Field and Modeling Analyses of Tundra Vegetation Communities Along Latitudinal Temperature Gradients

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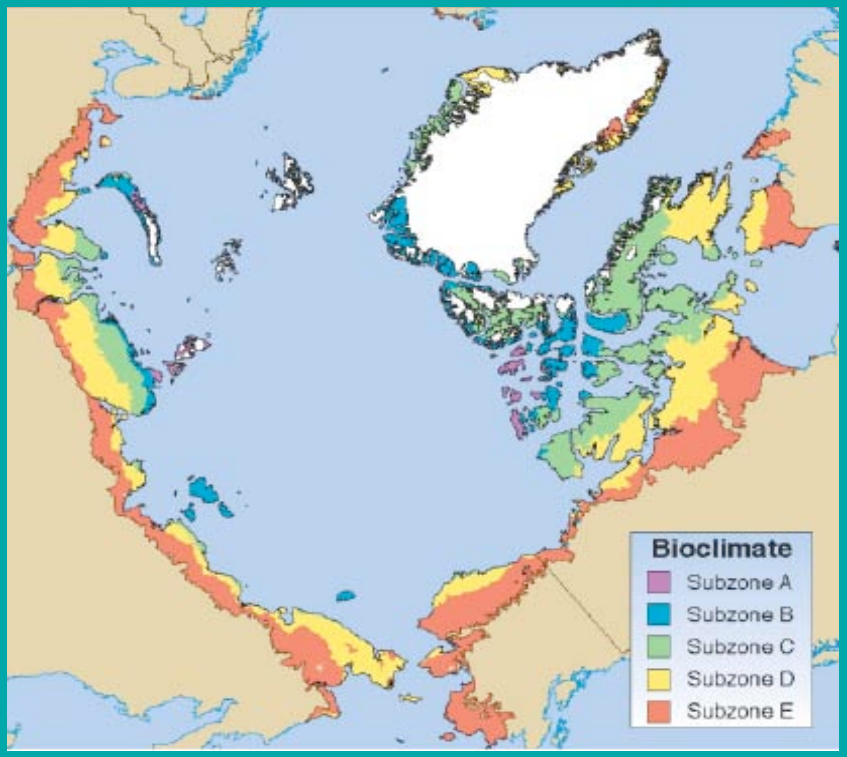


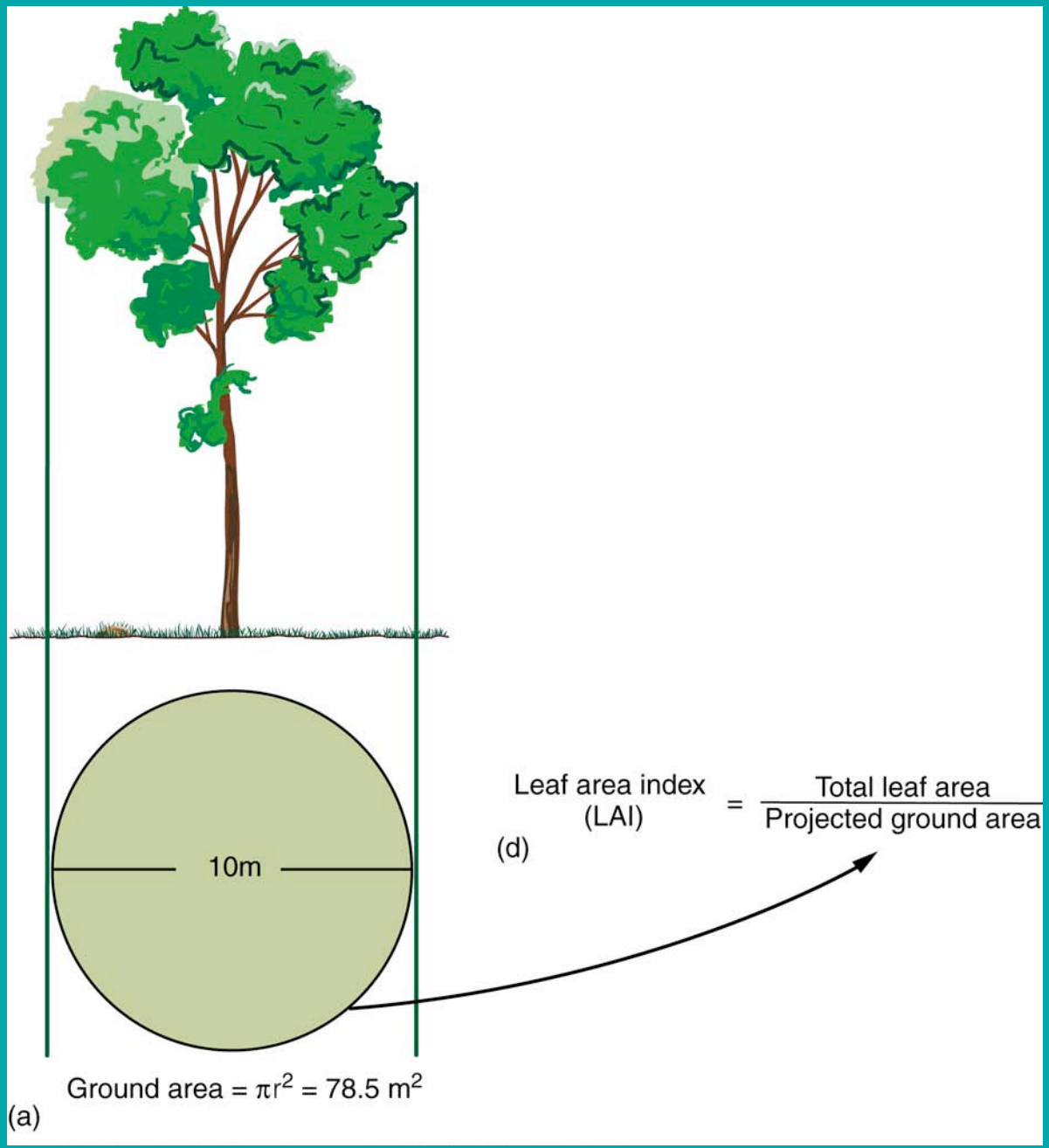
Field Analysis

Leaf Area Index (LAI)
Normalized Difference Vegetation Index (NDVI)
Vegetation Biomass
Foliar Nutrient Concentrations
Comparative analyses
Gradient analyses

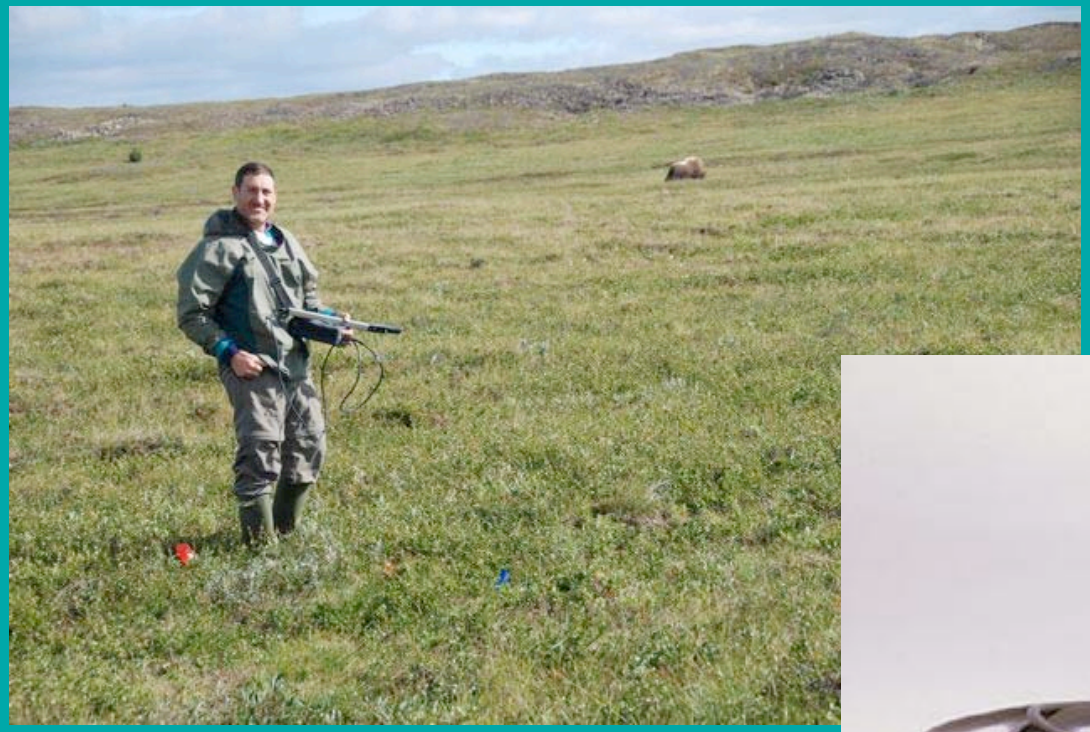
Modeling Analyses

1) ArcVeg (tundra vegetation dynamics)
2) BIOME4 (northern vegetation community changes)
3) TreeMig (latitudinal treeline dynamics)
4) GCM-DGVM (ecosystem-atmosphere dynamics)

Leaf Area Index

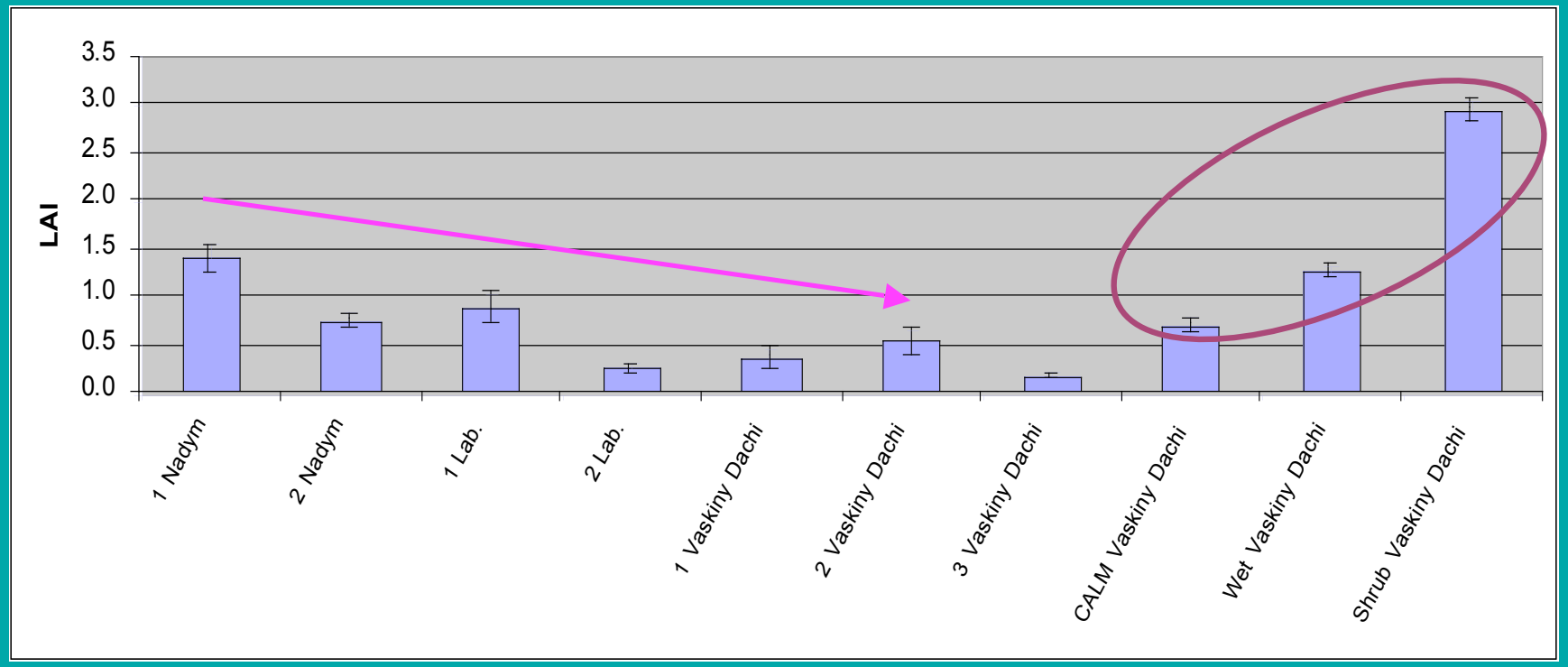


An Easier Way – the LAI-2000 Plant Canopy Analyzer



Each site (grid) at each location (Nadym, Laborovay, Vaskiny Dachi) had five 50-m transects and 5 releves.

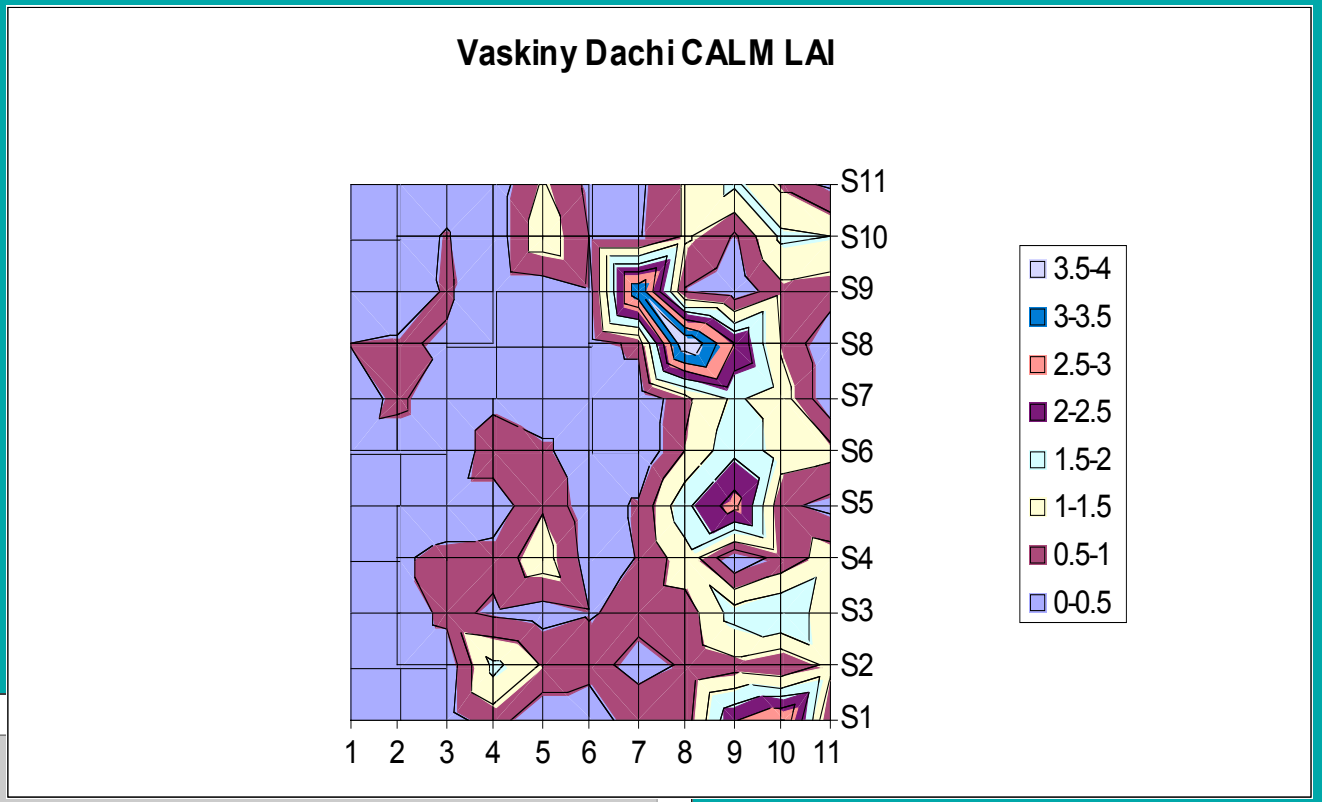
- LAI measurements were taken **every meter along each of the transects** (50 per transect), and **five measurements were taken for each releve**

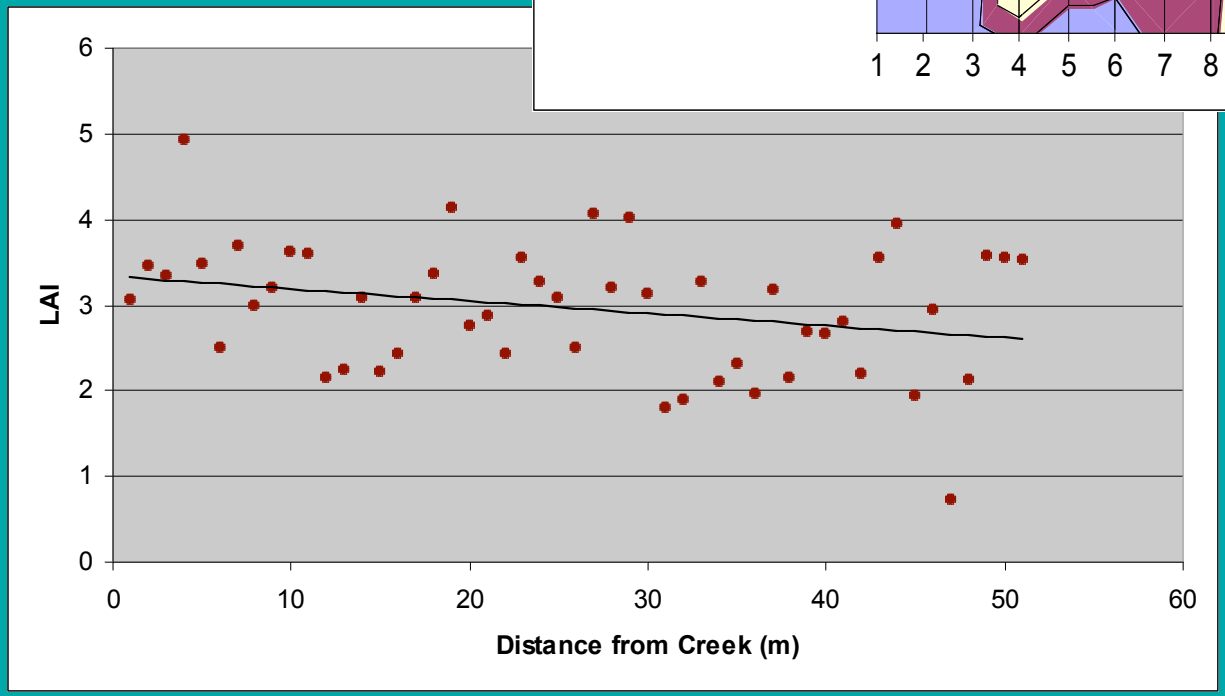


- **Latitudinal decline**

- **High local spatial heterogeneity**

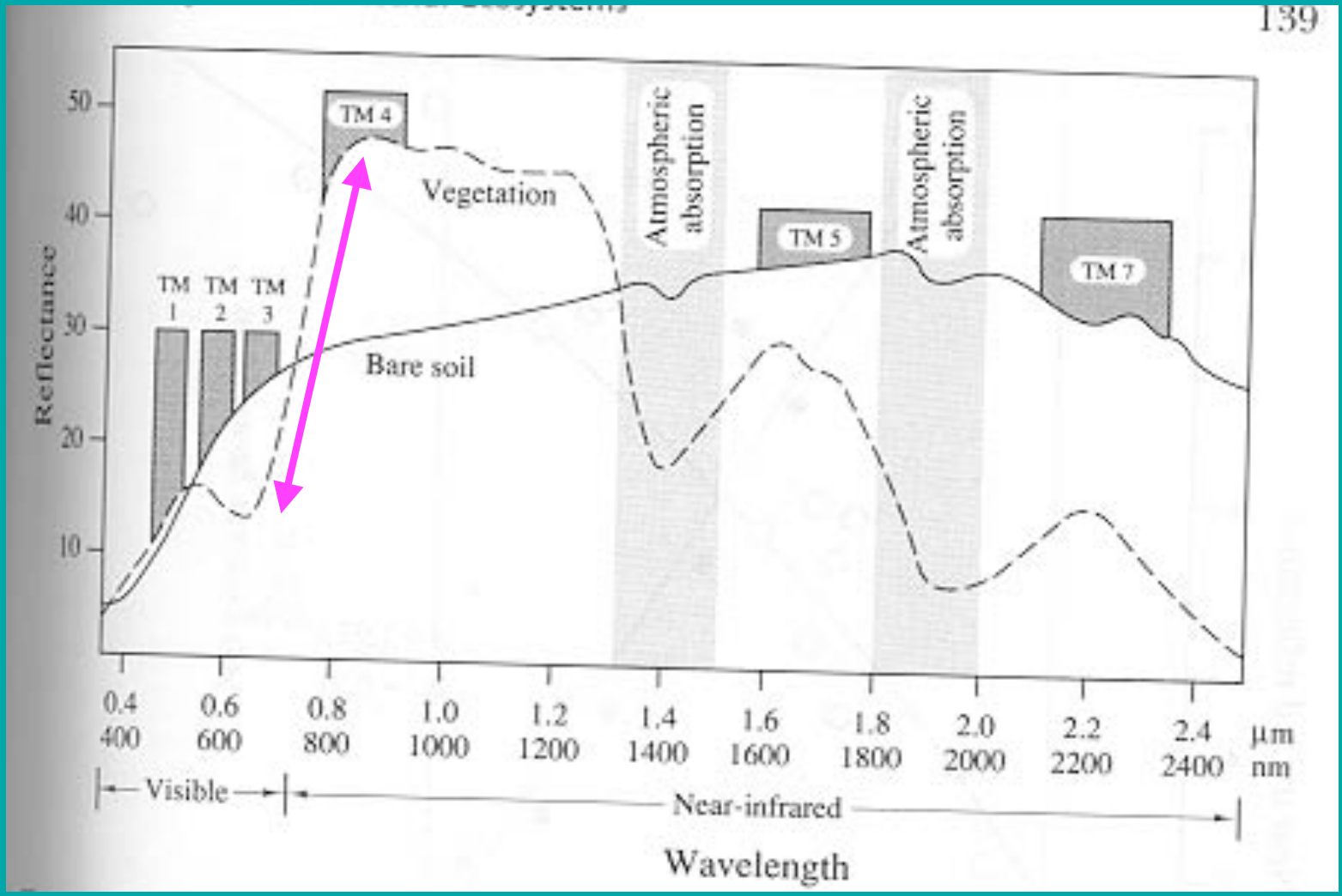
Spatial Variability





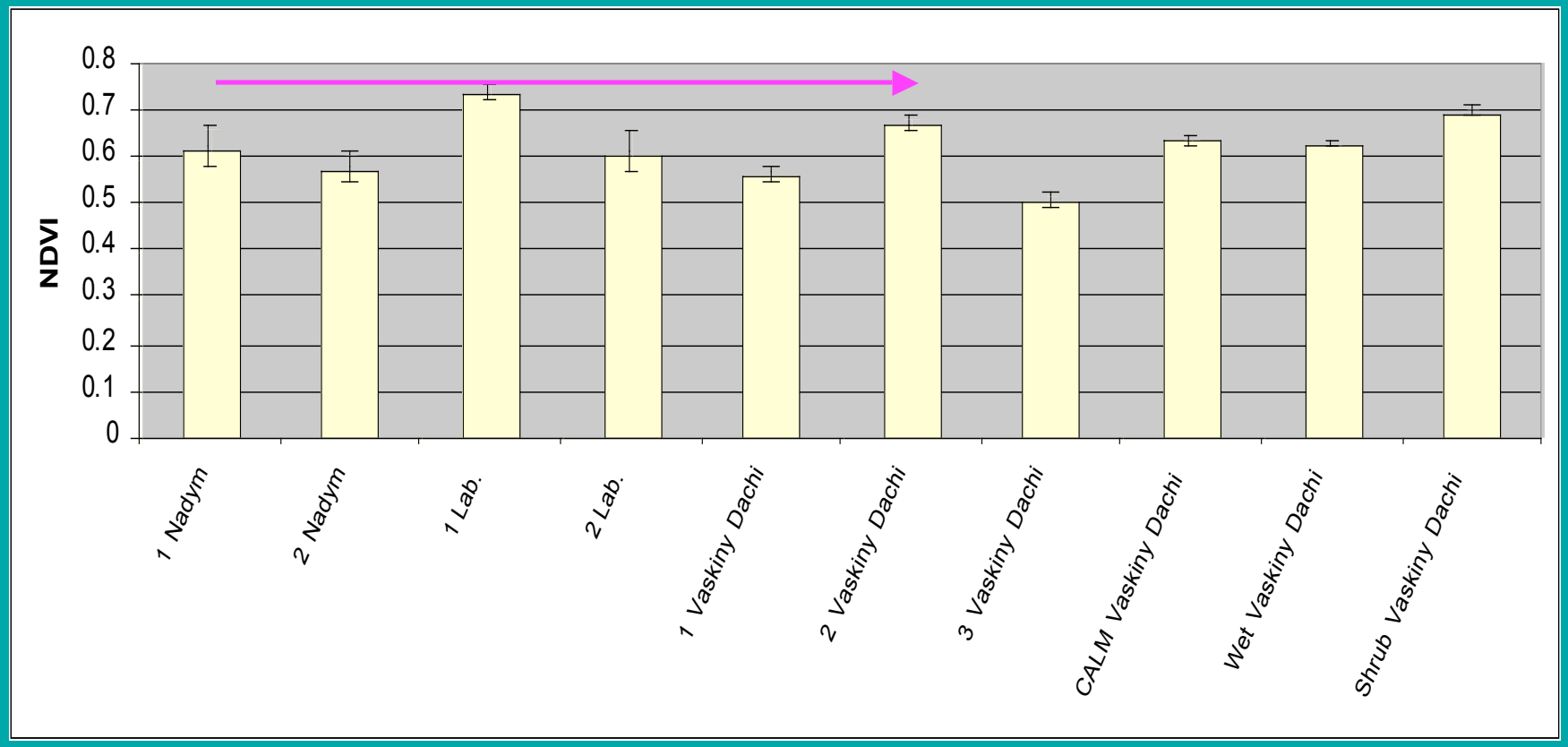
Remote Sensing - Normalized Difference Vegetation Index (NDVI)

NDVI = (Near InfraRed [NIR] - Red) / NIR + Red



Field Spec (PSII) – Handheld Spectroradiometer

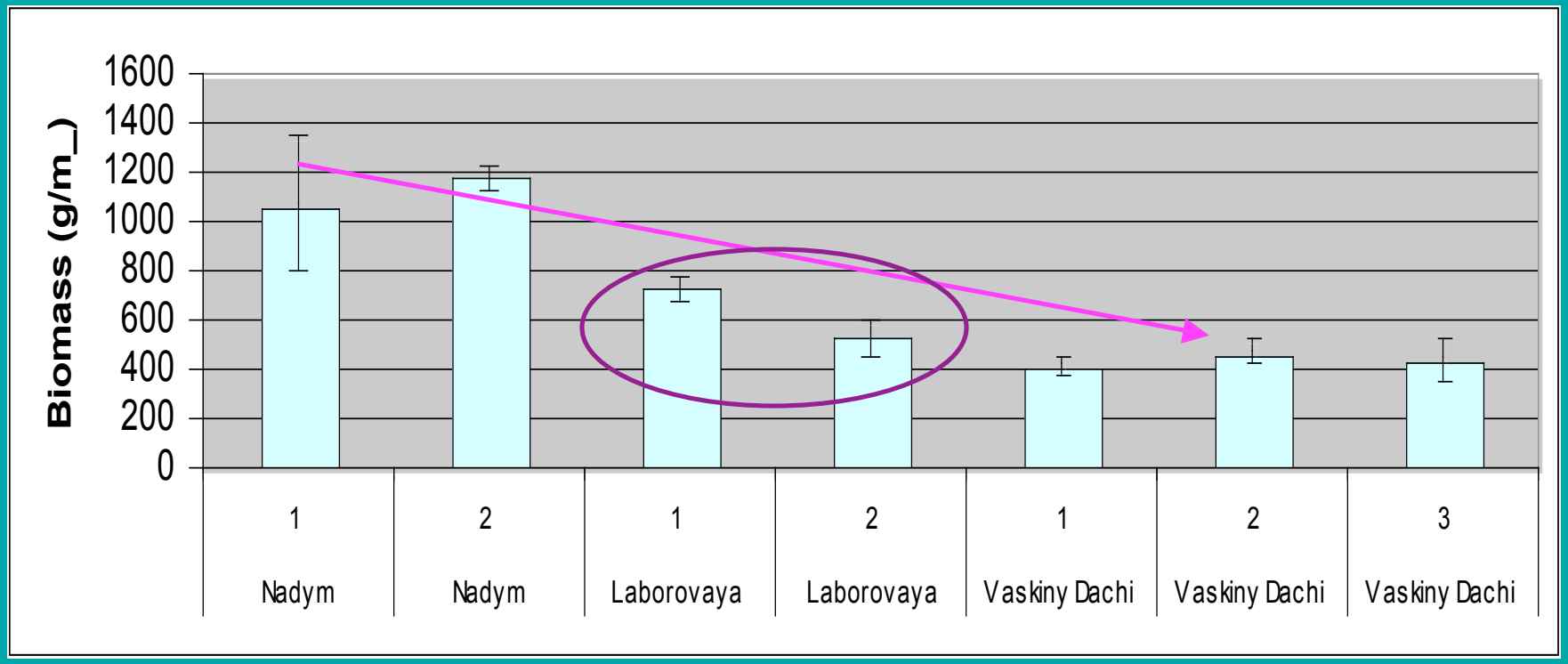
NDVI measurements were taken **every meter along each of the transects** (50 per transect), and **five measurements were taken for each releve**



- **No latitudinal decline**

- **Minimal local spatial heterogeneity**

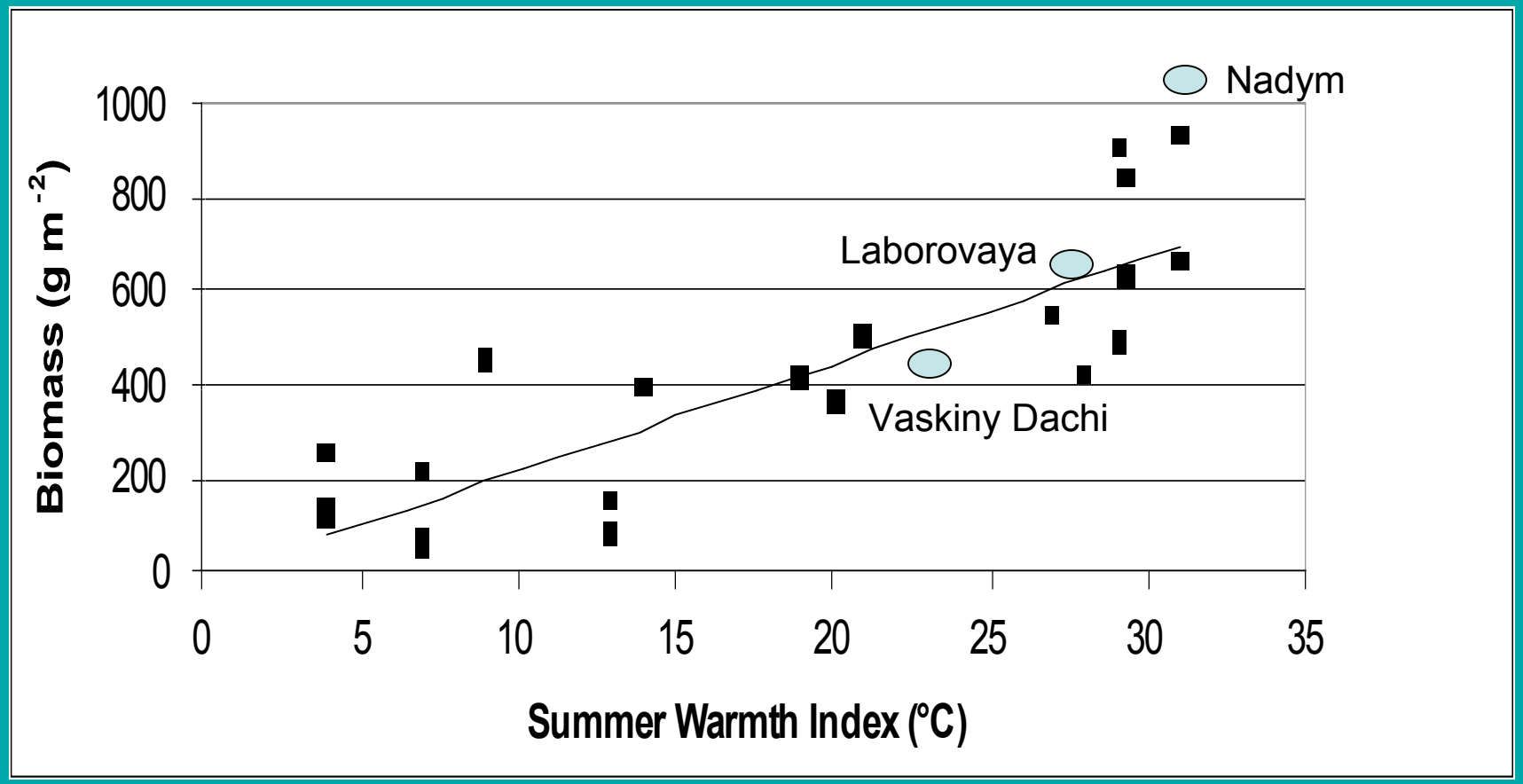
Biomass harvests were taken and analyzed for each of the releves at each of the sites.

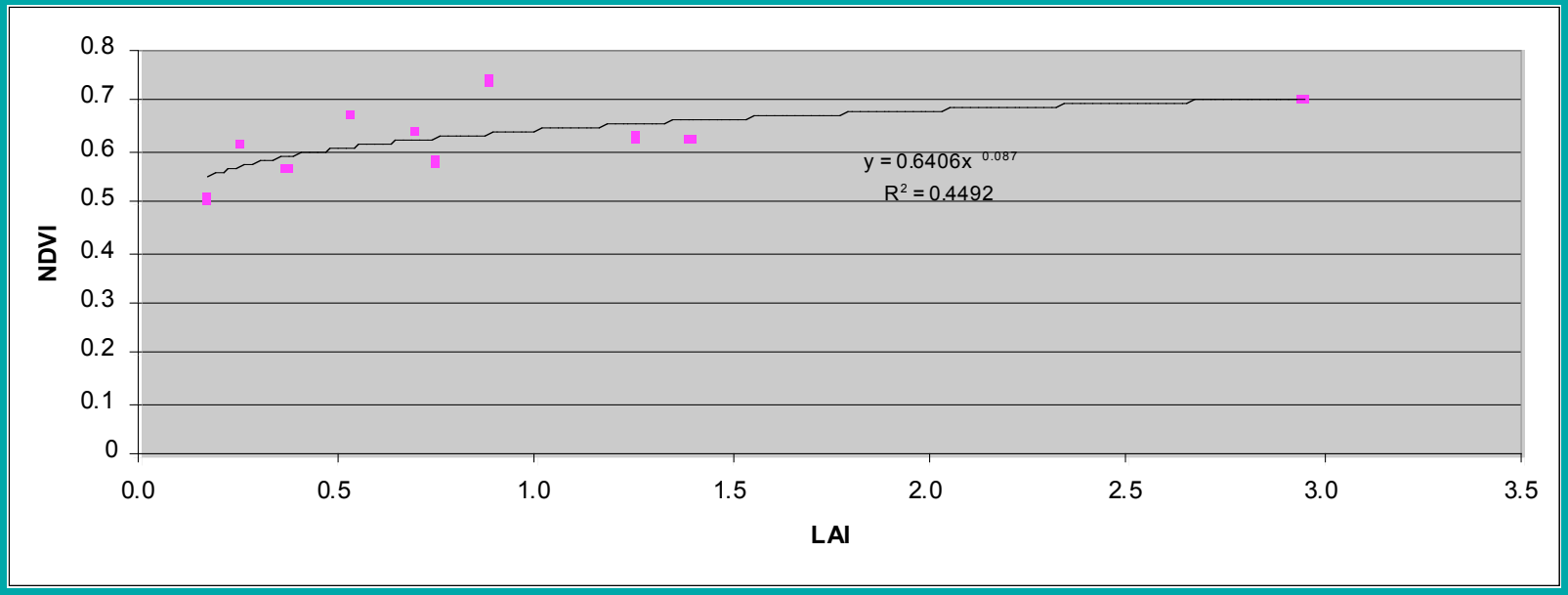


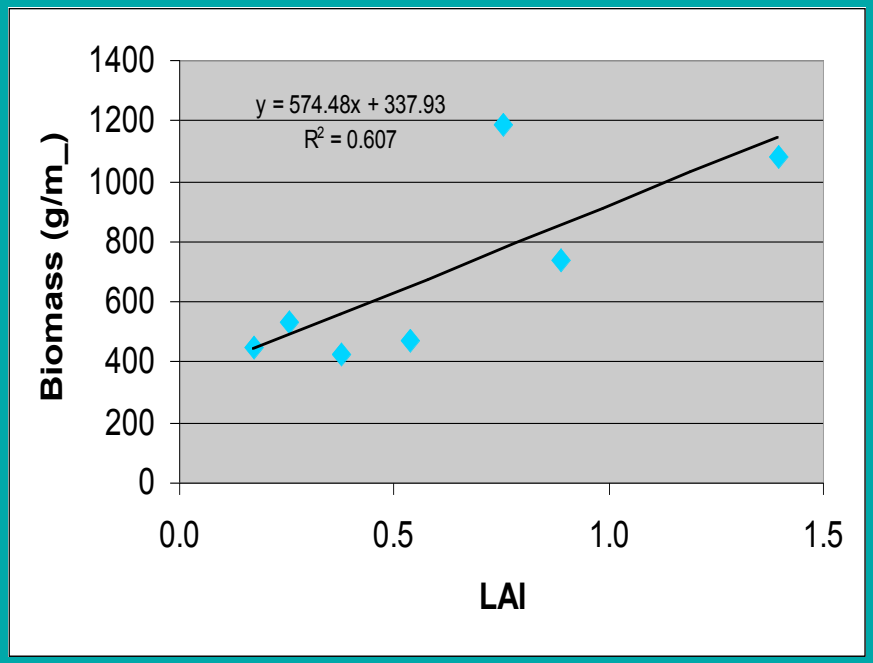
- **Latitudinal decline**

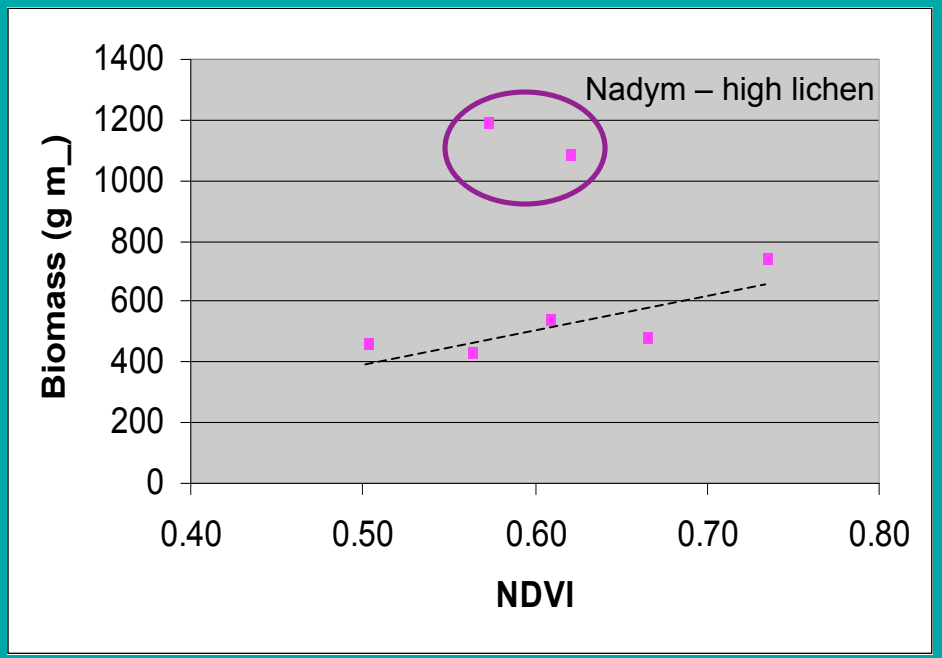
- **High local spatial heterogeneity**

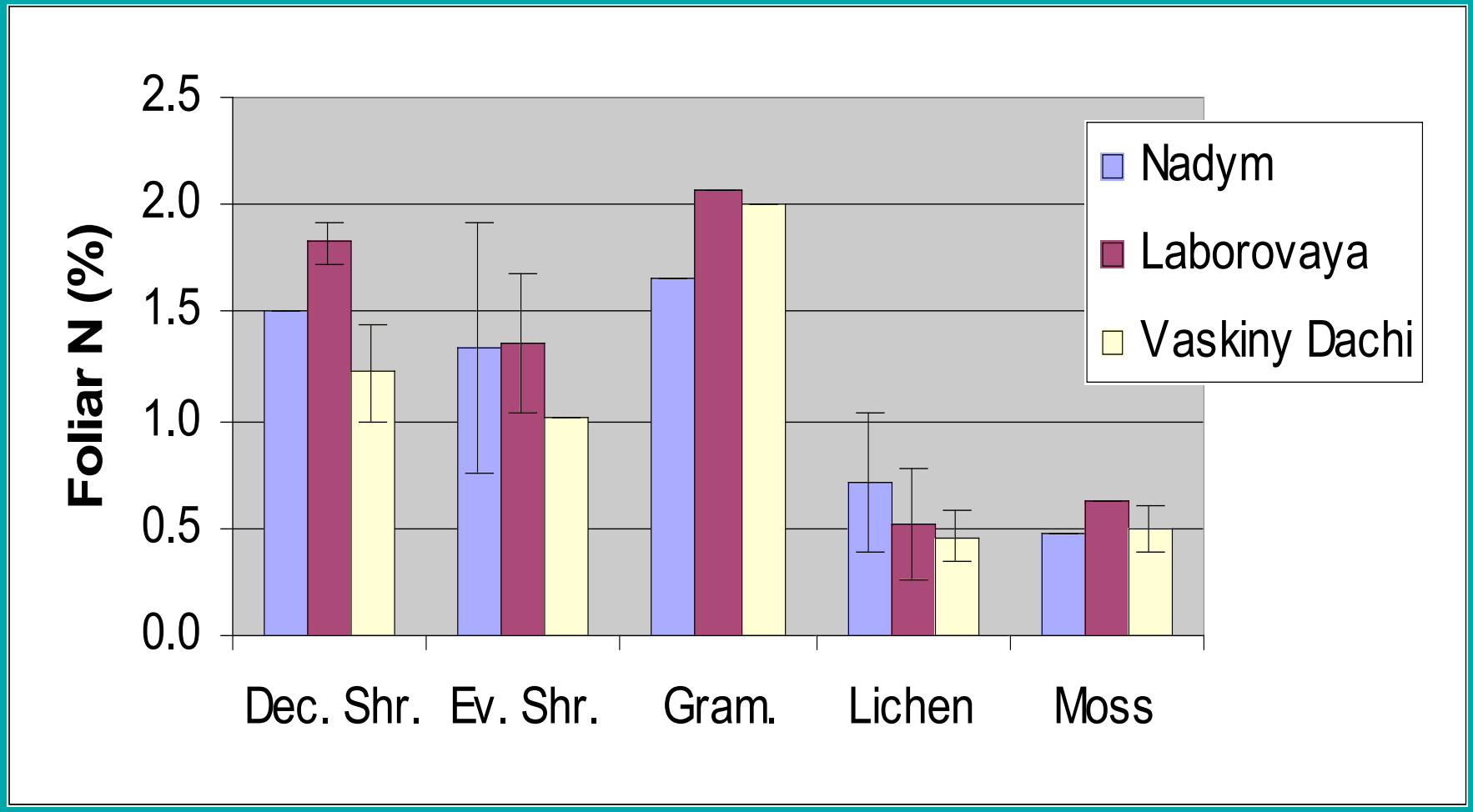
Comparison with North American Arctic Transect Data




NDVI
LAI
y = 0.6406x 0.087
R² = 0.4492
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5


Biomass (g/m_)
LAI
y = 574.48x + 337.93
R² = 0.607
1400
1200
1000
800
600
400
200
0
0.0
0.5
1.0
1.5


Biomass (g m_)
NDVI
Nadym – high lichen
1400
1200
1000
800
600
400
200
0
0.40
0.50
0.60
0.70
0.80


Foliar N (%)
2.5
2.0
1.5
1.0
0.5
0.0
Dec. Shr.
Ev. Shr.
Gram.
Lichen
Moss
Nadym
Laborovaya
Vaskiny Dachi

INTERNATIONAL POLAR YEAR

Simulating Future Changes in Arctic and Subarctic Vegetation

The Arctic is a sensitive system undergoing dramatic changes related to recent warming trends. Vegetation dynamics—increases in the quantity of green vegetation and a northward migration of trees into the arctic tundra—are a component of this change. Although field studies over long time periods can be logistically problematic, simulation modeling provides a means for projecting changes in arctic and subarctic vegetation caused by environmental variations.

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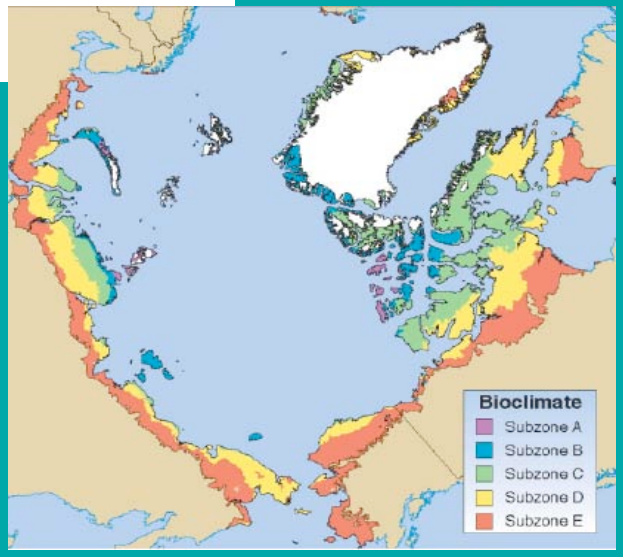


Epstein et al. 2007

ArcVeg – Tundra Plant Community Dynamics Model

- Originally designed for simulation of twenty plant types (combination of key species, genera, functional types); reduced to **eleven plant functional types** for circumpolar analyses

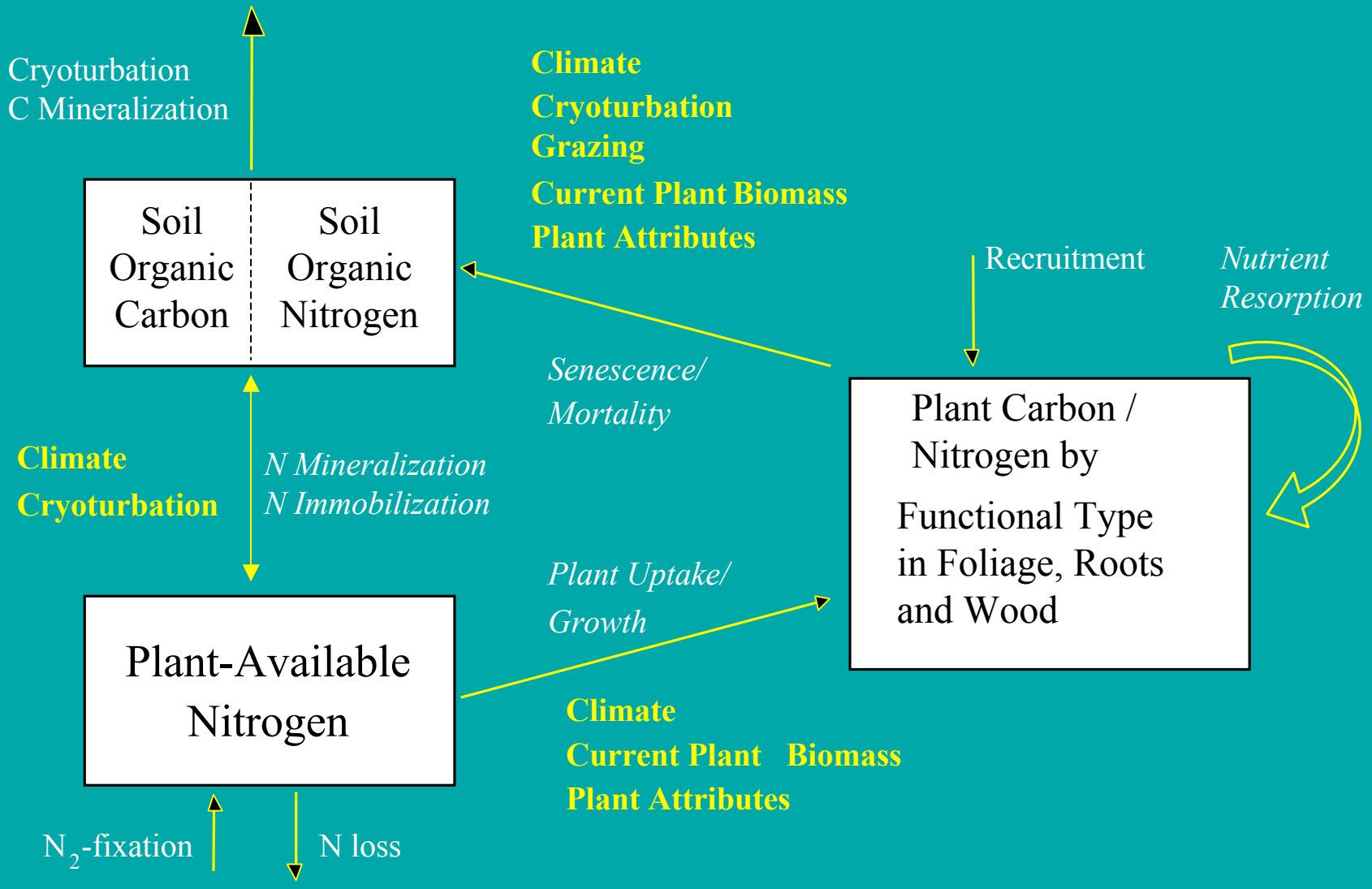
- Computationally based on **nitrogen mass balance**, as N is thought to be the key limiting nutrient in many tundra ecosystems

- **Point model**, although 100 1-m spatial replicates in 10 x 10 m grid

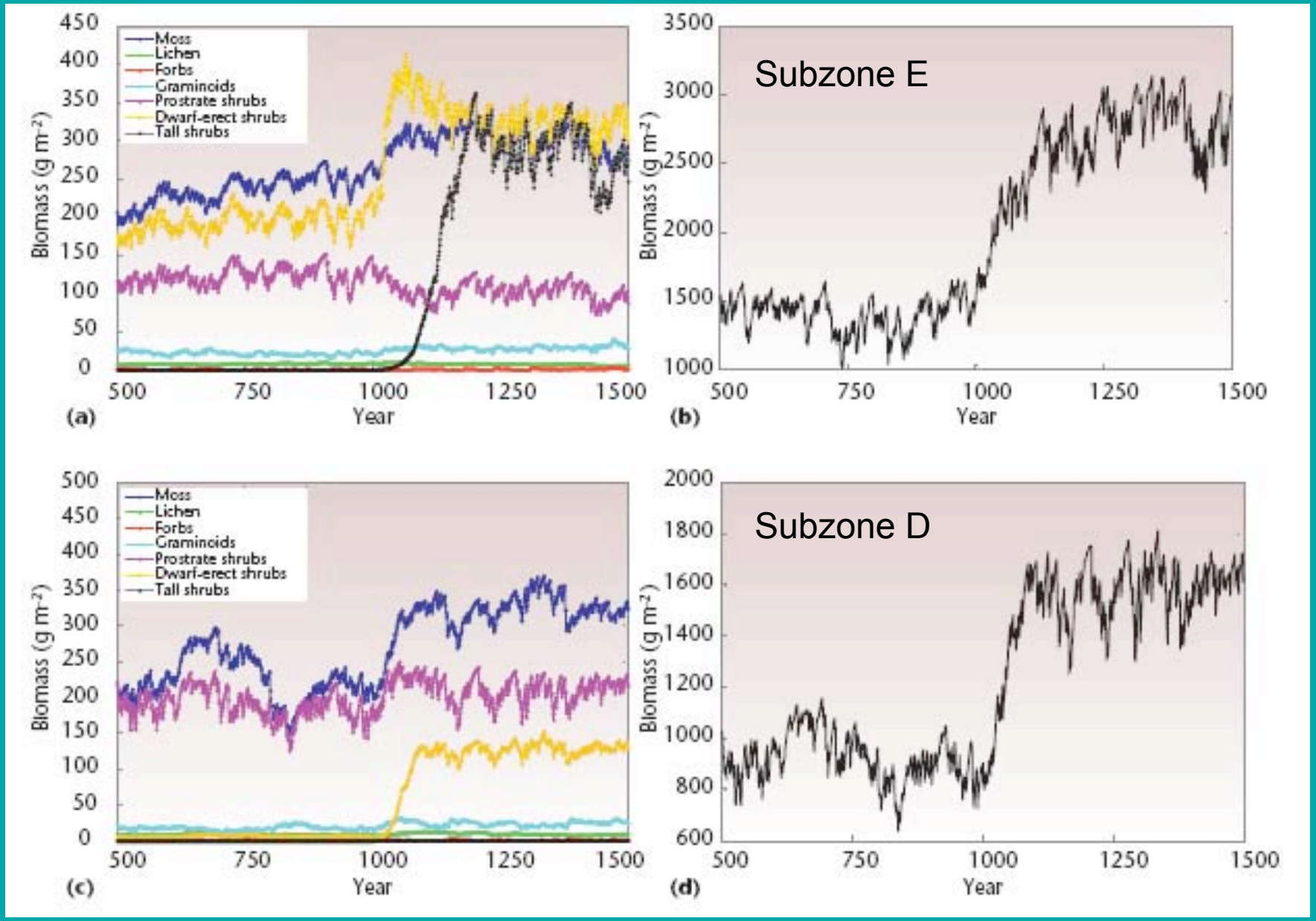
- **No grid cell interactions** with the exception of the patterned ground version (non-sorted "circles")

- Simulates the effects **freeze-thaw disturbances and herbivore grazing**

ArcVeg – Schematic



ArcVeg Examples for Low Arctic of North America



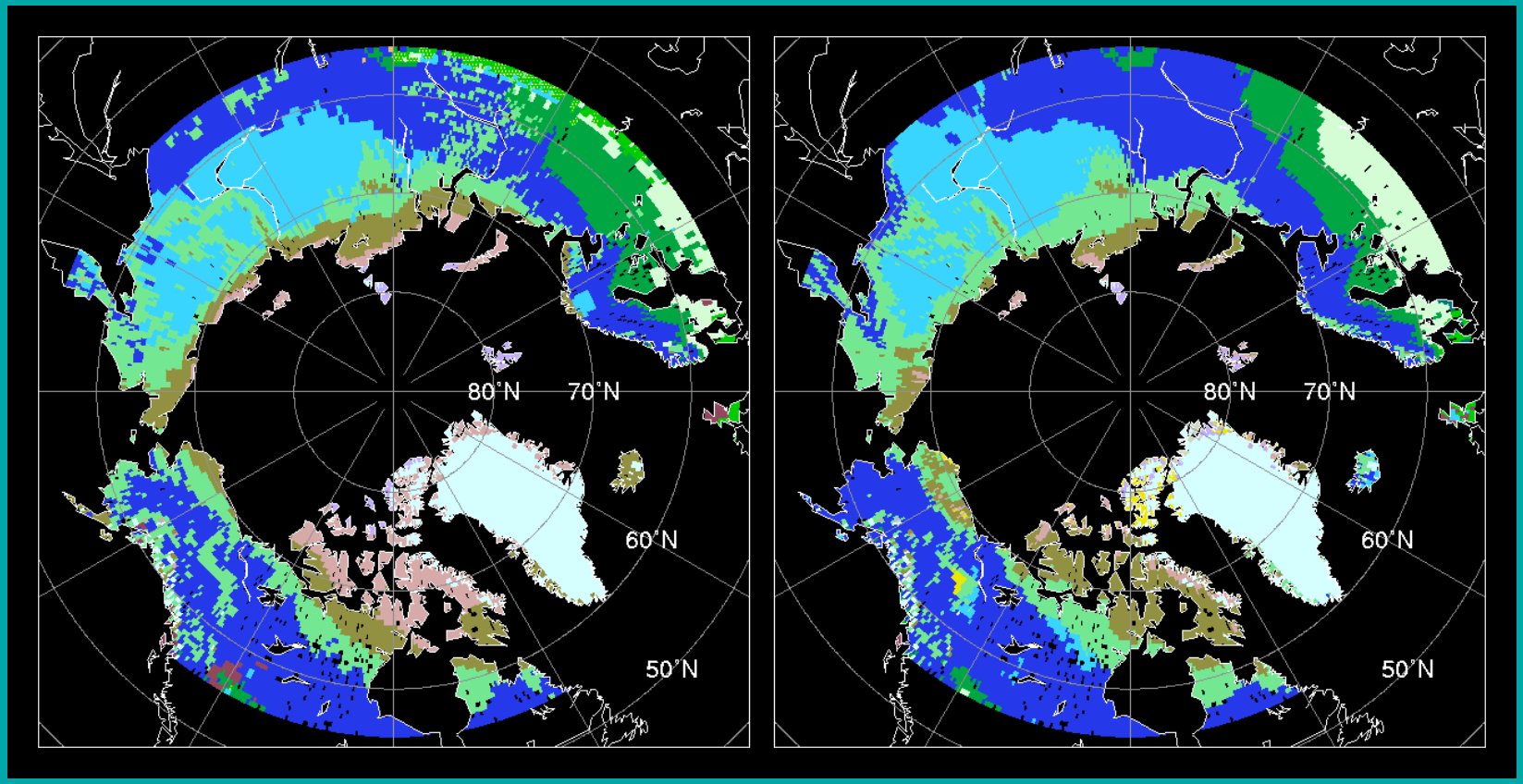
BIOME4 – Vegetation Type Biogeography Model

- Based on the plant functional type concept (rather than species) – **three tundra PFTs** in BIOME4
- **Five tundra biomes**, a cold parkland biome, and two boreal forest biomes are simulated, based on the resultant composition of the various PFTs.
- **Run on a spatial grid (0.5° x 0.5°),** but does not simulate interactions among grid cells
- Contains basic **ecophysiological equations** for photosynthesis, respiration, soil hydrology, and sunlight absorption
- Inputs include **monthly temperatures and precipitation**, solar radiation, soil texture and atmospheric CO2 concentrations

Present Vegetation

observed

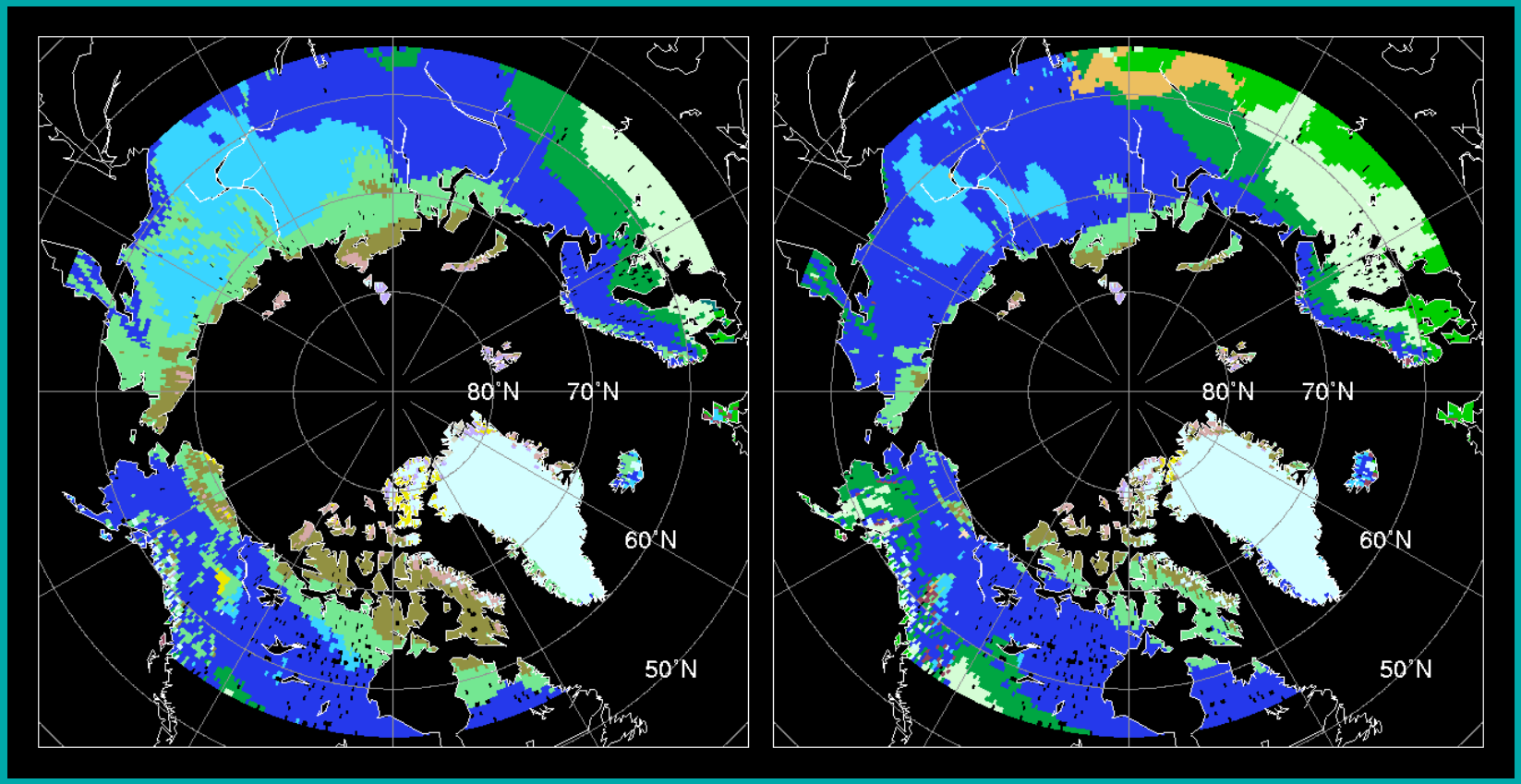
modeled



- Low shrub tundra (50.4%), Erect dwarf-shrub tundra (37.5%),
  Prostrate dwarf-shrub tundra (17.0%), Cushion forb, lichen, moss (42.2%)
- Bias toward simulation of forest over tundra

Future Scenario

present 2100



- Overall reduction of arctic tundra
- Expansion of low shrub tundra at the expense of other tundra vegetation types

TreeMig – treeline migration model

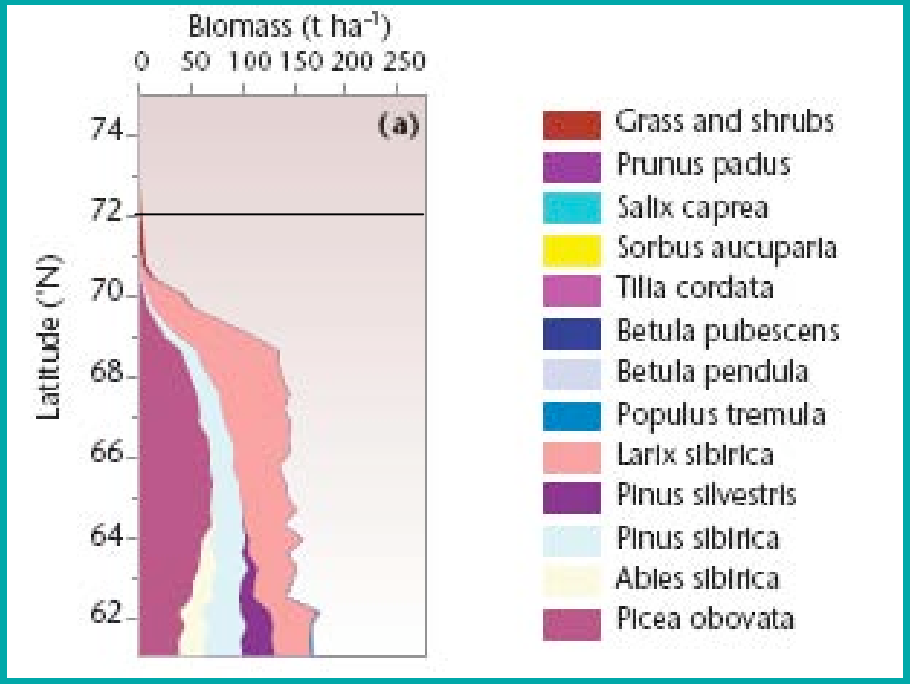
- Dynamic **forest stand model** that simulates forest population dynamics at the species level

- Processes include **seed production, seed dispersal**, seed bank dynamics, germination, growth, competition and mortality

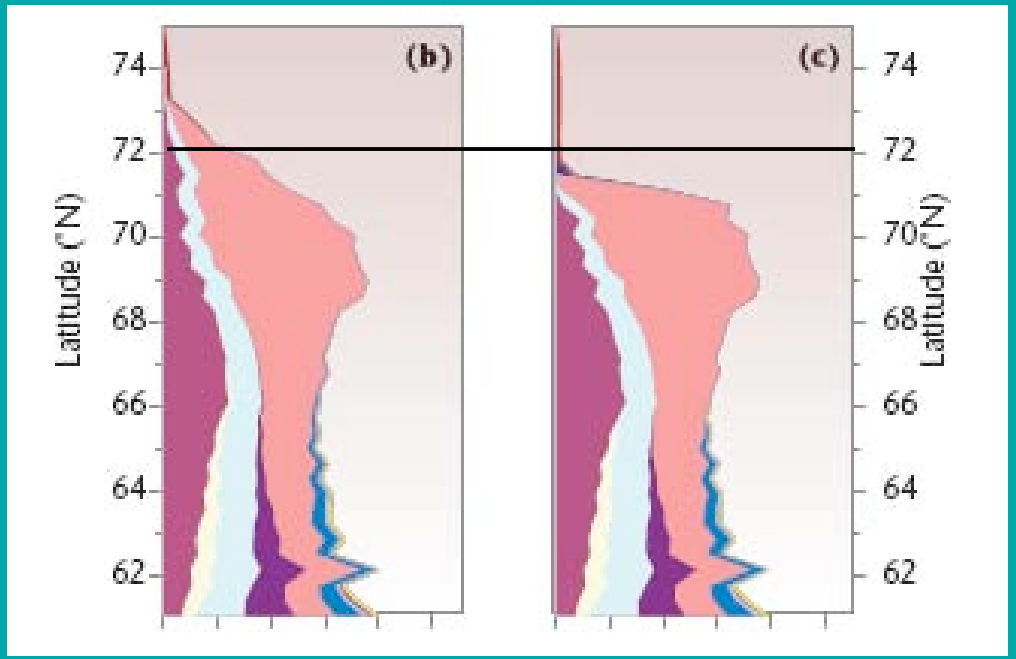
- Driven by **solar radiation and annual climate data**

- **Spatially explicit** movement of species along latitudinal gradient

- Typical **cell size is 1 km^2**



Current situation



Climate warming over 100 years with (c) and without (b) migration constraints

Climate and Land Surface Dynamic Modeling (Cook et al. 2007)

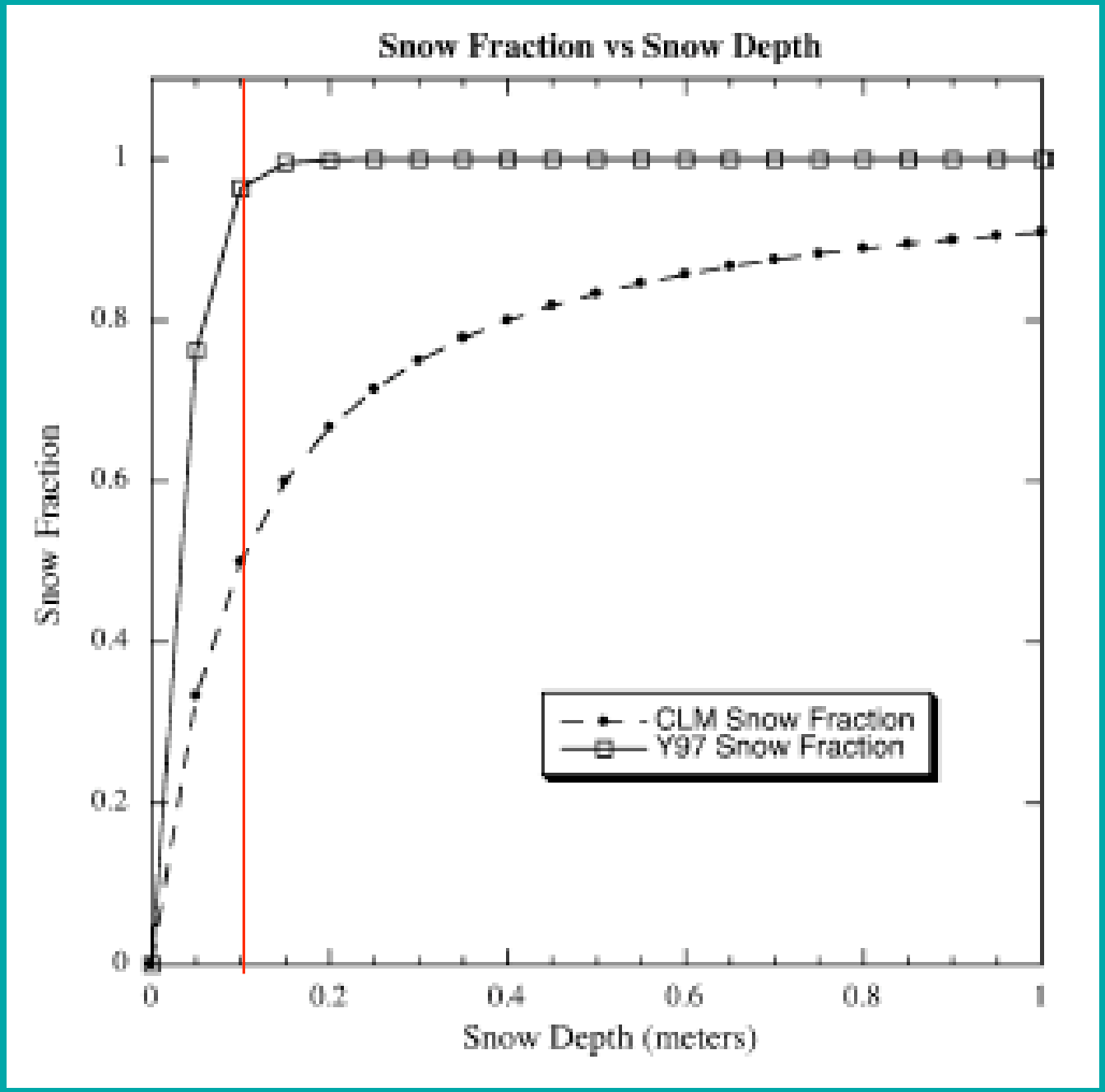
- Uses NCAR's **Community Atmosphere Model version 3 (CAM3),** a general circulation model, and **Community Land Model version 3 (CLM3),** a plant-functional-type vegetation dynamics model based on LPJ-DGVM

- **Grid cell resolution is approximately 2.8° x 2.8°,** with 26 vertical levels and a 20-minute time step

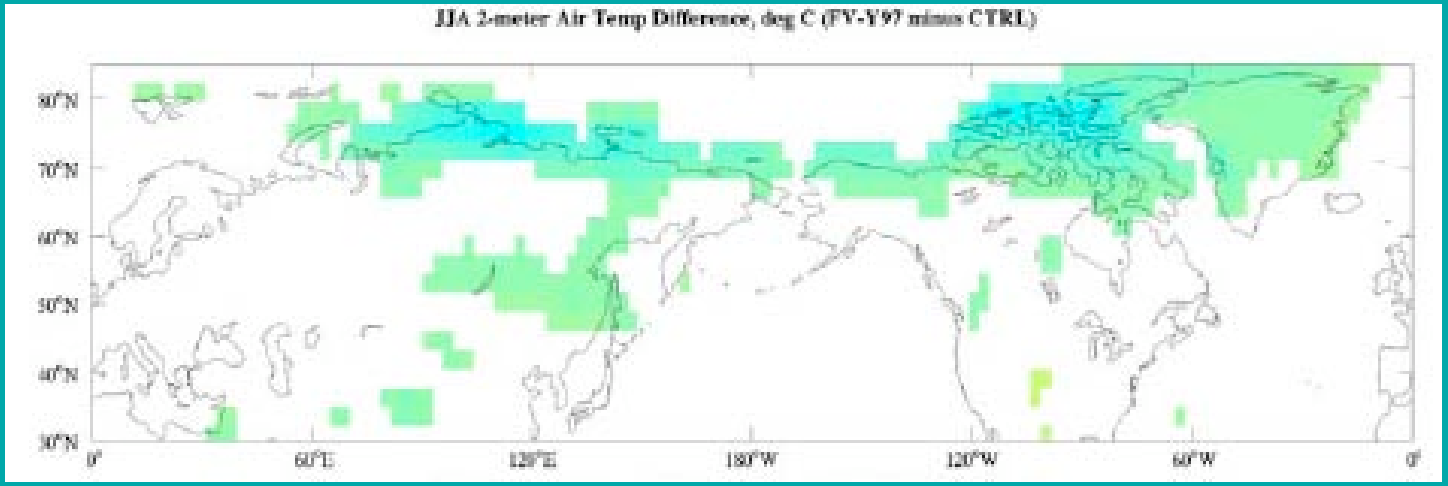
- Simulation of **energy, momentum, moisture, and carbon fluxes** between the land and the atmosphere

- Snow cover has strong albedo effect in model results; simulation of two **different relationships between snow depth and snow cover fraction**

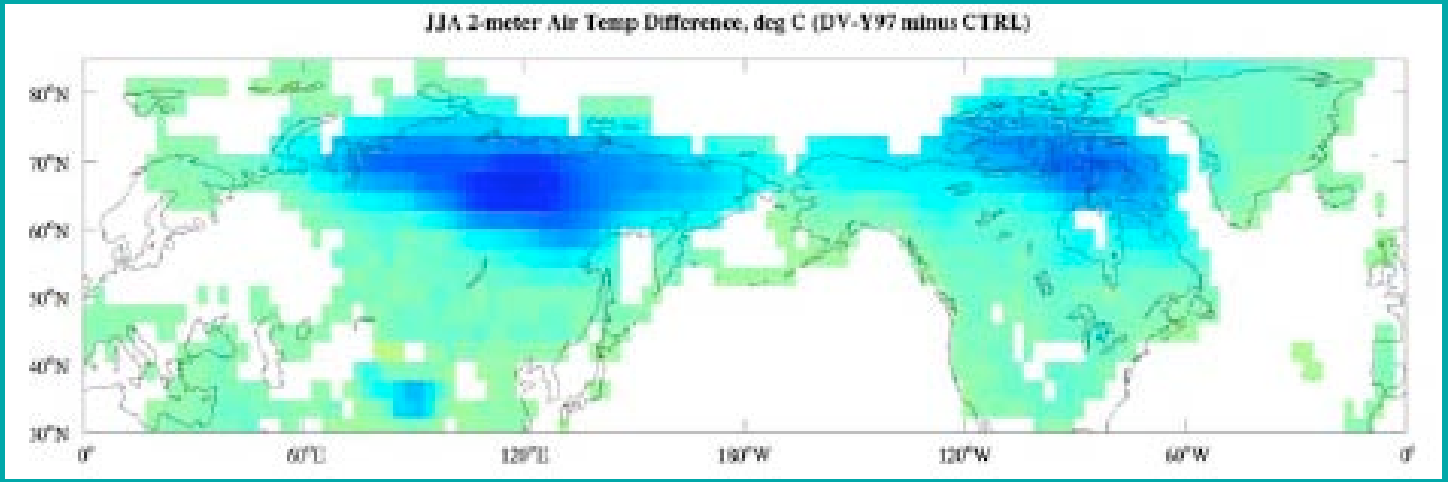
- Simulation with **fixed vegetation and dynamic vegetation**


Snow Fraction vs Snow Depth
Snow Fraction
Snow Depth (meters)
0
0.2
0.4
0.6
0.8
1
CLM Snow Fraction
Y97 Snow Fraction

Static vegetation



Dynamic vegetation



1) New snow cover parameterization increases albedo, which decreases air temperatures
2) Retreat of boreal forest exacerbates the temperature declines

More to come…

1) High Arctic field sites

2) Climate gradient analyses

3) LAI-NDVI-biomass-cover relationships

4) North America – Yamal comparisons

5) More modeling
   - Jed – BIOME4, TreeMig
   - Qin – ArcVeg (grazing, growing season length, nitrogen dynamics)