Analyzing the Land-Use Change Impacts of Oil and Gas Exploration Related Infrastructure Changes on Arctic Communities

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This document has been reviewed and determined not to contain export controlled technical data.

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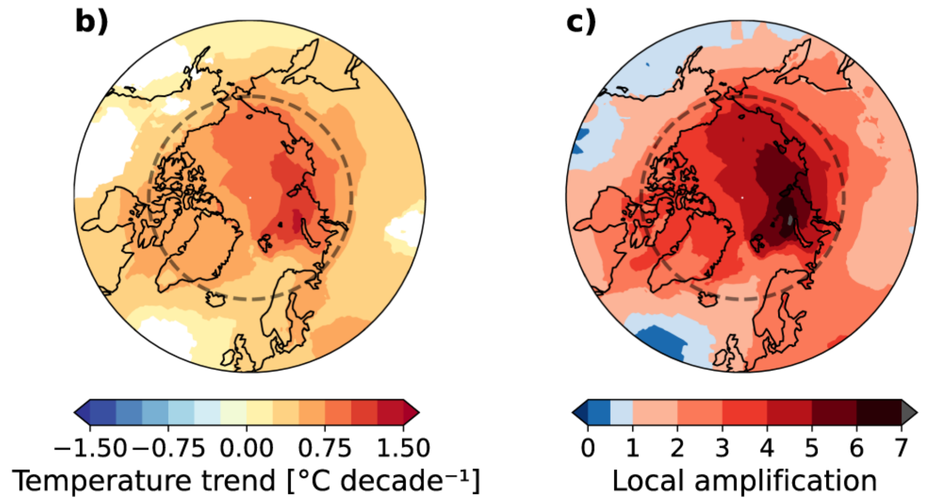
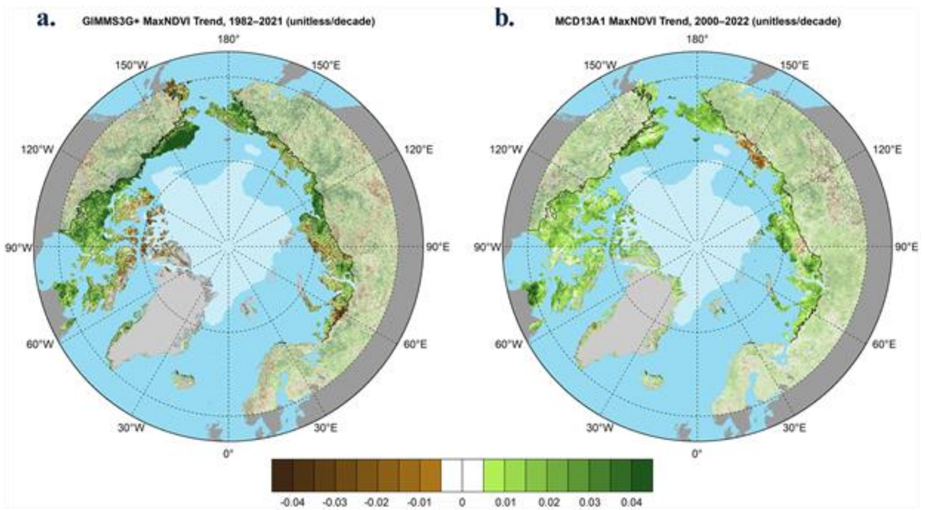
Motivation

- The Arctic is warming four times faster than the rest of the world
- Vegetation changes, such as greening and browning of the Arctic tundra, have been observed
- Thawing permafrost has led to deepening of the hydrologically and biogeochemically active layer, as well as changes in land cover



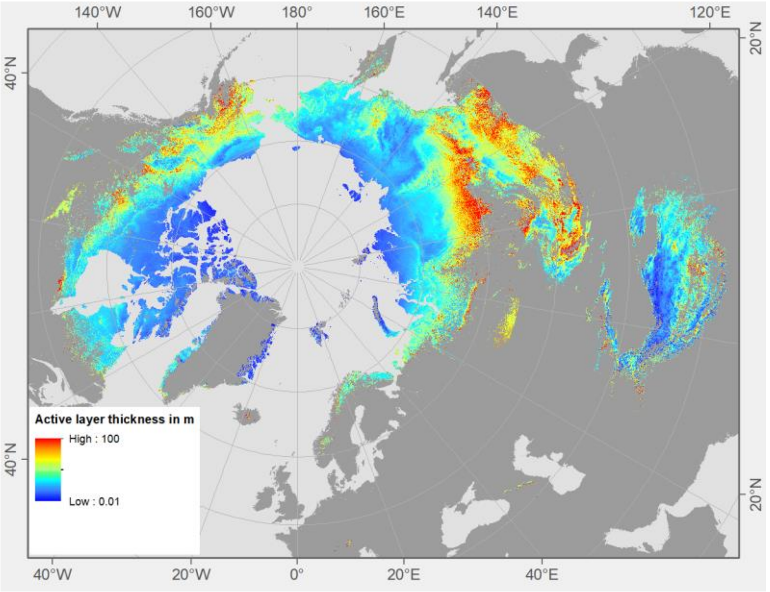
Source: Rantanen et al.2022

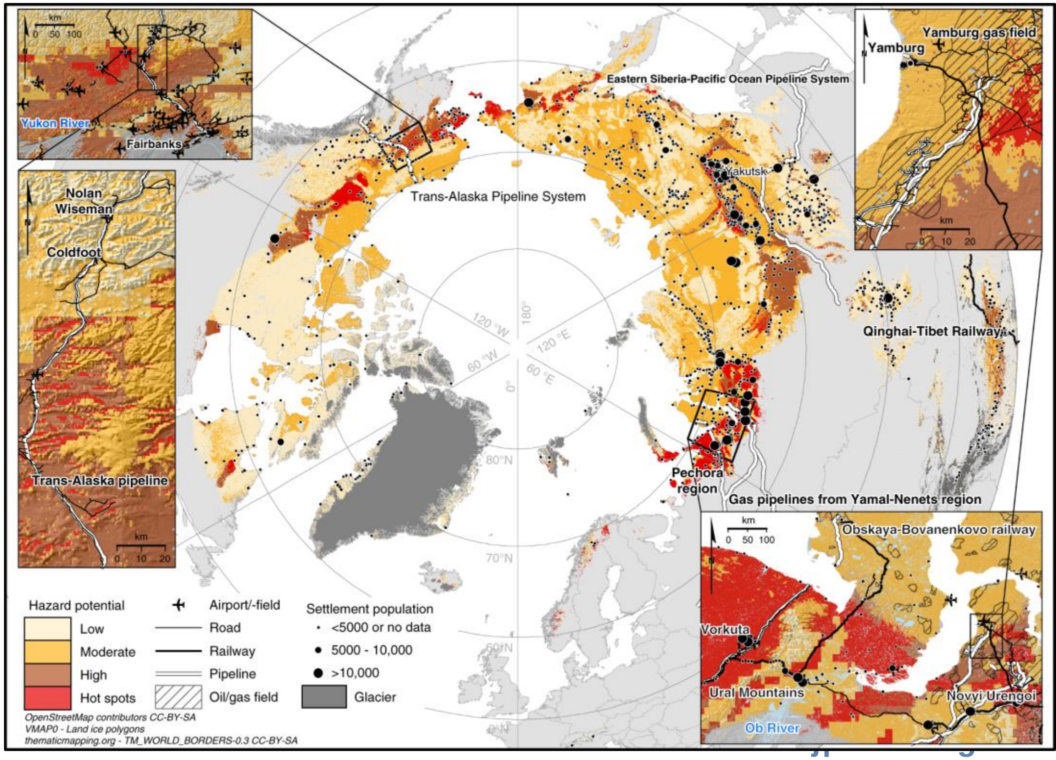


Source: Druckenmiller et al.2022

- Arctic coastal communities are vulnerable to climate change due to the combined effects of sea ice loss and permafrost thaw
- Currently, 70% of infrastructure in the permafrost domain is located in areas with high potential for thaw of near-surface permafrost by 2050 (Hjort et al. 2018).

Permafrost active layer thickness for the Northern Hemisphere (1997-2019) (Source: Obu et al. 2021)





Pan-Arctic infrastructure hazard map with hazard potential by risk level (low–high) for infrastructure damage by the middle of the century (2041–2060) (Source: Hjort et al. 2018)

The oil and gas industry

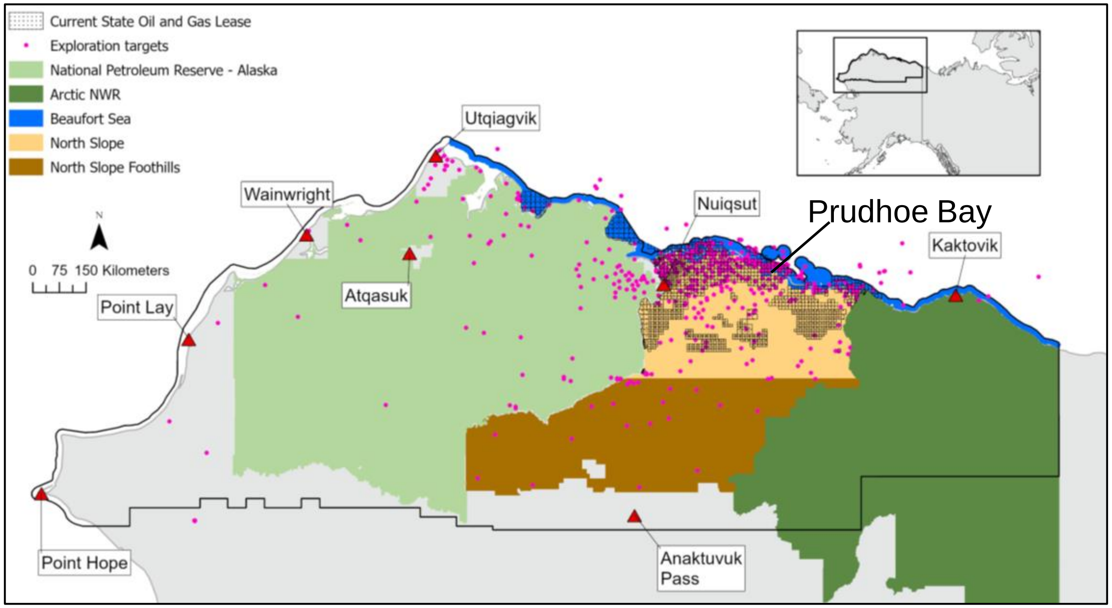
- In Western North America, annual drilling has increased from 269 to 8599 oil and natural gas wells from 1984 to 2014 (Klotz et al. 2023)
- Disturbances associated with oil and gas activities on the land include
  - clearing for exploration activities
  - seismic explorations
  - building infrastructure (pipelines, roads)
  - drilling
  - accidental spills and other hazards
- There is a need for improved oil and gas well databases and information on well pads to understand the full extent of impacts.

Image source: https://alaska.conocophillips.com/who-we-are/alaska-operations/alpine/

Objectives

Assess the impacts of oil and gas exploration on land and communities around Prudhoe Bay, Alaska

1. Determine timescales of oil/gas expansion from past and prospective infrastructure development around Prudhoe Bay
2. Develop a mixture modeling approach to track sub-pixel scale land cover changes associated with oil and gas exploration
3. Evaluate trends in land cover changes and their impact on communities in the North Slope Borough (NSB), and project future vulnerabilities due to planned oil and gas expansion

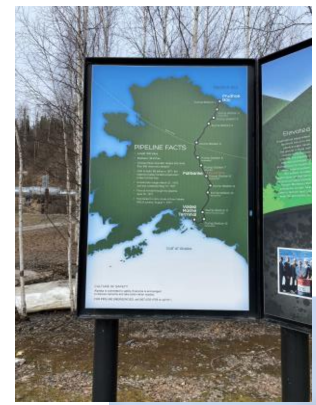


Timeline of oil and gas expansion in NSB

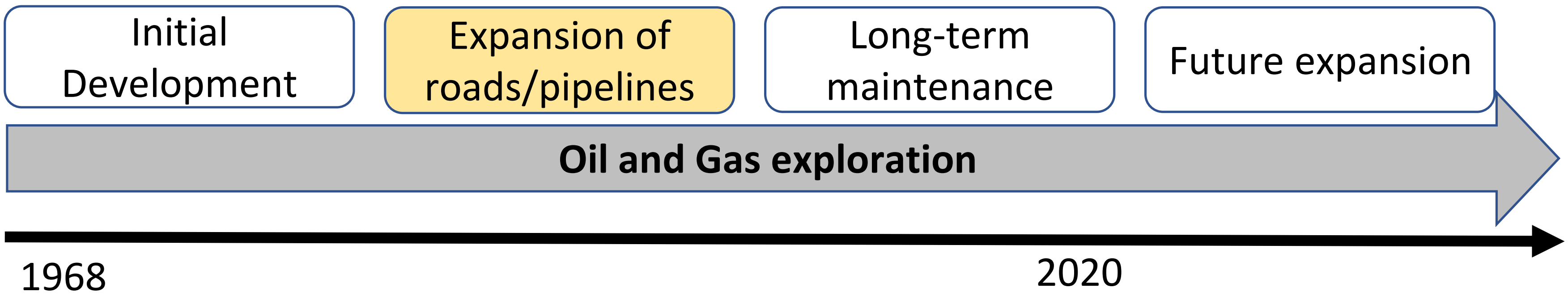
Initial Development | Expansion of roads/pipelines | Long-term maintenance | Future expansion

Oil and Gas exploration

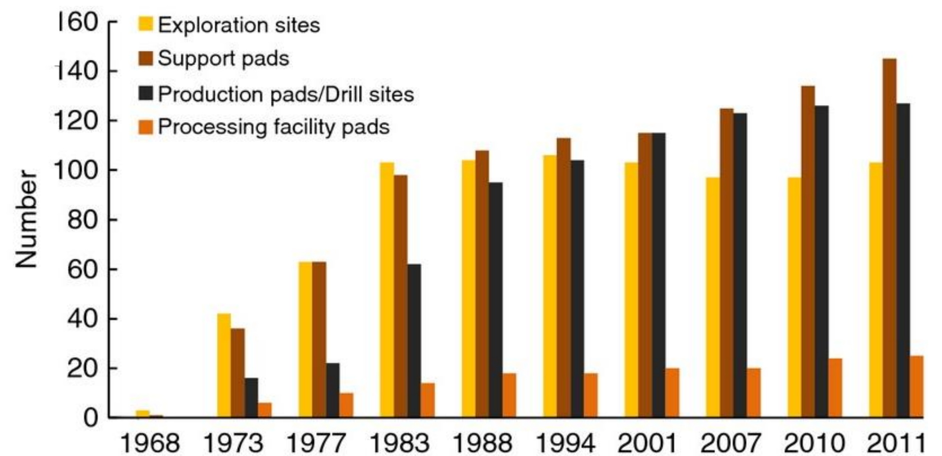
1968 → 2020



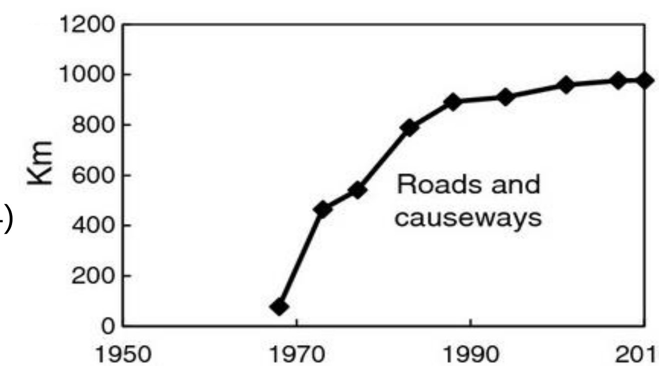
- Initial Development
  - Prudhoe Bay Discovery – 1968
  - Rapid growth of oil rigs from 1969 to 1977
    - ~213543 acres
  - Trans-Alaska pipeline built from 1974 to 1977
  - Many legacy wells have been plugged and managed for remediation

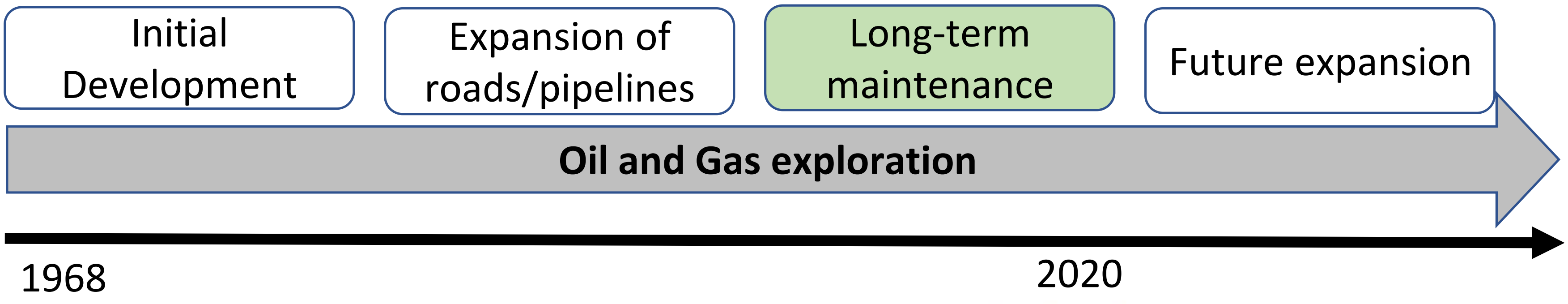


- Expansion of infrastructure
  - Large increment of footprint expansion was from 1973 to 1983
  - Road networks around Prudhoe Bay expanded rapidly till 1988 (Raynolds et al. 2014)



History of infrastructure in the North Slope region (Source of images: Raynolds et al. 2014)

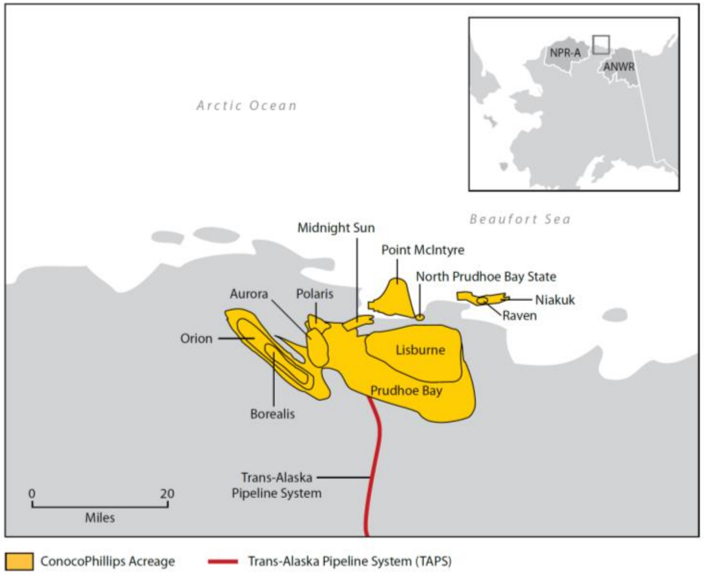




- Expansion to nearby areas
  - Satellite oil fields:
    - Midnight sun (from 1998, 3112 acres)
    - Aurora (from 2000, 7519 acres)
    - Orion (from 2002, 18853 acres)
    - Polaris (from 1999, 11681 acres)
    - Borealis (from 2001; 7757 acres)

Source: https://dec.alaska.gov/spar/ppr/response/sum_fy06/060302301/factsheets/060302301_factsheet_PB.pdf

Greater Prudhoe Area



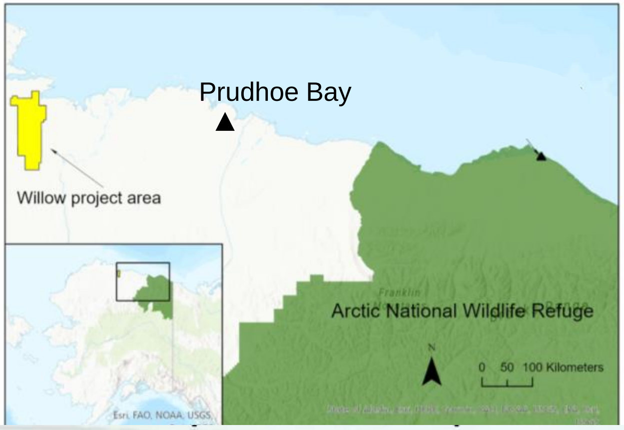
Source: http://static.conocophillips.com/files/resources/factsheet-alaska-march2018.pdf

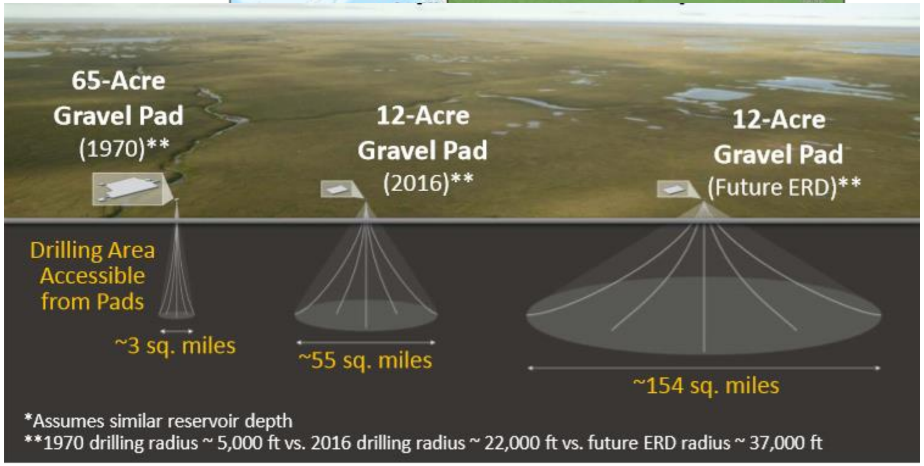
Initial Development | Expansion of roads/pipelines | Long-term maintenance | Future expansion

Oil and Gas exploration

1968 — 2020

- The Willow Project
  - Recently approved production facility in the NPRA
  - Designed to extract more than 100,000 barrels of oil a day for the next 30 years starting from 2024
  - Project footprint of about 500 acres
  - Up to 250 wells, hundreds of miles of new pipelines and roads and an airstrip
- New technology, but footprint and impact on the land remains

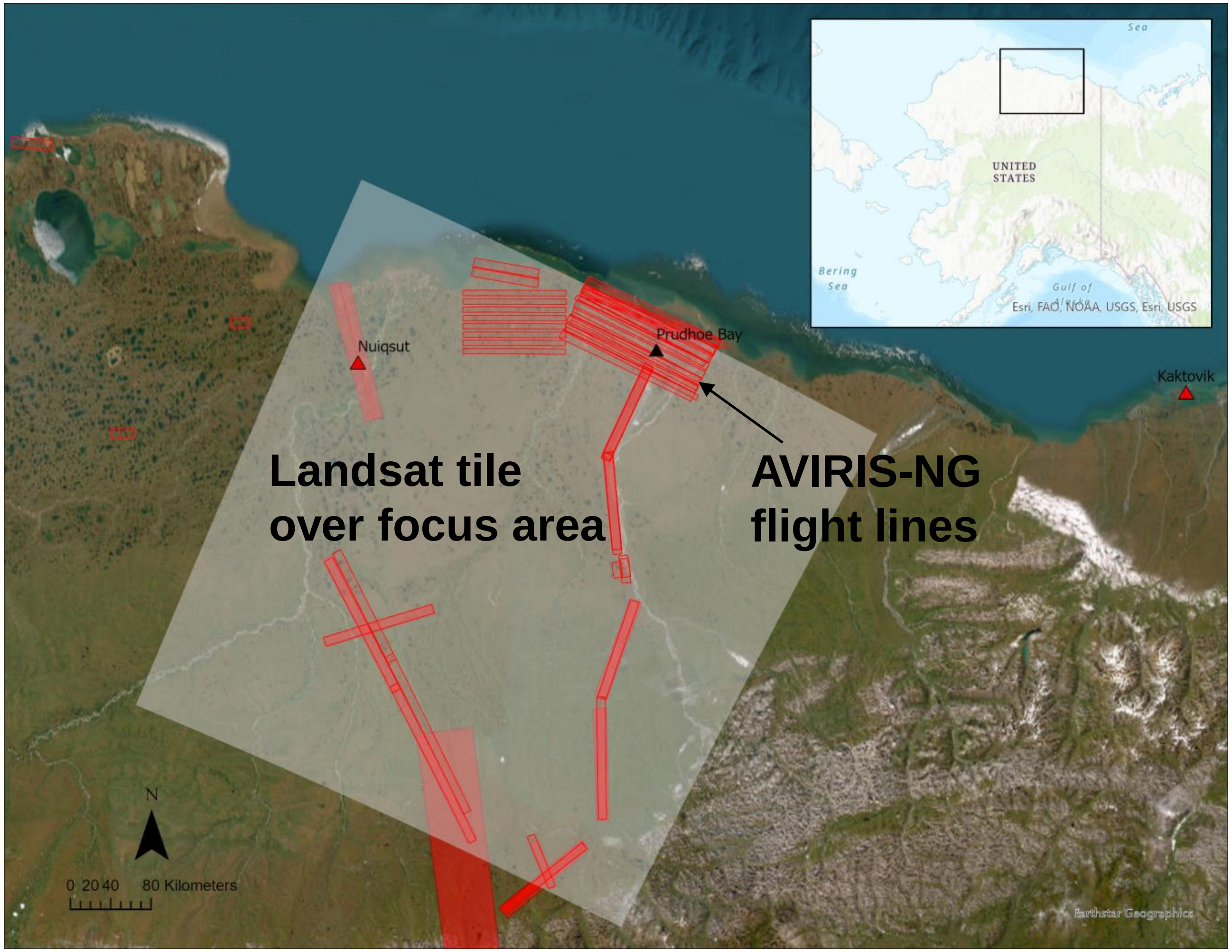




Source: https://eplanning.blm.gov/eplanning-ui/project/109410/590

Image source: https://www.conocophillips.com/sustainability/sustainability-news/story/responsibly-developing-alaska-s-willow-project/

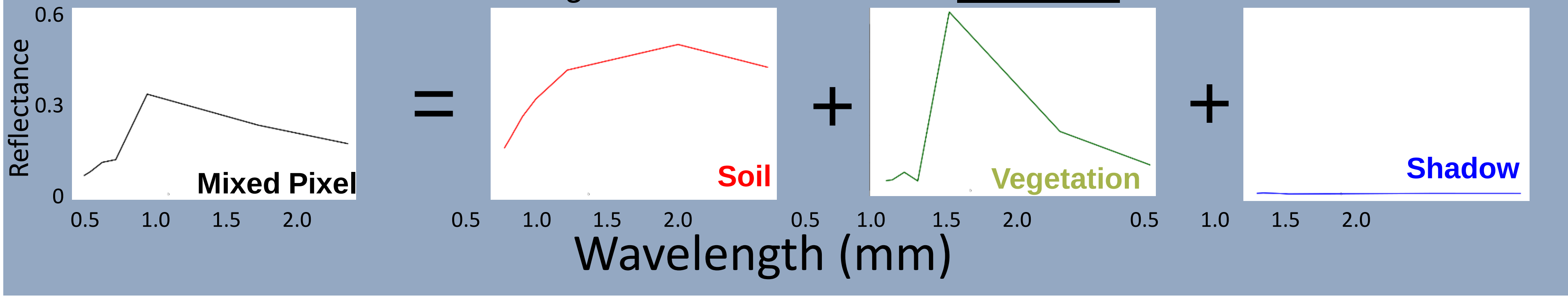
Study area and data for mixture modeling



- 56 Landsat 4-8 Collection-2 images:
  - 16 high-to-moderate quality (Class A)
  - 32 moderate-to-low quality (Class B)
  - 8 very low quality (Class C)
- Sentinel 2 images
- AVIRIS-NG data
- Maxar and Planet data

Spectral Mixture Models

*In a **single image**, a mixed pixel can be considered to be comprised of an area-weighted sum of constituent **materials.***

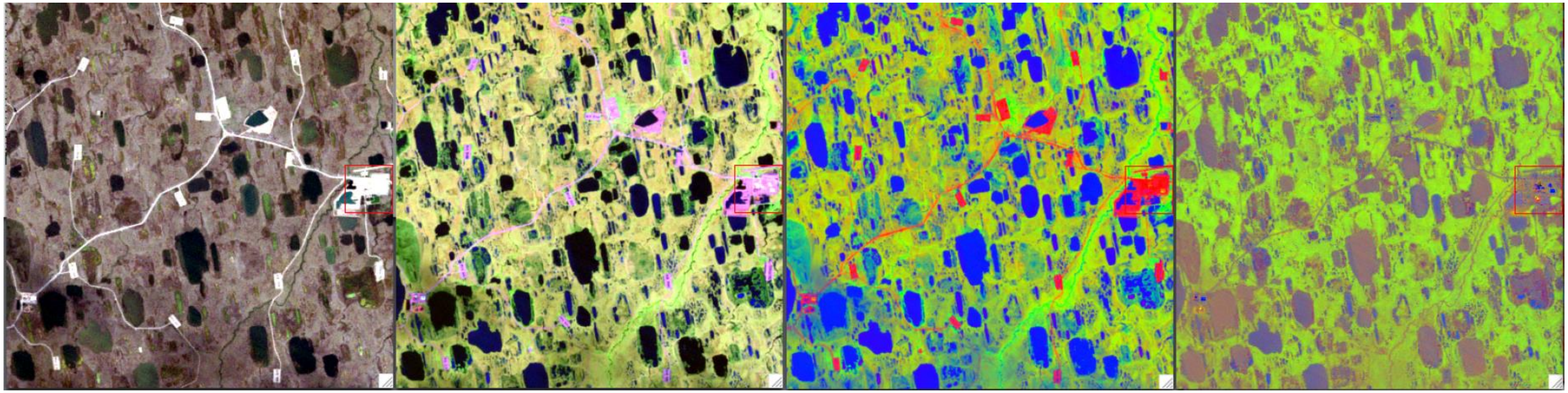


Spectral mixture analysis - workflow

- Identify local spectral endmembers from AVIRIS-ng flight line
  - Soil, rock and non-photosynthetic substrate (S),
  - Illuminated photosynthetic vegetation (V)
  - Dark targets like shadow and water (D).
- Resample AVIRIS-ng endmembers to simulate Landsat 4-7 TM/ETM+ and Landsat 8-9 OLI
- Linear spectral mixture analysis using endmembers
  - Obtain residual spectrum - Mixture Residual (MR).

Spectral mixture analysis - results

1.2 x 1.2 km spatial subset of an individual Landsat image



True color composite

False color composite
R = SWIR; G = NIR; B = Visible

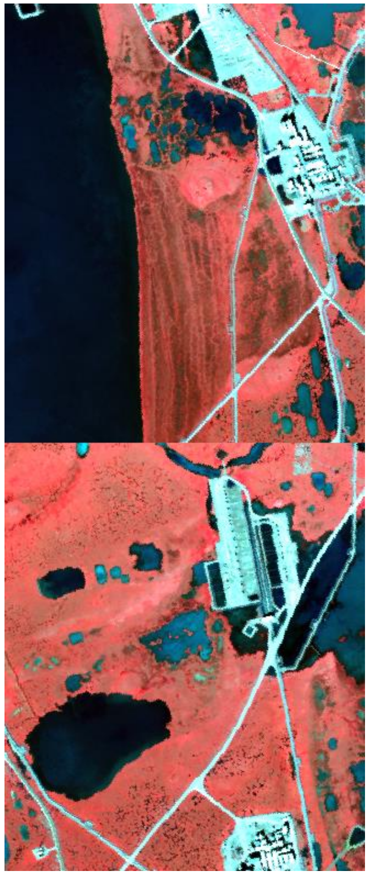
False color composite of the fraction images
R = Substrate; G = Vegetation; B = Dark

Spectral mixture residuals
R = SWIR2; G = SWIR1; B = Visible

The mixture residual spectral feature space is observed to effectively remove the high variance features associated with subpixel land cover mixing and accentuate subtle, spatially and spectrally coherent low variance features

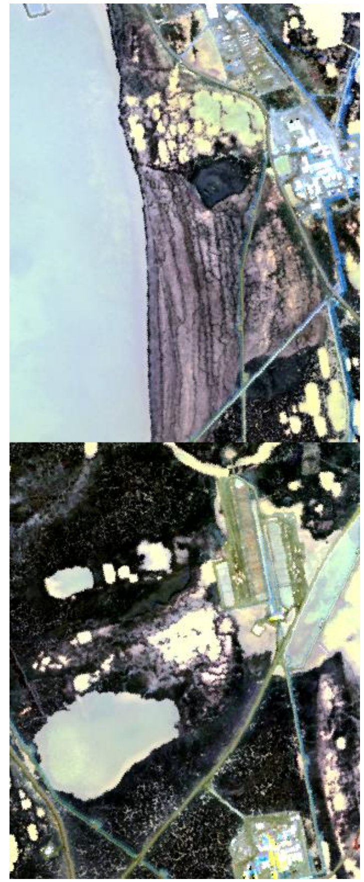
Oil and gas infrastructure from AVIRIS-NG image (2018) and Landsat image (2020)

True color composite



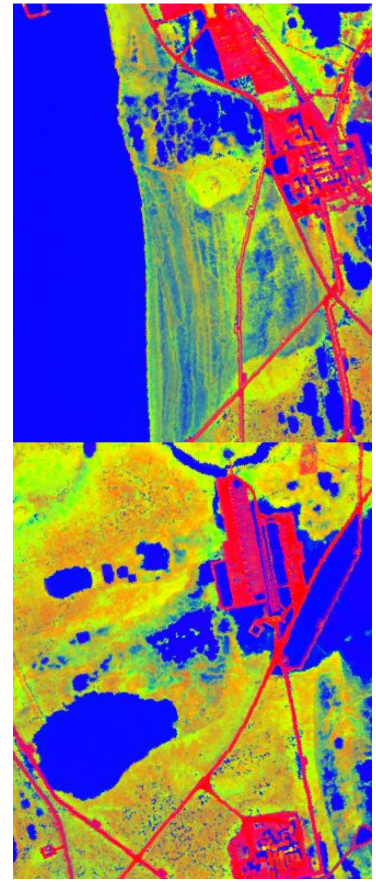
False color composite

(Infrared)

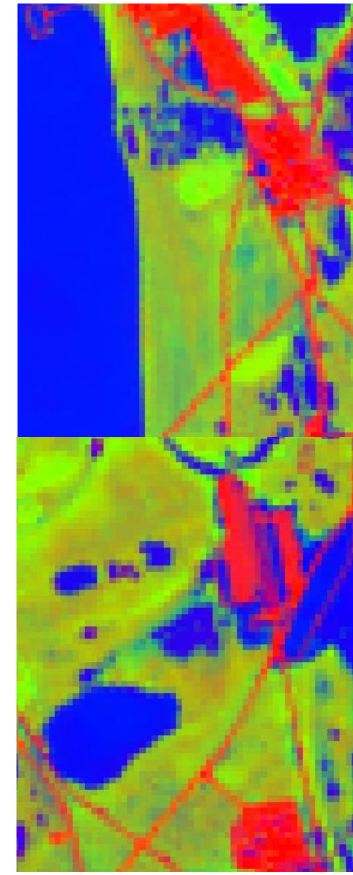


Spectral mixture residuals

R = 650 nm; G = 550 nm; B = 480 nm



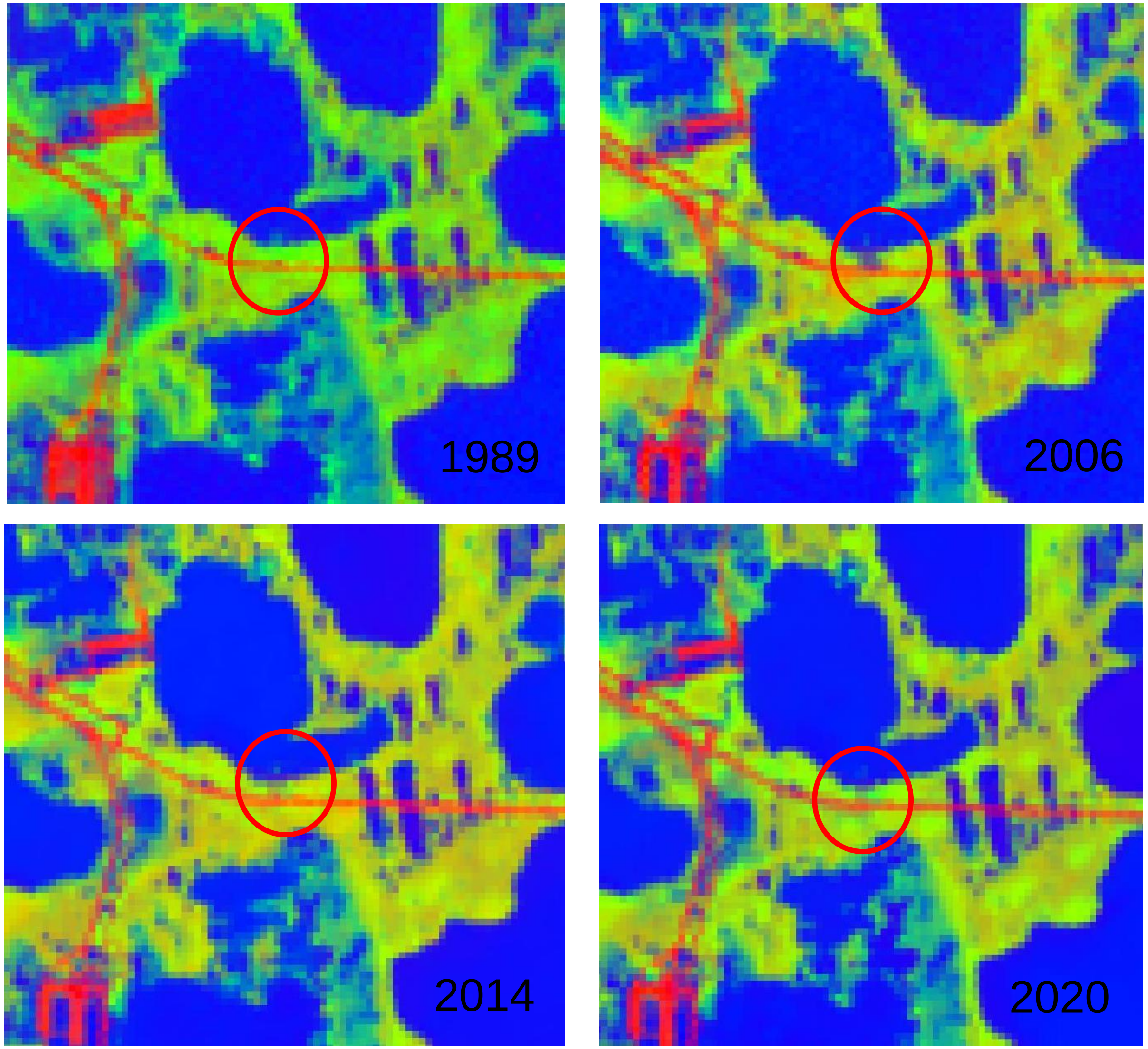
False color composite of the fraction images (AVIRIS)



False color composite of the fraction images (Landsat)

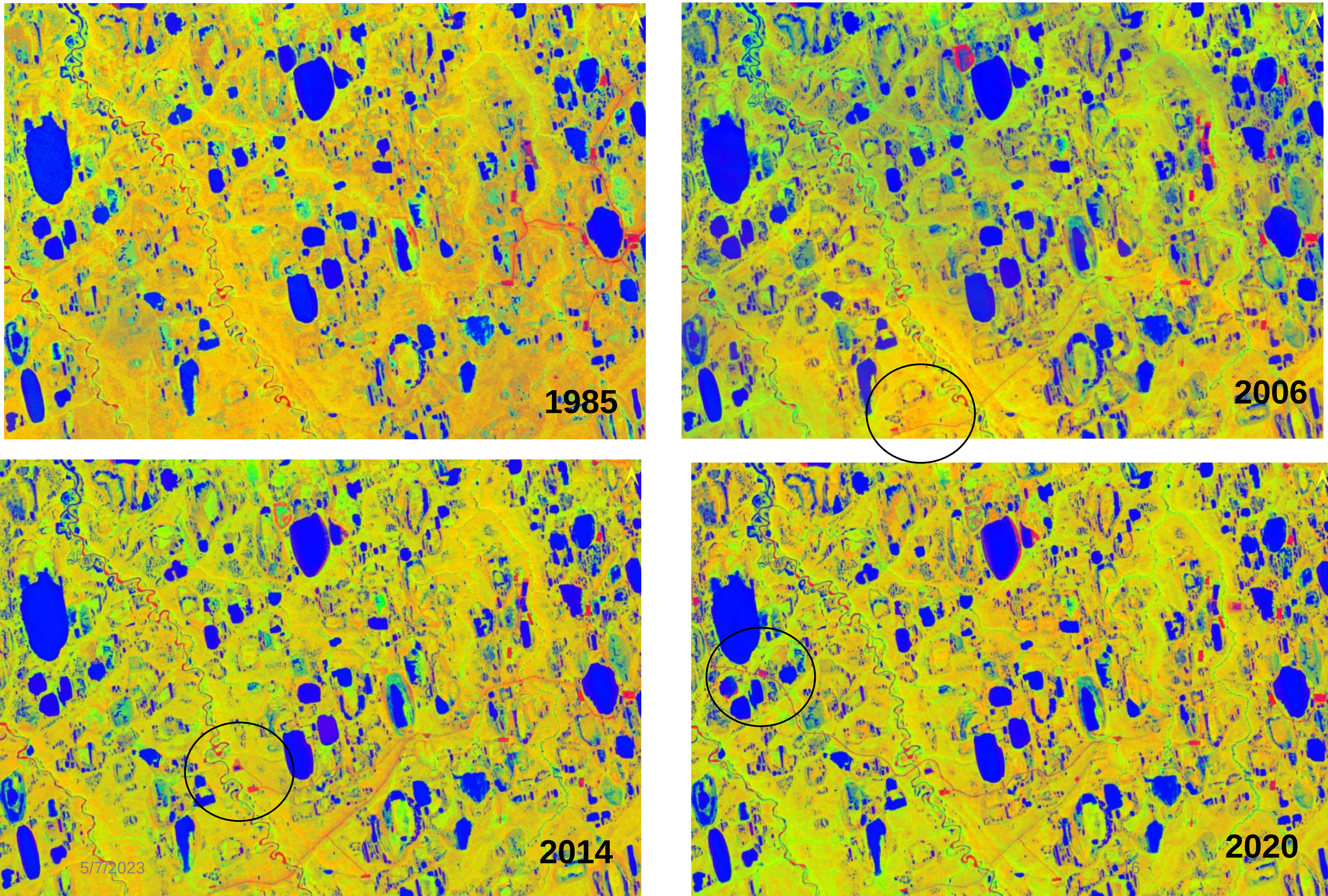
R = Substrate; G = Vegetation; B = Dark

Oil spill in Prudhoe Bay – March 2006



Source: Department of Environmental Conservation, Alaska

Expansion of oil and gas infrastructure over the years



Vulnerability Analysis

- Determining the factors impacting communities in the North Slope
  - Resource changes
    - Food system dynamics
    - Culture of subsistence hunting
    - Access to outside resources
  - Infrastructure durability
    - Thawing permafrost
  - Wildlife habitat
  - Impacts from oil spills and contamination
- **Understanding vulnerability at regional scales aids and qualifies remote sensing data**

Field visit - Summer 2023

- Kimberley Miner is leading field research in the North Slope (July 2023)
- Goals:
  - Visit communities and identify landscape changes around Prudhoe Bay and Toolik Field Station
  - Leverage ABoVE resources and contacts for field visits and planning
  - Get situational awareness of on-the-ground conditions
  - Understand the community and the way that change dynamics impact their lives.

Toolik Field Station
(Source: https://www.uaf.edu/toolik/)

References

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