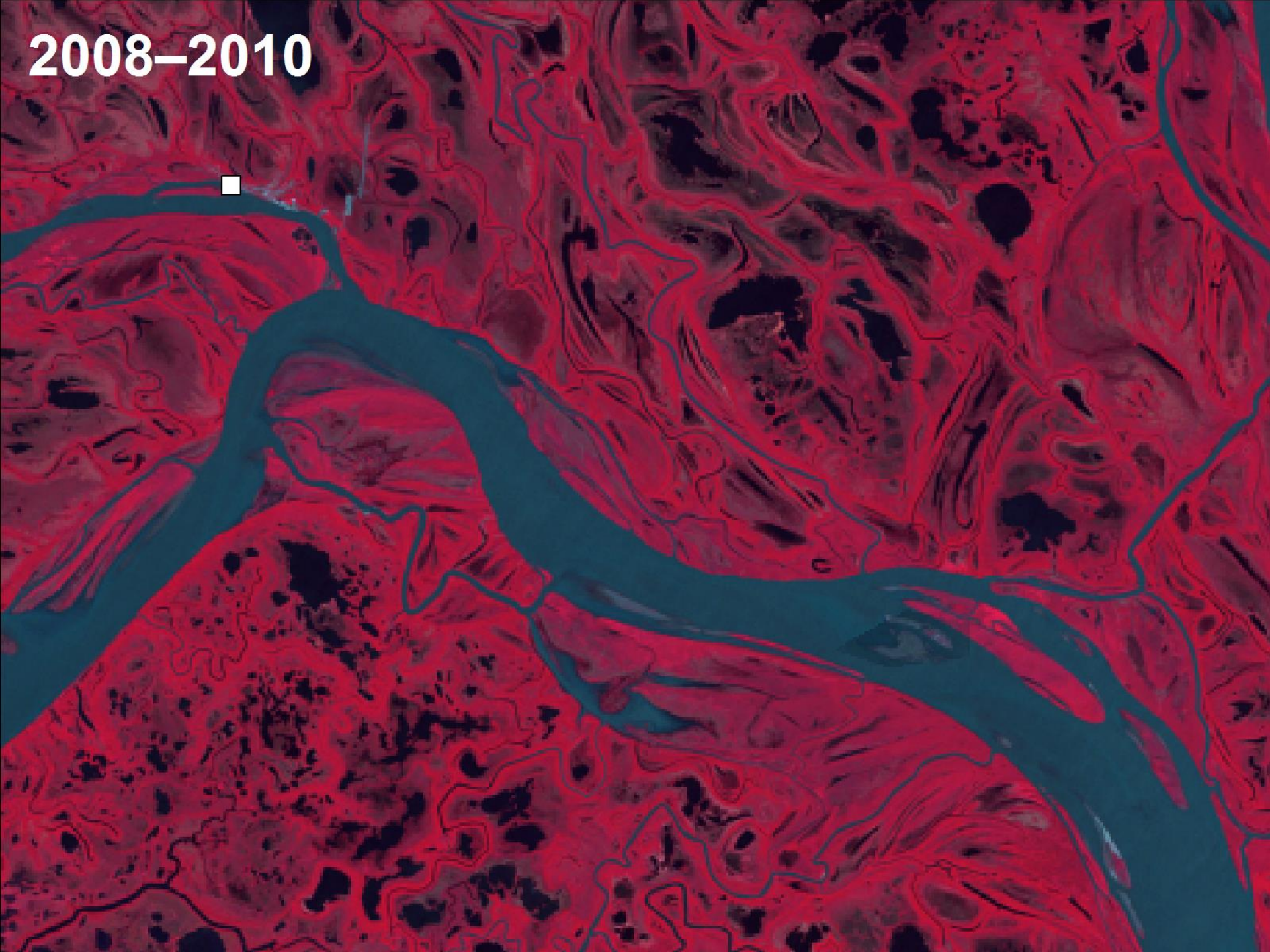

2002–2004

2005–2007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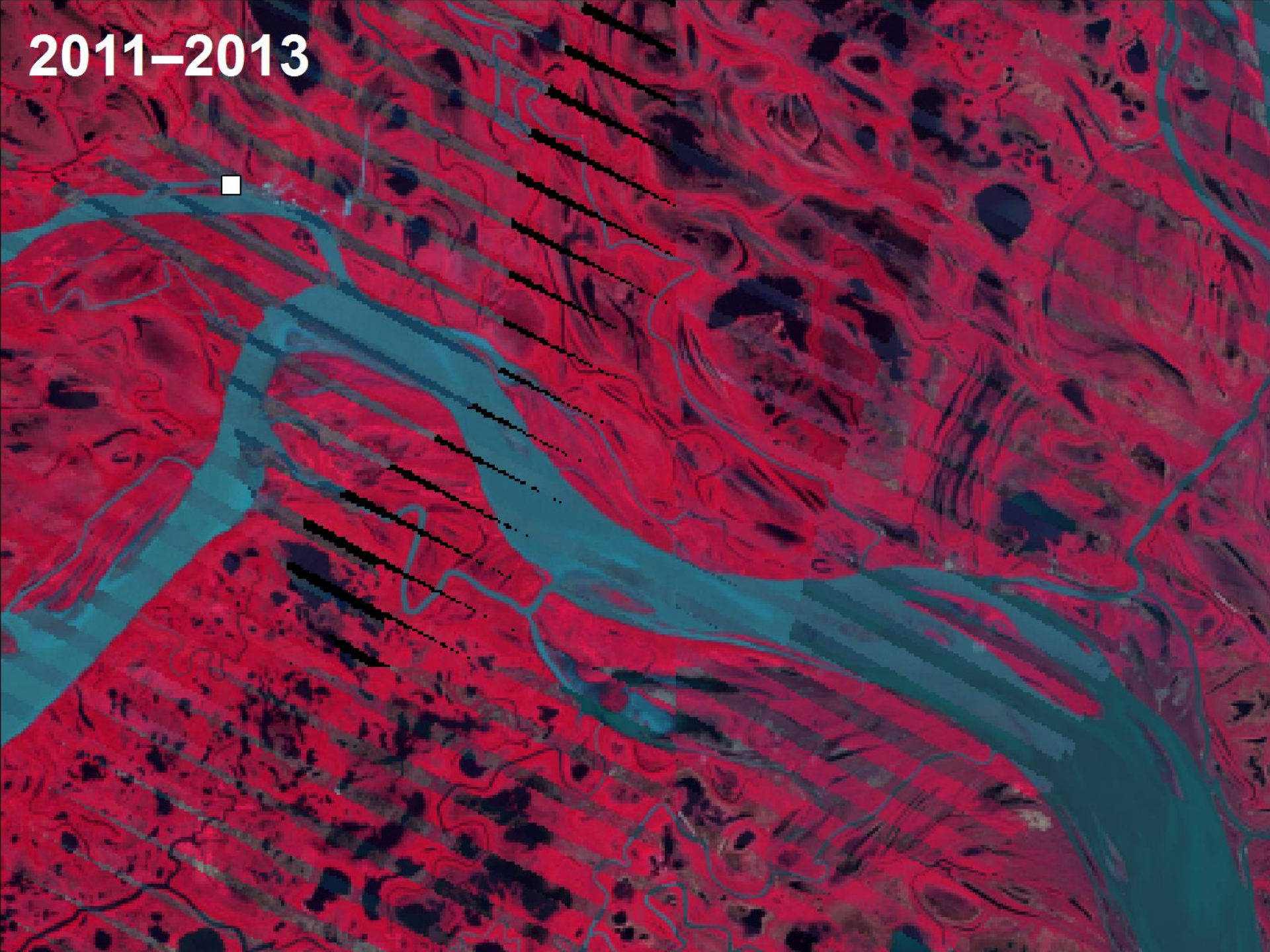
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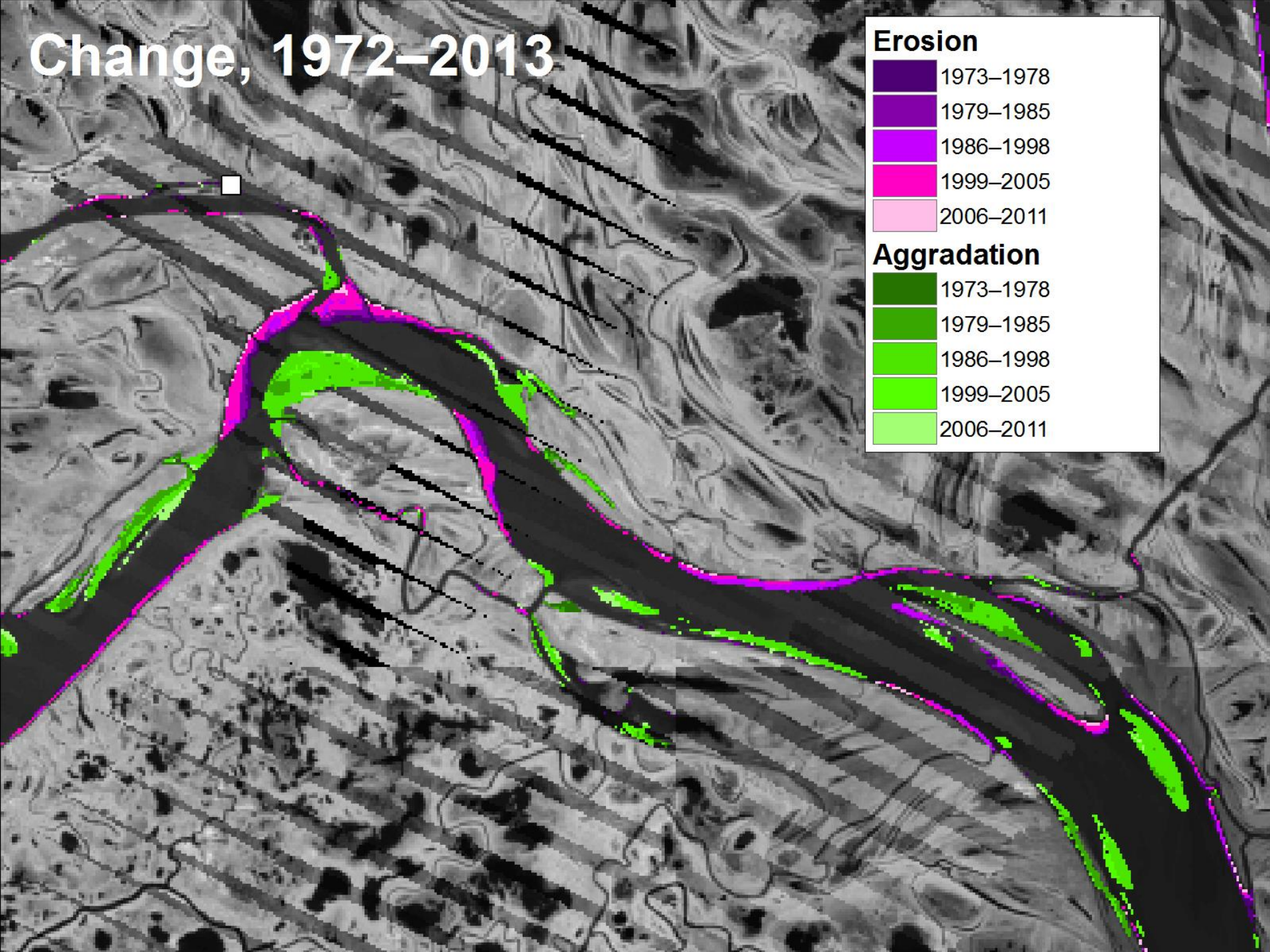
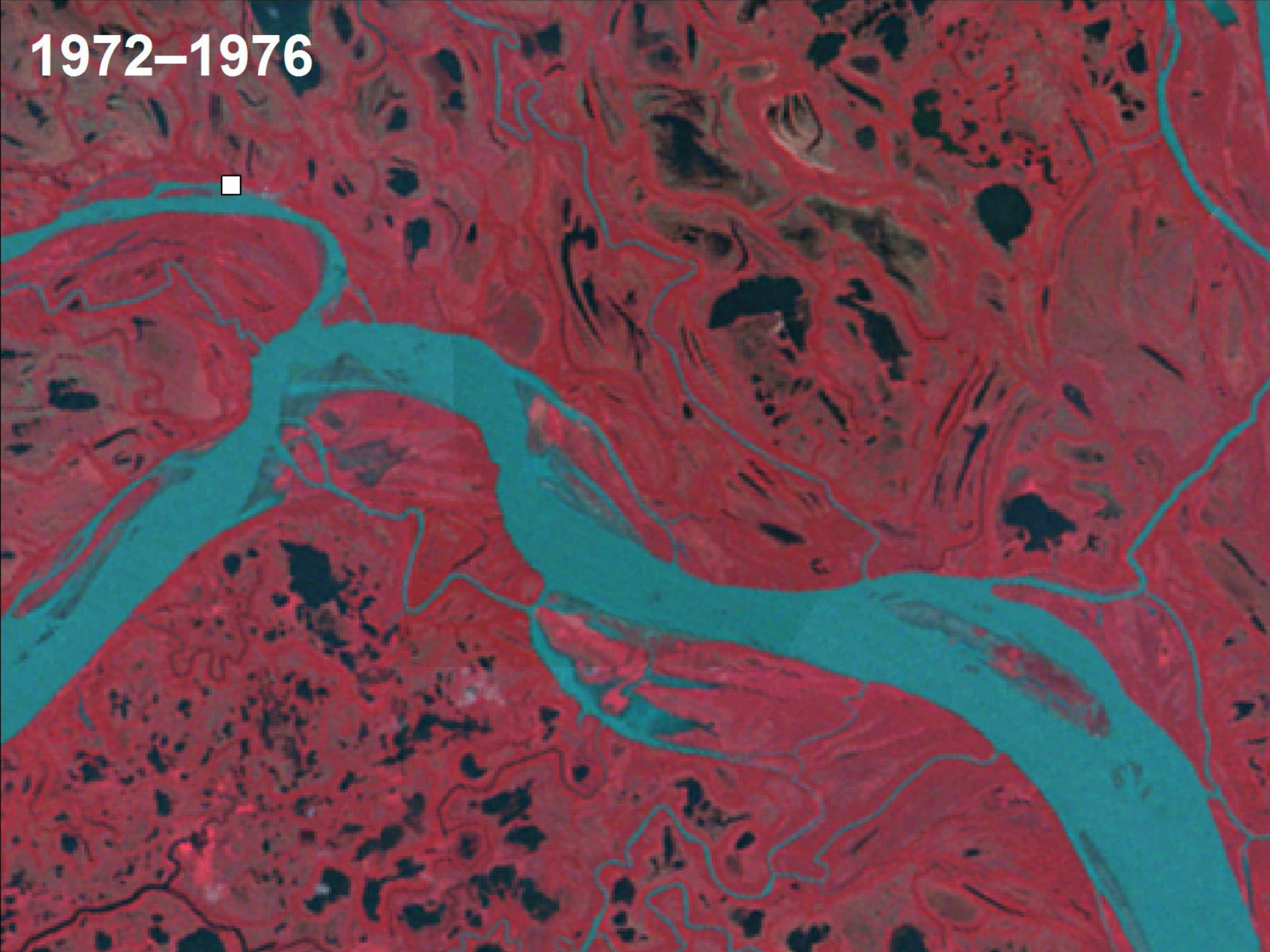

Change, 1972–2013
Erosion
1973–1978
1979–1985
1986–1998
1999–2005
2006–2011
Aggradation
1973–1978
1979–1985
1986–1998
1999–2005
2006–2011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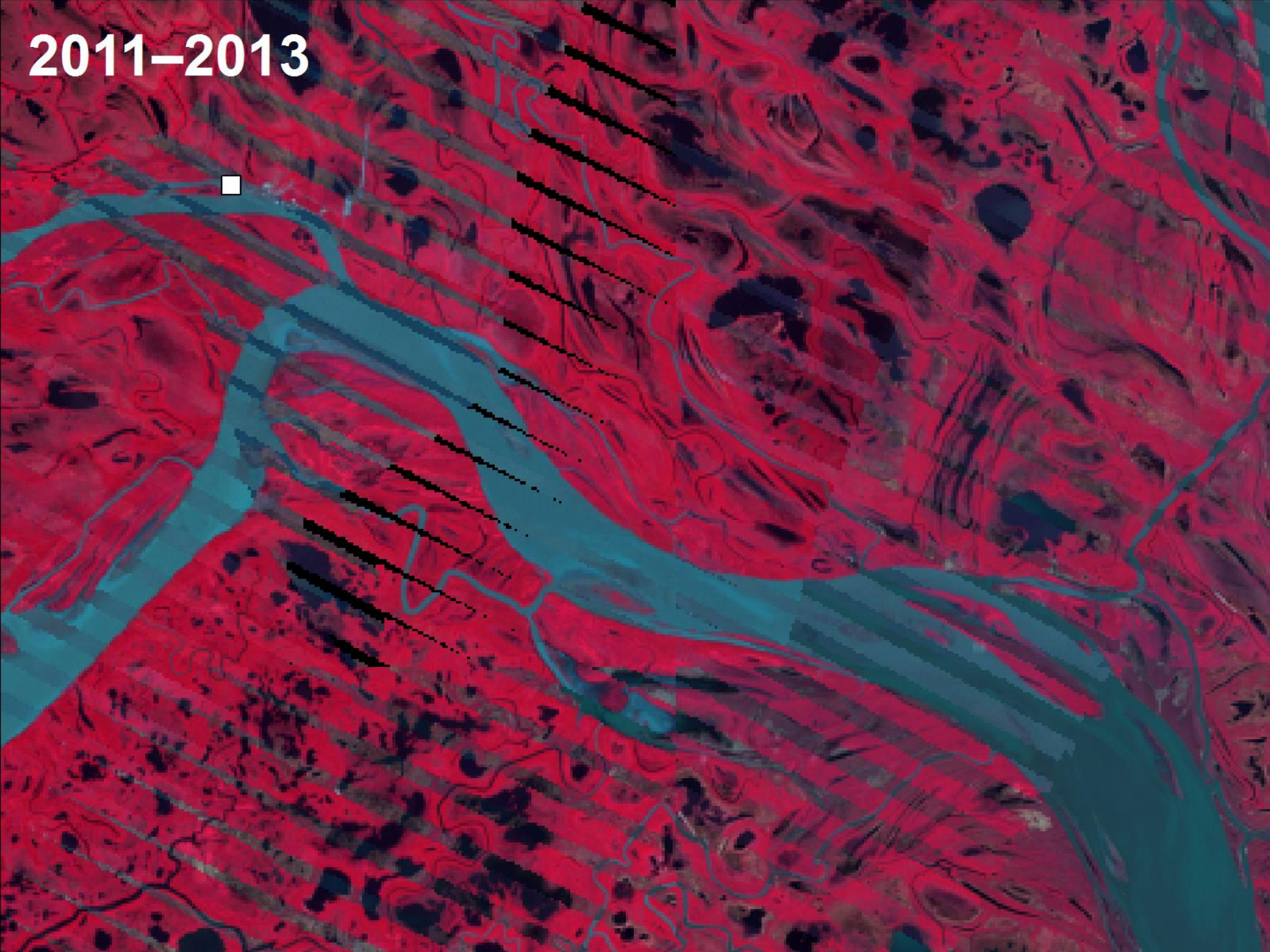
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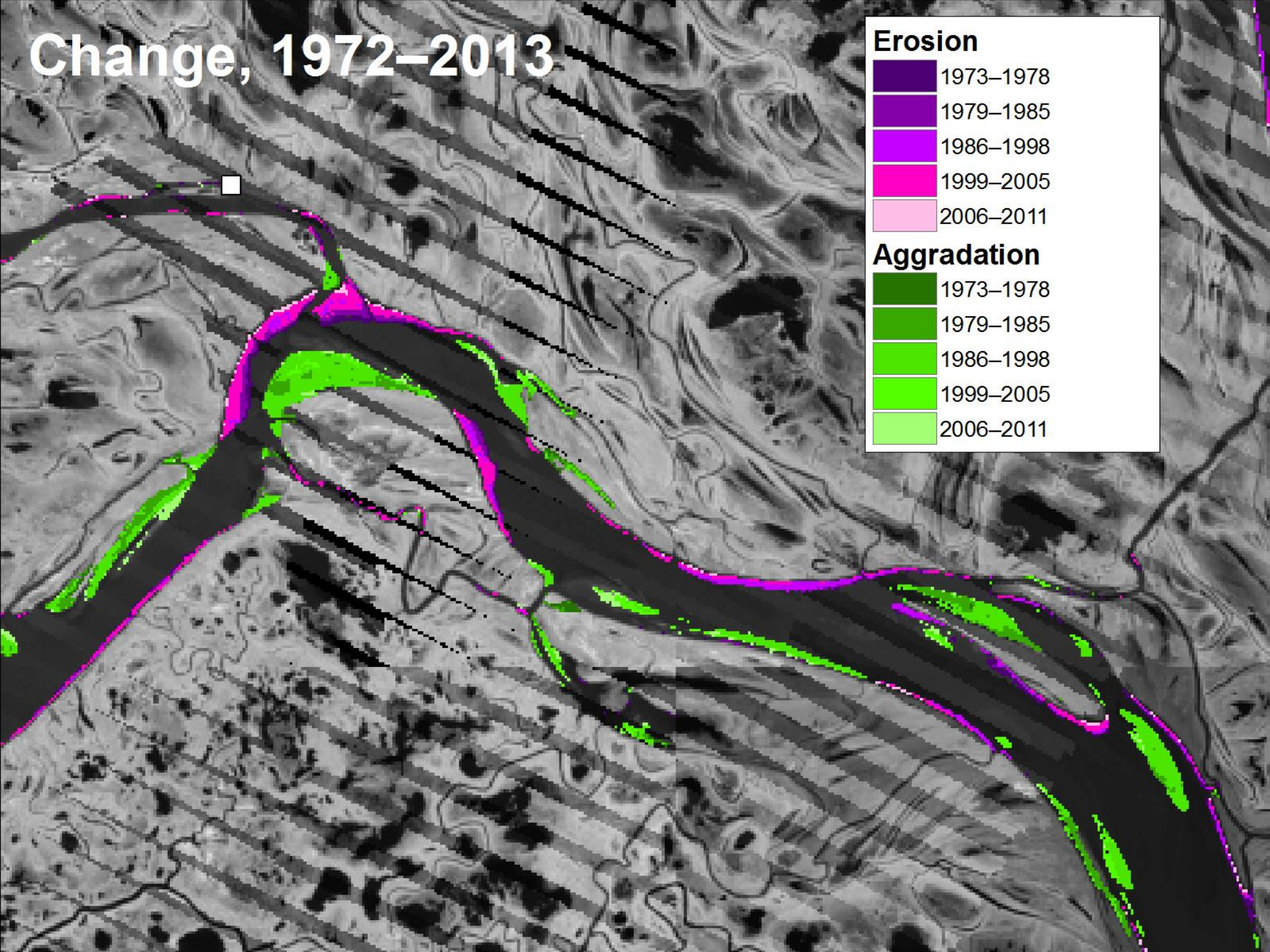
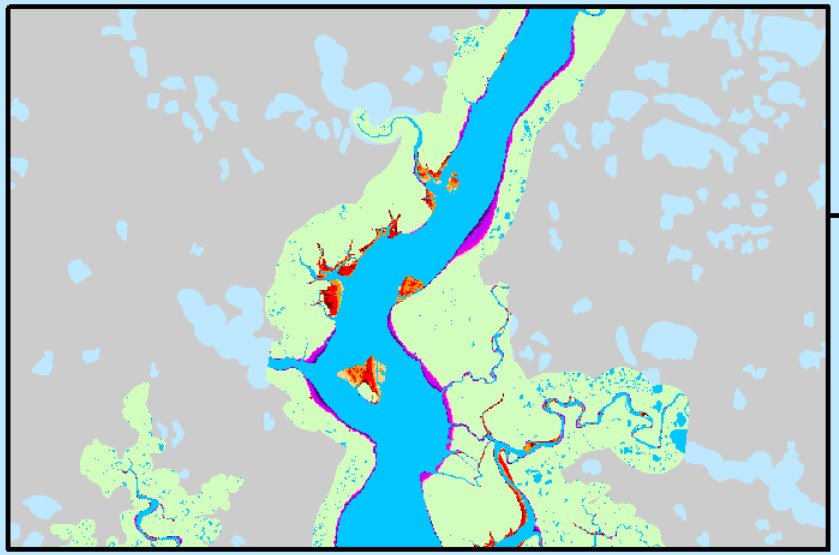
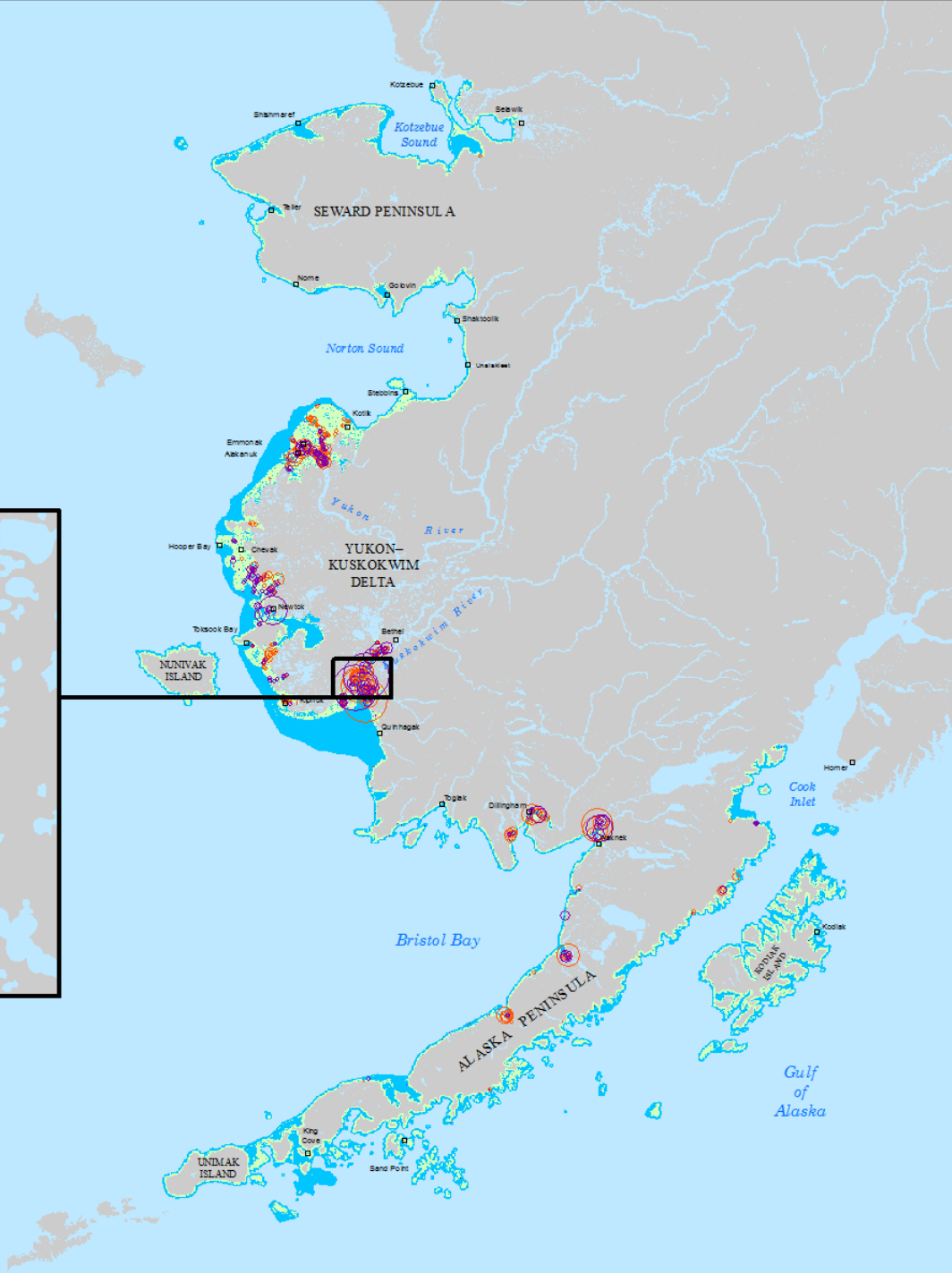

Change, 1972–2013
Erosion
1973–1978
1979–1985
1986–1998
1999–2005
2006–2011
Aggradation
1973–1978
1979–1985
1986–1998
1999–2005
2006–2011

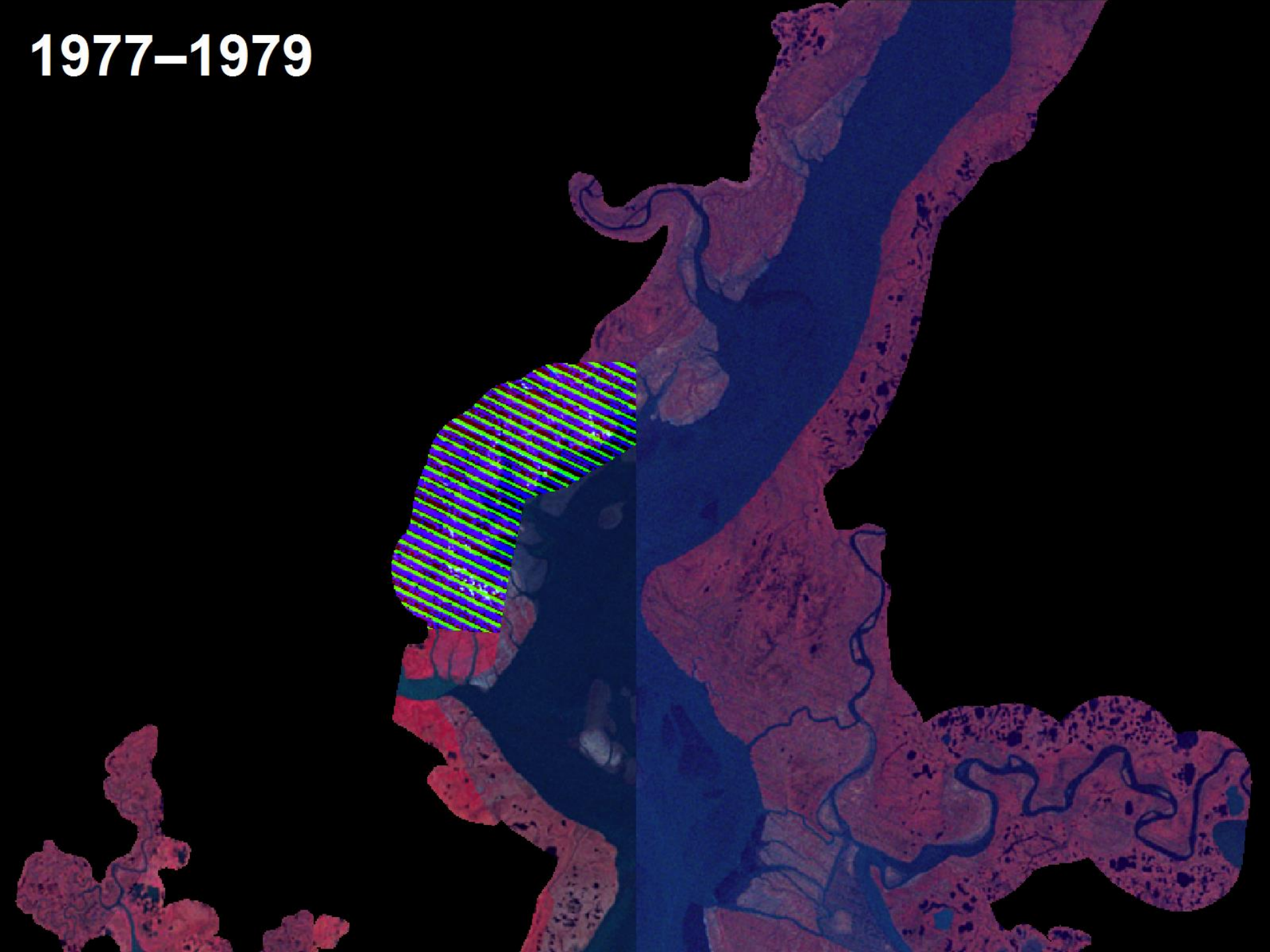
Kuskokwim and Eek Rivers Riverine Change

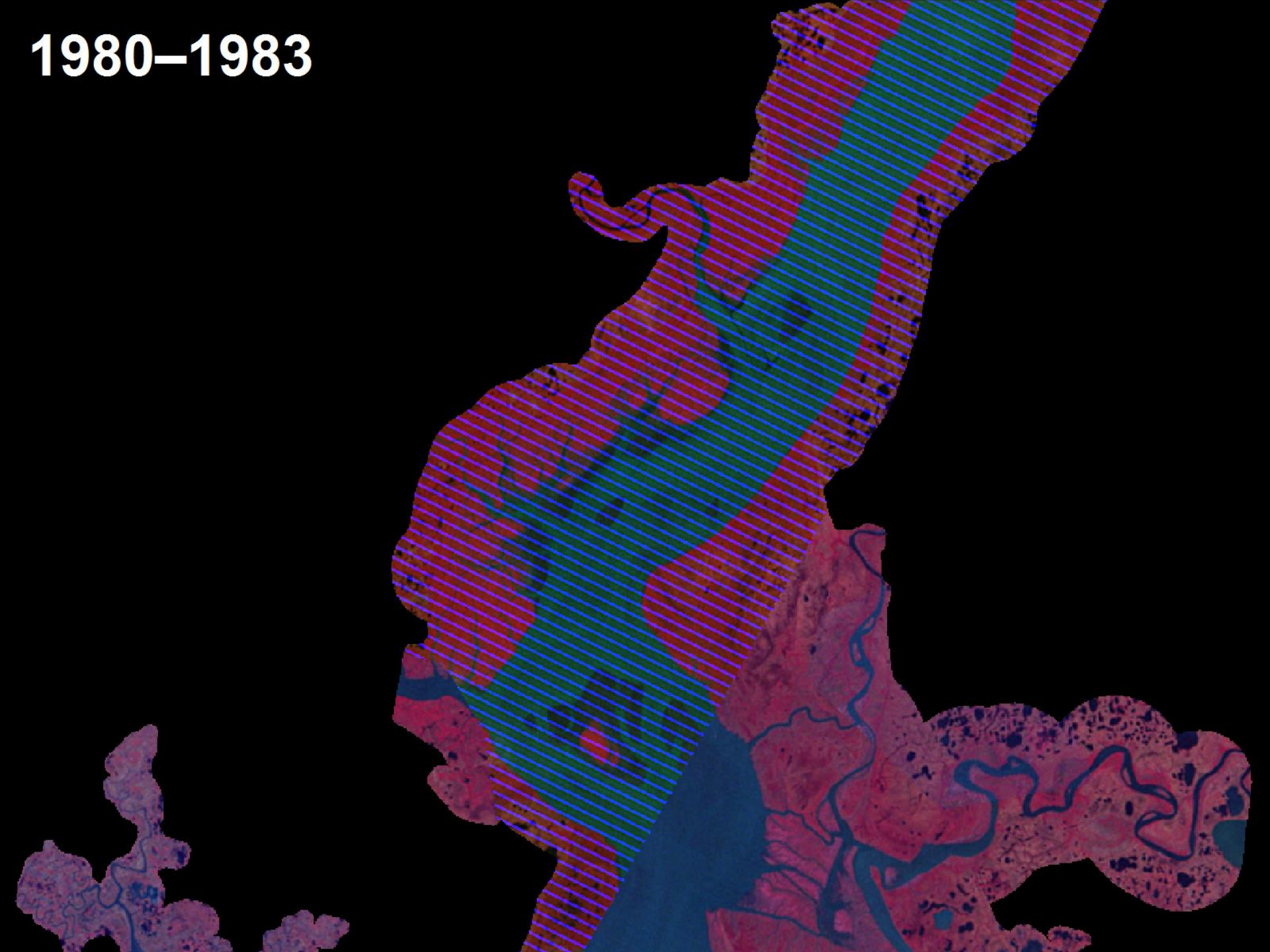




1972–1976

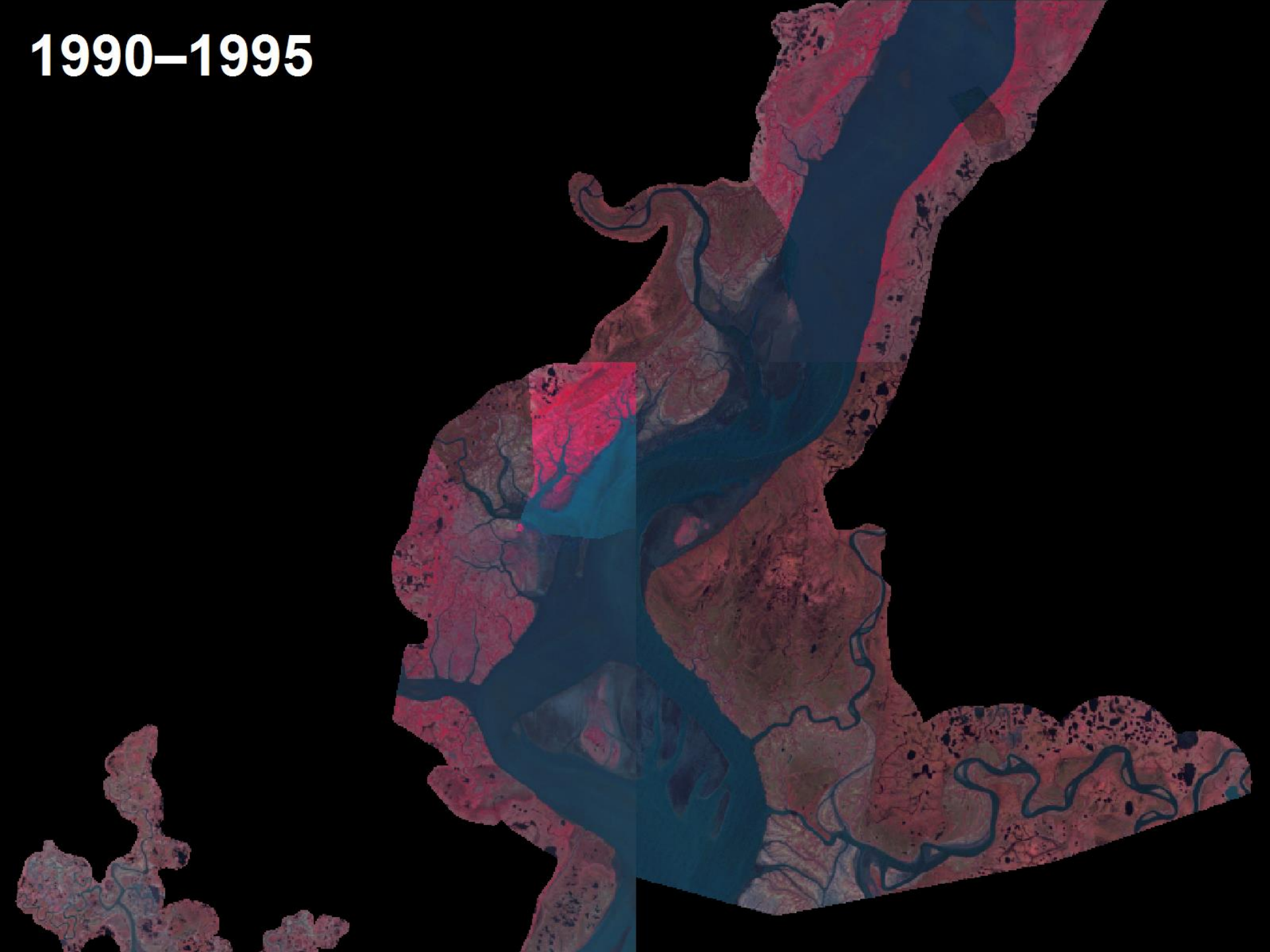
1977–1979

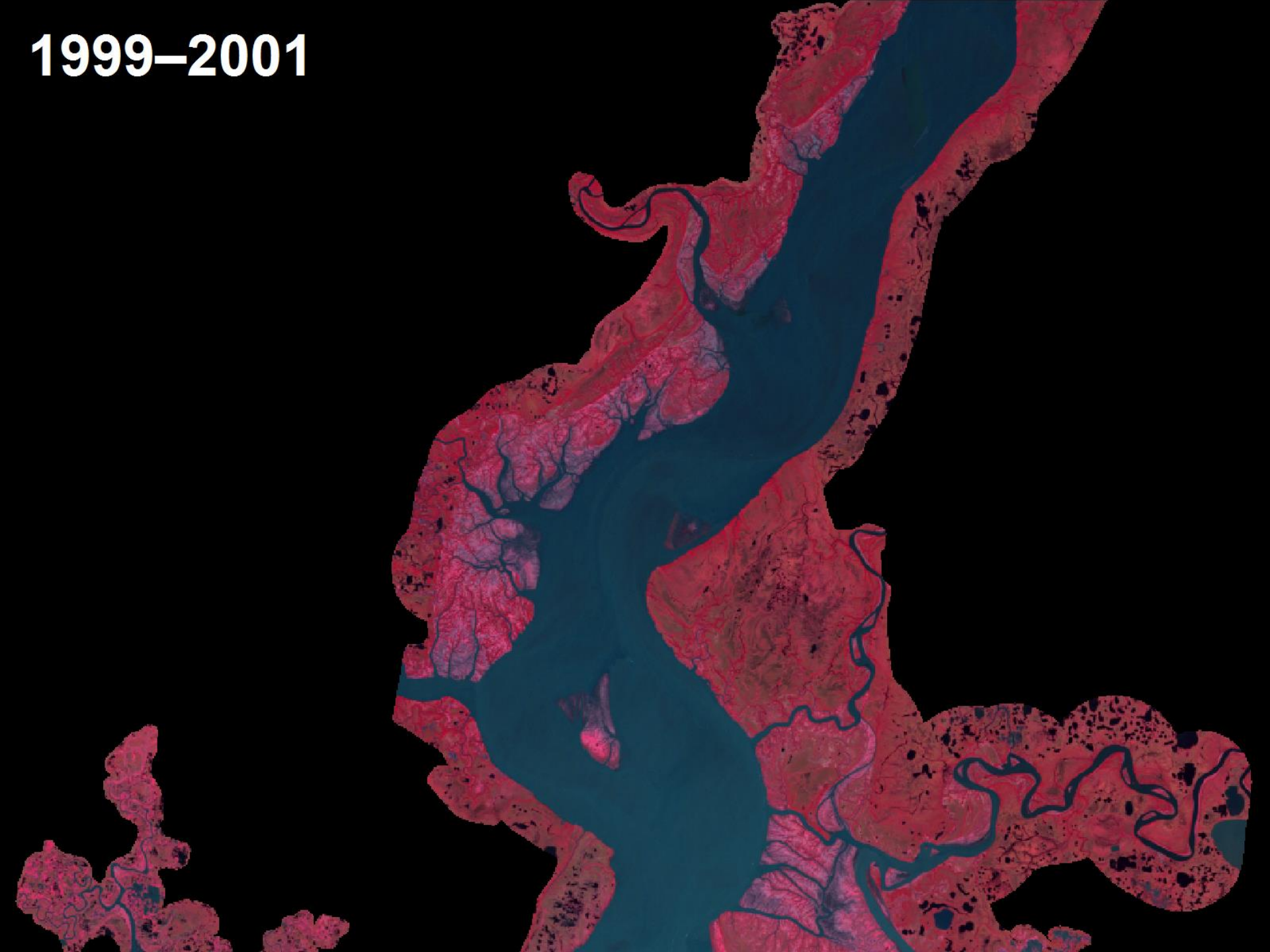



1980–1983

1984–1989

1990–1995

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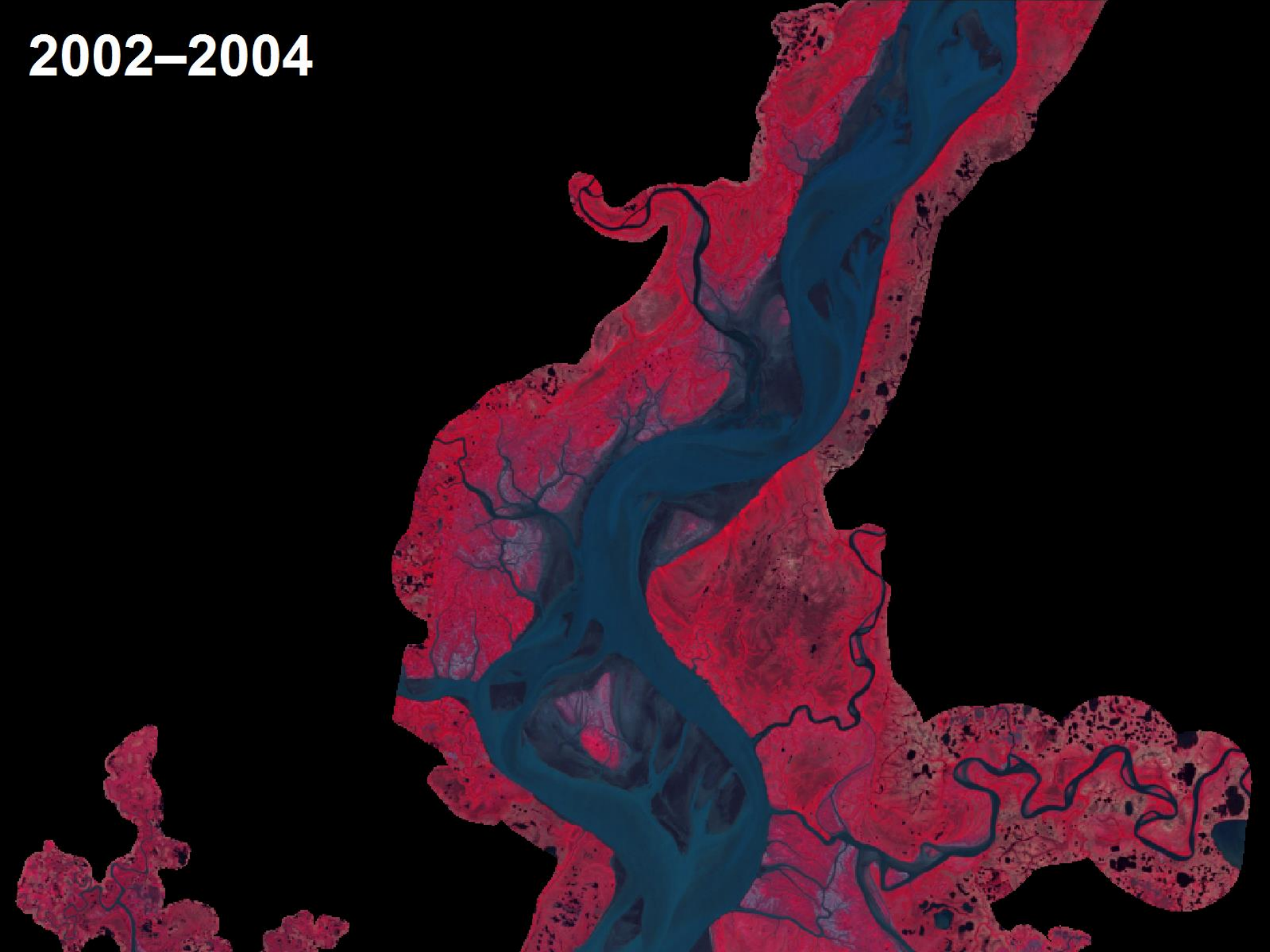
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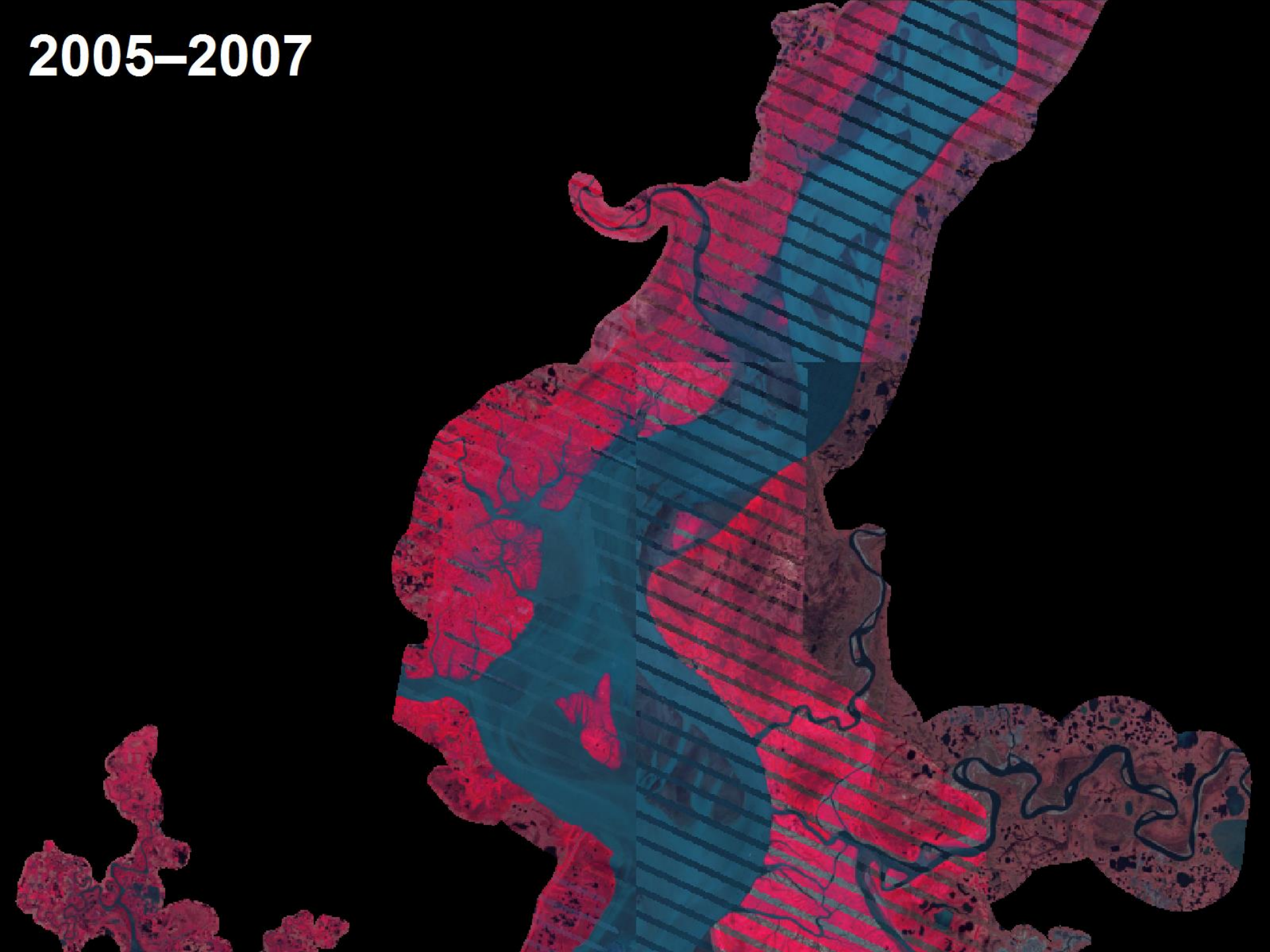
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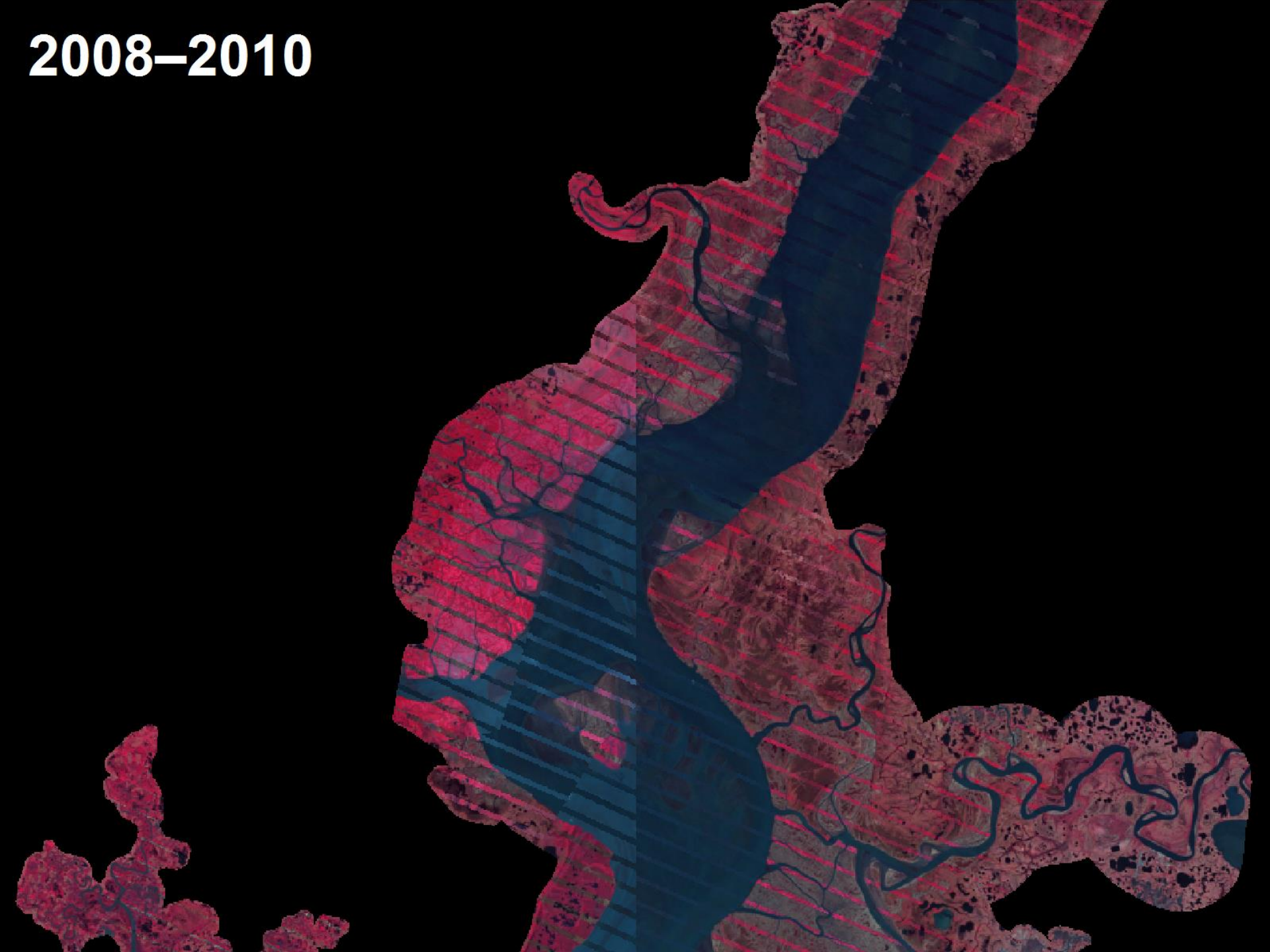
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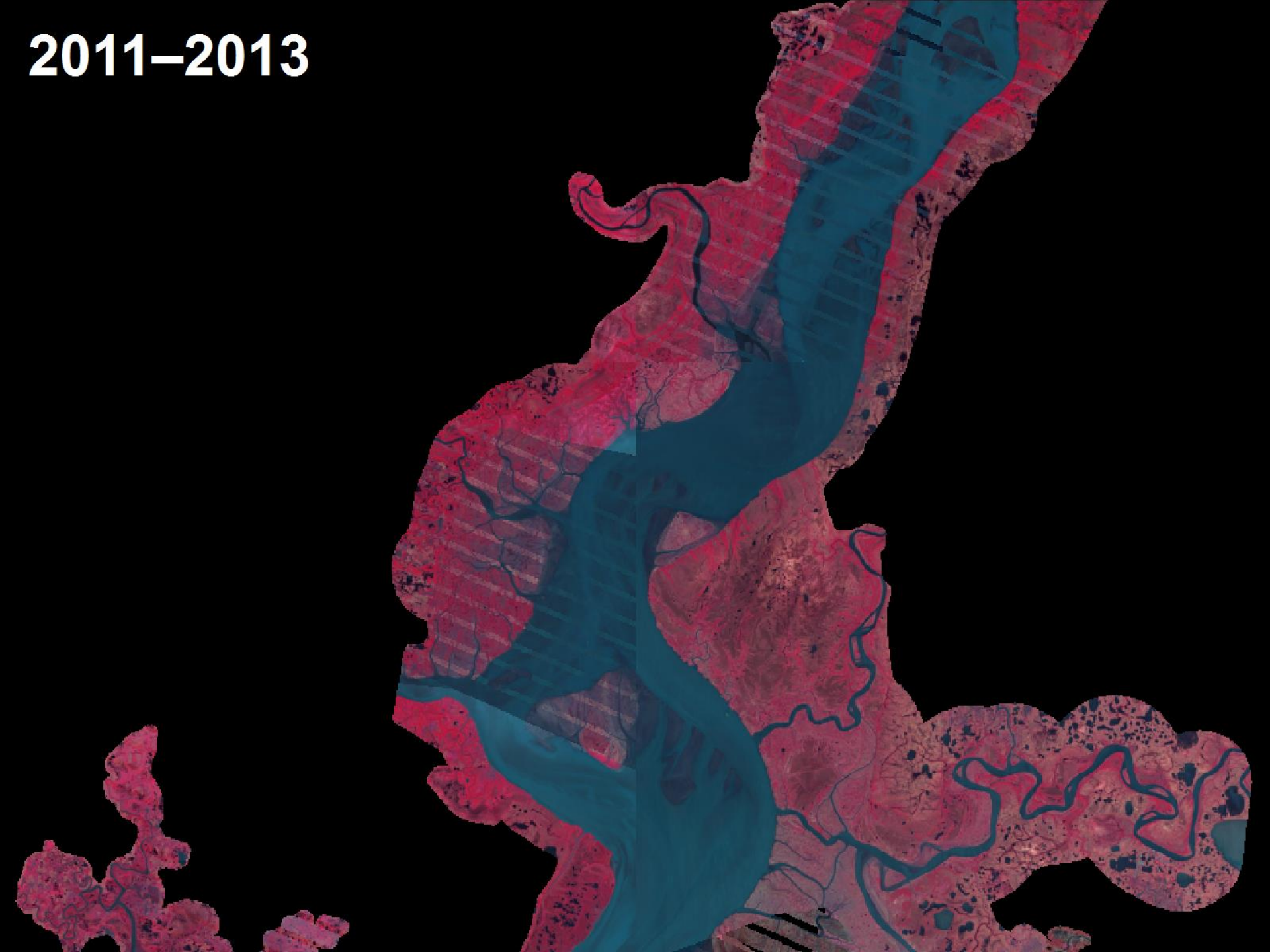
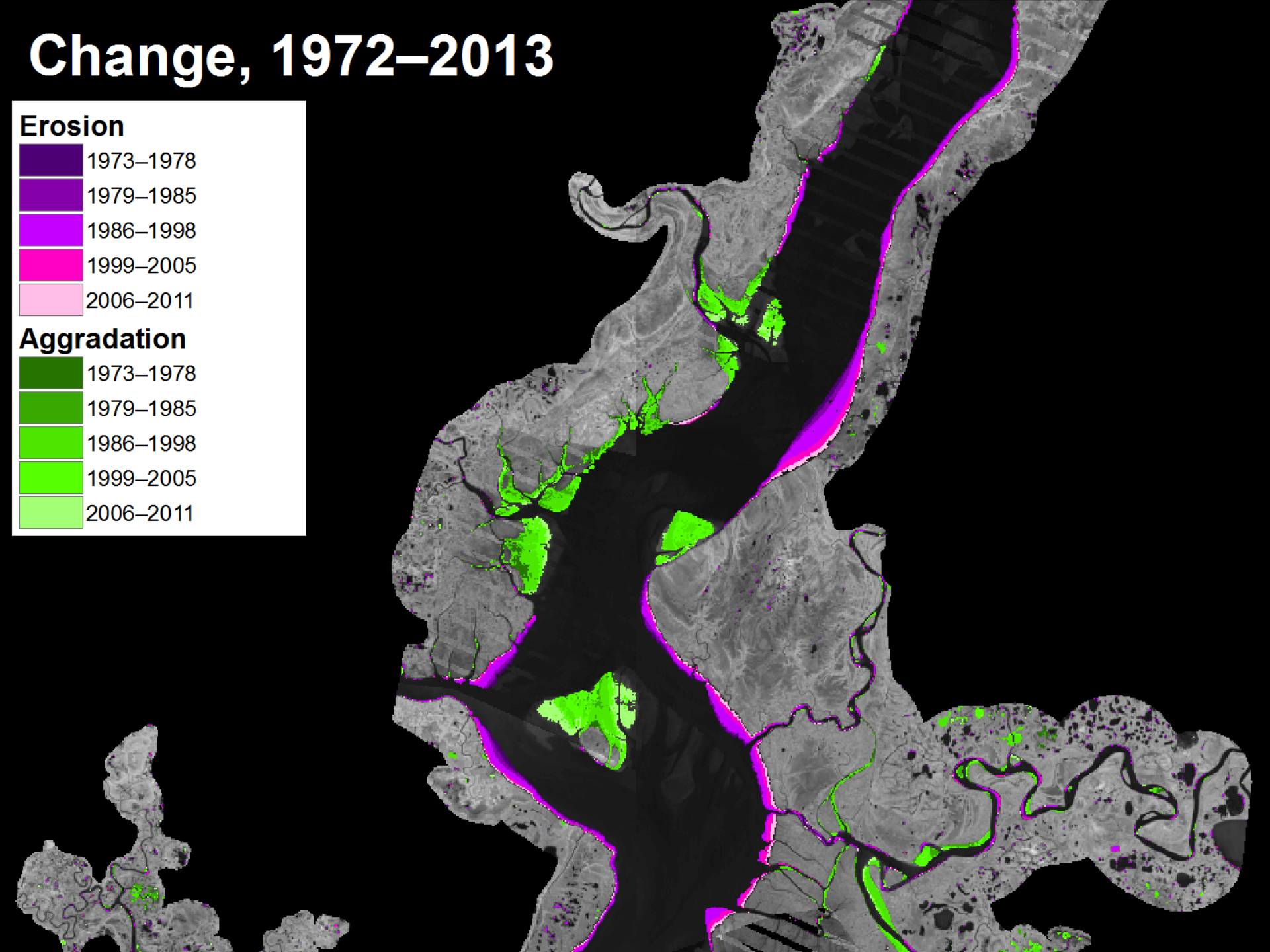
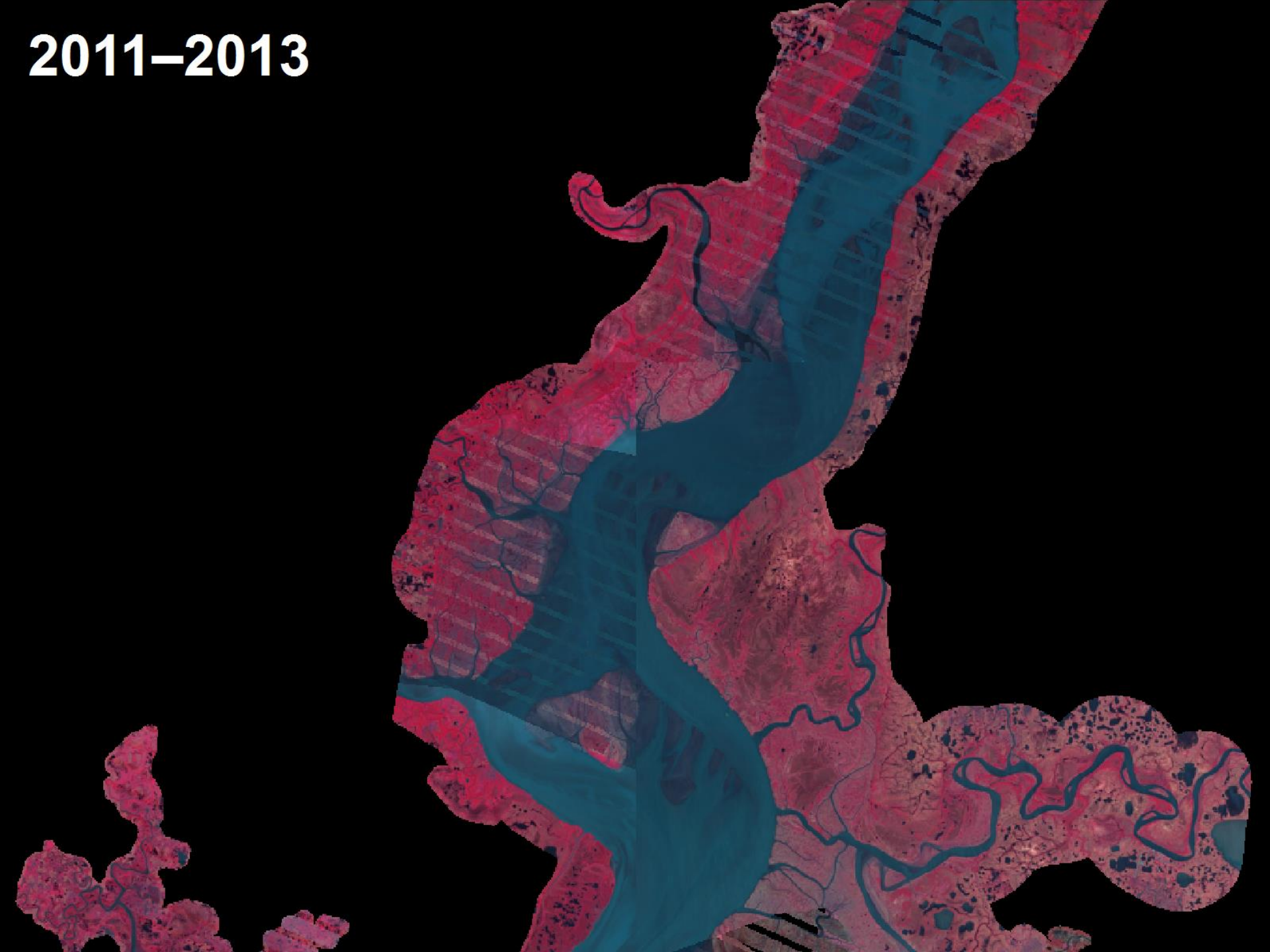


Change, 1972–2013

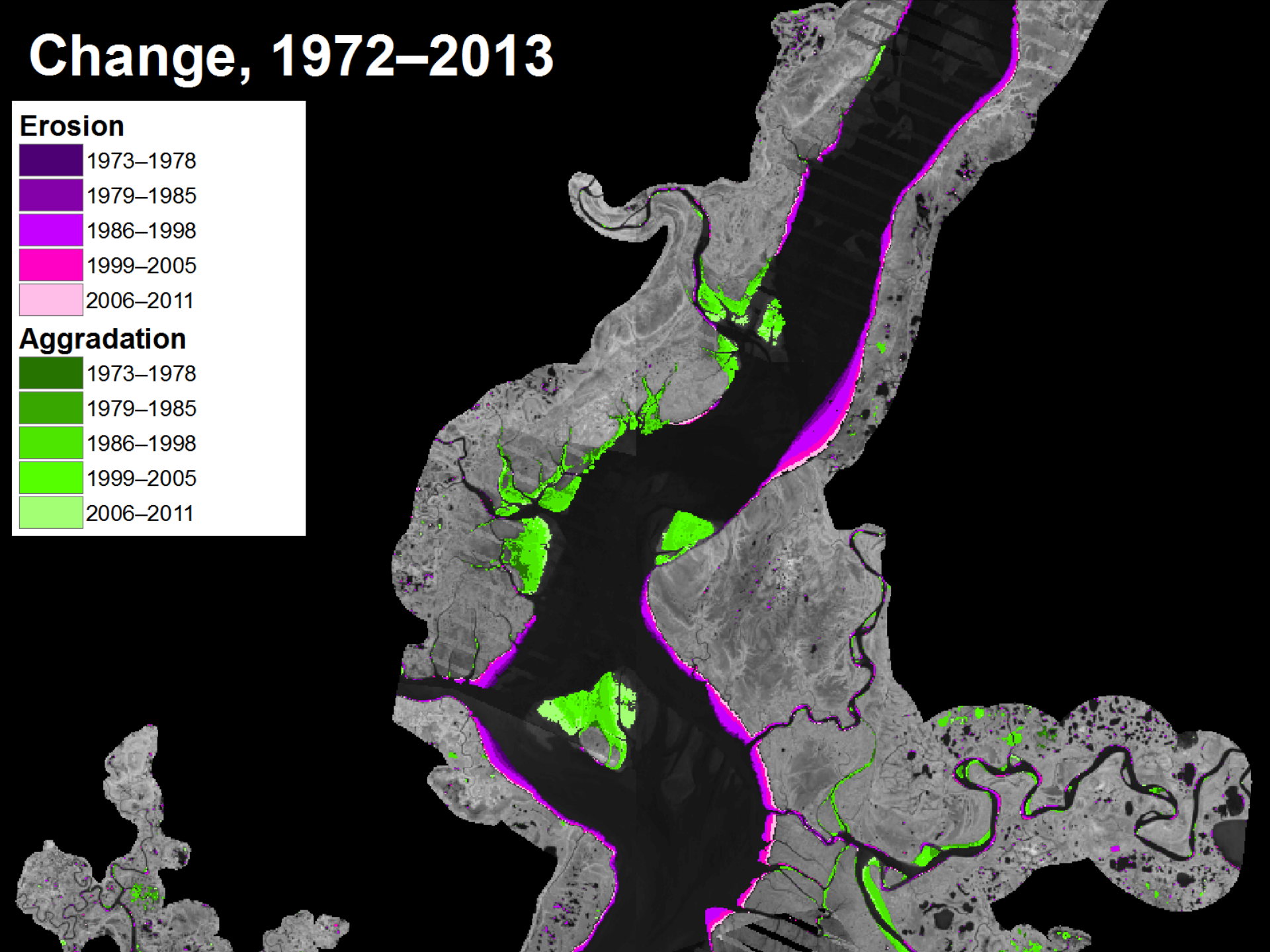


1972–1976

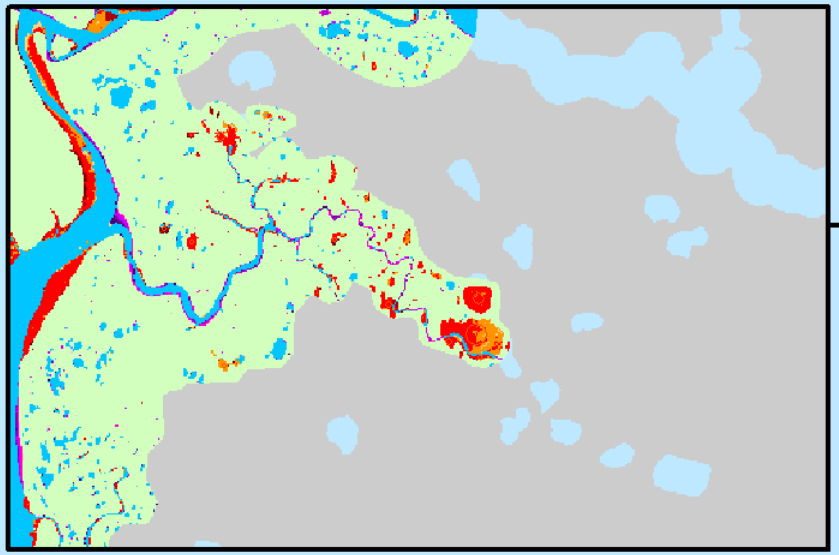
2011–2013

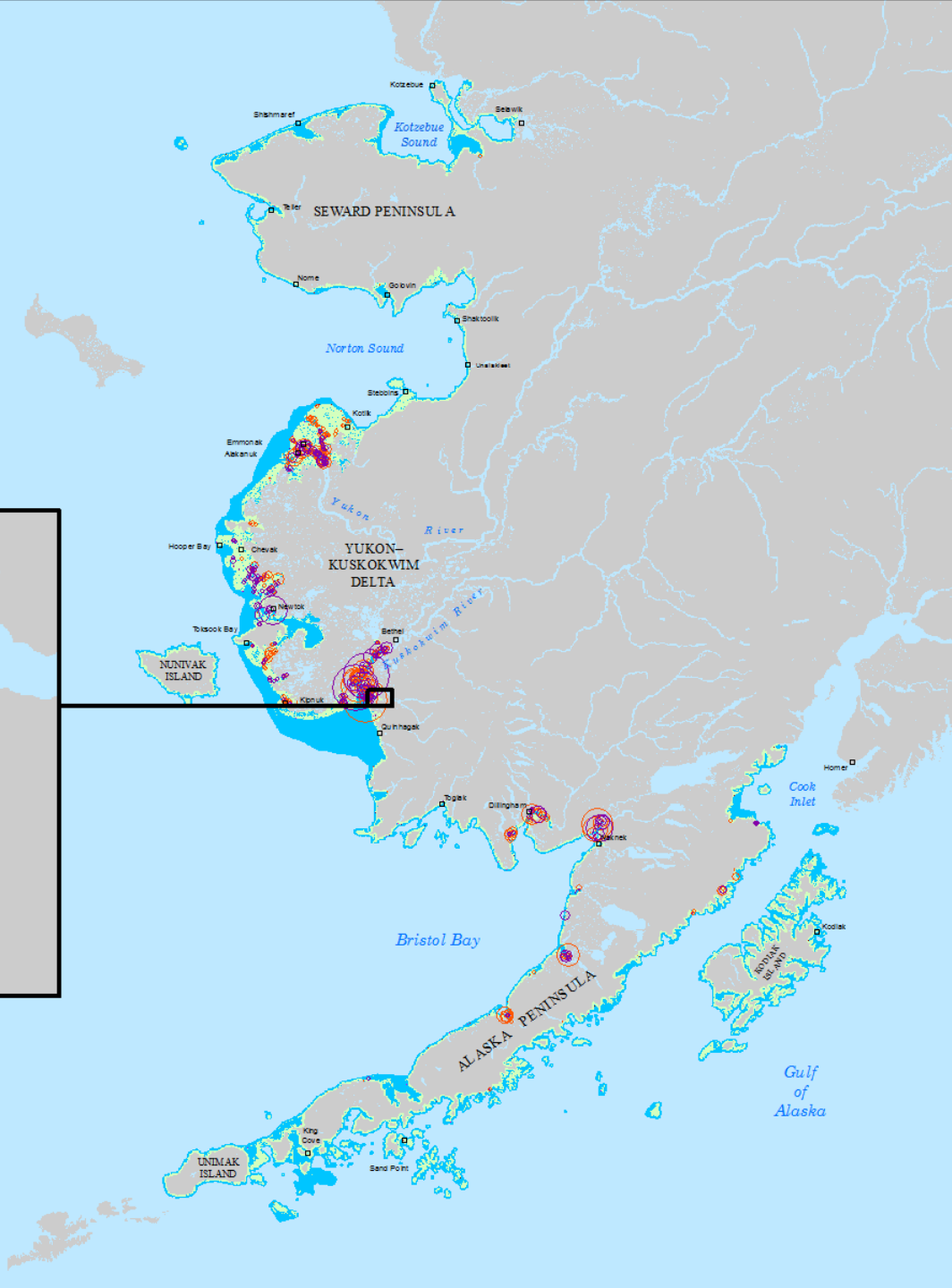


Change, 1972–2013



Apokak Sloush, Eek Channel Lake Drainage





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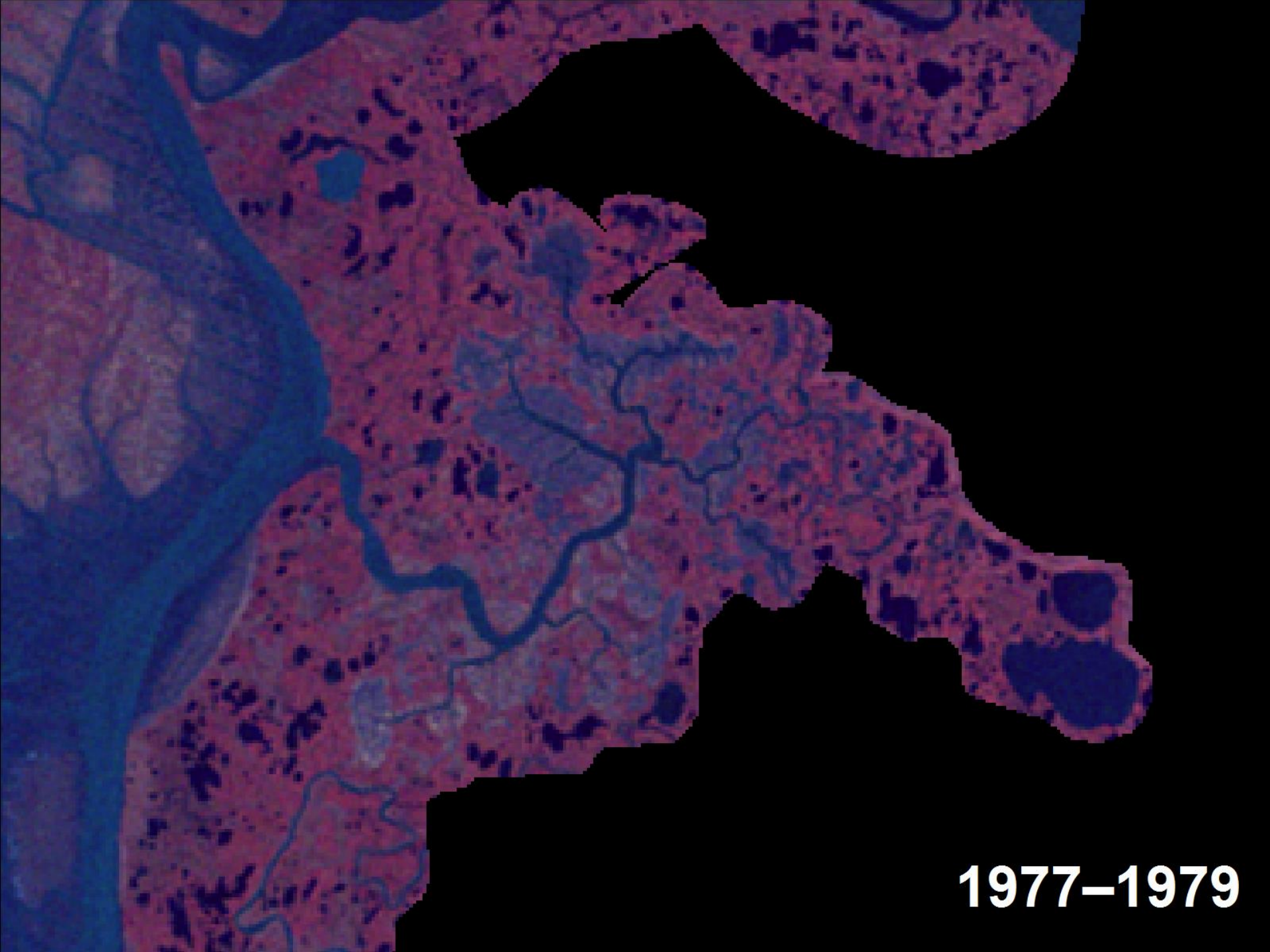
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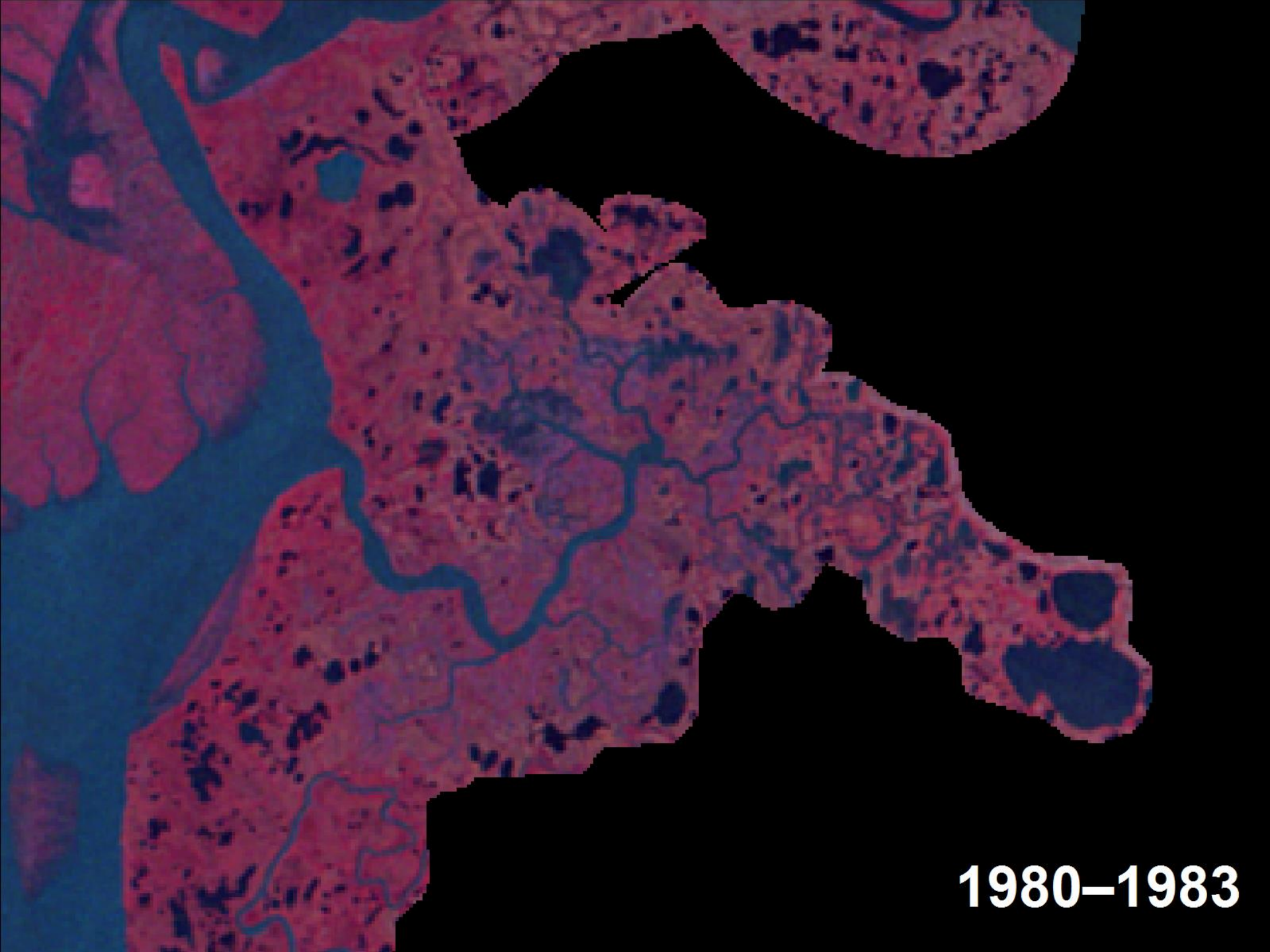
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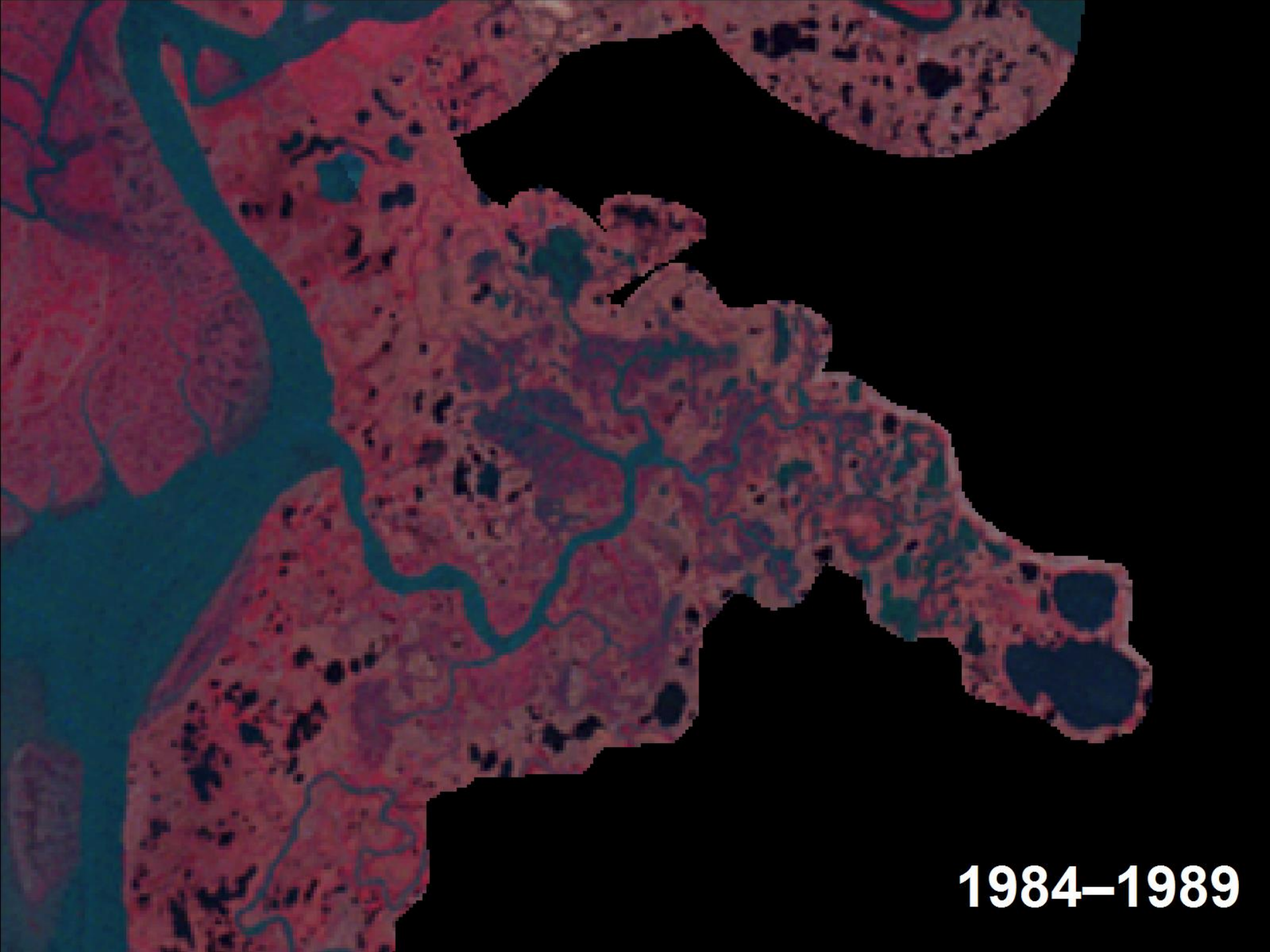
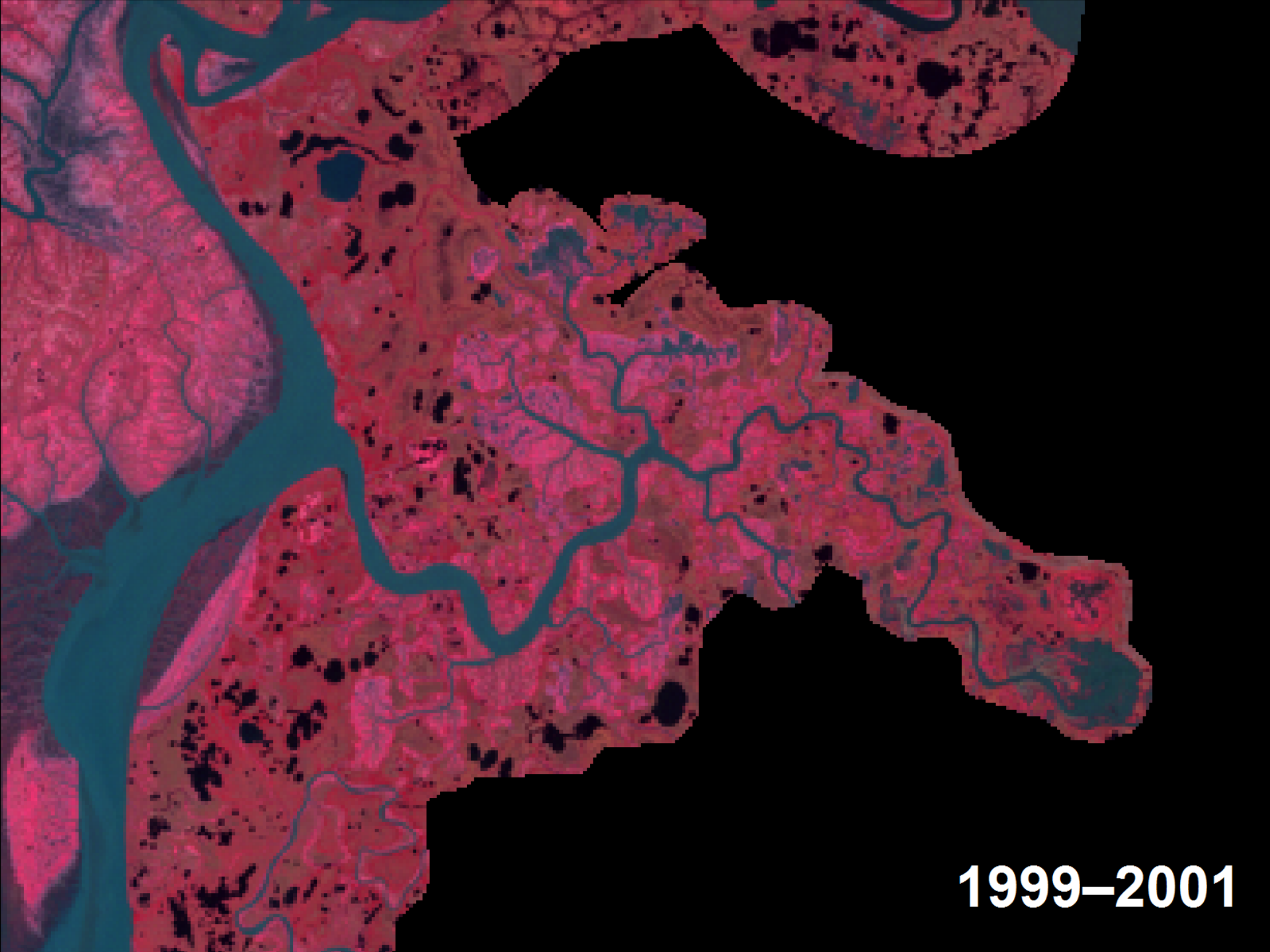

1984–1989

1990–1995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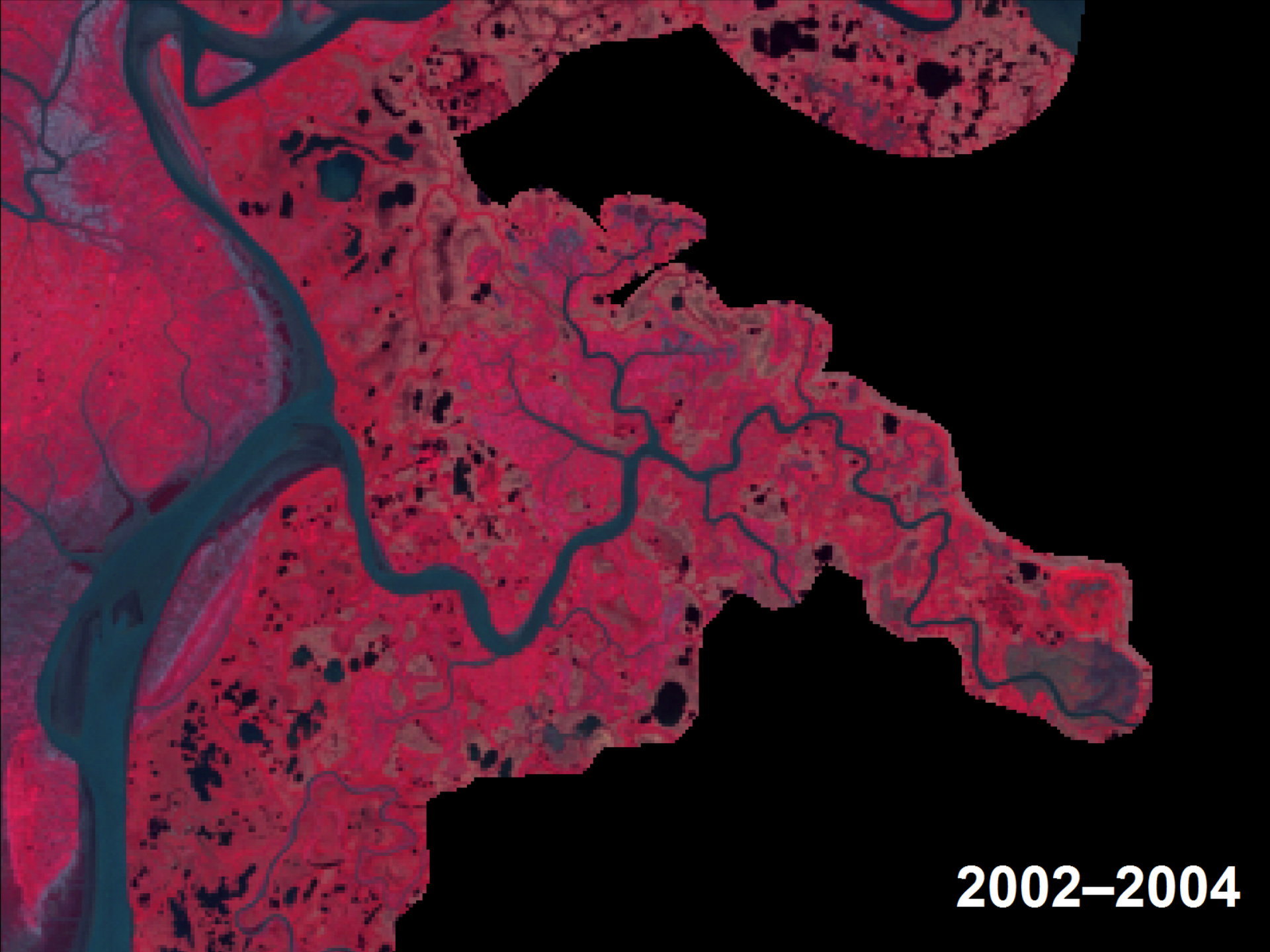
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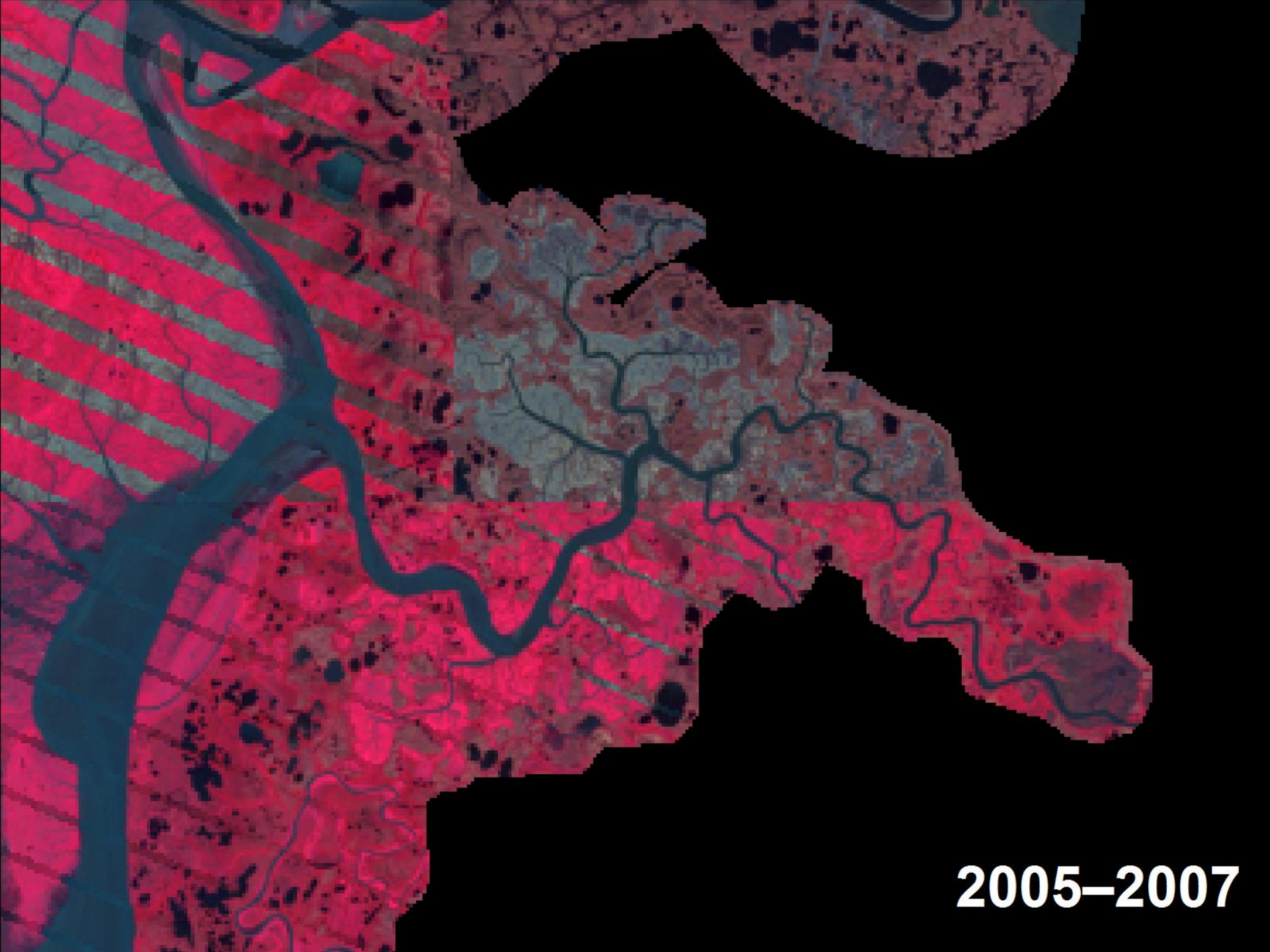
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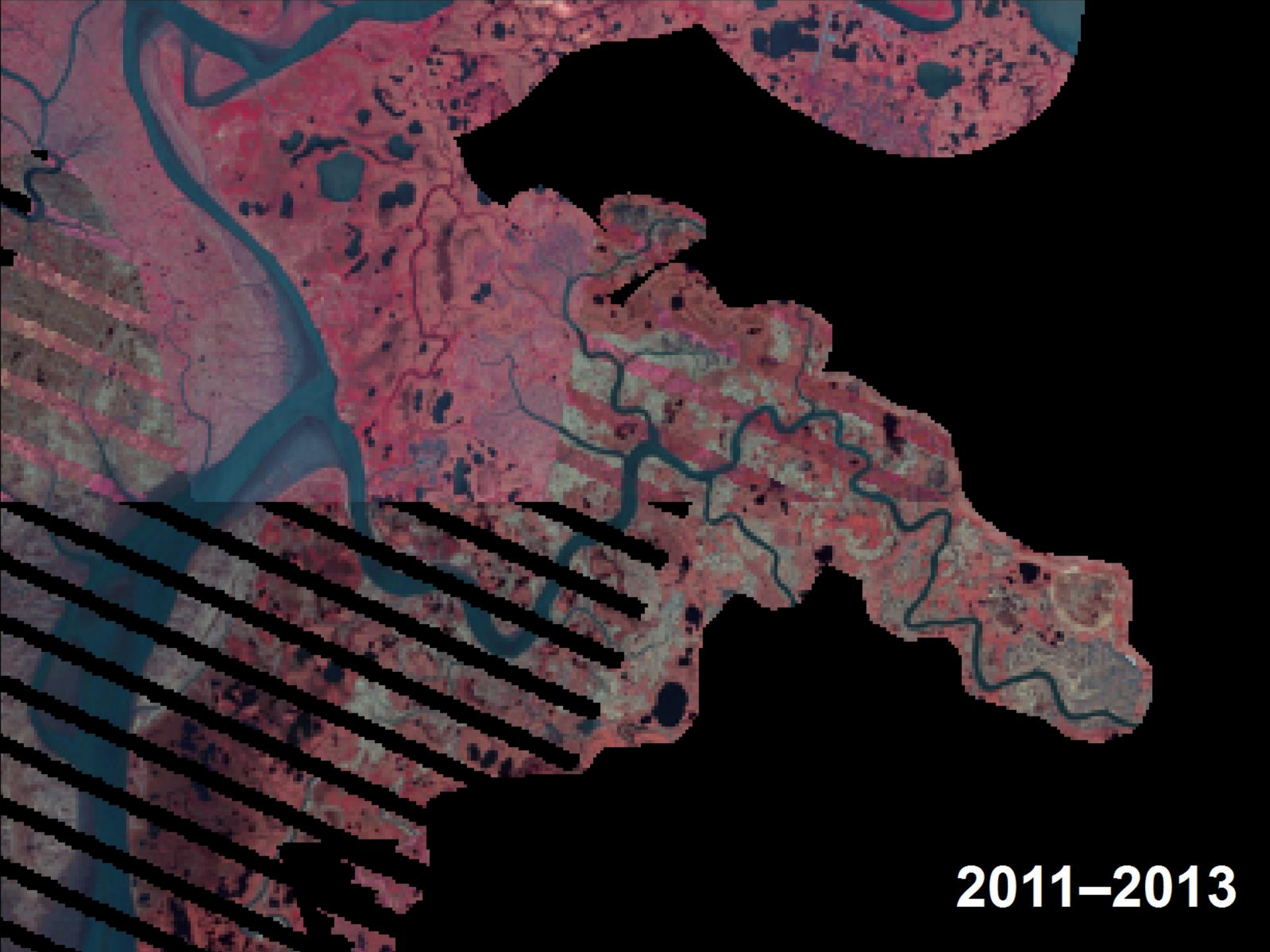
2008–2010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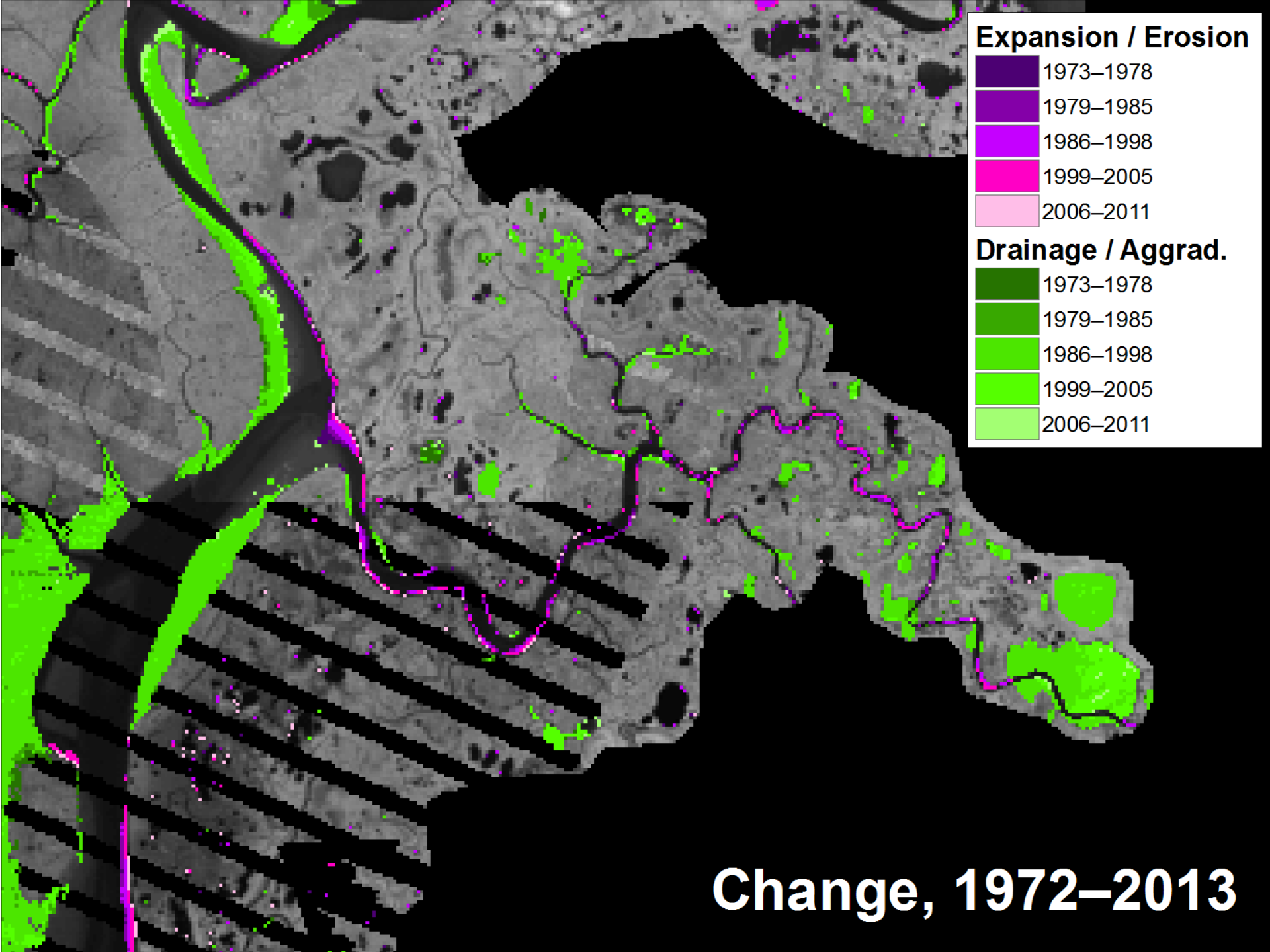
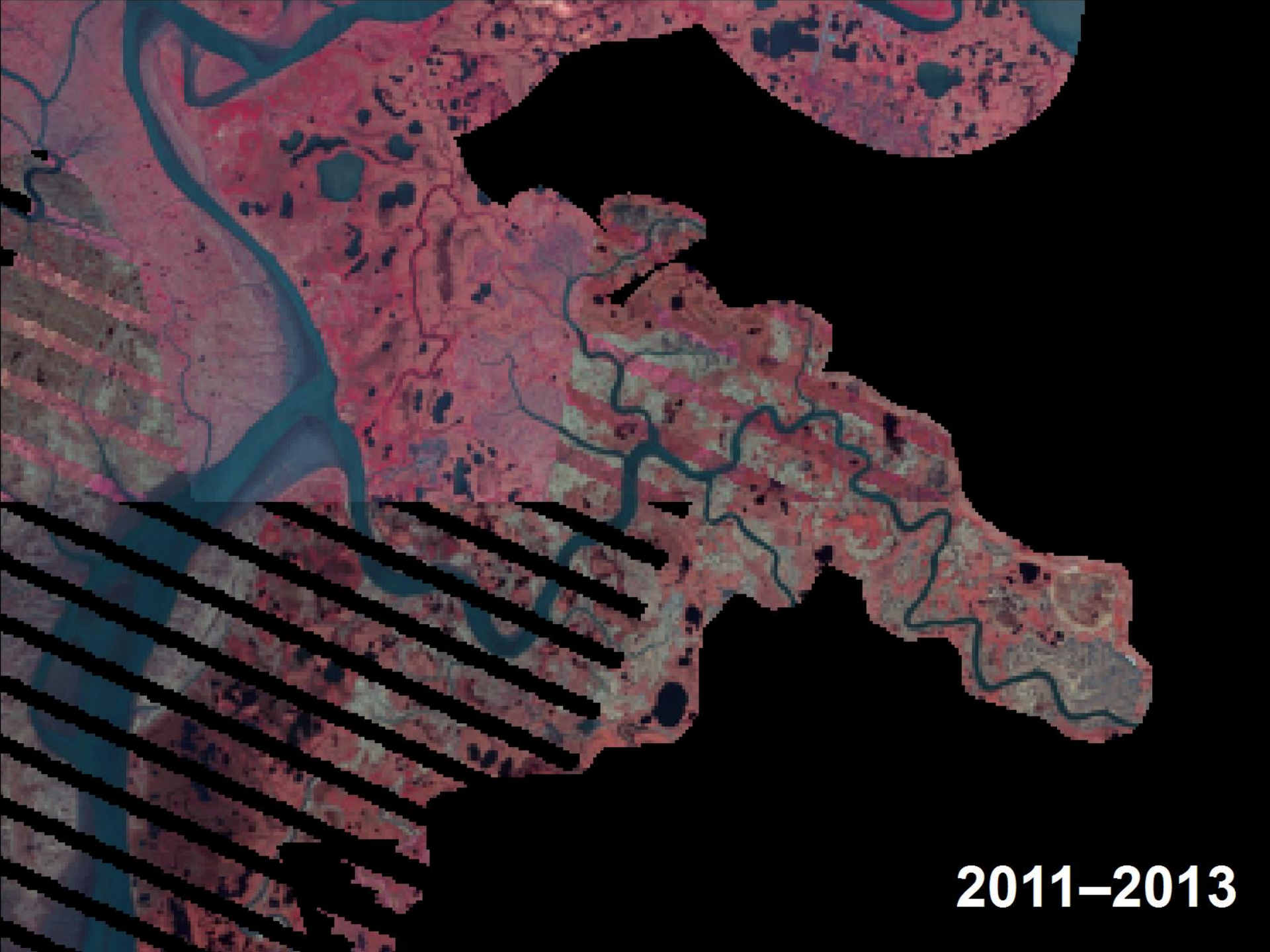

Expansion / Erosion
1973–1978
1979–1985
1986–1998
1999–2005
2006–2011
Drainage / Aggrad.
1973–1978
1979–1985
1986–1998
1999–2005
2006–2011
Change, 1972–2013

1972–1976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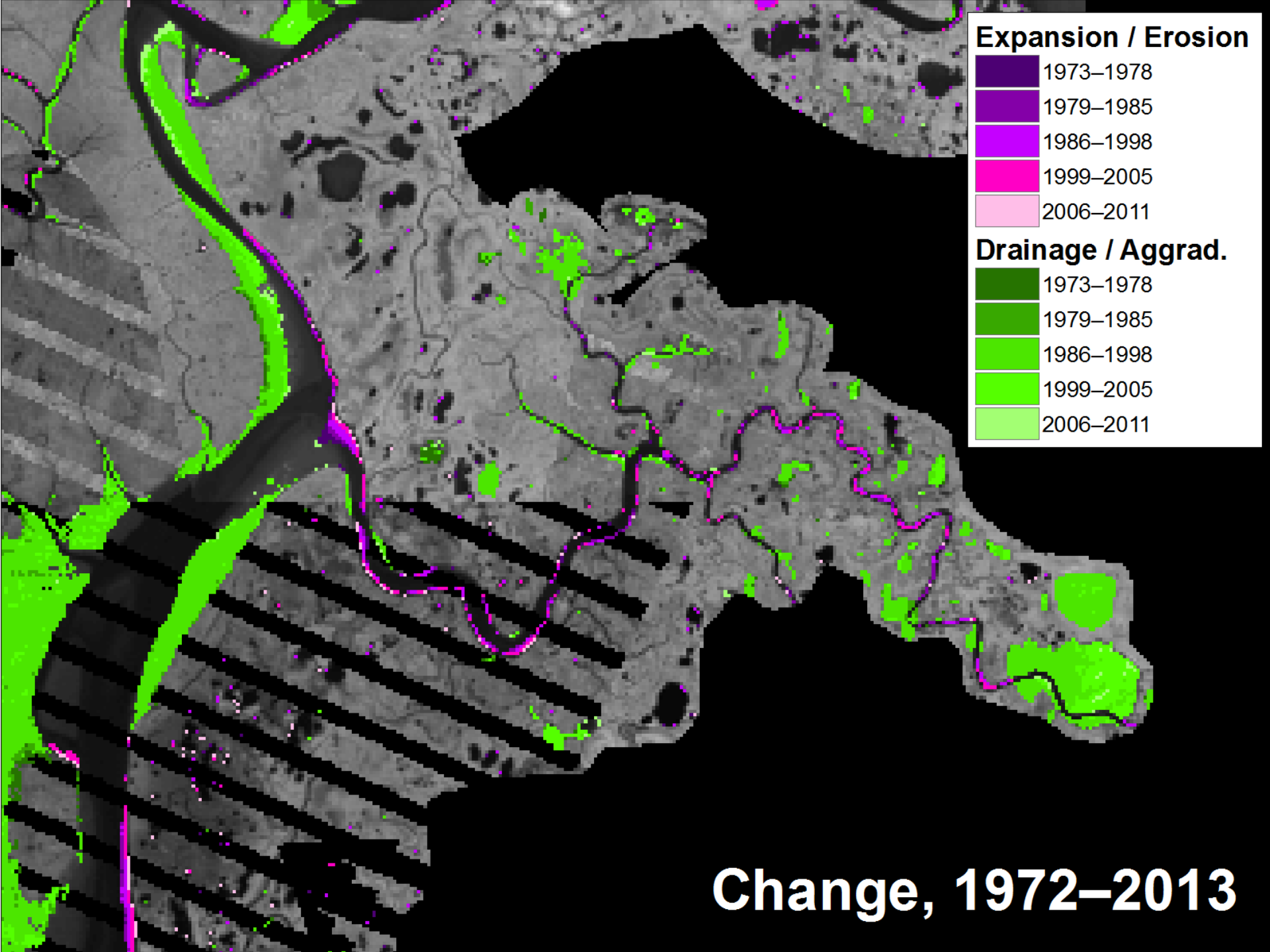
Expansion / Erosion
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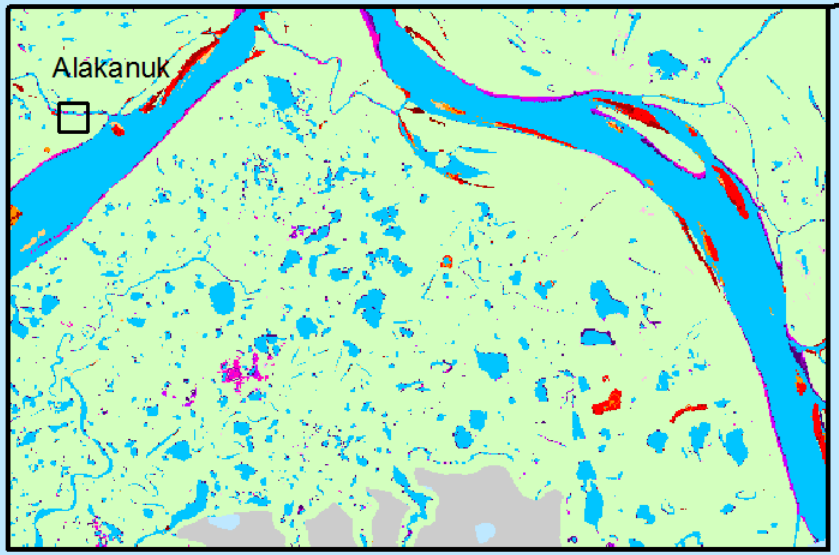
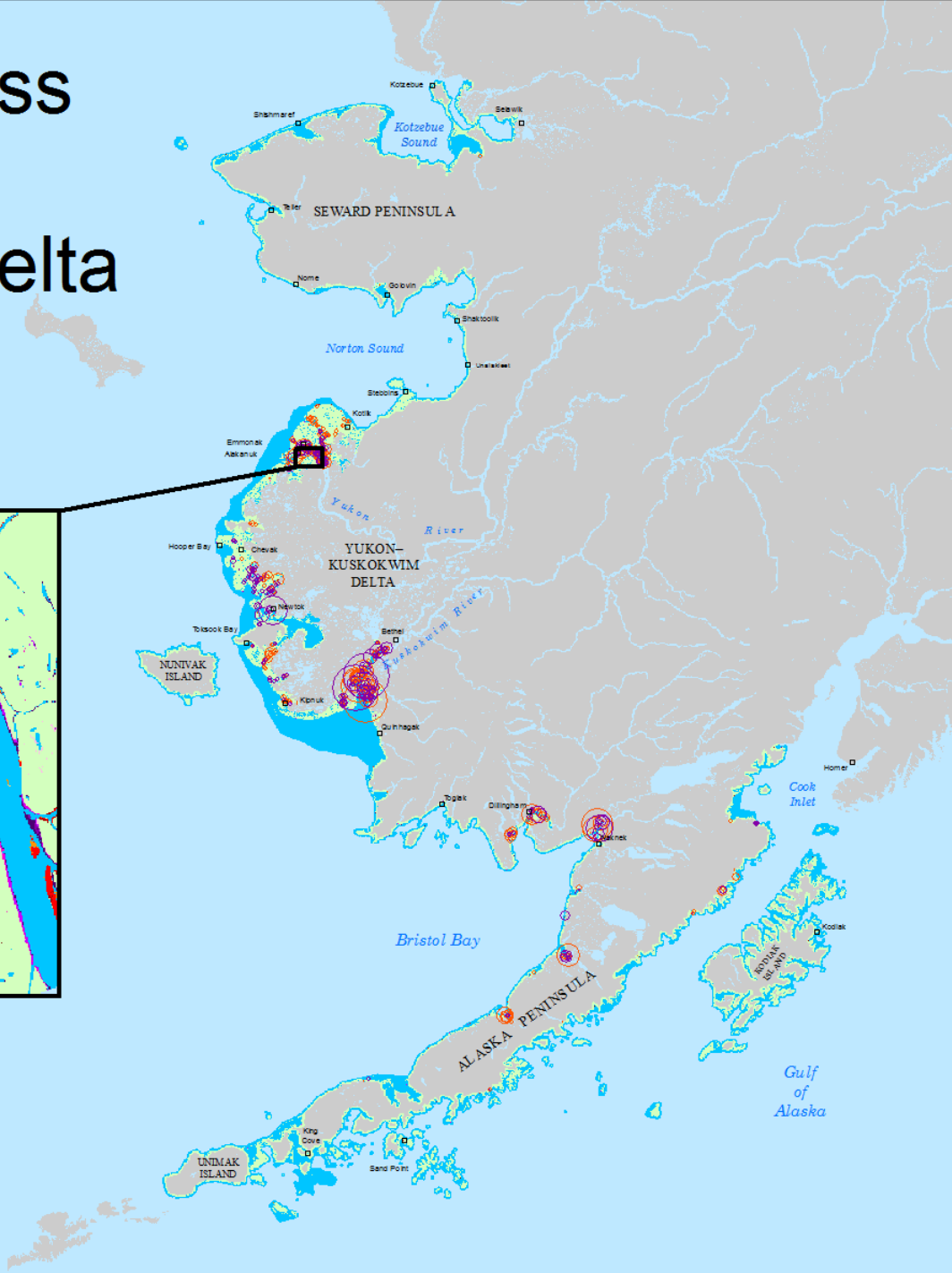
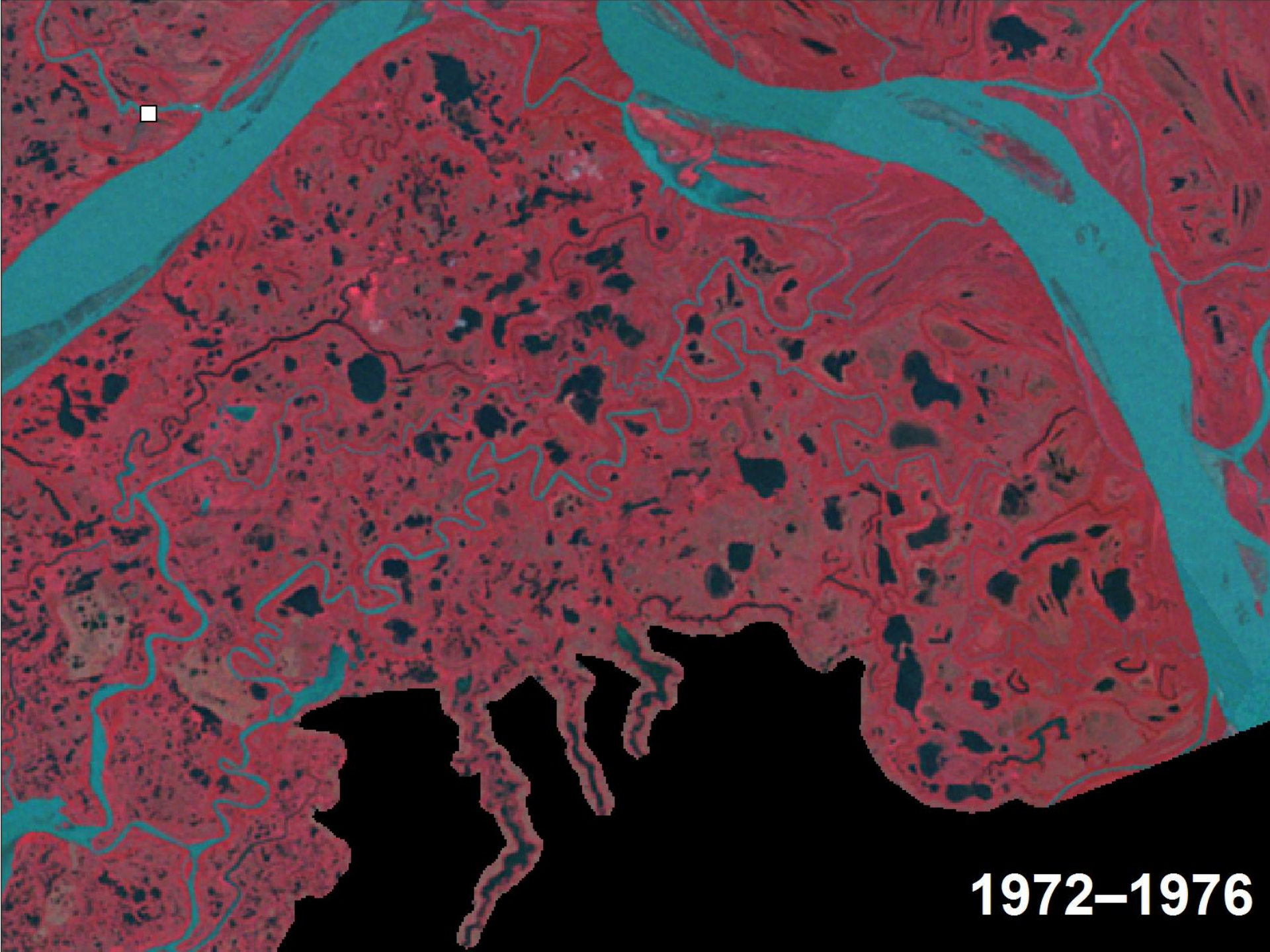
2006–2011
Drainage / Aggrad.
1973–1978
1979–1985
1986–1998
1999–2005
2006–2011
Change, 1972–2013

Across Kwikluak Pass from Alakanuk, Yukon–Kuskokwim Delta Lake Changes



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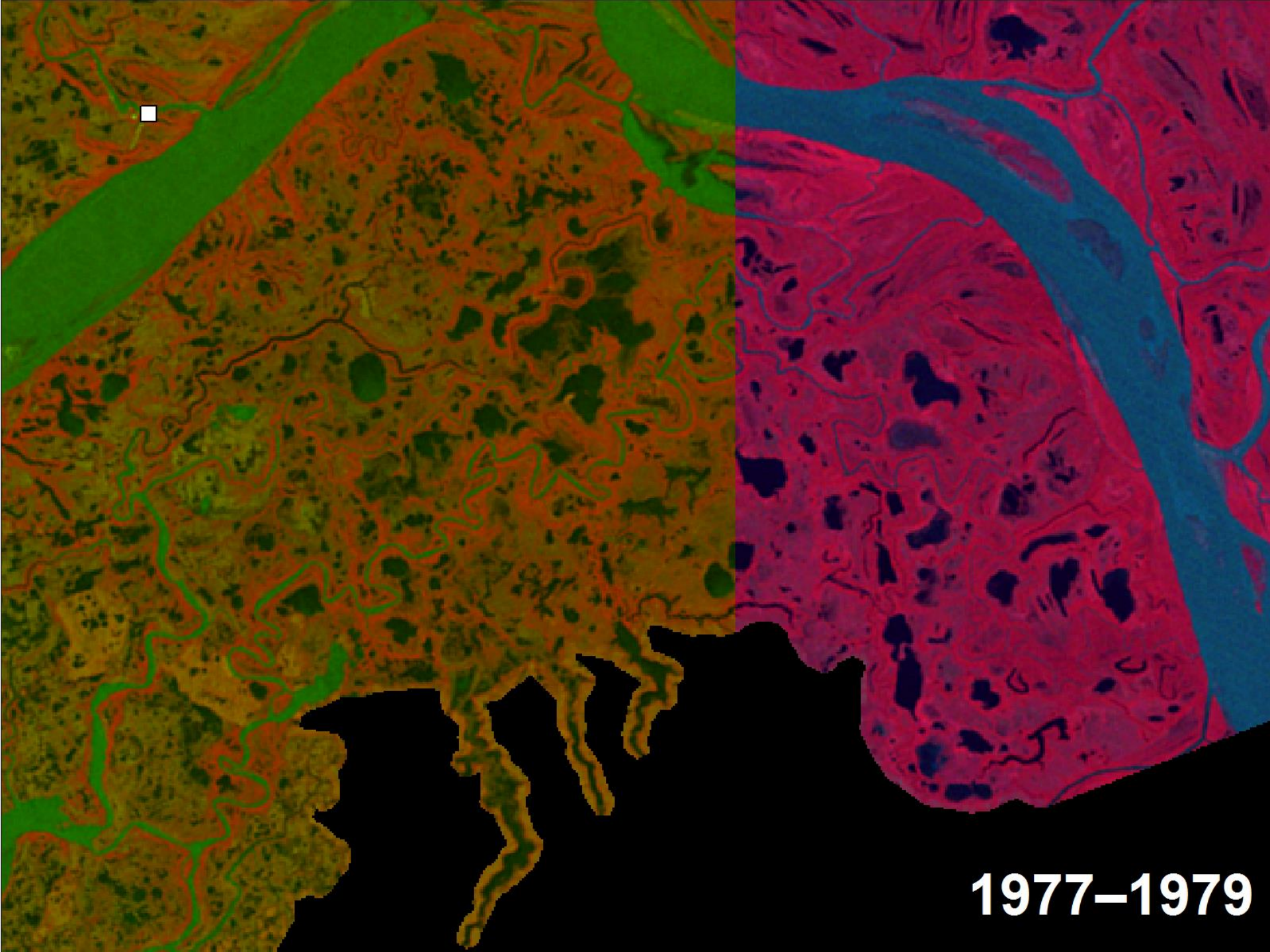
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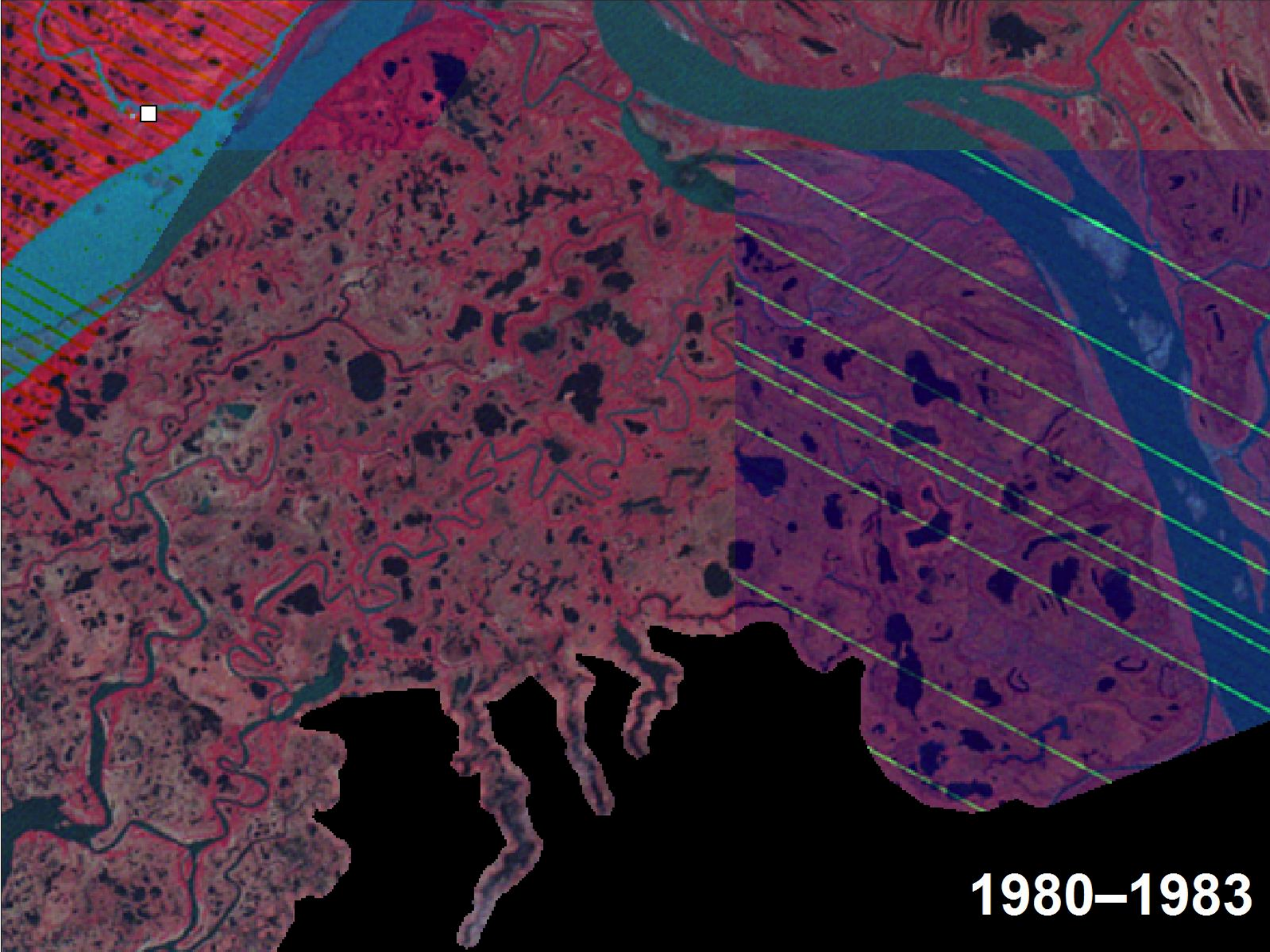
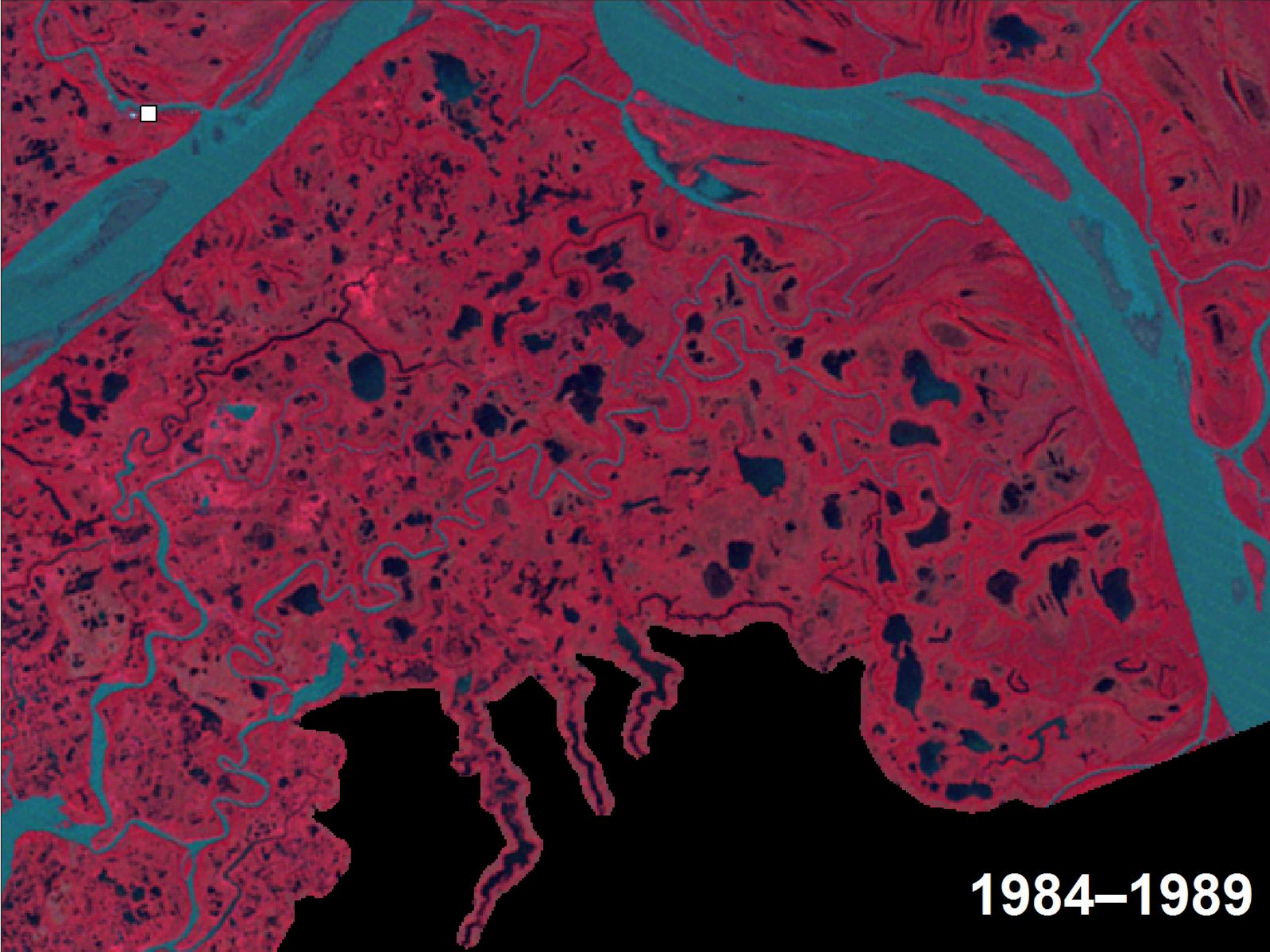

1980–1983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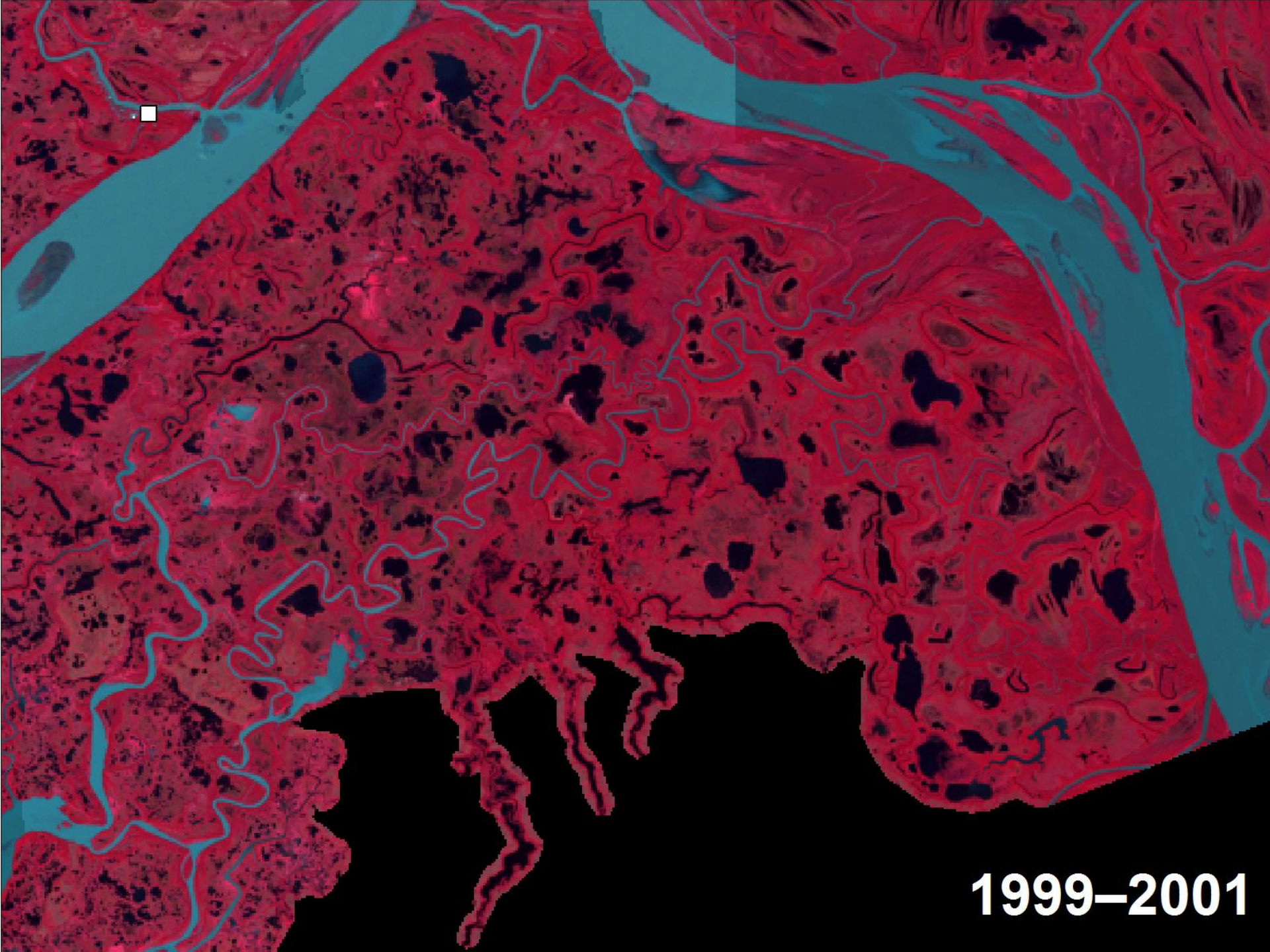
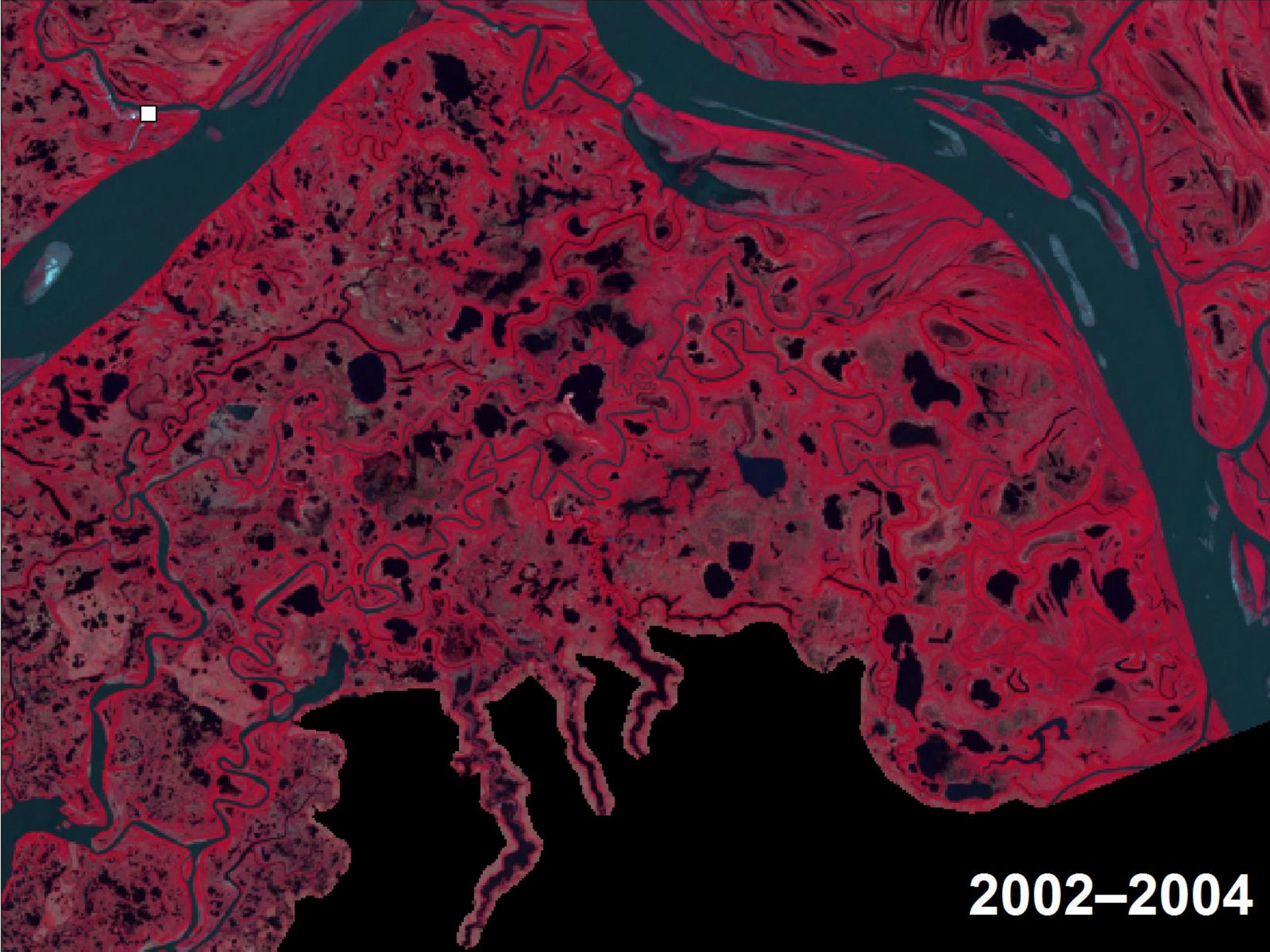

1999–2001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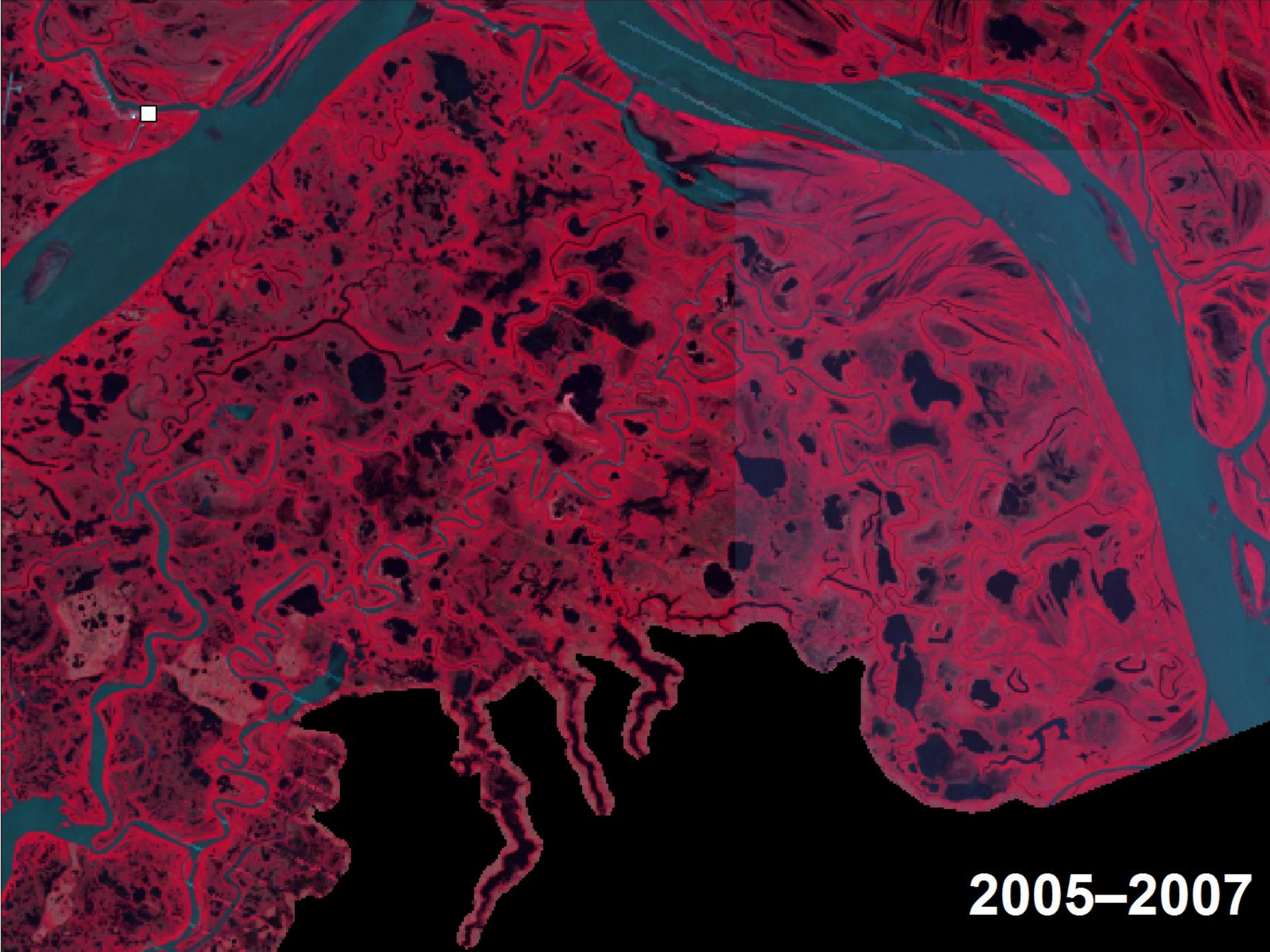
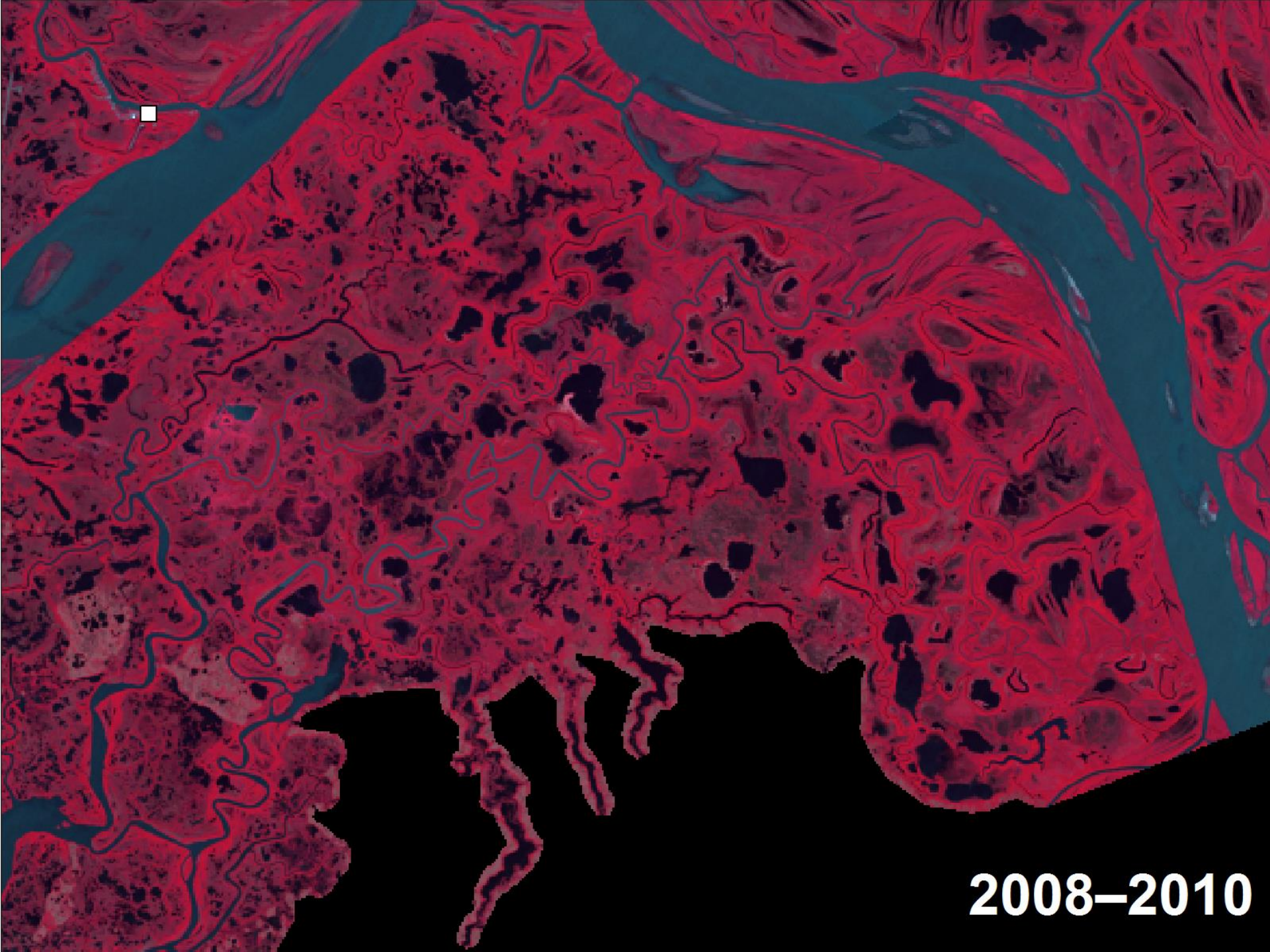
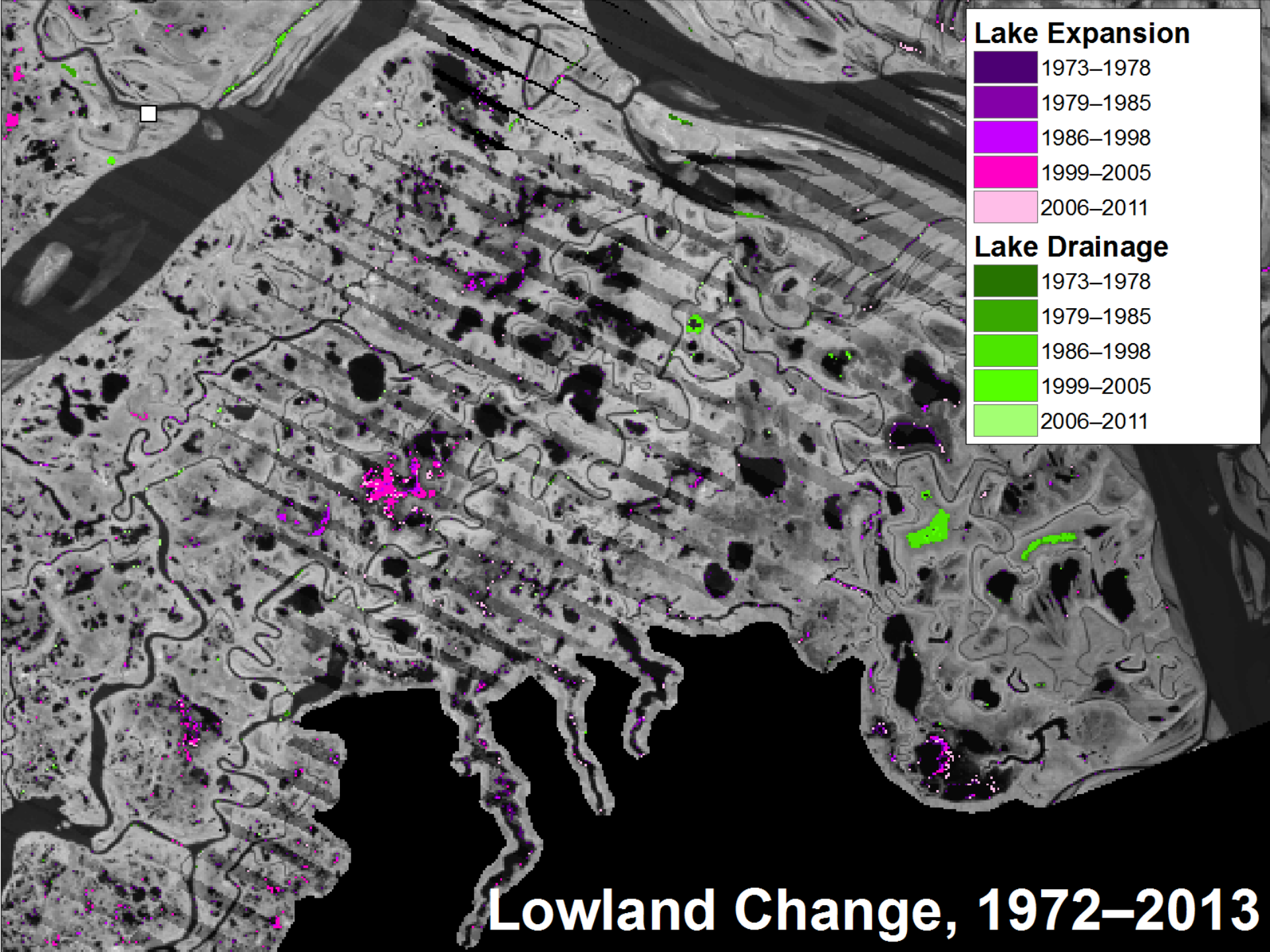
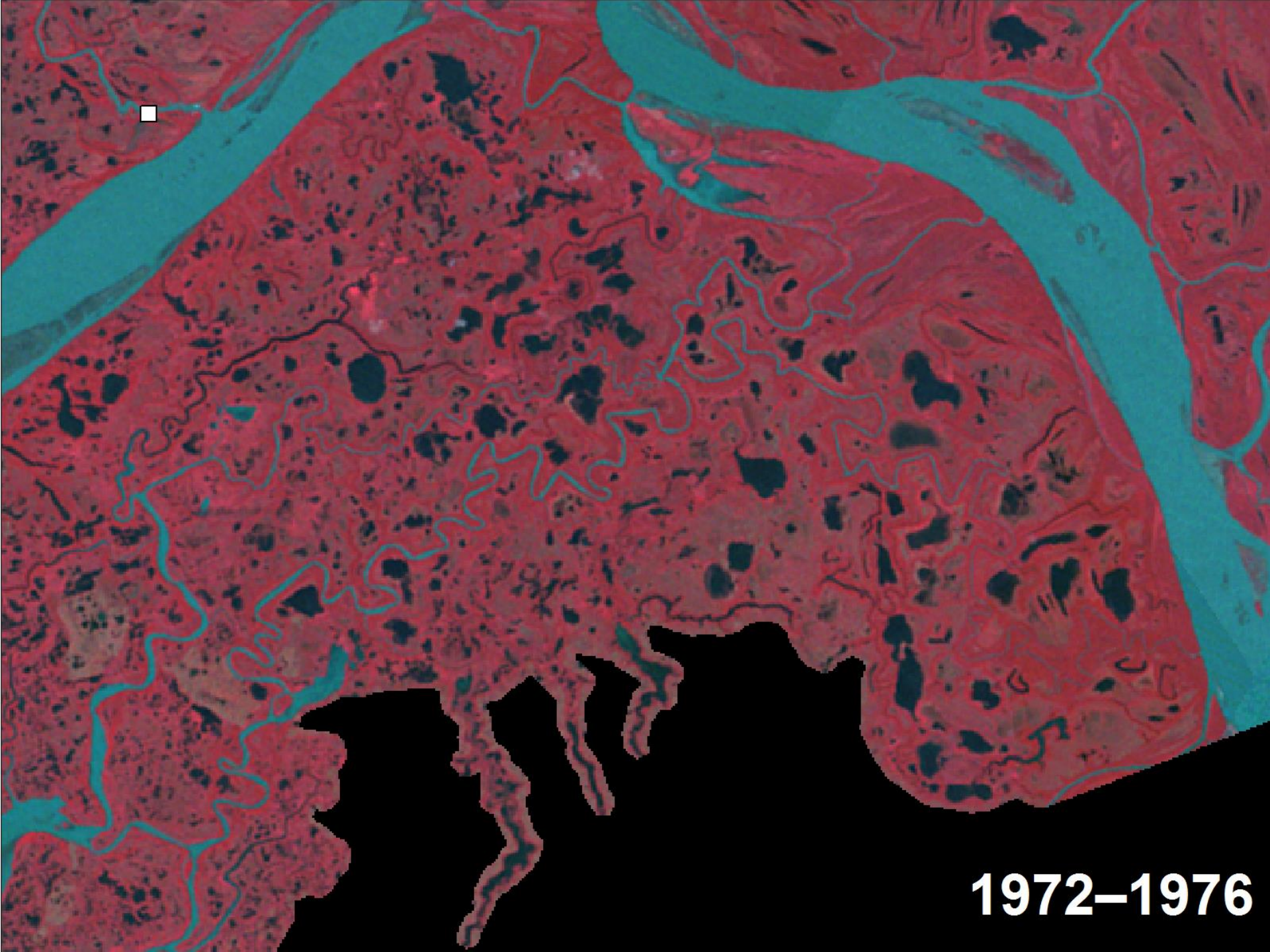

2005–2007

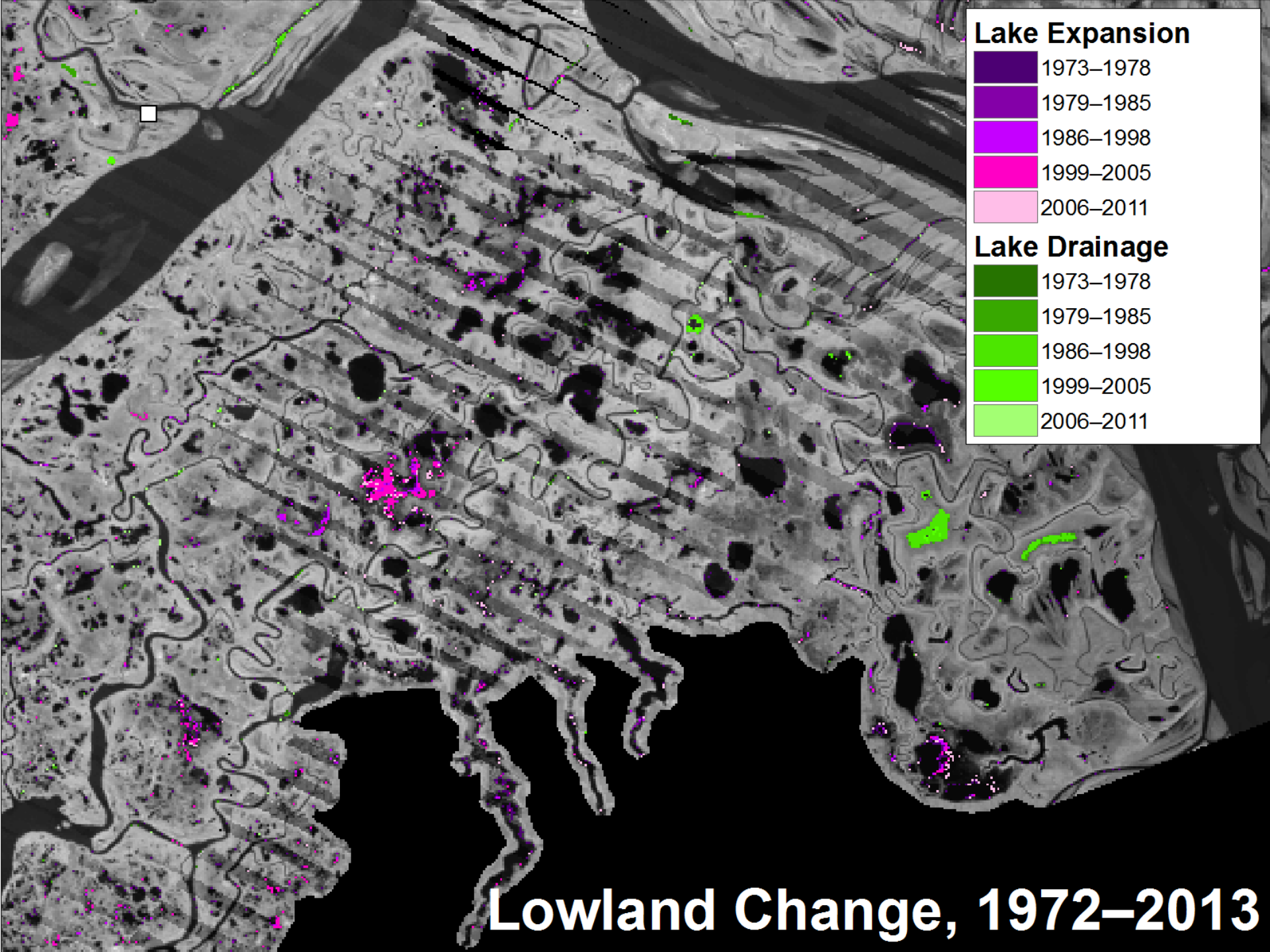

2008–2010

2011–2013


Lake Expansion
1973–1978
1979–1985
1986–1998
1999–2005
2006–2011
Lake Drainage
1973–1978
1979–1985
1986–1998
1999–2005
2006–2011
Lowland Change, 1972–2013


1972–1976

2011–2013


Lake Expansion
1973–1978
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1999–2005
2006–2011
Lake Drainage
1973–1978
1979–1985
1986–1998
1999–2005
2006–2011
Lowland Change, 1972–2013

Management Applications

- Local and regional analyses of vulnerability and coastal processes
- Summaries by coastline class, orientation and other factors (e.g., based on ShoreZone mapping) to explore associations of coastal change with geomorphic factors
- Eelgrass beds mostly regarded as noise due to large tidal fluctuations, but tying acquisitions to tide data could allow selection of low tide data for monitoring

Conclusions

- Large change patches (>5 ha) well mapped for 1972–2013 time-series
  - Coastal aggradation somewhat overmapped in tidal flats
- Including MSS imagery extended the effective start of the study period from 1999 to 1972 for much of the study area
  - Sparse data 1985–1998 makes interpretation of rates over time challenging

Conclusions

- To refine mapping further
  - Identify one or more regional focus areas
  - Archive of historical and modern imagery
  - Optimize thresholds for land and water discrimination
  - Provide more robust estimates of algorithm accuracy, including errors of omission
  - Could include areas further inland
  - Refinements from regional focus areas could readily be extrapolated

Conclusions

- Assess stability/calibration of Landsat NIR metric
  - Somewhat different response between MSS and TM
  - Landsat 8 OLI NIR bandpass is much narrower
- Going forward, the 30 m record (1985–present, but largely 1999–present) becomes more important as the record gets longer
  - More bands = more options for metrics
  - Better calibration and geometric accuracy = less noise

Conclusions

- Landsat imagery compiled for this effort could be repurposed for other analyses
  - Very wide composite period (March–October, when sea ice permitted) mean reprocessing of composites would be required for vegetation analyses
  - Much of the hard work has been done

https://westernalaskalcc.org/projects/SitePages/WA2013_24.aspx

Thank You