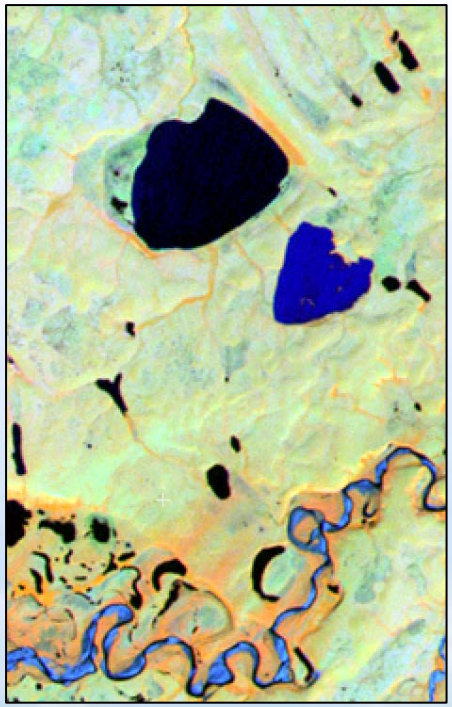
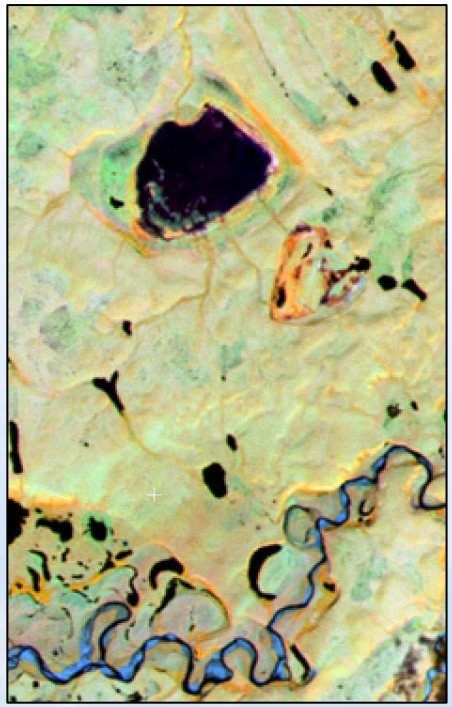
# Detecting Vegetation Changes in Tundra using 25-year Landsat Image Stacks





**Robert Fraser, Ian Olthof, Alice Deschamps, Mélanie Carrière, and Darren Pouliot**

Natural Resources Canada
Canada Centre for Remote Sensing

# Outline

1) Parks Canada Agency (partner) monitoring requirements

2) Recent vegetation changes in the Arctic

3) Method for analyzing change using 25-yr Landsat image stacks

4) Results to date for four national parks

5) Summary and conclusions

# Parks Canada Agency Monitoring Requirements

## Parks Canada and Ecological Integrity

*"Maintenance or restoration of ecological integrity,* through the protection of natural resources and natural processes, shall be the first priority of the Minister when considering all aspects of the management of parks."

Section 8. (2) Canada National Parks Act

## Park Management Plan

**Reviewed every 5 years**

## National EI Monitoring Framework

### Biodiversity

**Species Lists**
- native species
- alien species

**Focal Species**
- mortality/natility
- immigration/emigration
- viability/persistence

**Trophic Structure**
- size class distribution
- predation levels

### Structure & Processes

**Local Ecosystems**
- suite of measures that monitor most important structure and process changes at a local ecosystem scale

**Landscapes**
- suite of measures that monitor most important structure and process changes at a landscape ecosystem scale

### Stressors

**Inside Park**
- most critical in-park stressors

**Outside Park (GPE)**
- most critical GPE stressors

**Outside Park (Long Distance)**
- most critical long distance stressors

## State of the Park Report

**EI assessment every 5 years**

# Parks Canada Agency Monitoring Requirements

**Major challenges for monitoring Ecological Integrity in Arctic Parks**

- Large, remote, expense to collect field data
- Few baseline measurements
- Many changes expected to be gradual and subtle

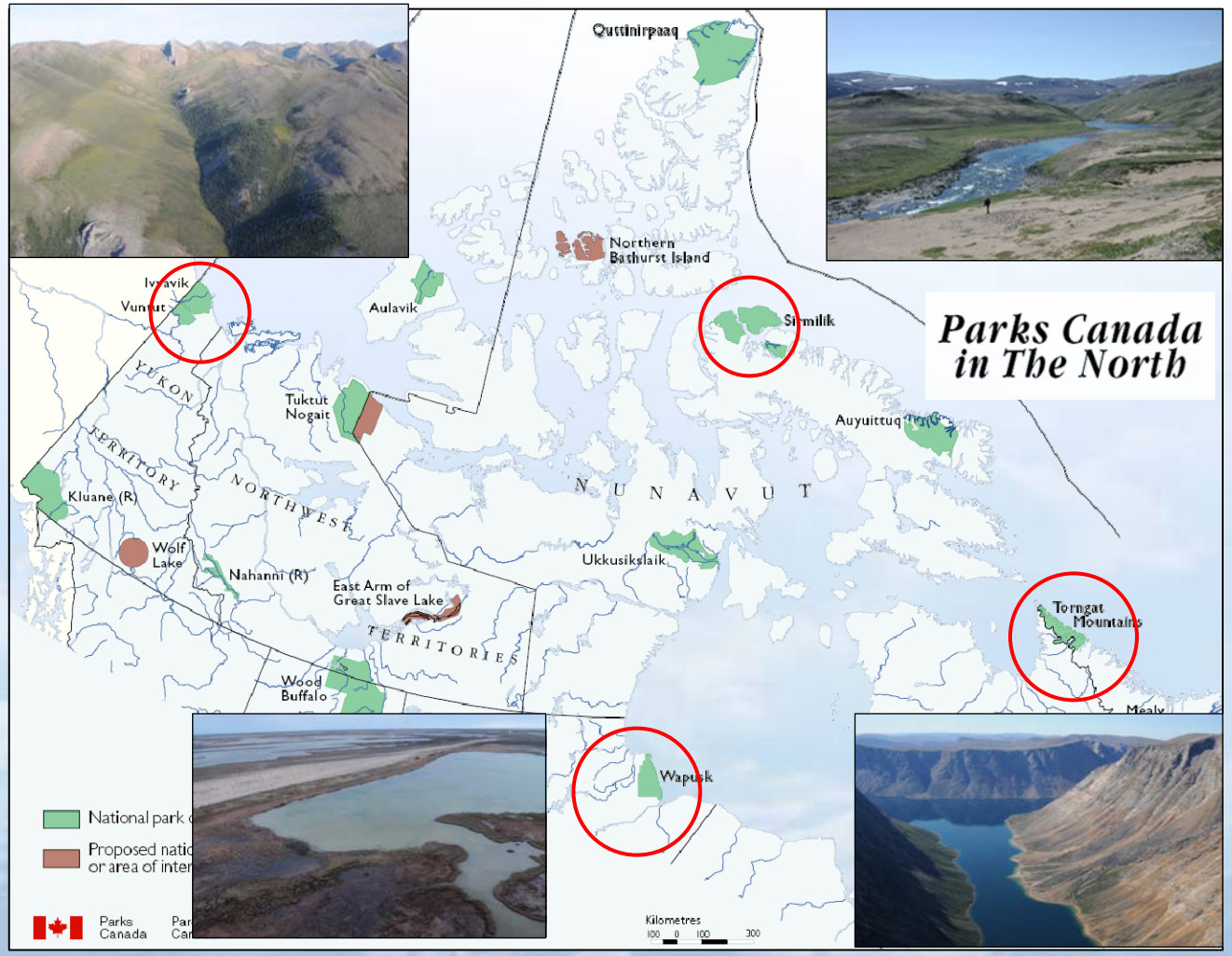
**Parks Canada anticipates satellite remote sensing will play a major role**

- Cost-effective for large-area monitoring
- ParkSPACE project (2008-2012) with Canada Centre for Remote Sensing developing RS-based methods and operational capacity
- ParkSPACE addressing land cover / vegetation change (this presentation), vegetation productivity and phenology, permafrost, and wetlands monitoring
- Developing operational methods based on Landsat imagery – data since 1985, continuity from LDCM, free from USGS

# ParkSPACE Pilot Parks for Developing Monitoring Methods

Ivvavik NP
Southern Arctic Ecozone

Sirmilik NP
Northern Arctic Ecozone




Wapusk NP
Hudson Plains Ecozone

Torngat Mountains NP
Arctic Cordilleran
Ecozone

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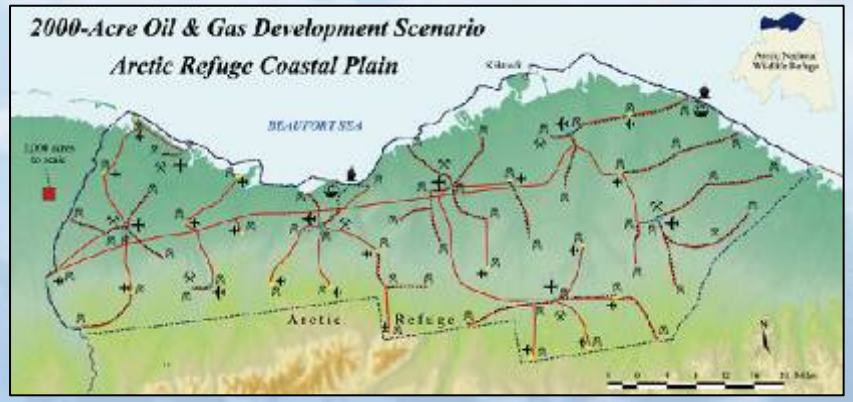
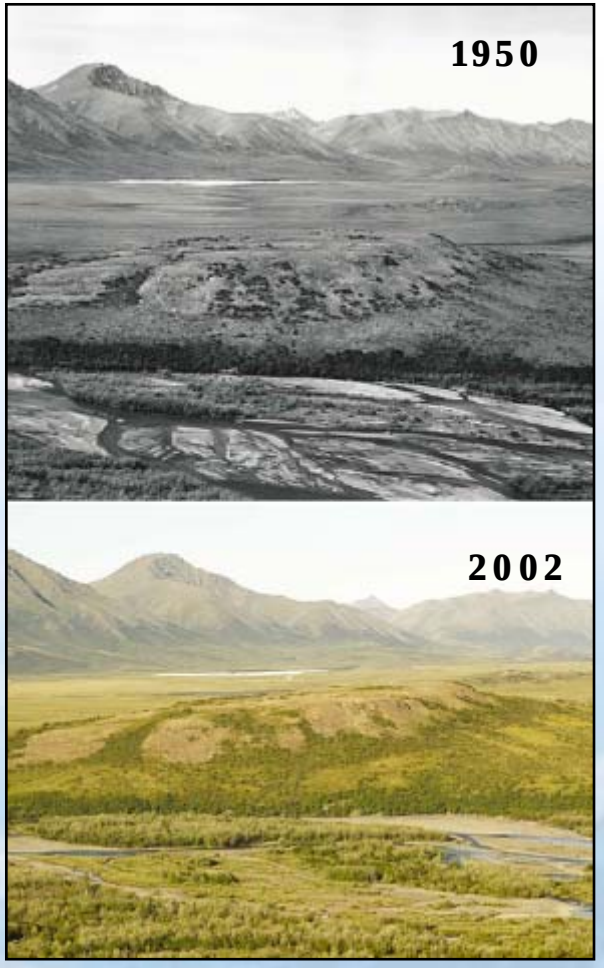
# Vegetation Change in the North

## (requirements for remote sensing)

- Many vegetation changes of interest will be gradual and subtle by comparison to those in forested zone
- E.g. – increase in the density and extent of shrub species
- In Arctic, optical data are **highly sensitive to variation in shrub biomass** (e.g. live foliar deciduous shrub - Riedel et al. 2005, *IJRS*)
- Changes may also be expressed as shifts in vegetation community composition (e.g. shrub outcompeting lichen)
- Also need to be able to identify rapid changes (e.g. from development, mining, disturbance, etc)

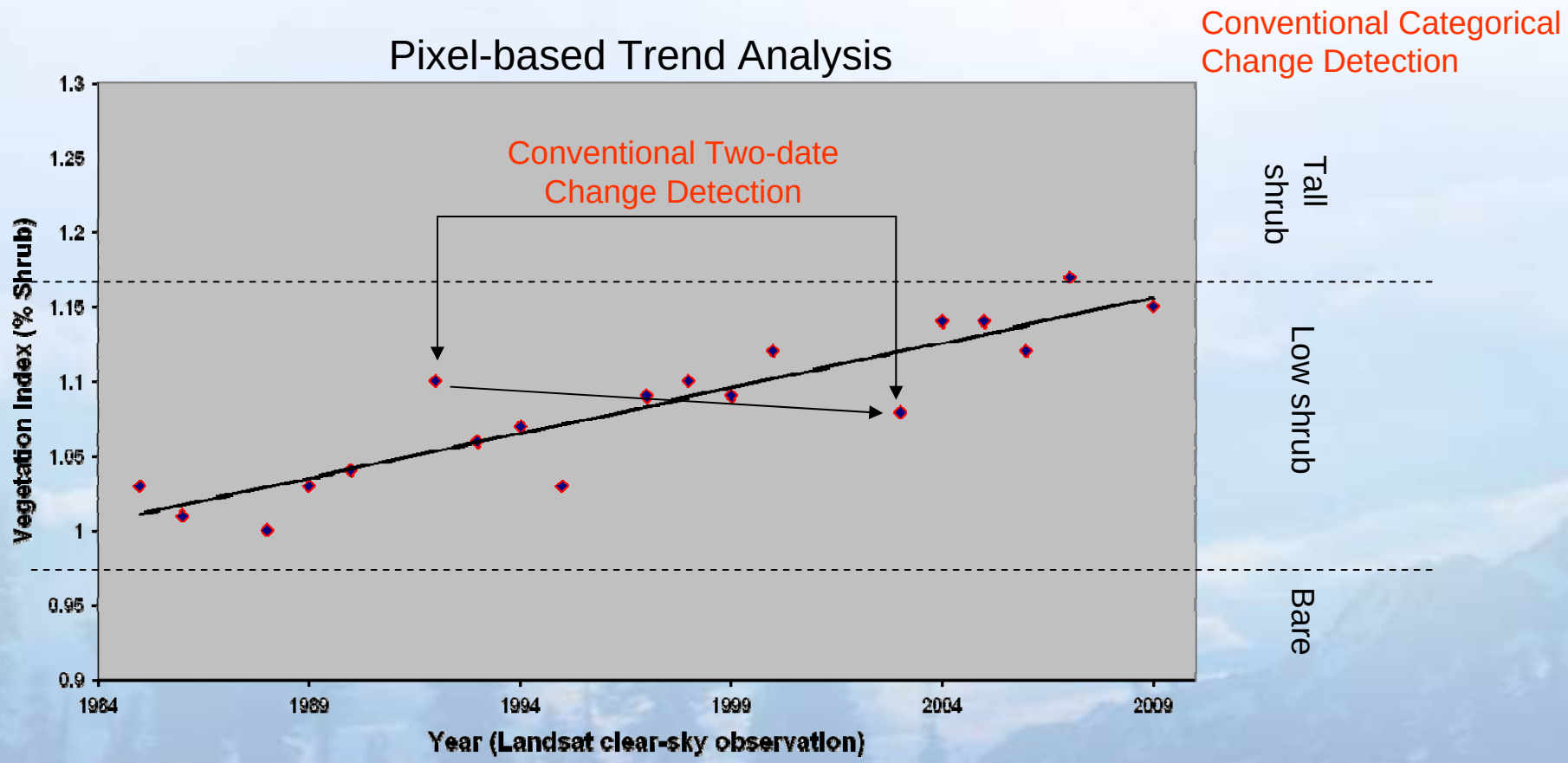



**Vegetation changes in Alaska (Sturm et al., 2001, *Nature*)**

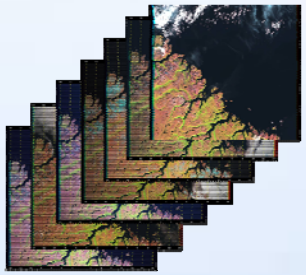
# ParkSPACE Change Detection Approach

- Analyze change based on **long-term Landsat trends** (e.g. Kennedy et al., 2007 RSE; Huang et al., 2009 RSE) instead of conventional two-date approach. This will provide higher signal-to-noise.
- Map vegetation change as a **continuous variable** (e.g. % shrub fraction) rather than categorical variable (e.g. low shrub vs tall shrub). This will provide greater sensitivity for detecting subtle, within-class changes.



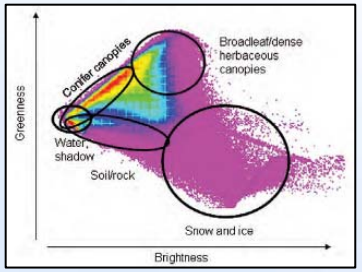
# Change Detection Steps

**1. Build 25-year Landsat Image Stack (cloud-masked, growing season, clear-sky TOA)**

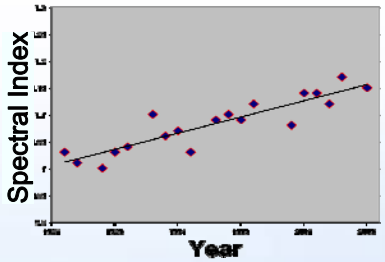


**2. Extract Time Series Values for <u>each</u> Pixel**

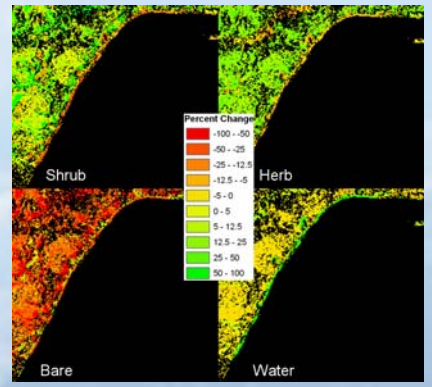
<u>Four Spectral Indices:</u> NDVI, Tasseled Cap Brightness, Greenness, Wetness



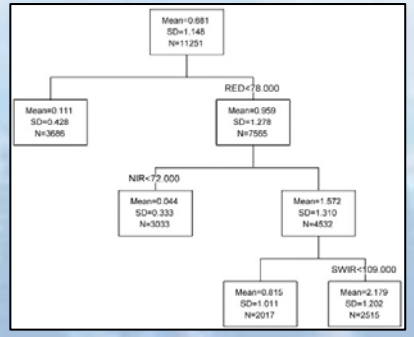

**3. Trends in Landsat indices using linear robust regression (insensitive to outliers)**




**4. Relate Trends to Change in Sub-pixel Land Cover Fractions**
(%shrub, % herbacious, %bare, %water)



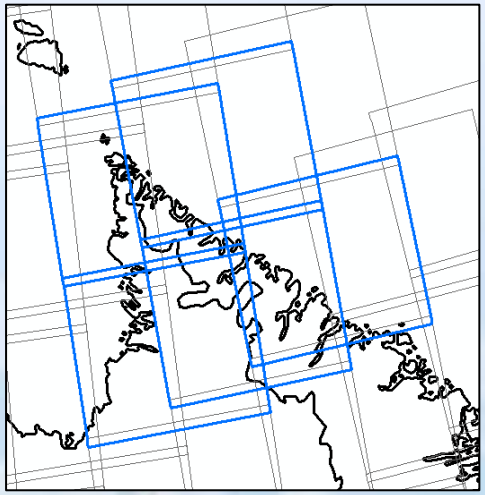

**Build Regression Tree Models to Estimate Land Cover Fractions**
(%shrub, % herbacious, %bare, %water)



# Landsat Satellite Image Data Collection

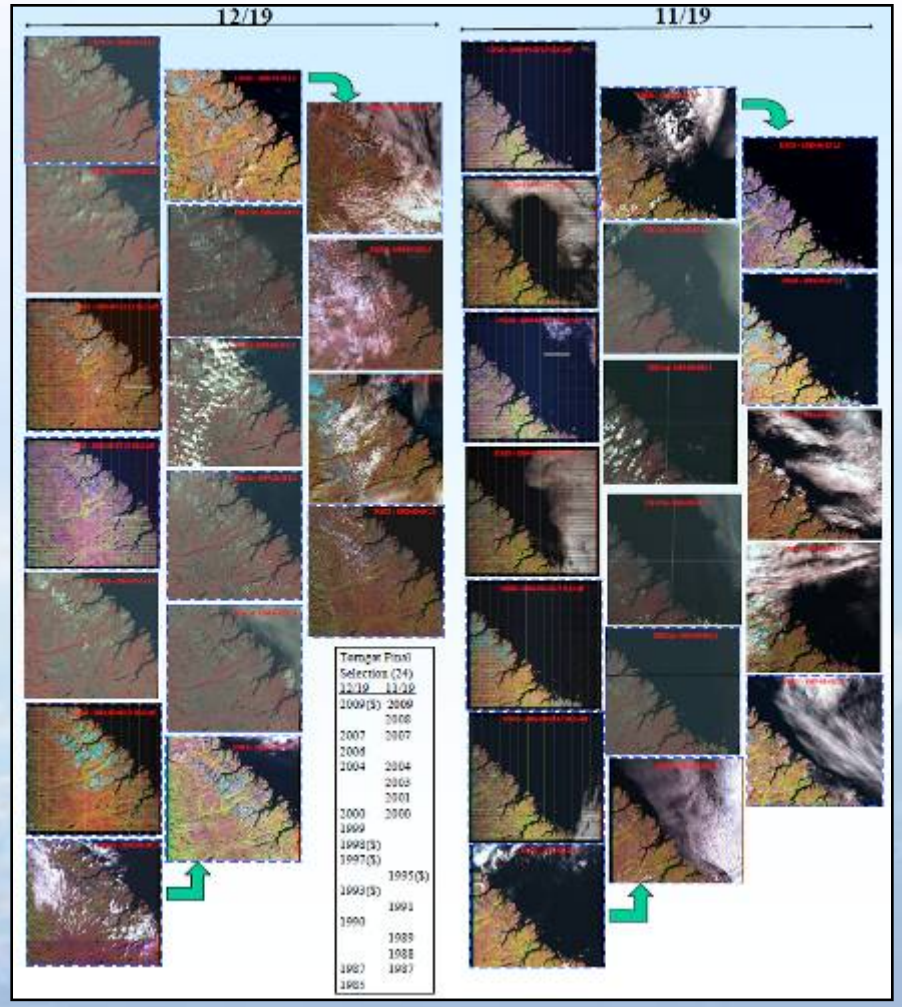
## Example - Torngat Mountains National Park

1. Select overlapping WRS frames providing optimal repeat coverage



Torngat WRS2 frames
11-13/19, 12-13/18

2. Identify potentially suitable growing season (July-August) scenes from USGS and CCRS archives

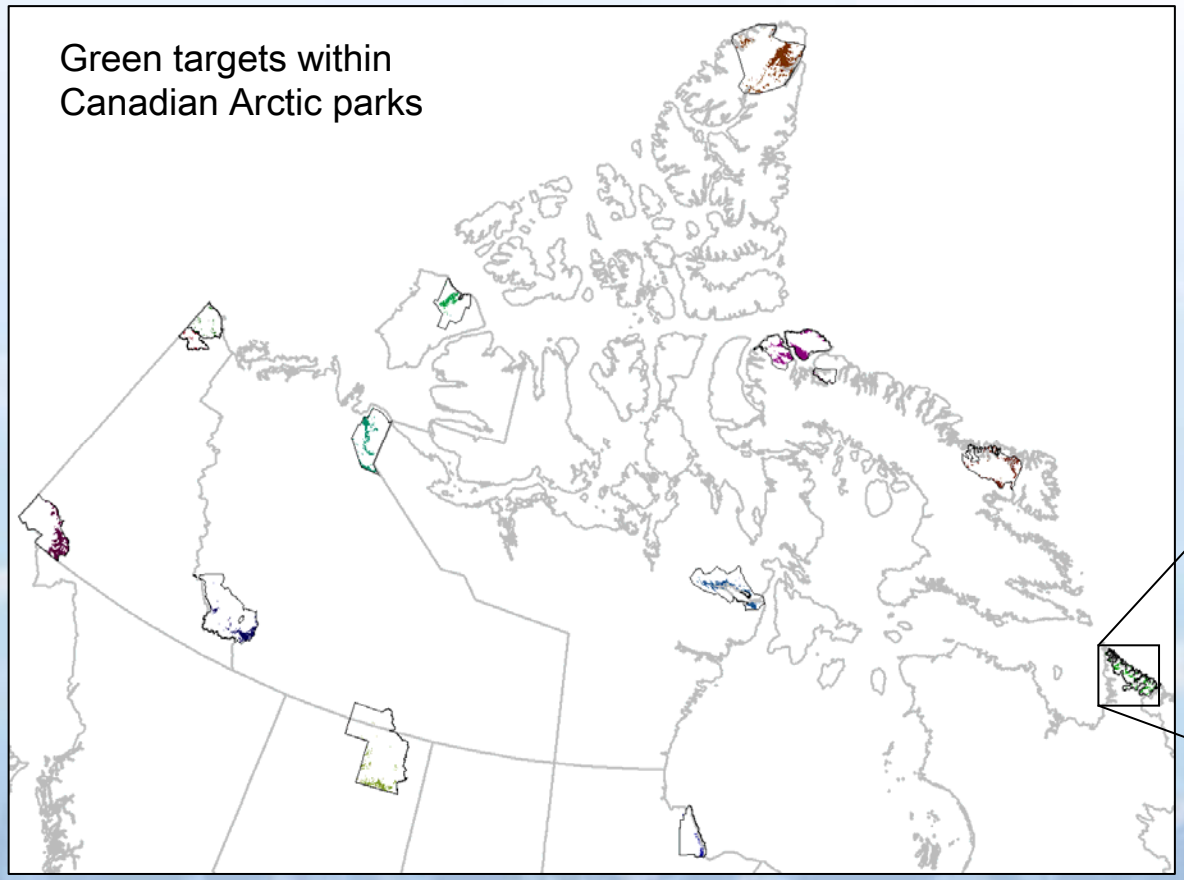


# Landsat Satellite Image Data Collection

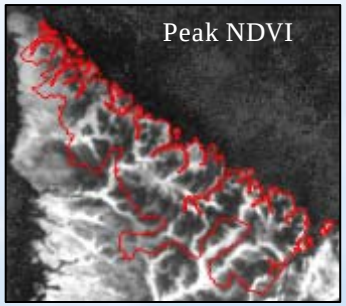
<u>Landsat provides single snapshots during growing season</u>

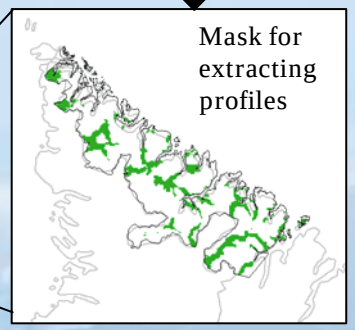
How to ensure sampling isn't biased in terms of capturing peak phenology?

**Approach** - Extract 10-day NDVI curves from coarse resolution (1km) AVHRR imagery for greenest targets (shrub) in each park and compare Landsat date NDVI with peak NDVI

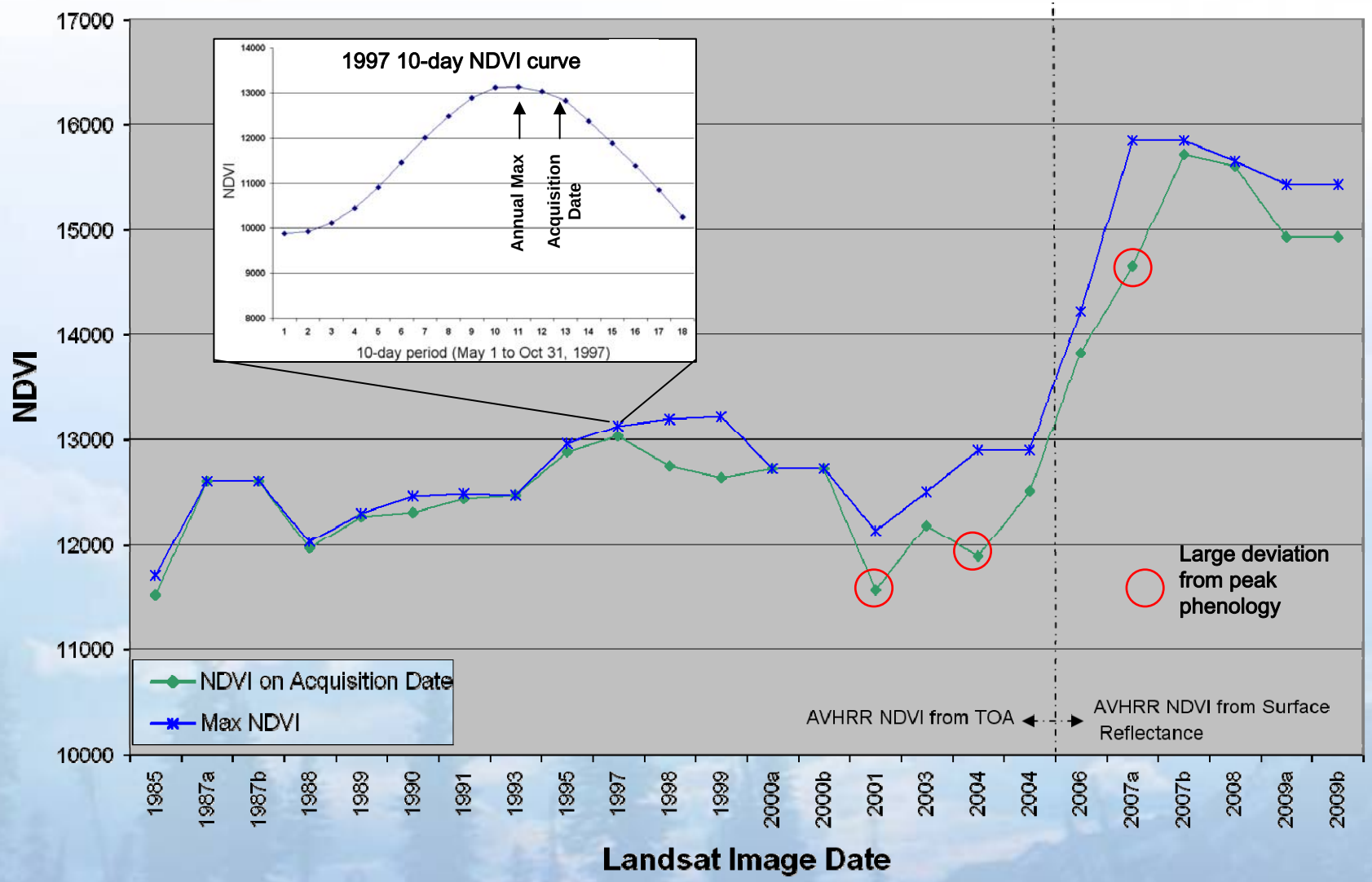



Torngat Mountains NP



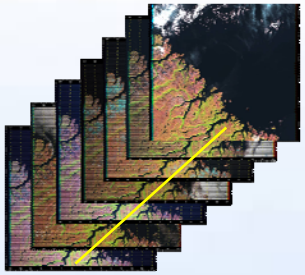



# Comparison of AVHRR-NDVI for Landsat acquisition dates and peak NDVI for corresponding year (Torngat Mts NP)

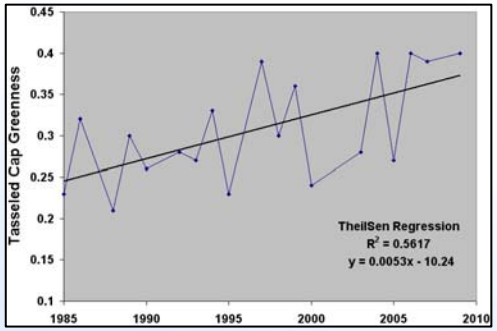


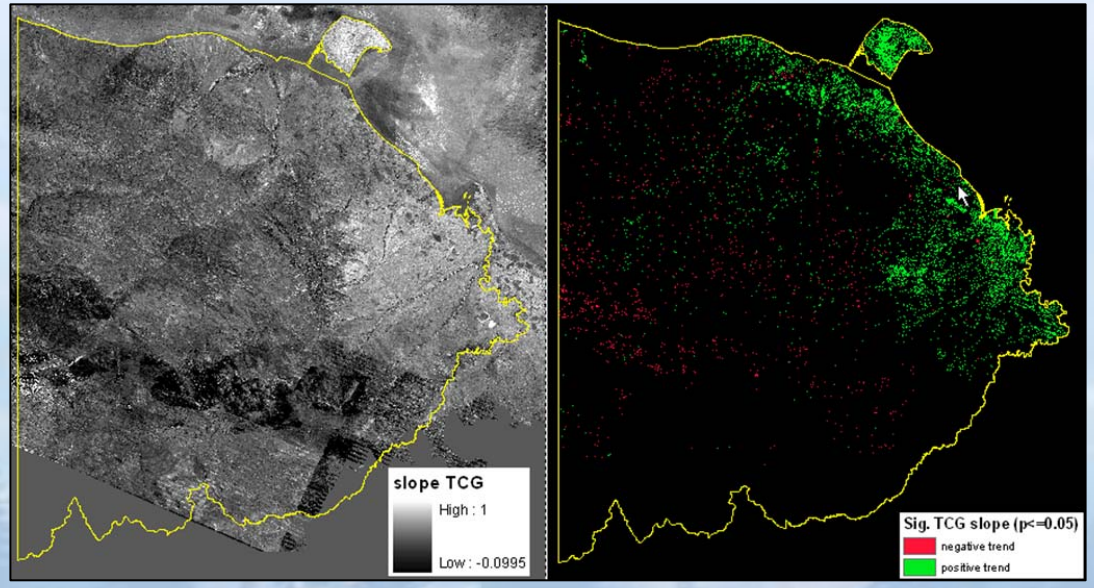
# Compute Trends in Landsat Spectral Indices

Landsat Image Stack
(phenology screened, cloud-masked)



Per-pixel Trend Analysis
(NDVI, TC Brightness, Greenness, Wetness)




Ivvavik Park – TC 1986-2009 Greenness Slopes

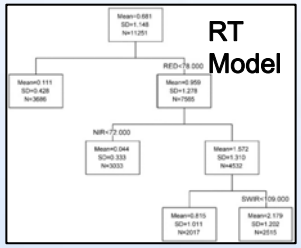
# Relate Spectral Trends to Change in Sub-pixel Land Cover Fractions

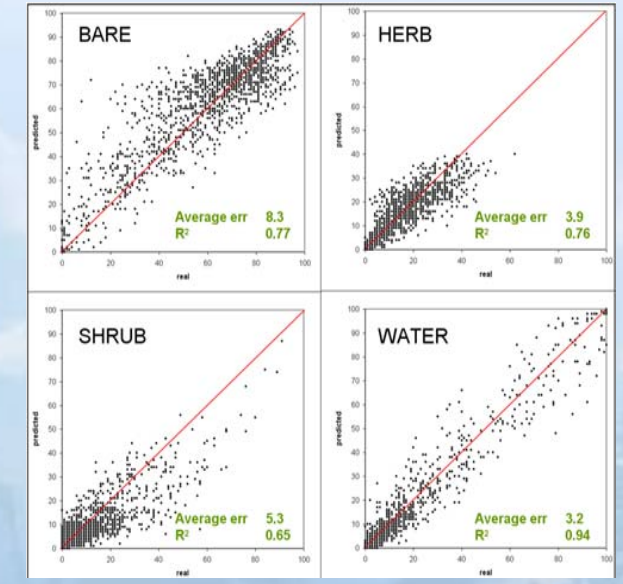
## Train Regression Tree Models to Estimate Land Cover Fractions

(%shrub, % herbacious, %bare, %water)

Olthof, I., & Fraser, R. H. (2007). Mapping northern land cover fractions using Landsat ETM+. *Remote Sensing of Environment*, *107*, 496–509.

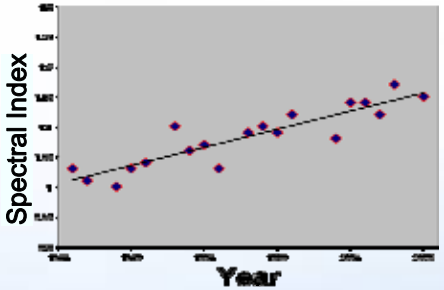
High-resolution (IKONOS) land cover used to quantify LC fractions within 30-m Landsat pixels



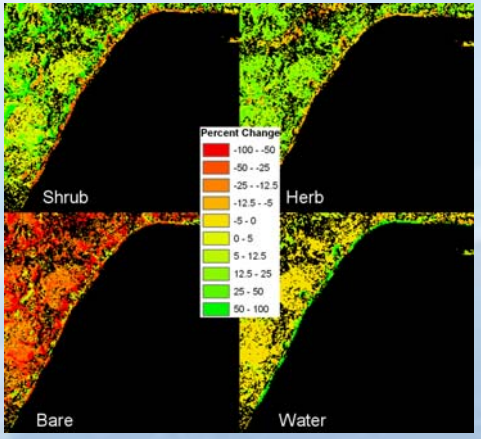

30% testing holdout

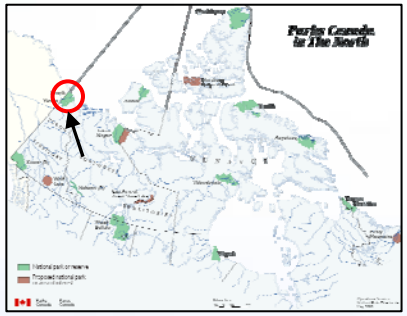
## Landsat Spectral Index Trends




## Land Cover Fraction Change

(%shrub, % herbacious, %bare, %water)

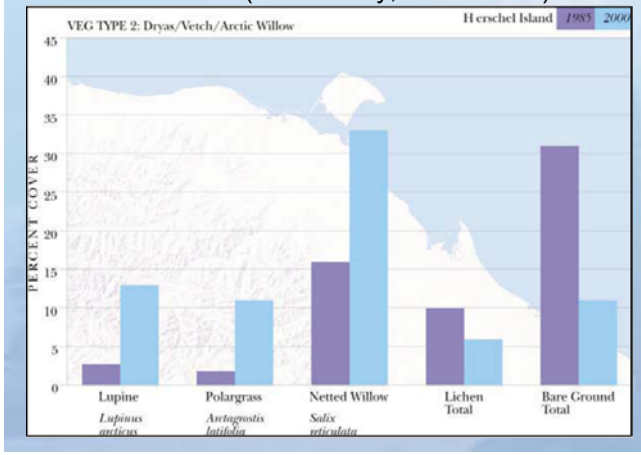


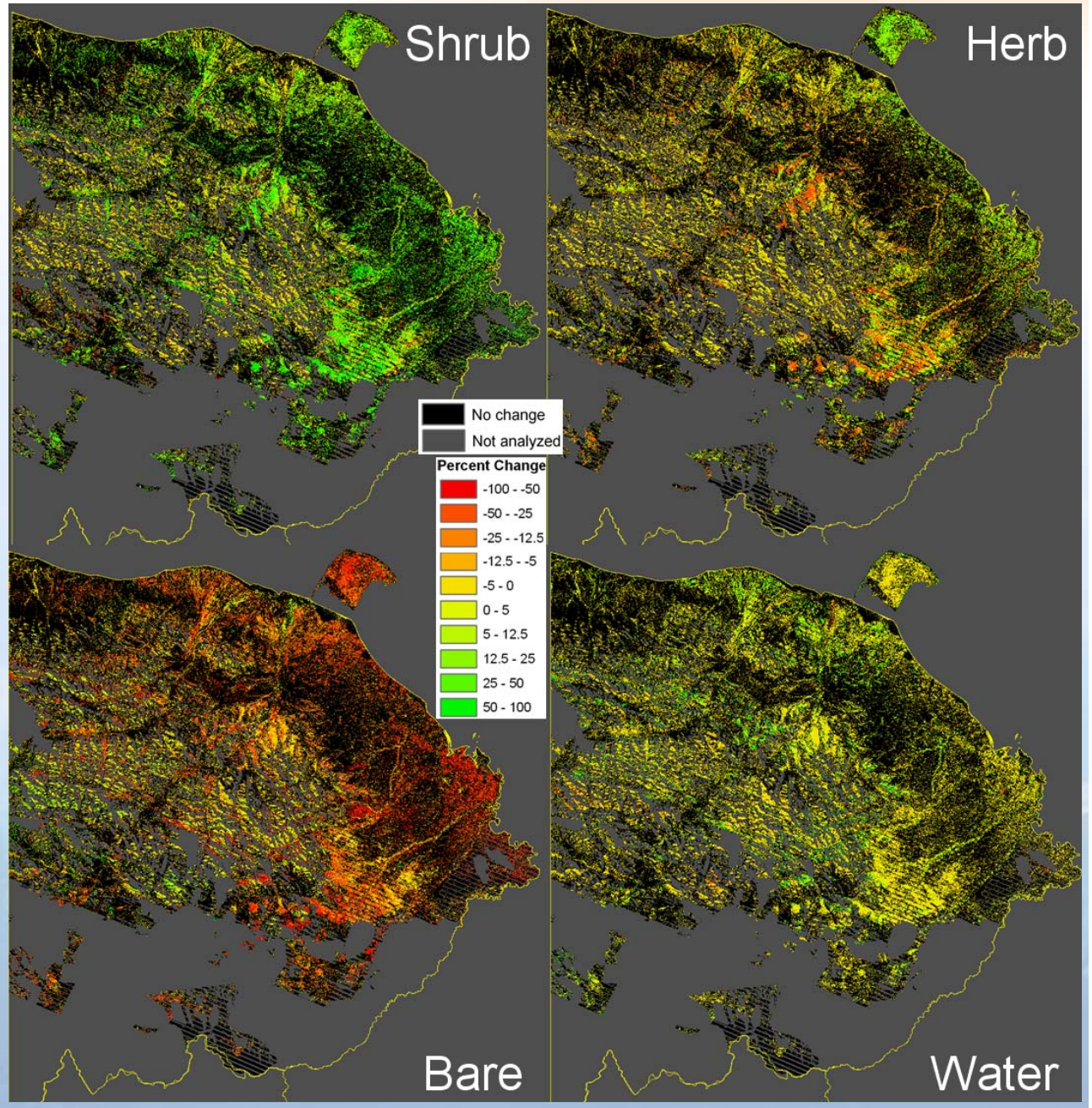



# <u>Results</u> - Ivvavik LC Change Fractions (1986-2009)

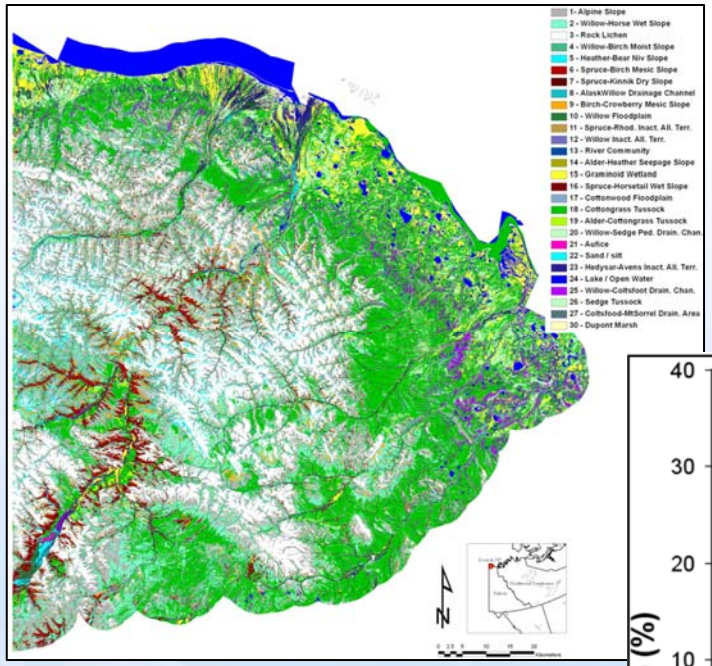
| | average %change |
|---|---|
| **bare** | -6.4 |
| **herb** | -0.5 |
| **shrub** | 5.5 |
| **water** | 1.5 |

Herschel Island and coastal zone changes corroborated by 1985-2000 field measurements (K. Kennedy, Yukon Govt)



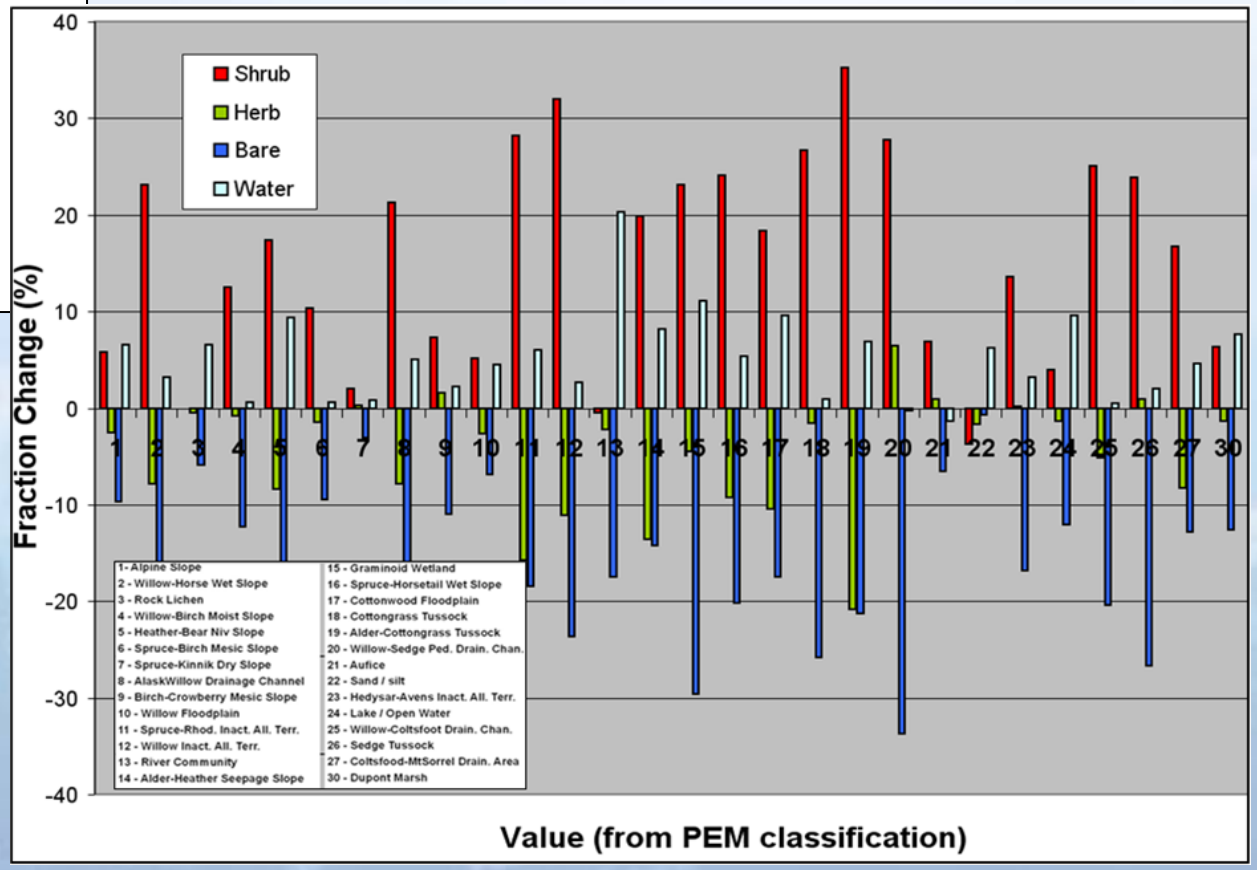



# Results - Ivvavik LC Change Fractions by Ecosystem Type

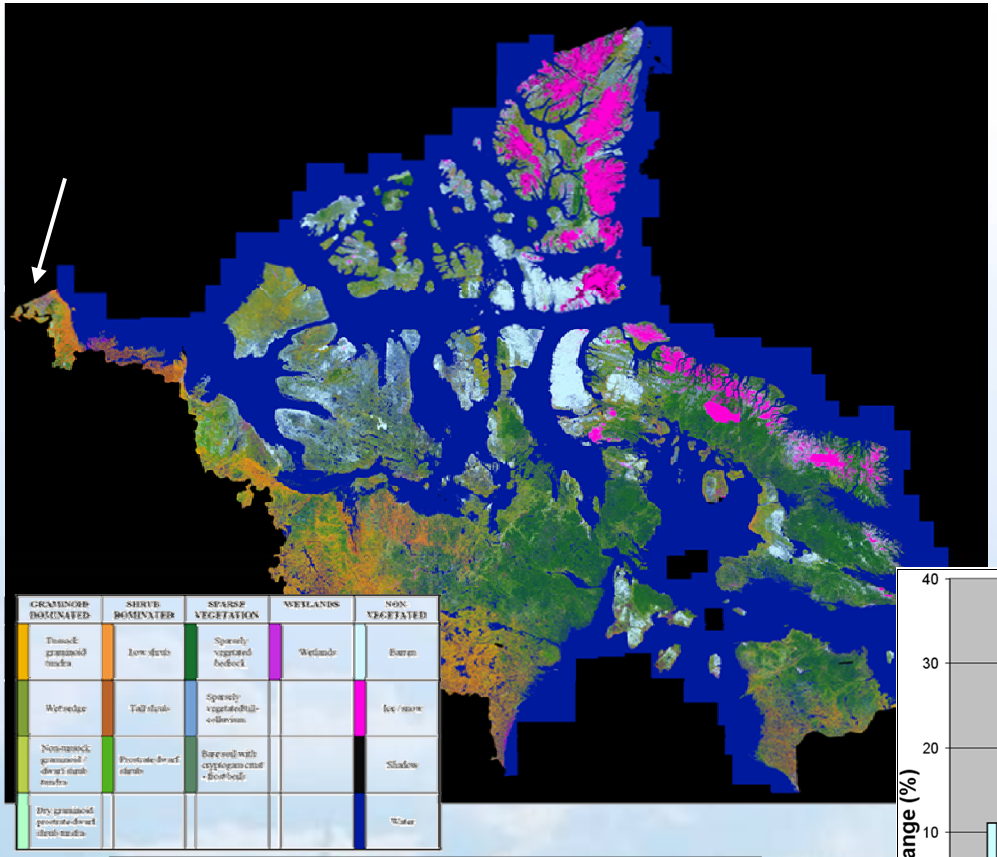



Ecosystem Map
(from 10m SPOT HRVIR imagery and DEM terrain parameters – Fraser et al., submitted)

- Can examine trends for particular ecosystems of interest
- Dominant Pattern - almost all vegetated ecosystems show increase in shrub fraction and decrease in bare fraction



# <u>Results</u> - Ivvavik LC Change Fractions by Land Cover Type

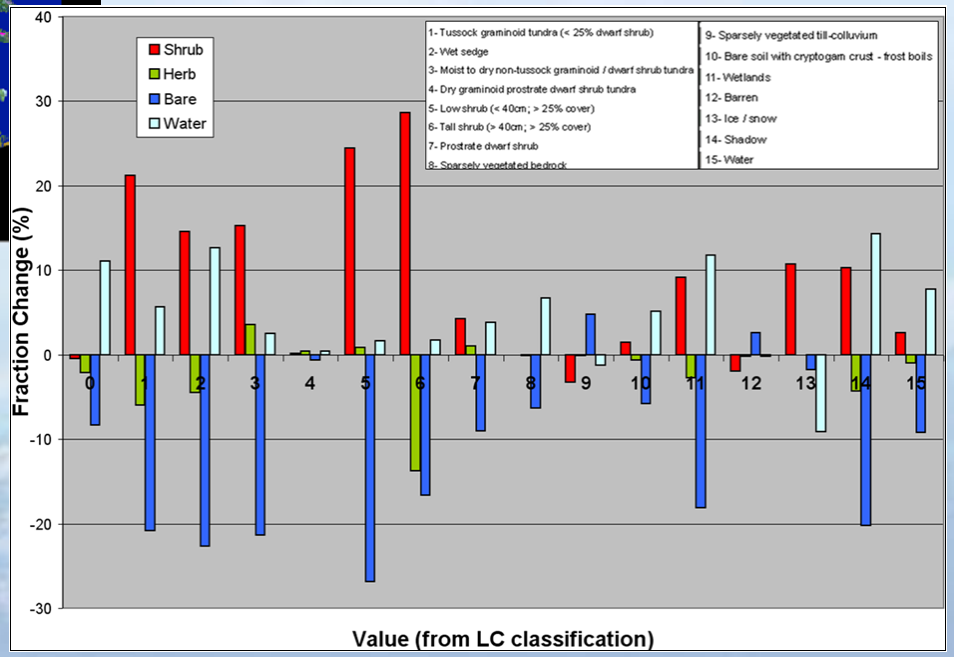



*Can. J. Remote Sensing*, Vol. 35, No. 2, pp. 152–165, 2009

**Development of a circa 2000 land cover map of northern Canada at 30 m resolution from Landsat**

Ian Olthof, Rasim Latifovic, and Darren Pouliot

- Examine trends by land cover – provides basis for comparison across North
- Dominant Pattern – Higher biomass land cover types show the largest increase in shrub fraction

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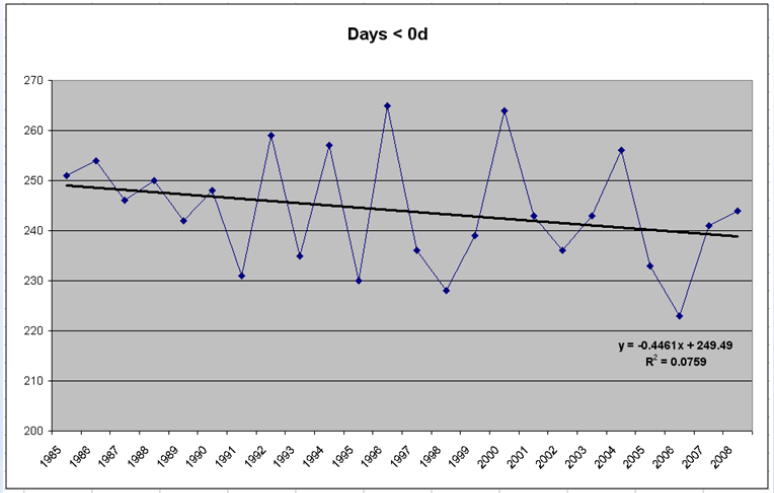
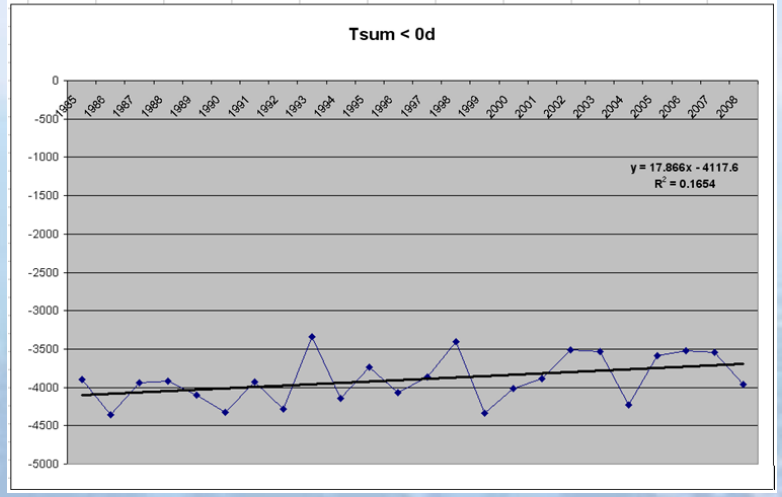
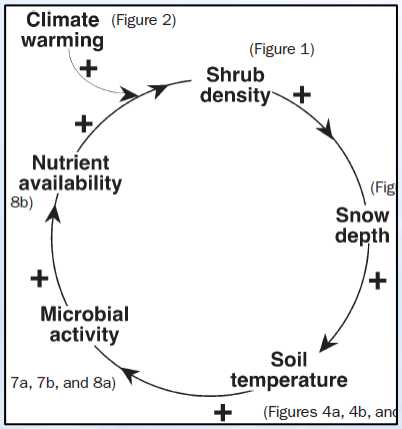
# What Could be Causing a Shrub Increase in Ivvavik?

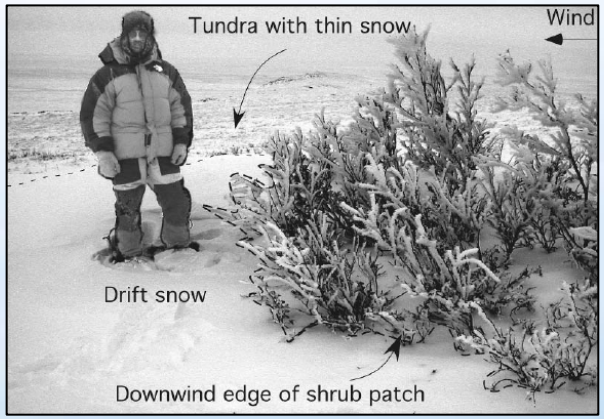
**Milder Winters Occurring**
(winter temperature indices derived using NARR data over Ivvavik)




- Sturm et al. (2005, *J. of Climate*) describe a positive feedback effect:



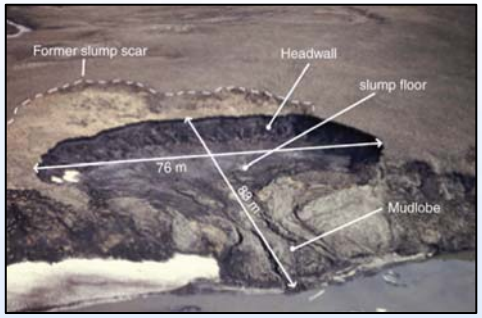




- Increased winter soil temperatures and nutrient mineralization might also be expected from milder winters in Ivvavik, independent of any shrub feedback effect

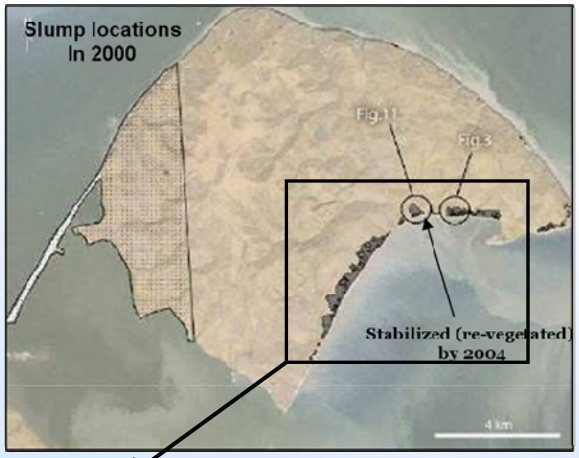
# <u>Results</u> – Ivvavik (Herschel Island) Coastline Changes

Lantuit and Pollard (2008, *Geomorphology*)

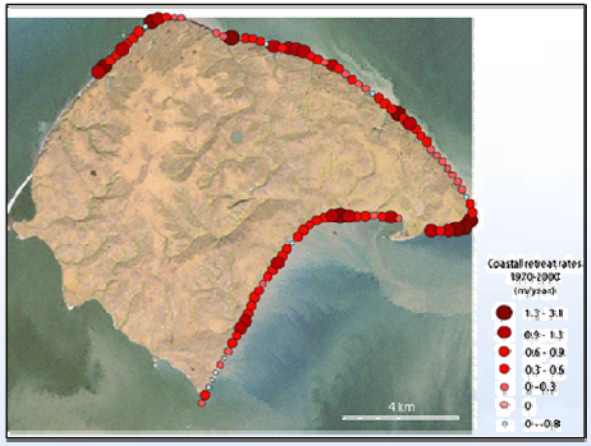
Coastal Slumping

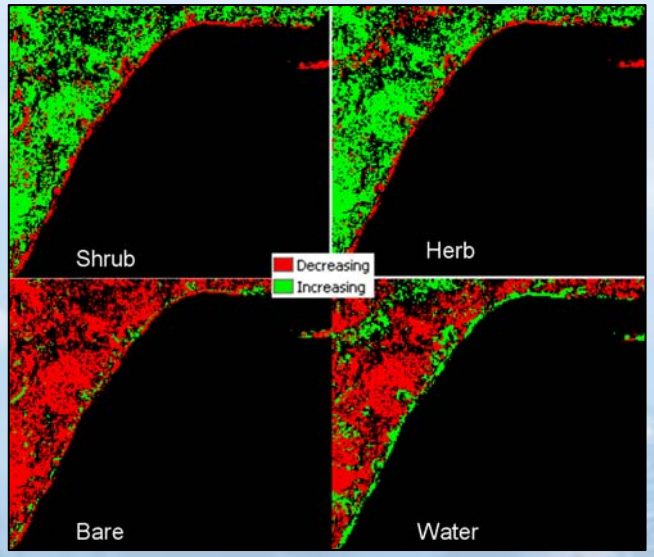



Thaw Slumping

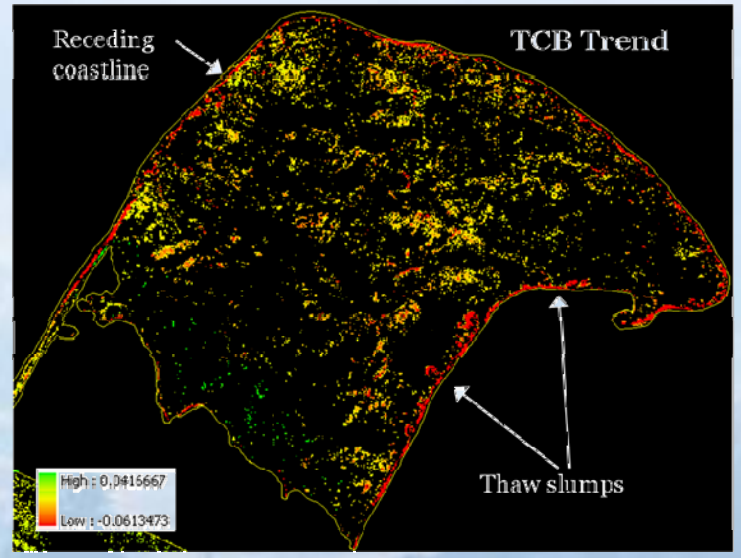



Coastal Erosion

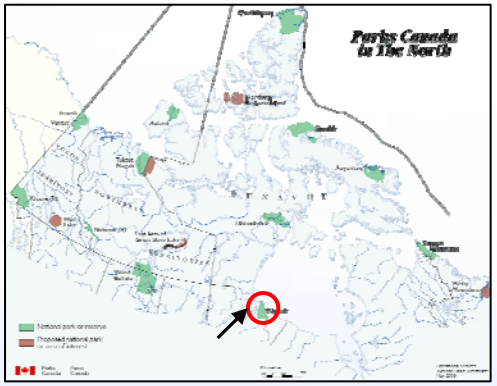



LC Change Fractions (1986-2009)



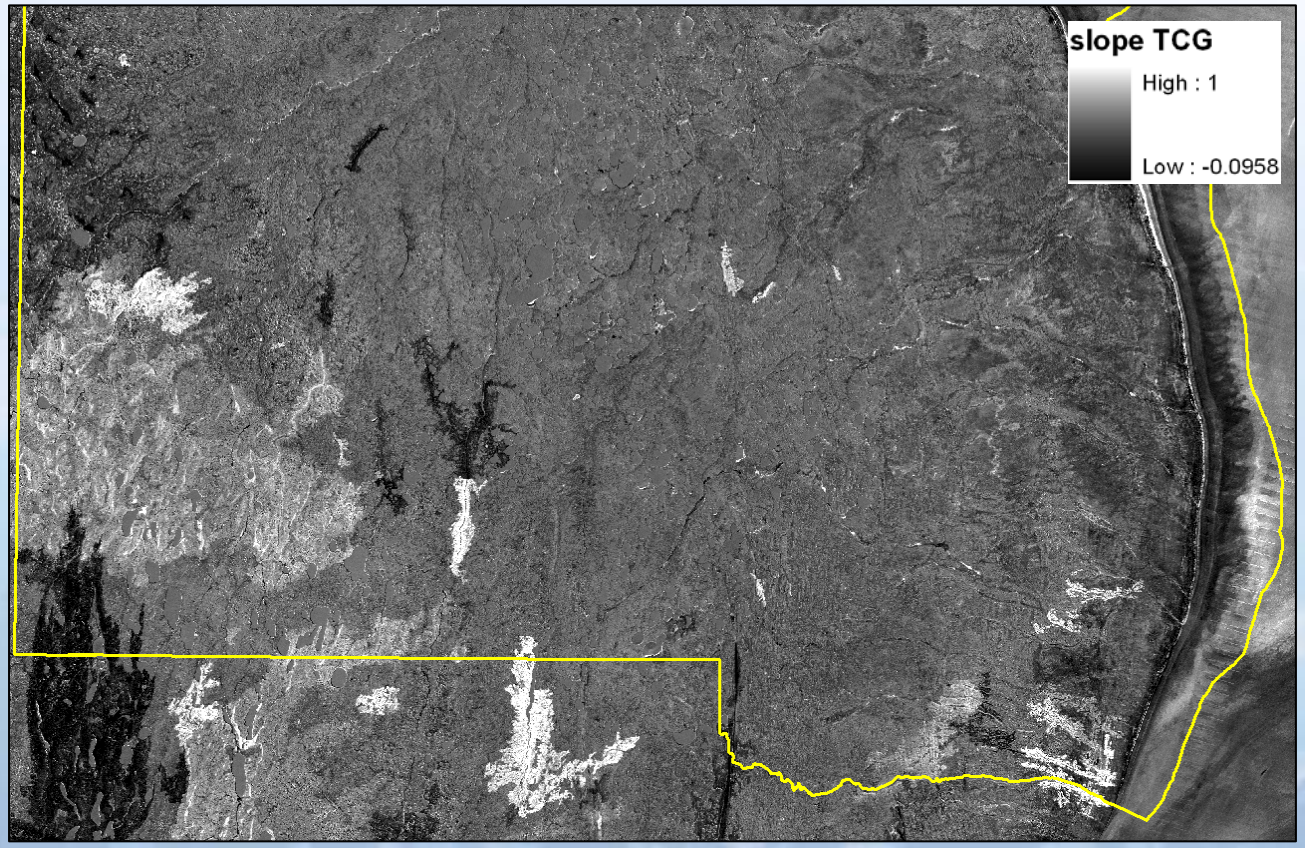

Tasseled Cap Brightness Trend (1986-2009)




# Results – Wapusk Spectral Trends

Burning and regeneration patterns in ‘lichen spruce bog’ in southerly portion of park

1985-2009 TC Greenness trend




**Forest and Tundra Fires in the Hudson Bay Lowlands of Manitoba**

*Ryan Brook*[1]

*Abstract*

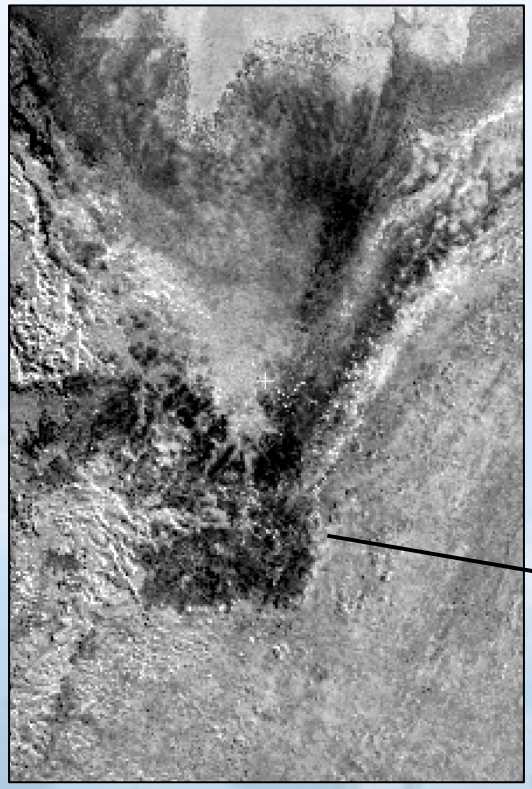
Forest and tundra fires occur frequently over large areas within the Hudson Bay Lowlands and are predicted to increase in frequency and extent in response to climate change. This study provides a detailed measure of fire extent and frequency within the region for the period 1994-2001.

Pan-sharpened Quickbird

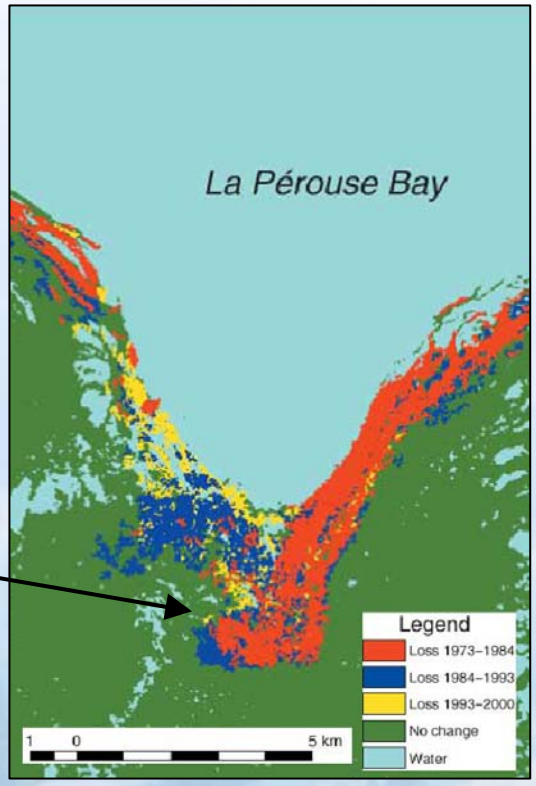
Natural Resources Canada
Canada Centre for Remote Sensing

# Results – Wapusk Spectral Trends

Degradation of graminoid-willow salt marsh by snow geese around La Perouse Bay at north tip of park



1985-2009 TC Greenness trend




Extent of vegation damage

*Arctic, Antarctic, and Alpine Research, Vol. 37, No. 3, 2005, pp. 269–275*

**Goose-induced Changes in Vegetation and Land Cover between 1976 and 1997 in an Arctic Coastal Marsh**

*Journal of Ecology* 2006 94, 234–242

**A biotic agent promotes large-scale catastrophic change in the coastal marshes of Hudson Bay**

ROBERT L. JEFFERIES, ANDREW P. JANO* and KENNETH F. ABRAHAM*

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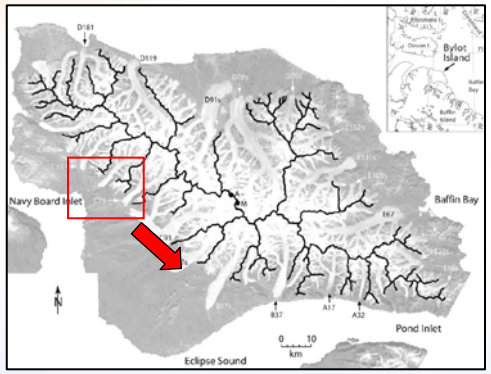
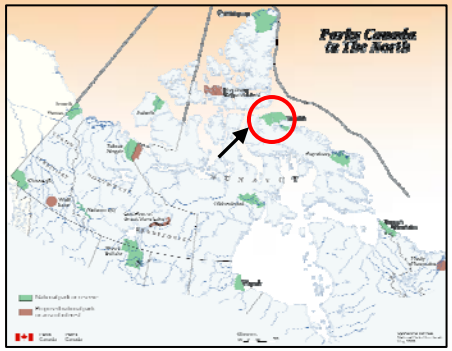
Natural Resources Canada
Canada Centre for Remote Sensing



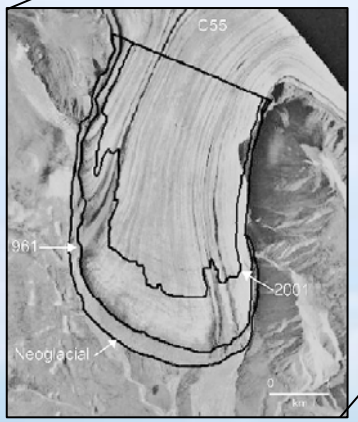

# Results – Sirmilik Spectral Trends

## Widespread Glacier Retreat on Bylot Island




1992-2008 Landsat TC Wetness trends

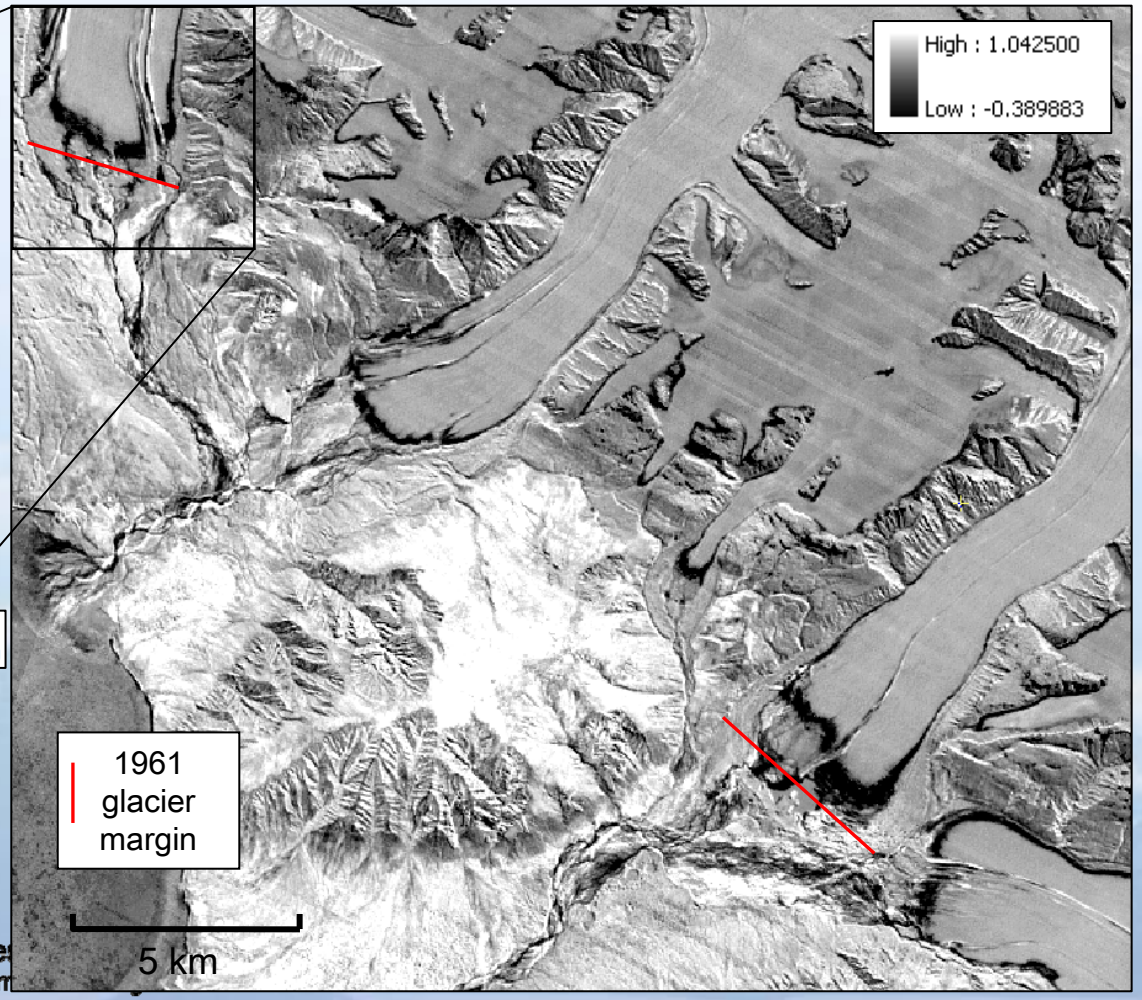
(conversion of ice to bare causes large drop – appears dark)




Dowdeswell et al.

*Arctic, Antarctic and Alpine Research, Vol. 39, No. 3, 2007, pp. 402–411*

**On the Glaciers of Bylot Island, Nunavut, Arctic Canada**



Natural Resources
Canada Centre for Rem

# <u>Results</u> – Sirmilik Spectral Trends

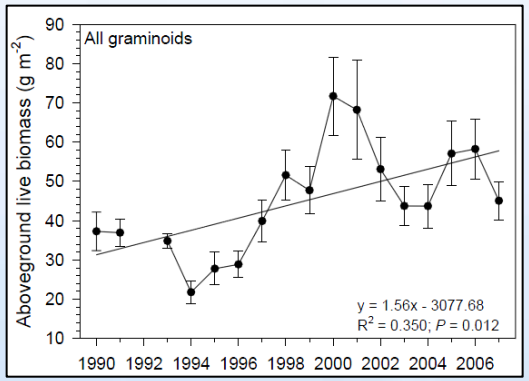
## Widespread Glacier Retreat on Bylot Island

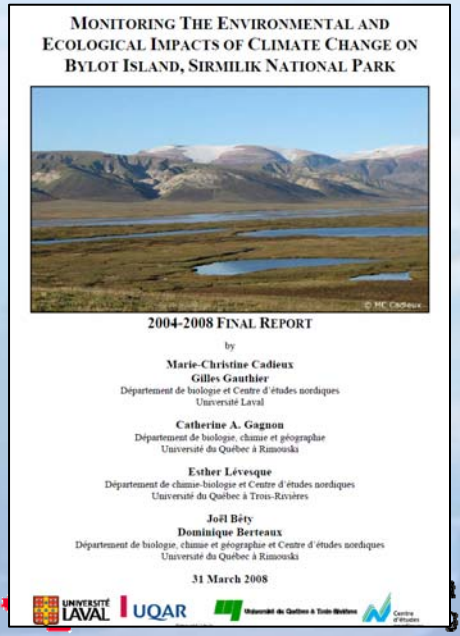
Lawren Harris (Group of Seven)
Mount Thule, Bylot Island (1930)

From Pond Inlet (2010)

# Results – Sirmilik Spectral Trends

Plant production measured in wetlands has increased by 84% over the last 18 years



MONITORING THE ENVIRONMENTAL AND ECOLOGICAL IMPACTS OF CLIMATE CHANGE ON BYLOT ISLAND, SIRMILIK NATIONAL PARK

2004-2008 FINAL REPORT

by

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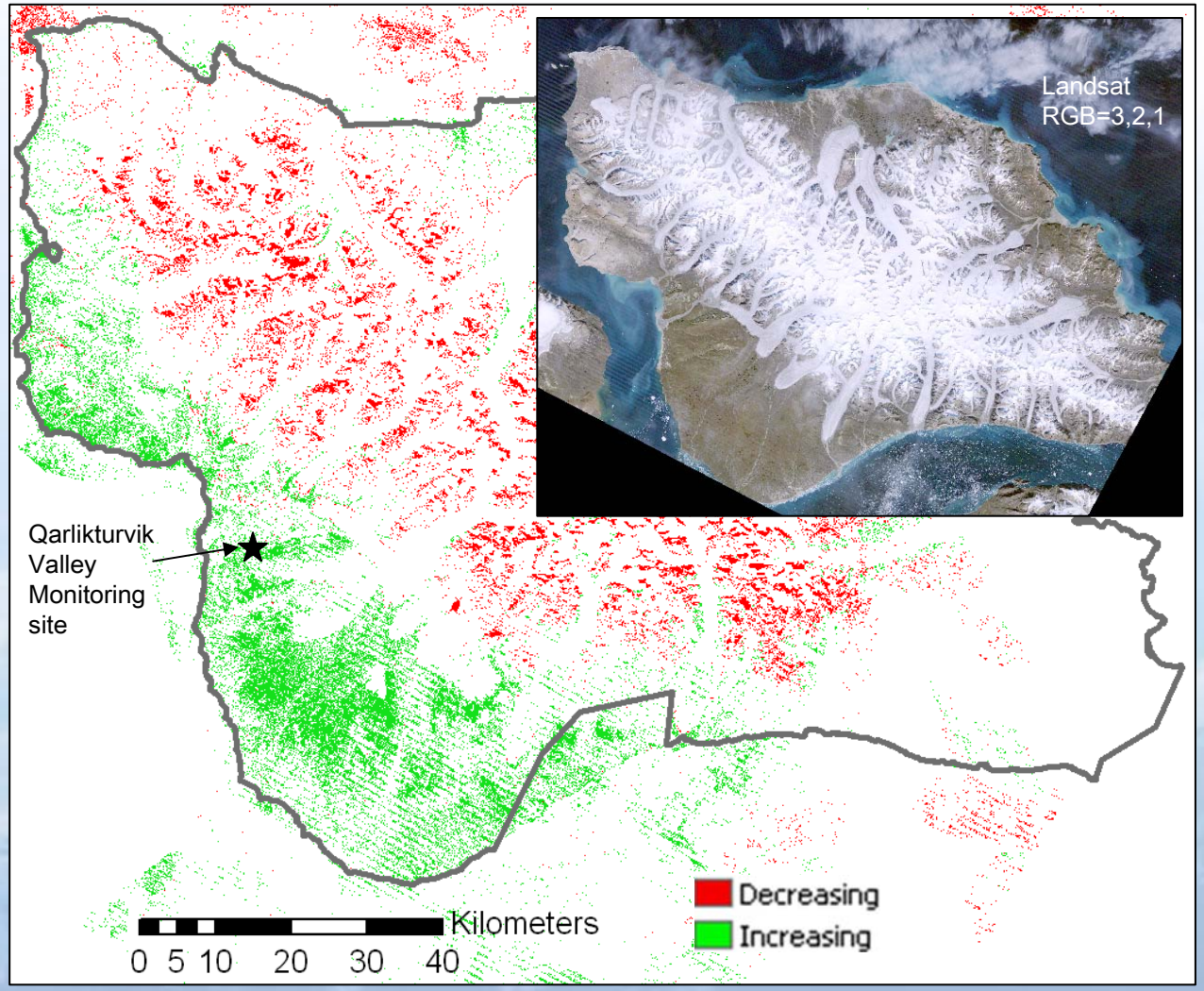
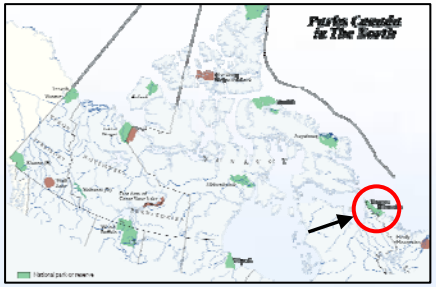
31 March 2008

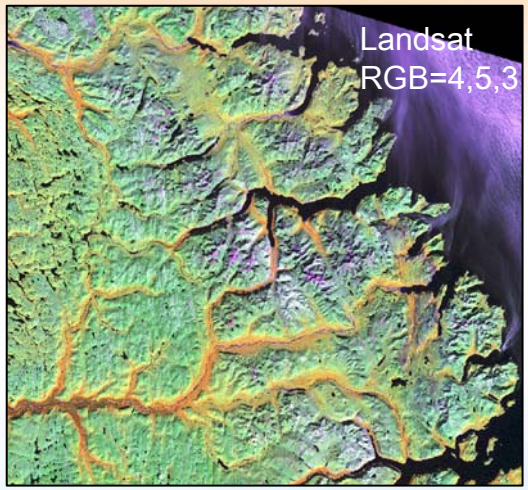
1992-2008 Landsat TC Greenness trends (p<0.05)



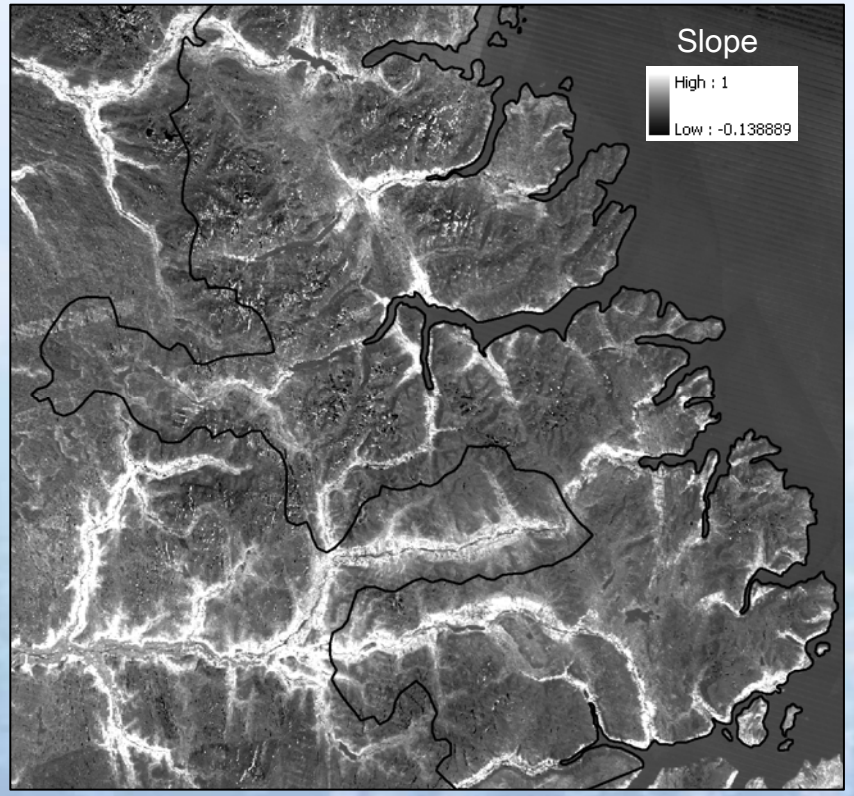
# <u>Results</u> – Torngat Mountains Spectral Trends

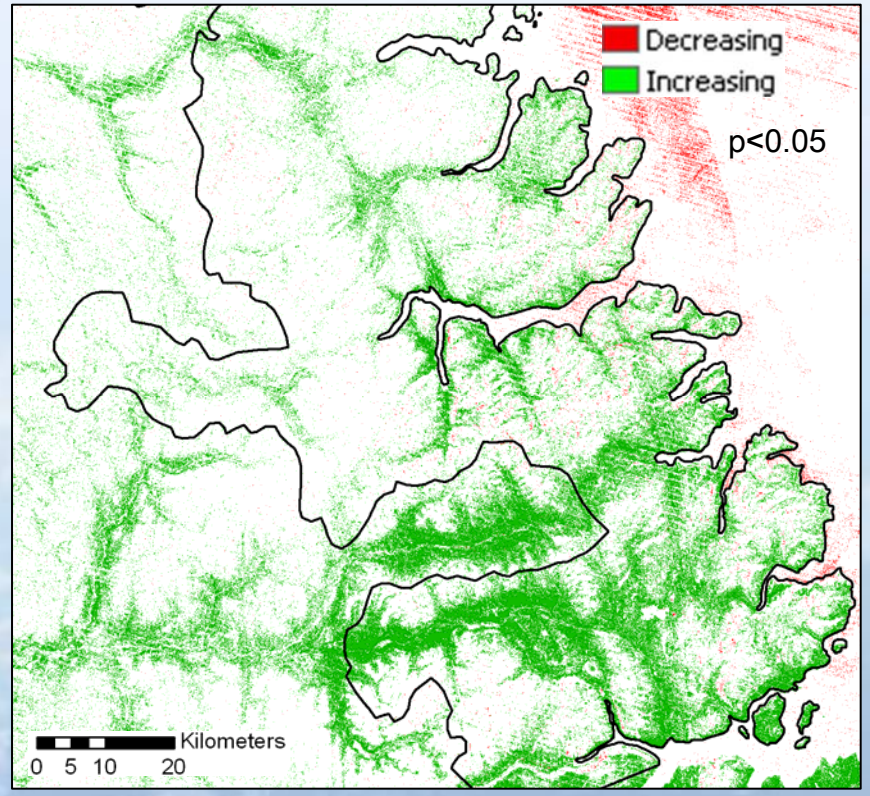
Widespread Greening Trend Observed in Valleys





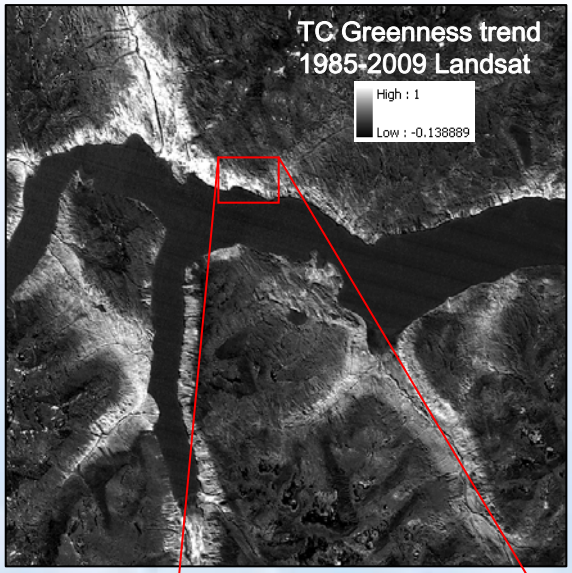

1985-2009 Landsat TC Greenness trends

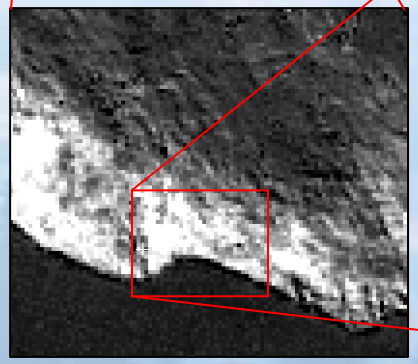


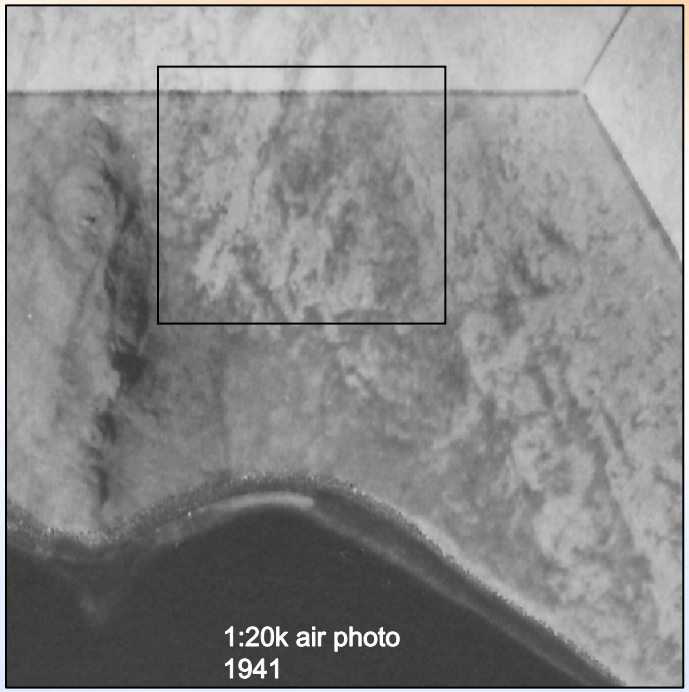



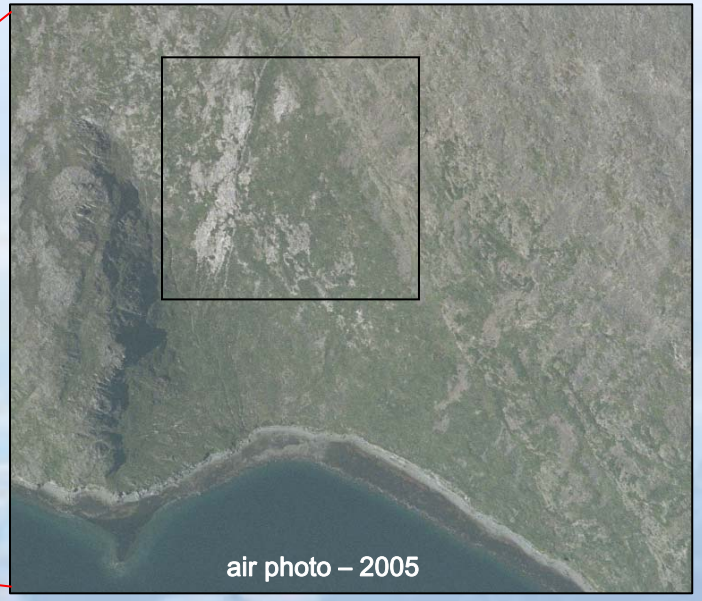
# Torngat Mountains - Corroboration of Results

Comparison of aerial photos to Landsat trend image



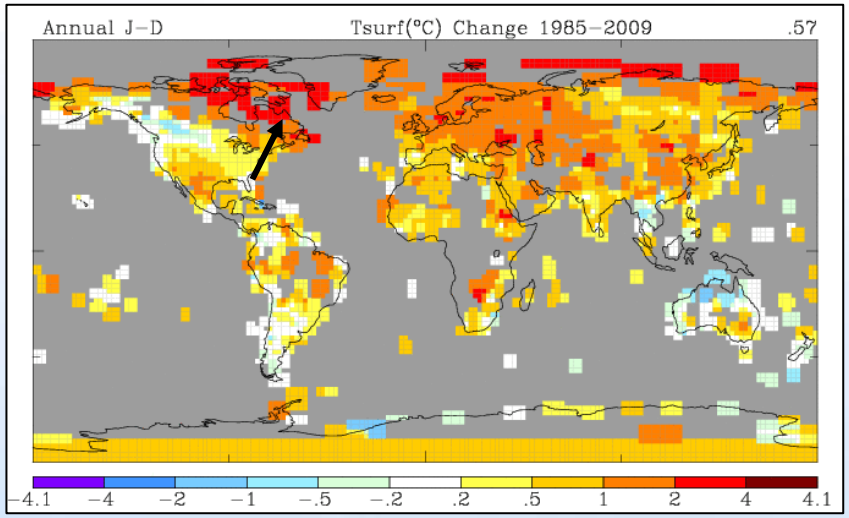


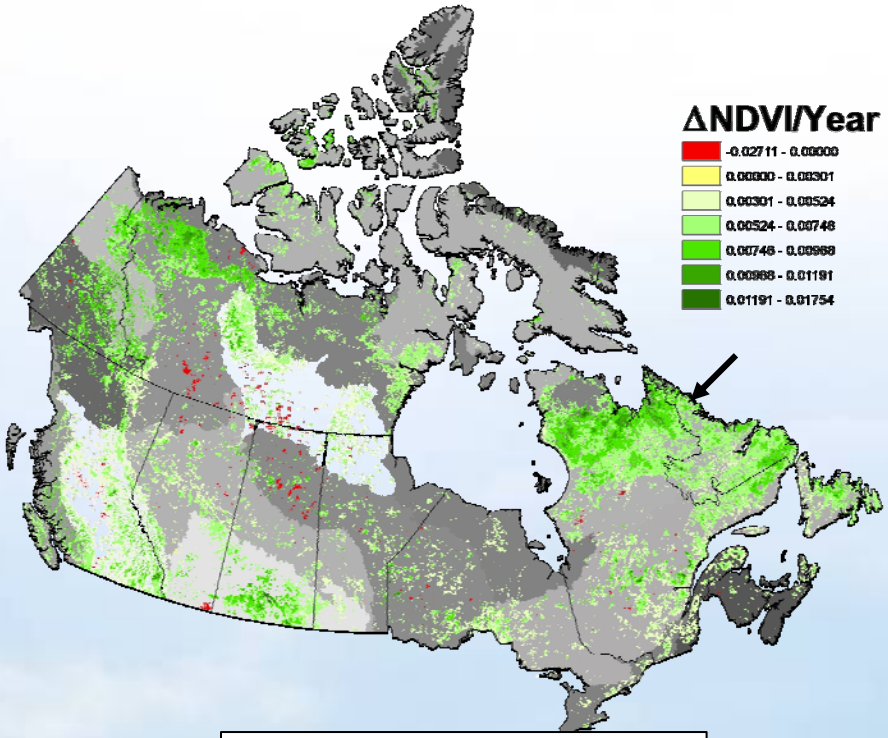

Suggestive of shrub increase but not conclusive

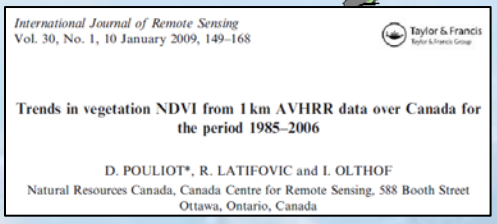
# Torngat Mountains - Corroboration of Results

NASA GISS Surface Temperature Analysis




Trends from Coarse Resolution Satellite Imagery





*International Journal of Remote Sensing*
Vol. 30, No. 1, 10 January 2009, 149–168

Taylor & Francis

**Trends in vegetation NDVI from 1 km AVHRR data over Canada for the period 1985–2006**

D. POULIOT*, R. LATIFOVIC and I. OLTHOF
Natural Resources Canada, Canada Centre for Remote Sensing, 588 Booth Street
Ottawa, Ontario, Canada

George River repeat aerial photo observations
(100 km to east of Torngat)

Increasing erect ligneous vegetation in the Canadian eastern Arctic : a case study from the forest-shrub tundra transition zone

Tremblay, B. and Lévesque, E., In: Arctic Change 2008

"Preliminary results indicate a substantial and almost ubiquitous erect shrub increase in the past 40 years; dwarf birch (Betula glandulosa) being the main species responsible for this. Moreover, results show that low tree cover, consisting chiefly of larch (Larix laricina), is also expanding and that local tree line is moving upslope."

# Summary and Conclusions

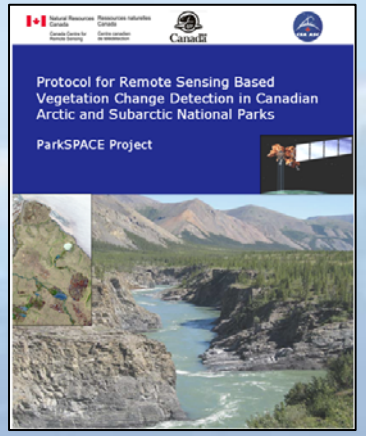
- Long-term trend analysis of Landsat image stacks is a relatively new change detection approach (e.g. Kennedy et al., 2007; Huang et al., 2009) that can be used to detect a range of changes in Arctic and Sub-Arctic environments: greening and increased shrubiness, thermokarst-related erosion, wildfire and regeneration, glacier recession, and damage to vegetation by wildlife.

- Three of our four pilot parks demonstrated an increase in greenness or fractional shrub coverage

- Spectral trends can be assigned further physical meaning by training a regression tree sub-pixel classifier for basic cover types (e.g. shrub, herbacious, water, bare)

- Parks Canada Agency plans to adopt the change detection protocol for reporting in future State of the Park Reports


## Acknowledgements

Funding from Canadian Space Agency GRIP Program

Support from Parks Canada Agency
(Donald McLennan, Paul Zorn, Jean Poitevin, Sergei Ponomarenko, Rajeev Sharma, Paul Dixon, Justin Quirouette, and many others)