Controls on arctic tundra vegetation dynamics on the Yamal Peninsula, Russia – an integrative study using ArcVeg and multi-temporal Landsat imagery

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Introduction

Objectives:

- Understand ecological controls on tundra vegetation on the Yamal Peninsula, Russia
- Detect land use changes and effects on tundra vegetation

Methodology: Ecosystem model and remote sensing

Outline:

- ArcVeg and modeling
- Change detection based on multi-temporal Landsat imagery
- Summary

Factors affecting arctic tundra vegetation

- **Tundra Productivity/ Biomass**
  - **Physical Controls**
    - **Climate zones**
      - Temperature
      - Precipitation
    - **Soils**
      - Soil organic nitrogen
      - Active layer depth
  - **Biological Controls**
  - **Anthropogenic Factors**
    - **Animal Husbandry**
      - Grazing
      - Trampling
    - **Climate Warming**
      - Temperature increase
      - GHG, permafrost …
    - **Land Use Change**
      - Population increase
      - Road, oil/gas development

Simulating effects of soils, grazing, climate warming on tundra community dynamics along the Yamal P.

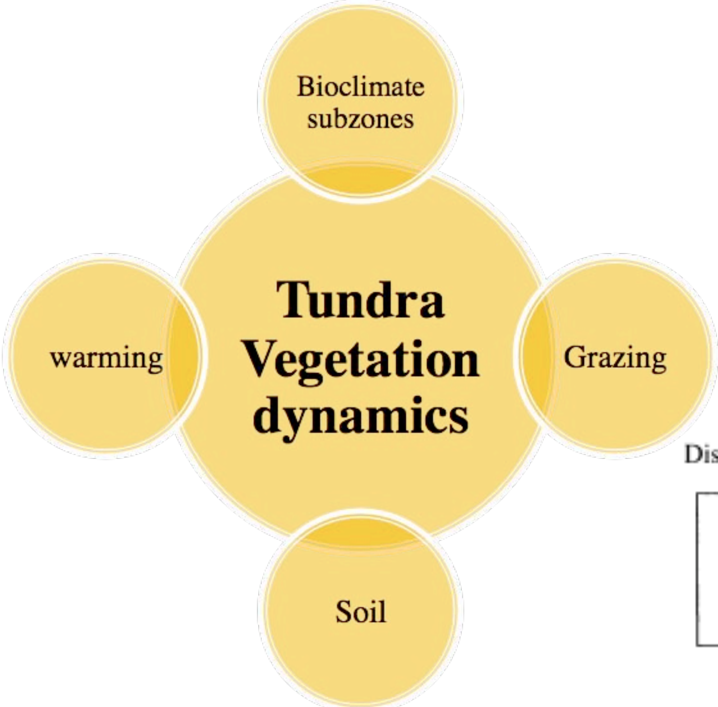
Study background:

- Lack of understanding on the interactive effects of soil nutrients, climate, and animal grazing

Research questions:

- (1) How do SON levels affect tundra vegetation in terms of total biomass and net primary productivity (NPP) and responses to warming?
- (2) How does grazing affect tundra vegetation in terms of total biomass and NPP and responses to warming?
- (3) How do SON, grazing and climate interact to affect tundra vegetation?

ArcVeg – a vegetation dynamics model



- Climate (Bioclimate subzones - spatial)
- Climate warming (temporal)
- Grazing
- Soil nutrients

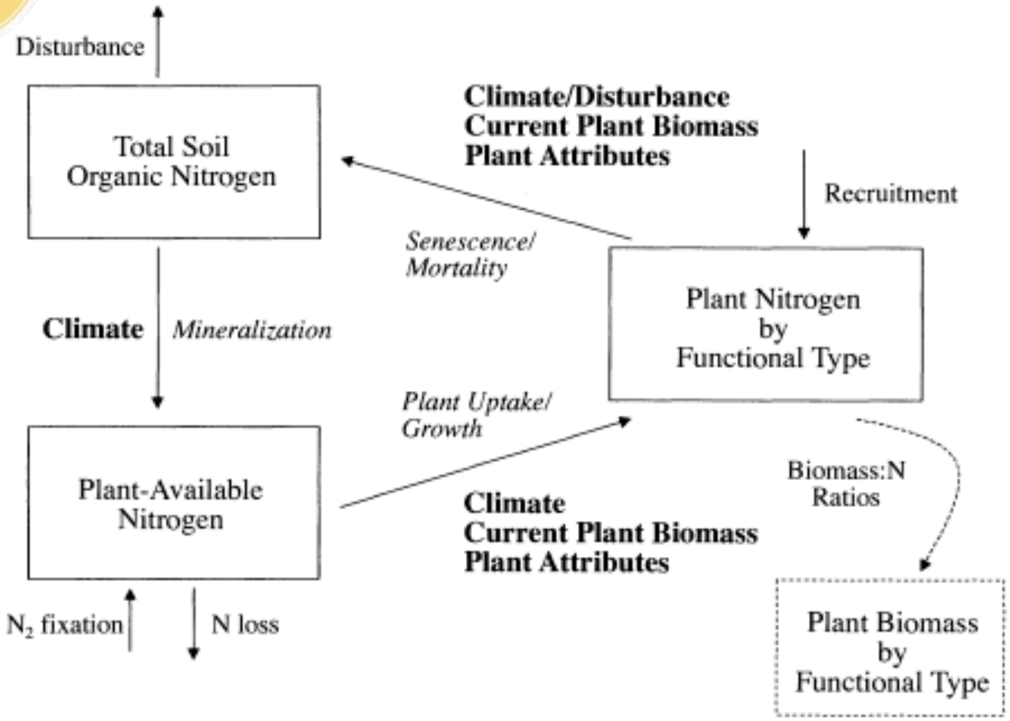
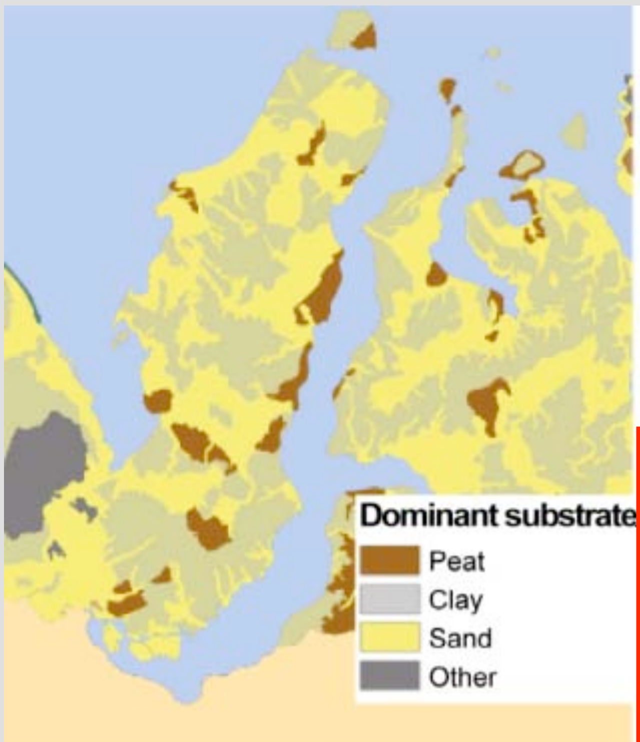


FIG. 1. ArcVeg flow diagram. Model pools are in boxes. The main processes are in italics inside the arrows, and the controls on these processes are in bold outside of the arrows. The dashed arrow and box represent the conversion of plant nitrogen to plant biomass in order to report the results as plant biomass.

Epstein et al. 2000

Controls on tundra vegetation dynamics on the Yamal Peninsula, Russia – Model input

- ArcVeg simulations with field collected data (subzones, soils)



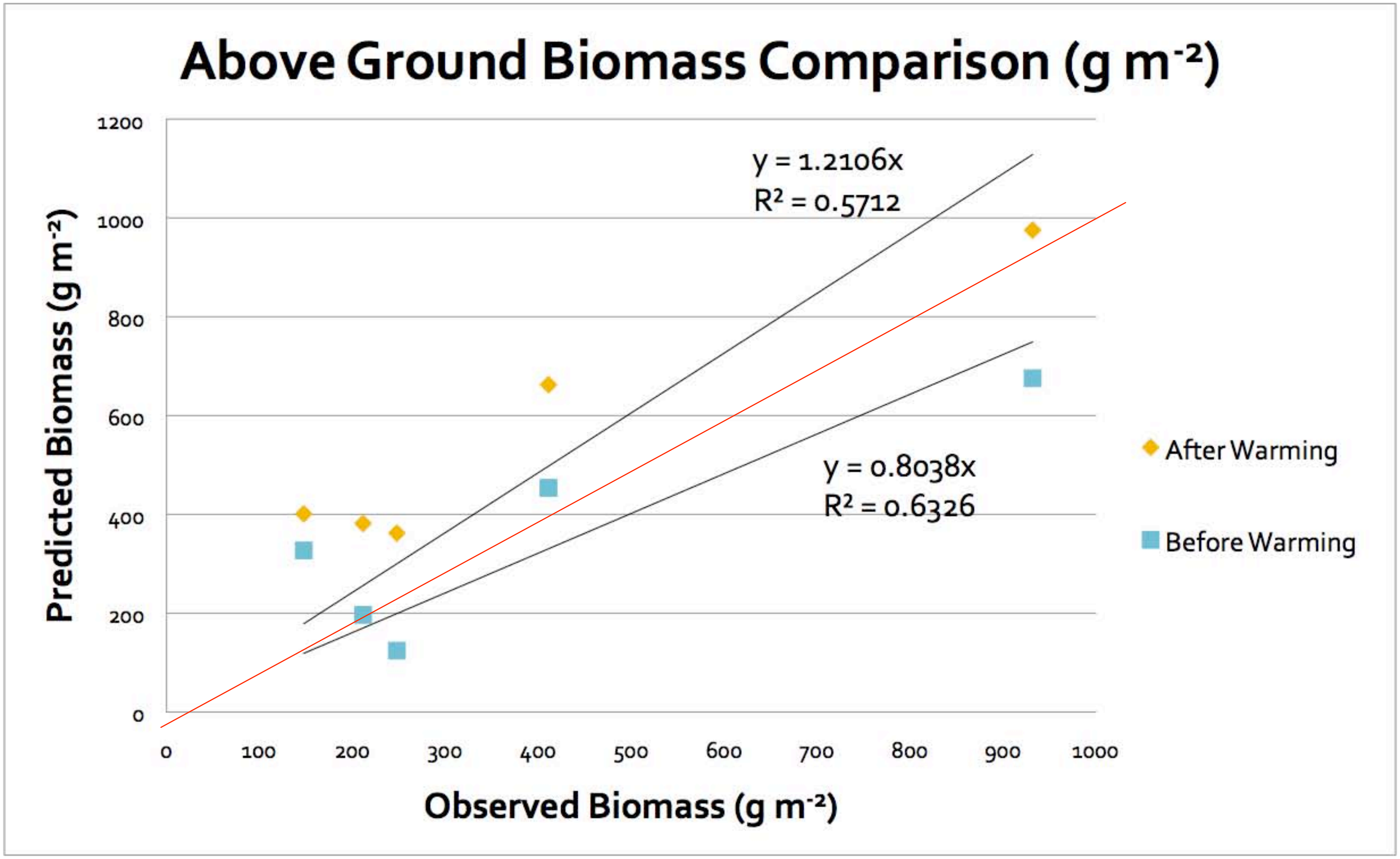
Walker et al. (2009)

- Bioclimate subzones
- Soil nutrients – soil organic nitrogen

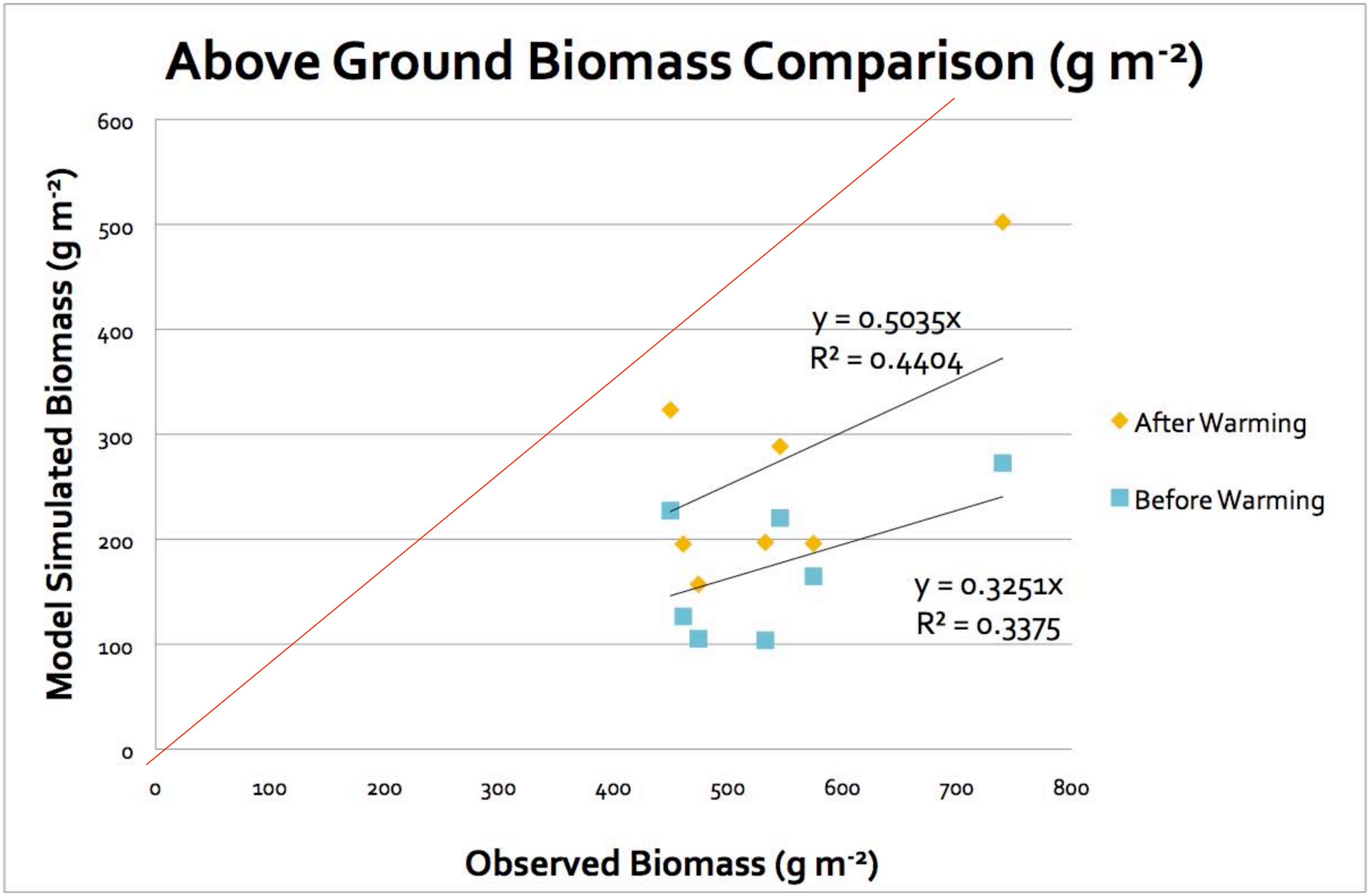
- Grazing: 0.1, 25% and 0.5, 25%
- Warming: 1 subzone warming/ 2°c warming

Subzone	sites	C%	N%	%Sand	%Silt	%Clay	Bulk Density (g/m^3)	Active Layer Depth(cm)	SON (g/m^2)
E	LV-1	1.72	0.06	18.00	59.32	22.68	1.21	81.20	570
E	LV-2	0.59	0.01	93.60	3.60	2.80	1.29	114.60	148
D	VD-1	1.25	0.03	28.90	60.80	10.30	1.34	71.75	271
D	VD-2	1.46	0.04	38.28	53.88	7.84	1.37	68.60	202
D	VD-3	1.31	0.05	92.80	4.64	2.56	1.18	113.80	498
C	KH-1	1.10	0.06	24.47	52.07	23.47	1.47	56.33	484
C	KH-2	1.18	0.07	65.60	26.60	7.80	1.22	75.50	599

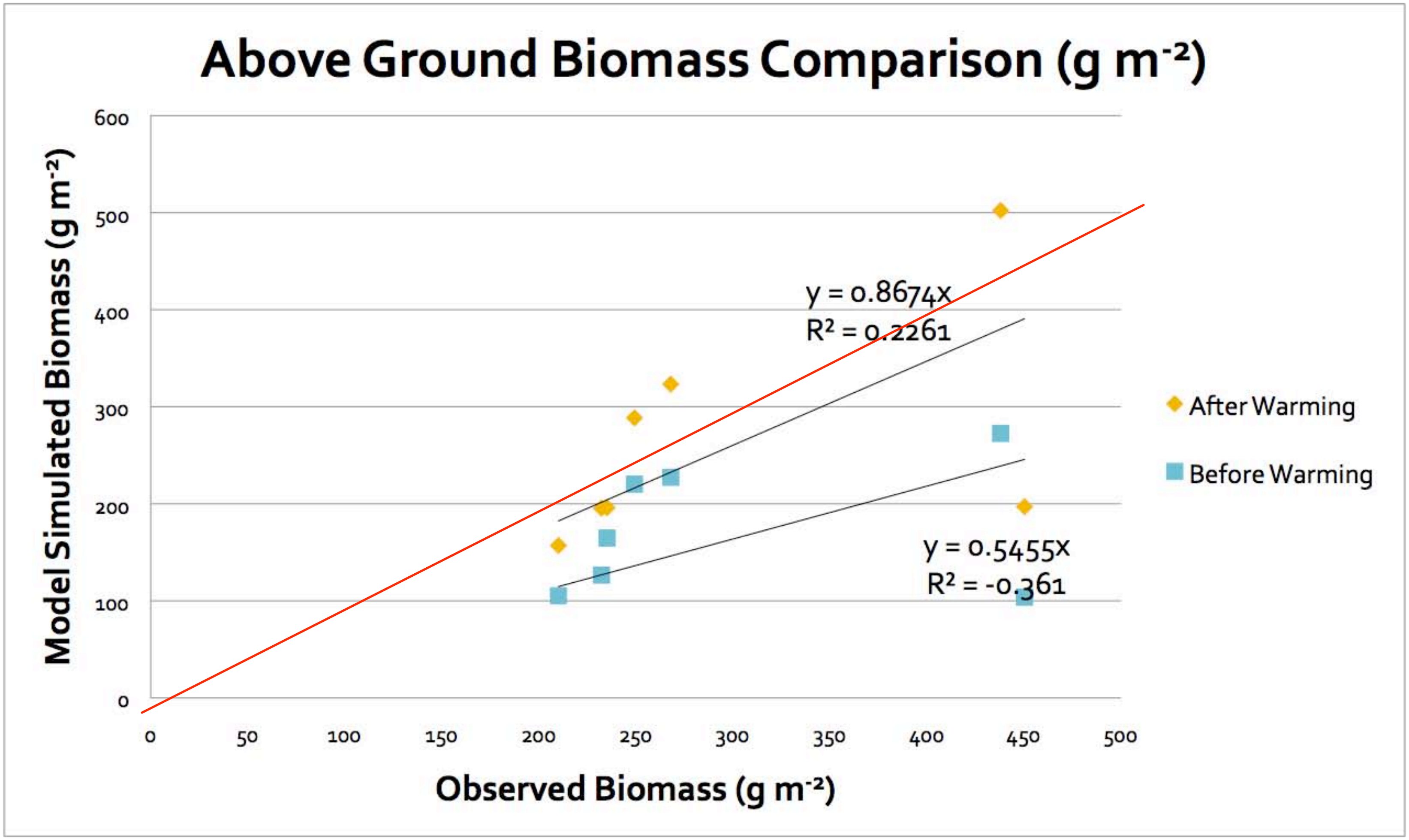
Model Validation in NAAT



Model Validation in YAT

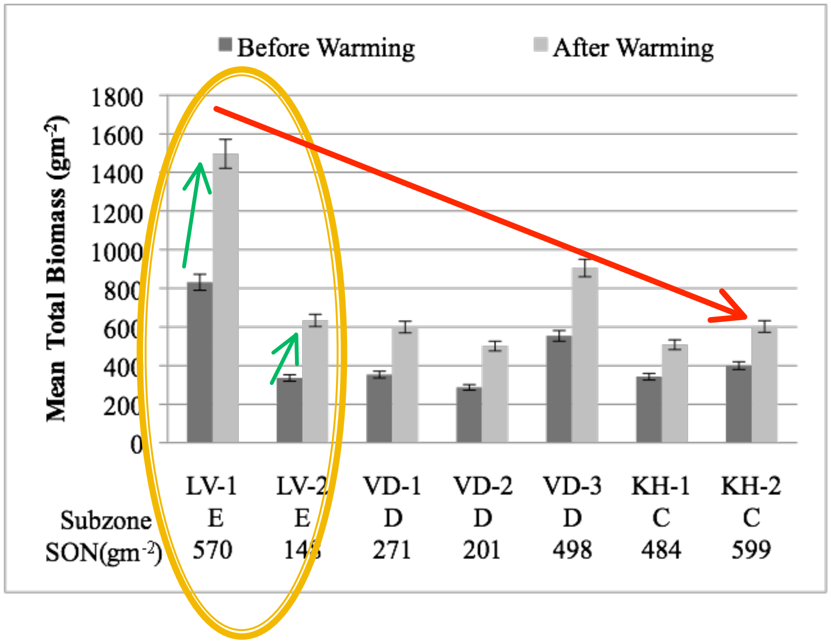


Model Validation in YAT - MOSS



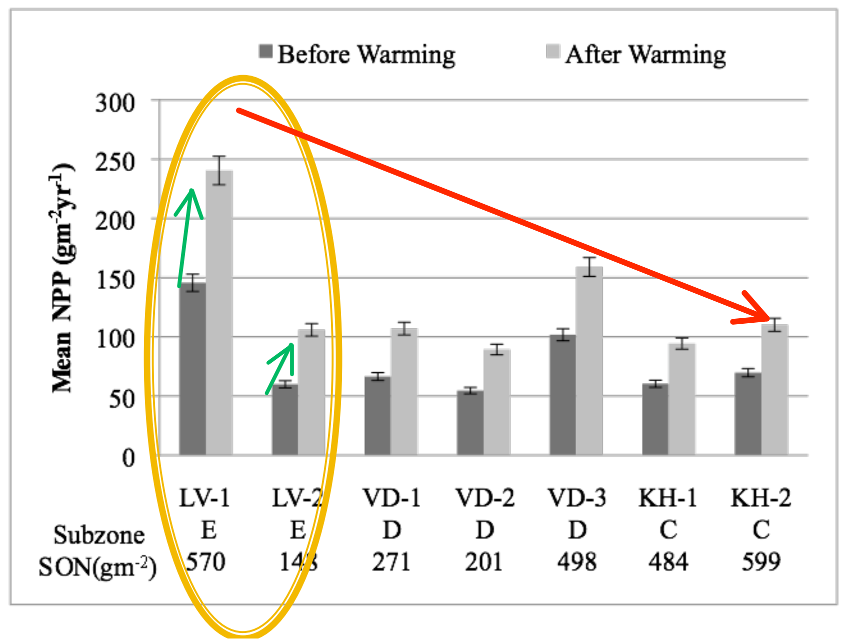
Results

Soil and warming effects (Total biomass and NPP)



- SON determines how much TB/NPP each site can support
- The magnitude is modified by climate subzones

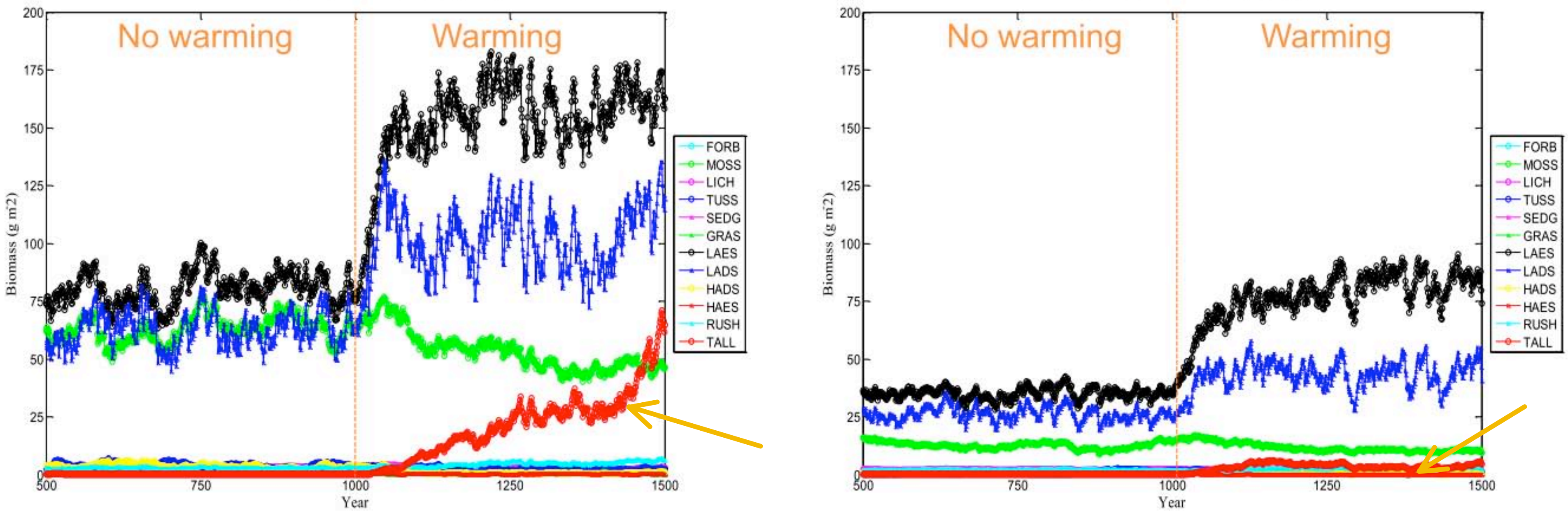
- Warming causes more absolute increase in TB/NPP for nutrient rich sites; while more relative increase in TB/NPP in nutrient poor sites.



Results Soil and warming effects (PFT)

Subzone E (LV)

SON = 570 g/m^2 SON = 148 g/m^2



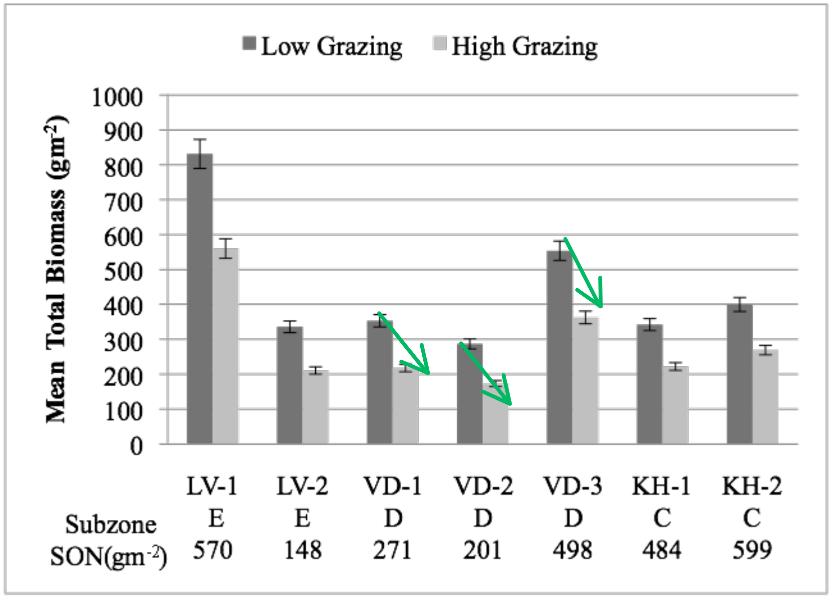
Above ground biomass of each PFT simulated with ArcVeg shows that:

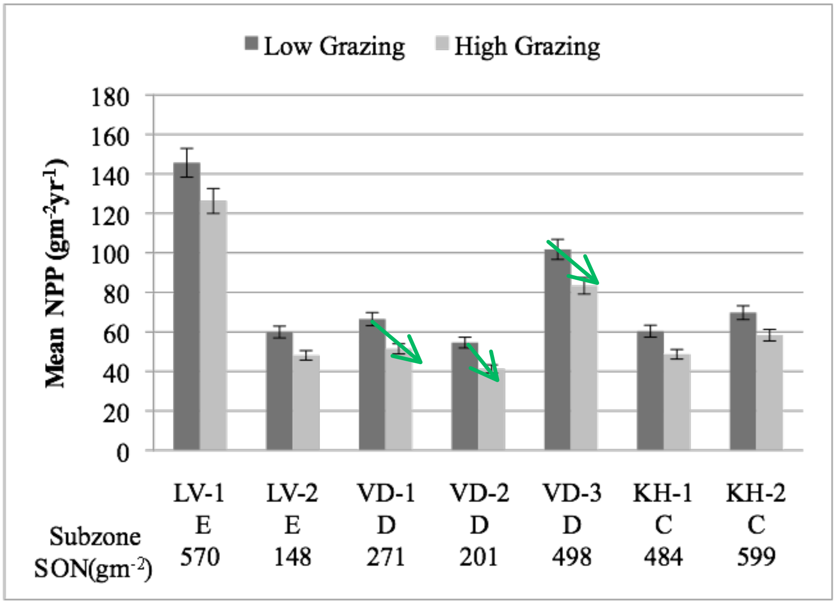
•SON significantly affects PFT richness in each site.

- Response to warming is more significant in high SON site than in low SON site.
- Note the changes in tall shrubs after warming.

Results

Soil and Grazing effects (Total biomass and NPP)





- Increase grazing frequency generally causes **decrease in TB/NPP**

SON (g m^{-2})	Total Biomass (g m^{-2})	NPP (g m^{-2} Year^{-1})
VD-1 (271)	135	15
VD-2 (201)	114	13
VD-3 (498)	191	18

Soil - SON Efficiency and Productivity Efficiency

$$SON\ efficiency = NPP/SON$$

Sites (SON)	Before Warming	After Warming
LV-1 (570)	0.26	0.42
LV-2 (148)	0.4	0.72

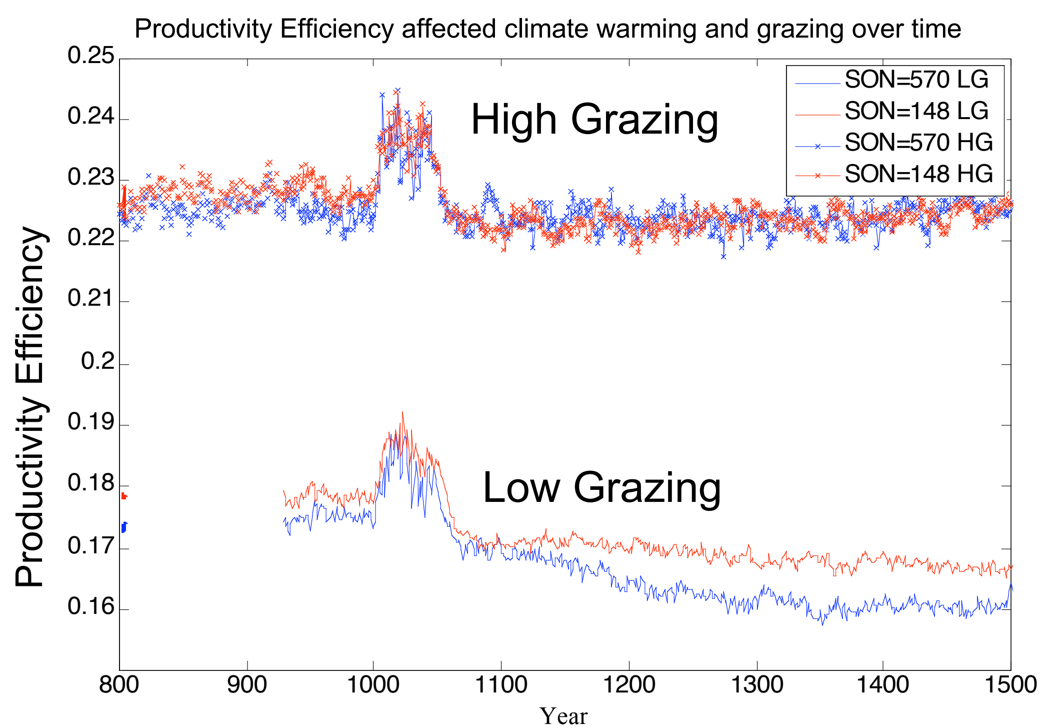
➢ Nutrient-poor sites generally have higher SON efficiency than nutrient-rich sites

Model simulated NPP is controlled by:

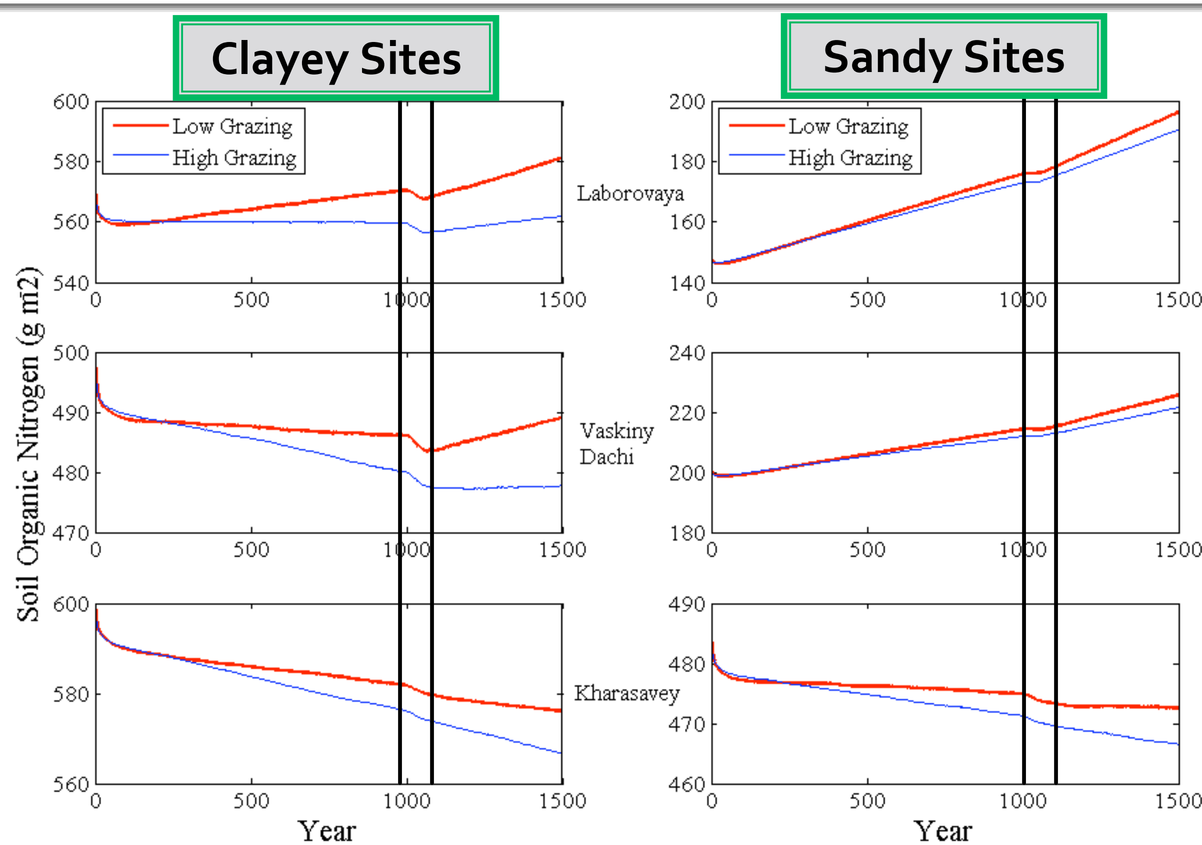
- •Temperature (subzone and warming)
- •Herbivore
- •Nutrient supply

$$Productivity\ efficiency = \frac{NPP(t)}{Biomass(t-1)}$$

SON, Warming , Grazing effect



Interaction Effects of Herbivore and Warming on SON pools



- Higher grazing frequency led to either slower SON accumulation rates or more rapid SON depletion rates.
- Warming accentuated these differences caused by grazing, suggesting the interaction between grazing and warming may yield greater differences in SON levels across sites.

Summary

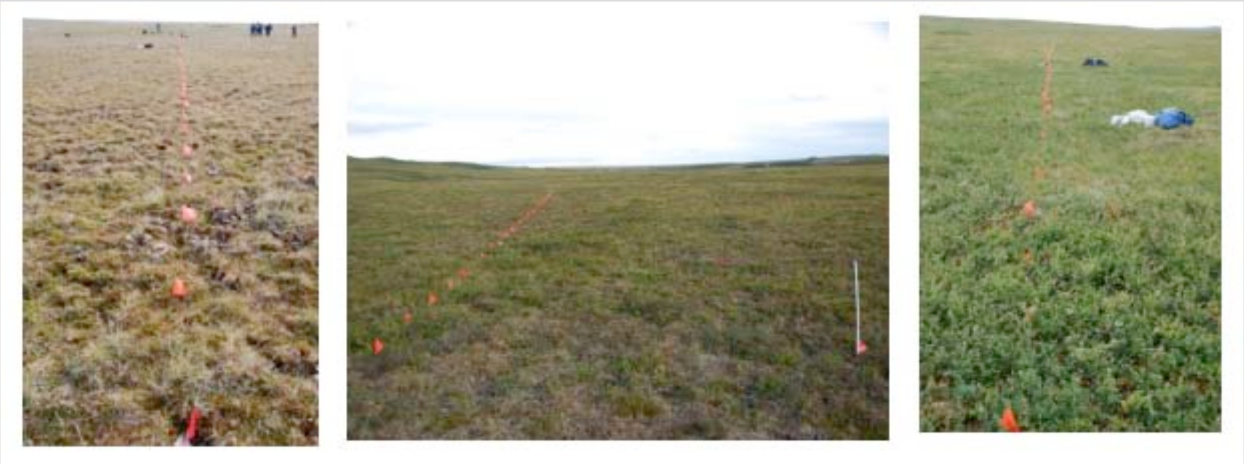
- Soil nutrients are a limiting factor to plant growth, and also limit the plant responses to climate warming.
- Warming and grazing are affecting plant biomass and NPP in opposite directions.
- Grazing suppresses plant responses to warming effects.
- The interaction between grazing and warming may yield greater differences in SON levels across site.

Land use change detection and effects on tundra vegetation

Land Cover Land Use Changes along the Yamal Peninsula, Russia (Multi-temporal image analysis)

Background

Yamal Arctic Transect



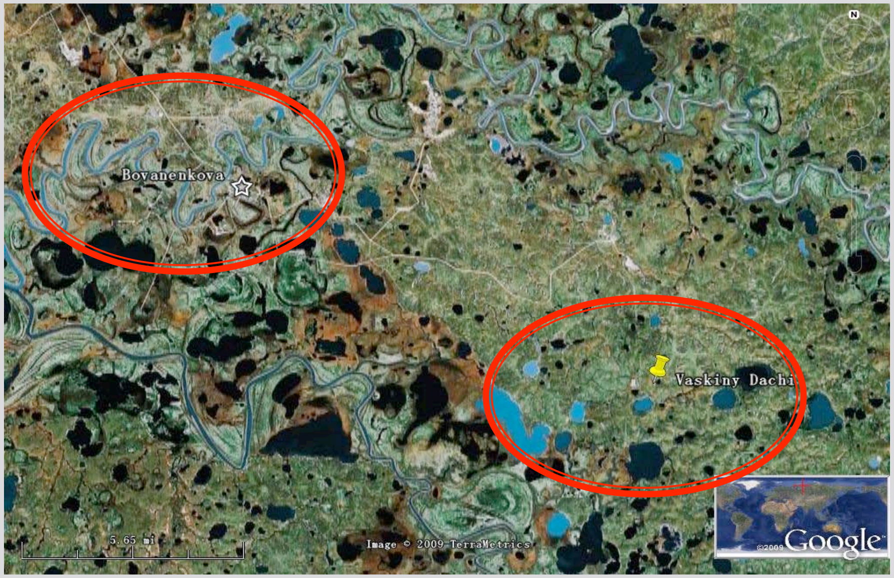
Zonal vegetation at Kharasavey(subzone C) Vasikiny Dachi (subzone D), and Laborovaya (subzone E). Note the increasing greenness with warmer temperatures toward the south. Photo: D.A. Walker.

Locations of field sites across the Yamal Arctic Transect (YAT)
(Walker et al. 2009)

Background

- Oil and gas industry
- Road and pipeline construction
- Surface hydrology including Thermakarst lakes
- Vegetation
- Permafrost

LUC related changes



Research Objectives

- Methodology to detect changes
- Identify changes across the Yamal Peninsula
- Analyze the causes of the changes
- Identify the spatial influence of specific land use changes

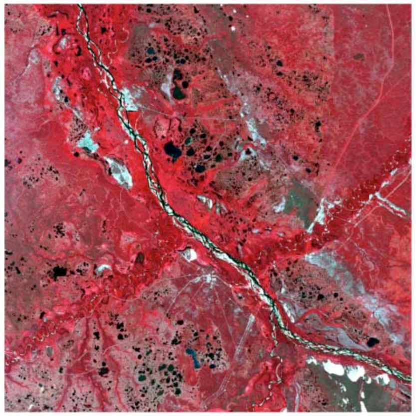
Methodology

We classify our imagery based on four-integrative indices for Landsat TM/ETM+:

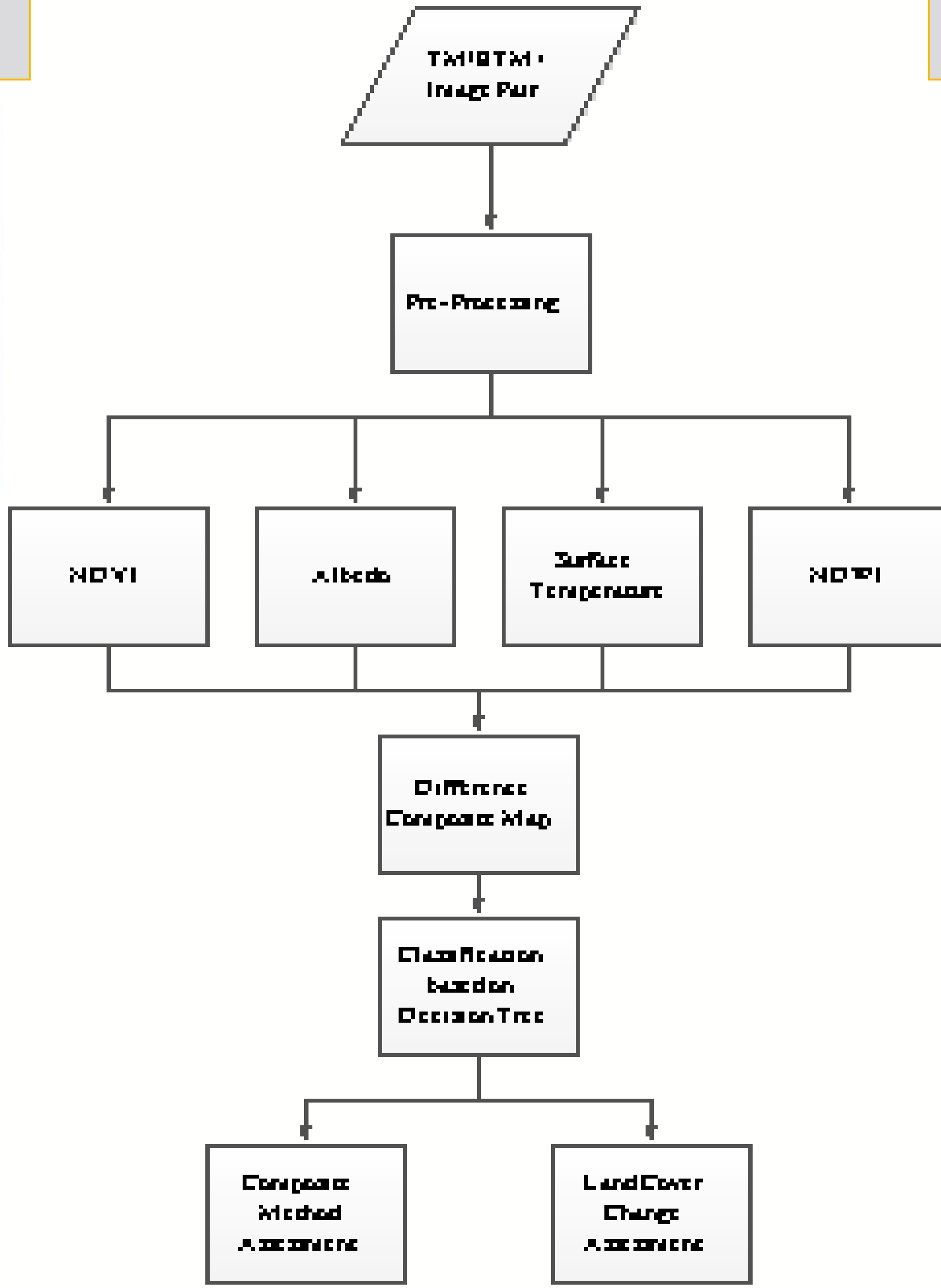
- NDVI = f (band3, 4) (Rouse et al, 1989)
- Albedo = f (band 1,3,4,5,7) (Liang, 2001)
- Land surface temperature = f (band6) (Qin et al., 2001)
- NDWI = f (band4,5) (Gao, 1996)

Image Processing Flow Chart

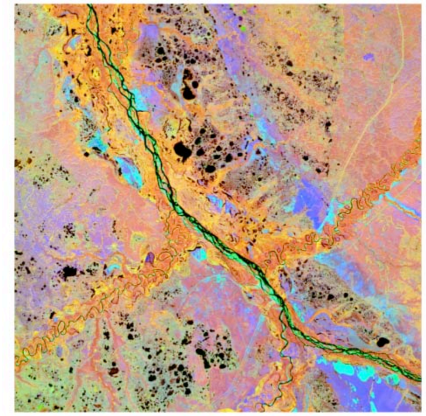
Multispectral Image
2007



- Red - Band 4
- Green- Band 3
- Blue - Band 2



Integrative indices
2007



- Red- NDVI
- Green- Albedo
- Blue- Ts

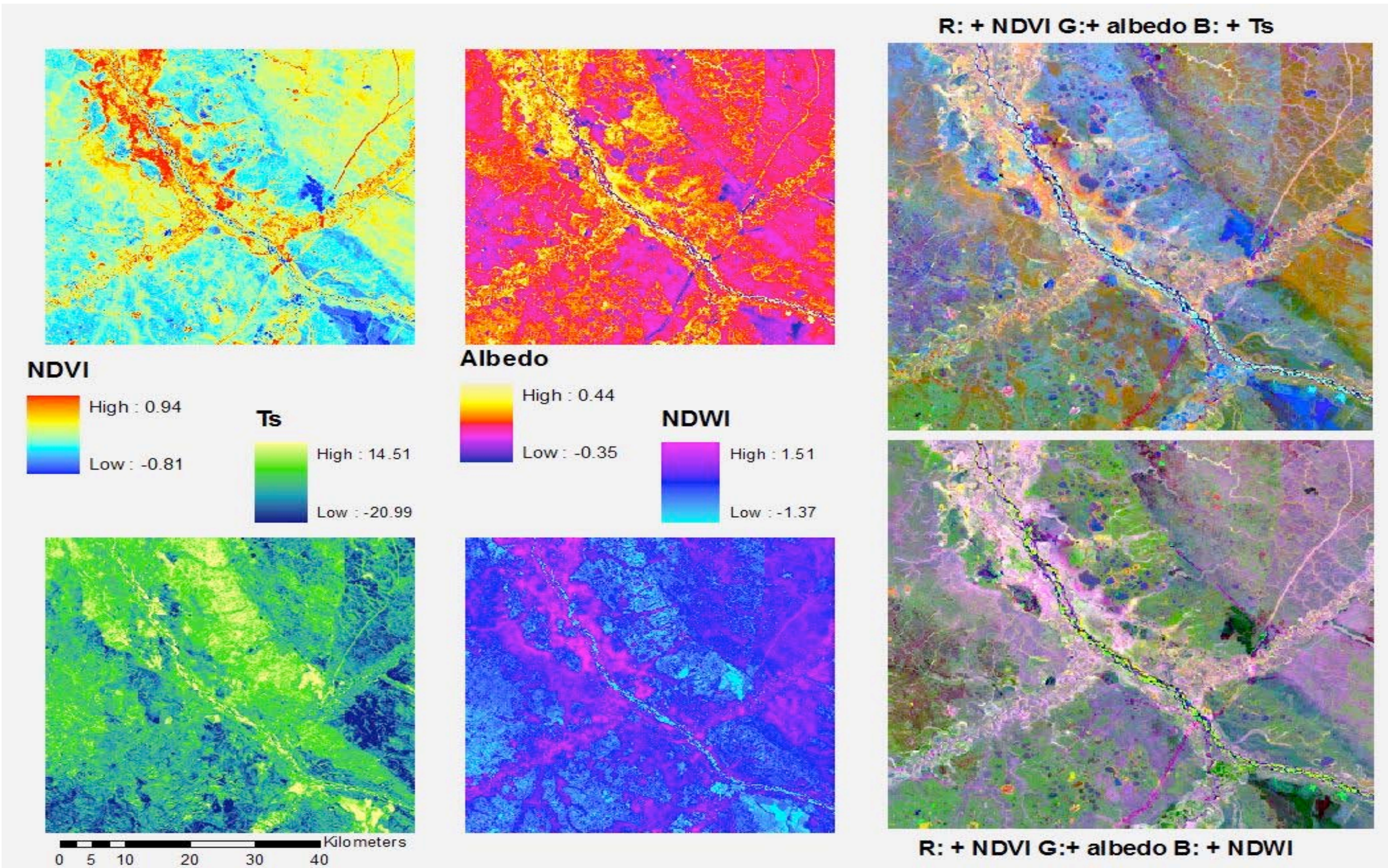
Table 1. Satellite images used in the study

Study sites	Date	Mission and Sensor	Path/row
Nadym			
	1988-6-19	Landsat-4, TM	160/14
	2007-7-7	Landsat-5, TM	160/14
	2006-7-15*	Landsat-5, TM	160/14
Laborovaya			
	1988-8-2	Landsat-4, TM	164/10
	2006-6-25	Landsat-5, TM	164/10
Vaskiny Dachi/Kharasavey			
	1988-8-7	Landsat-4, TM	167/10
	2000-7-7	Landsat-7, ETM+	167/10
Belyy Ostrov			
	1988-8-7	Landsat-4, TM	167/8
	2000-7-16	Landsat-5, ETM+	167/8

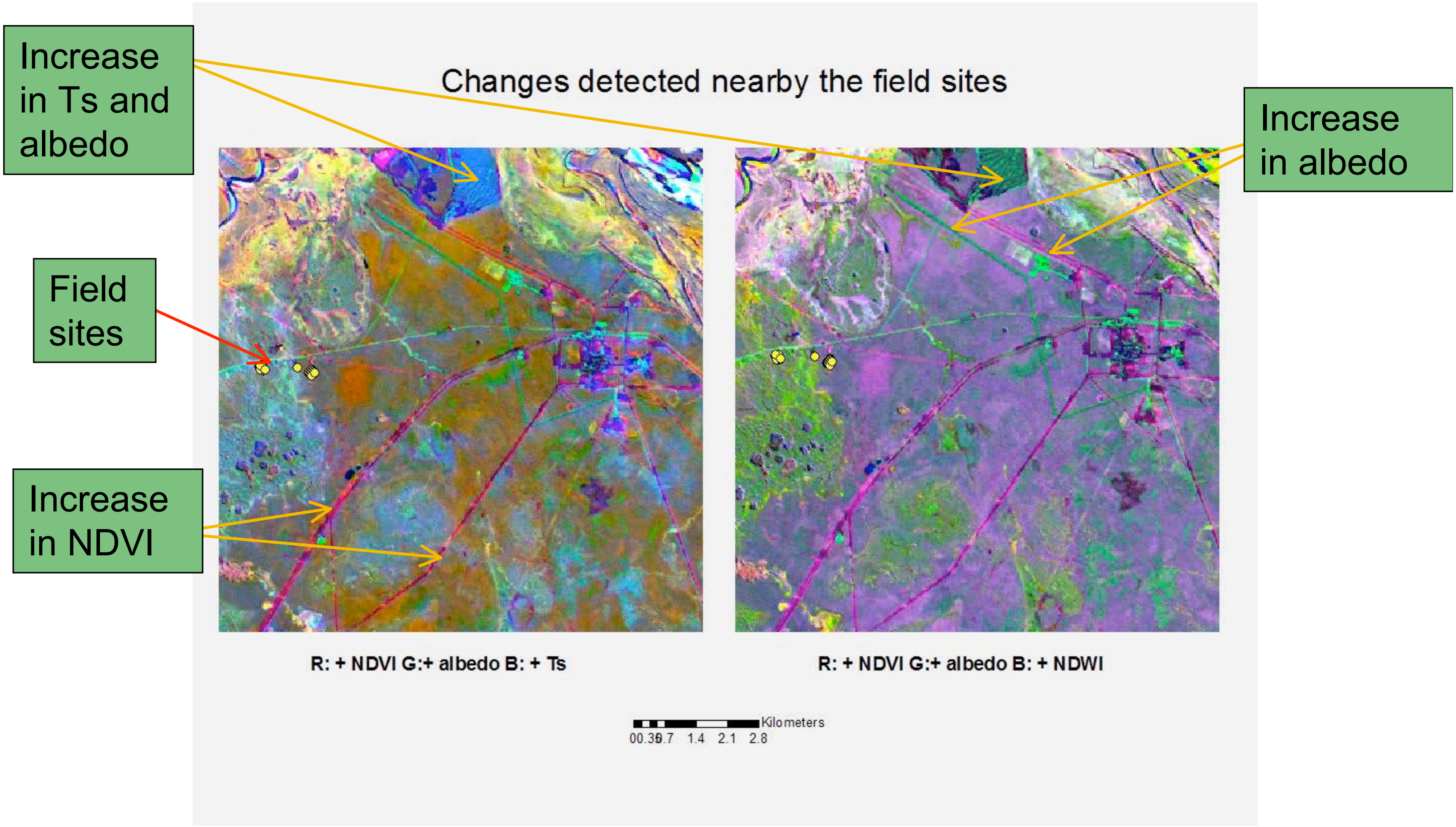
Results

- Nadym region as the example which encompasses city, gas and oil development, grazing and climate change

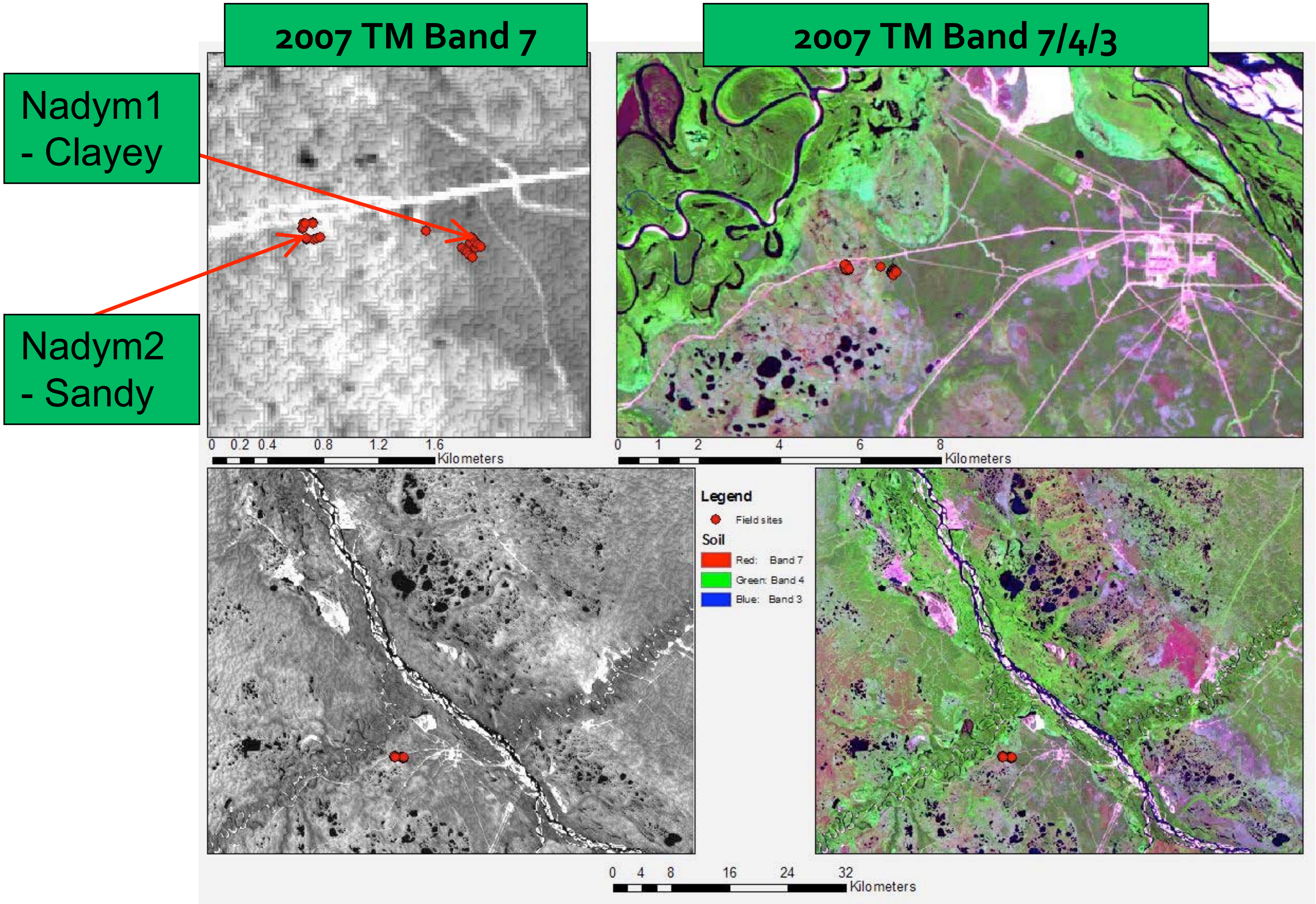
Difference 2007-1988 for four indices



Changes detected near the Nadym field sites

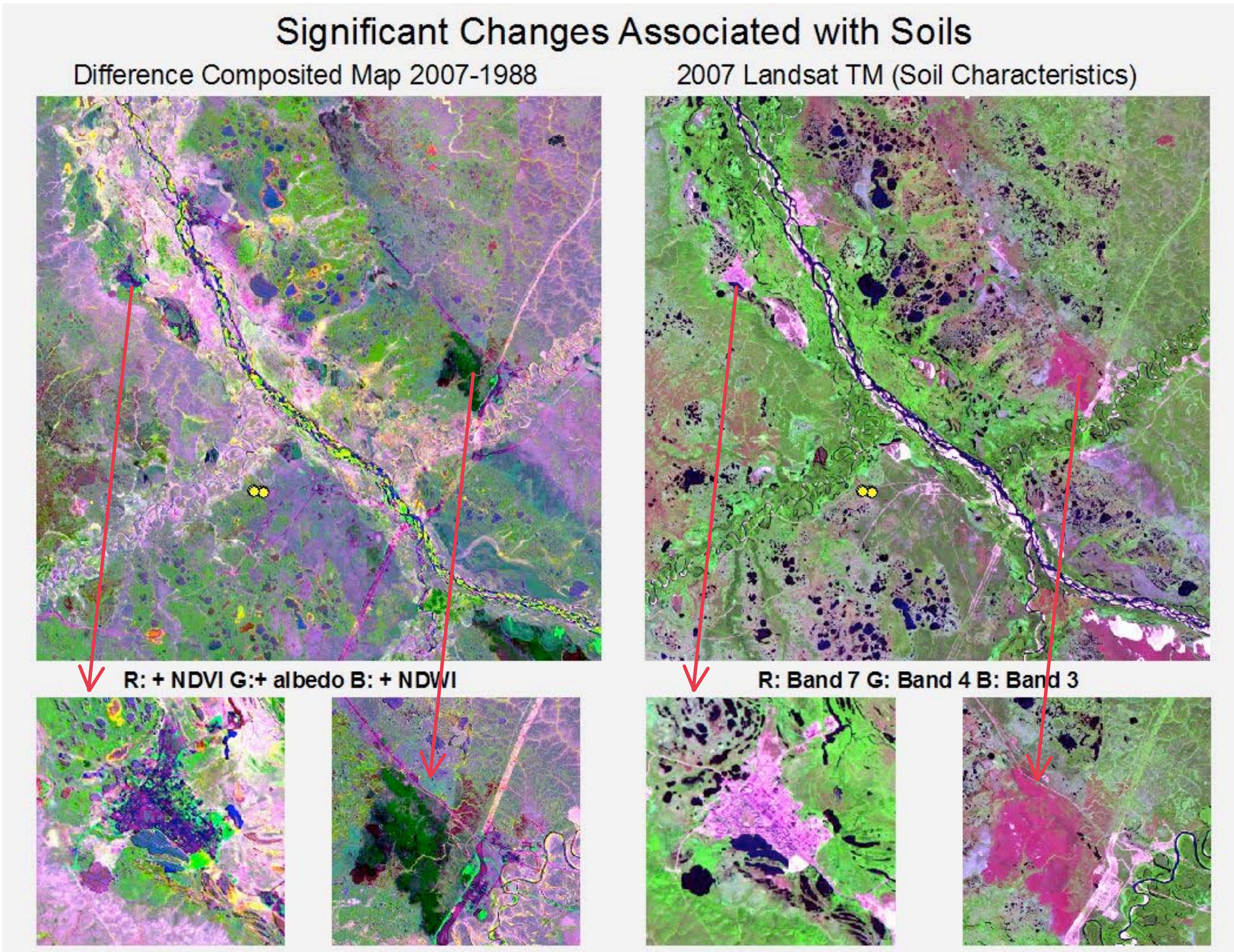


Soil



2007 TM Band 7
2007 TM Band 7/4/3
Nadym1 - Clayey
Nadym2 - Sandy
0 0.2 0.4 0.8 1.2 1.6
Kilometers
0 1 2 4 6 8
Kilometers
Legend
Field sites
Soil
Red: Band 7
Green: Band 4
Blue: Band 3
0 4 8 16 24 32
Kilometers

Changes detected associated with Soils



Summary

- Based on the integrative indices, it is easier to interpret changes occurred in decades
- We detected changes such as new facilities, road/pipelines, recovery of vegetation on disturbed regions, reduced moisture content on the ground, etc.
- Further detailed analysis is needed.

Acknowledgment

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