Satellite and land-based observations of environment, vegetation and NDVI along two Arctic Transects:

Partial results from the IPY Greening of the Arctic Project

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Abstract

Detailed land-based observations of tundra environments, vegetation, and spectral properties are needed across the full Arctic climate gradient to interpret recently detected circumpolar changes in tundra NDVI (Bhatt et al. 2010). The Normalized Difference Vegetation Index (NDVI) is an index of vegetation greenness and photosynthetic capacity (Tucker and Sellers 1986). Here we summarize the climate, soils, vegetation composition and structure, and spatial and temporal patterns of NDVI along the North America Arctic Transect (NAAT) and the Eurasia Arctic Transect (EAT). The transects have similar patterns of summer warmth and vegetation physiognomy, but important differences in precipitation, soil pH, floristic composition and biomass that affect the spatial and temporal patterns of peak NDVI (MaxNDVI), but there is little difference in the relationship between MaxNDVI and biomass along the two transects. The results point to important differences in productivity and NDVI of acidic vs. nonacidic tundra regions and relatively maritime vs. more continental portions of the Arctic that could have important implications for an increasingly maritime Arctic.

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The North America and Eurasia Arctic Transects

Bioclimate subzones

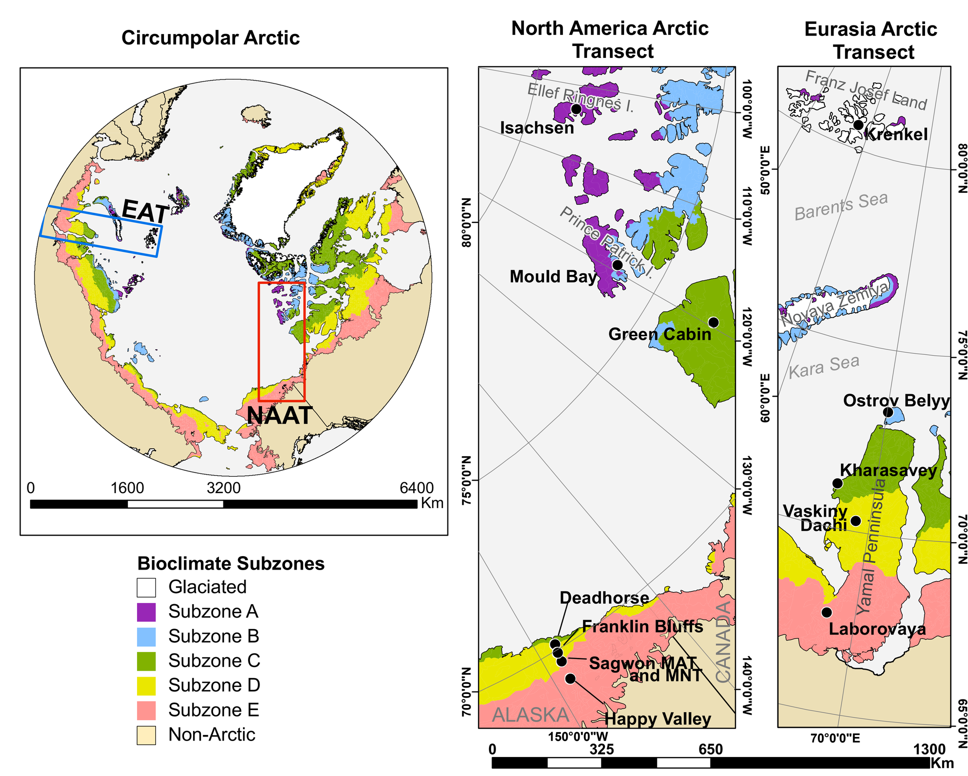


Figure 1. Bioclimate subzones for the circumpolar Arctic, the The North America Arctic Transect (NAAT) (Walker et al. 2008) and the Eurasia Arctic Transect (EAT) (Walker et al. 2011) based on the Circumpolar Arctic Vegetation Map (Walker et al. 2005). The straight-line distance from the northernmost to southernmost locations on the transects is 1750 km for the NAAT and 1500 km for the EAT.

Summer warmth index

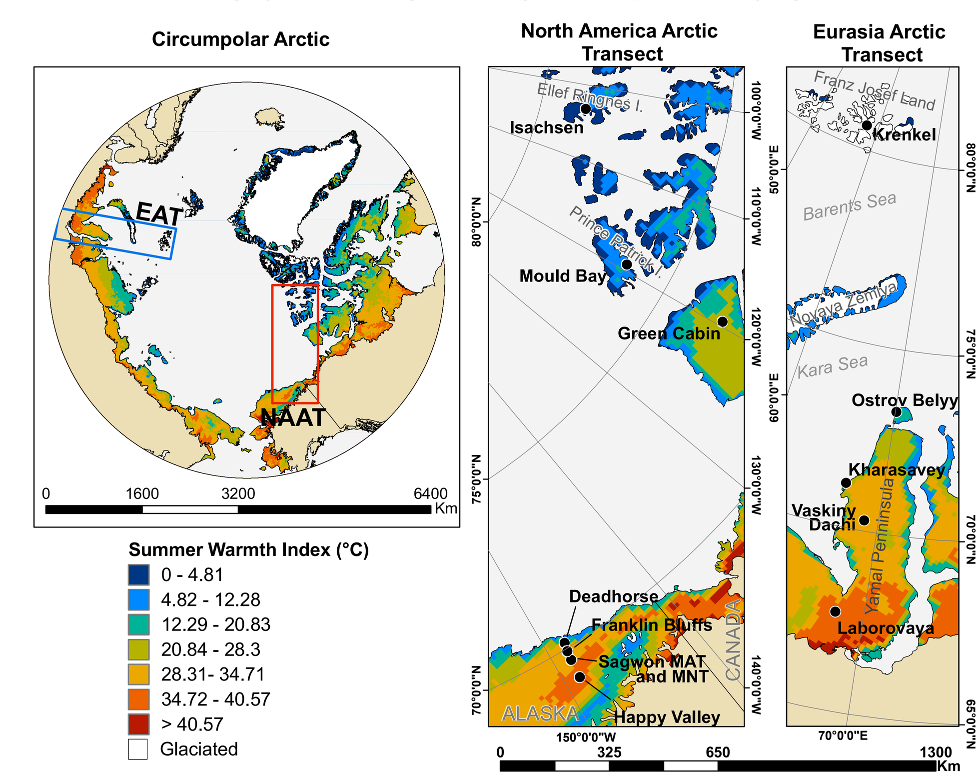


Figure 2. Mean summer warmth index (SWI) is the average (1982-2010) sum of the mean monthly temperatures above 0 ˚C derived from the AVHRR thermal bands (Raynolds et al. 2008).

Maximum NDVI

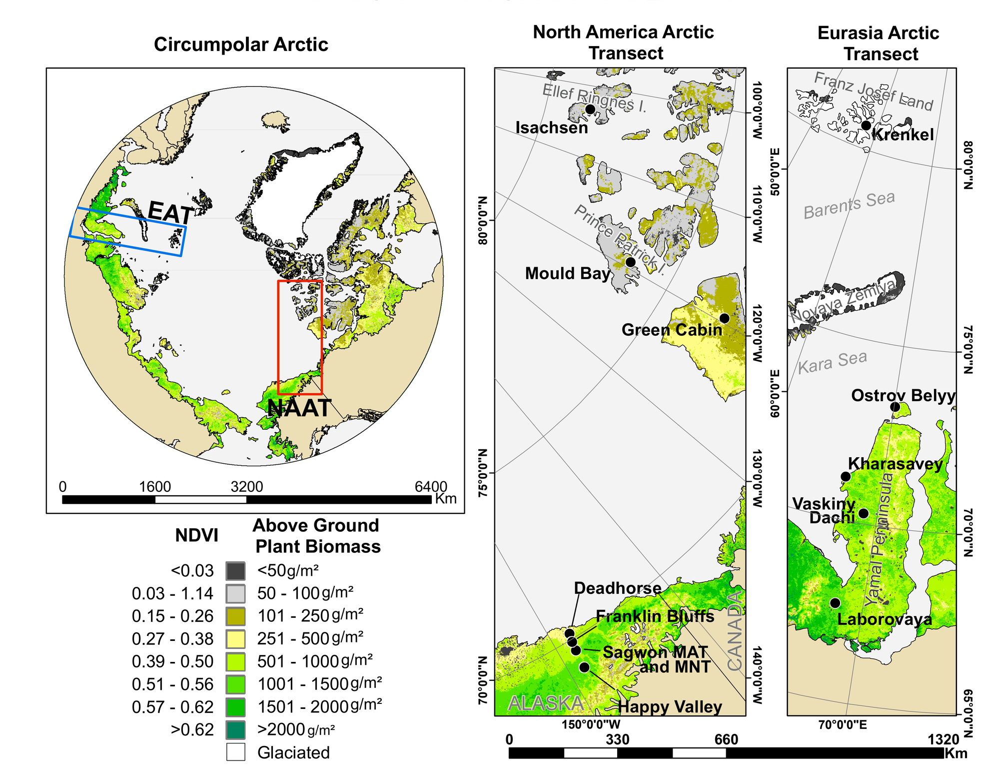


Figure 3. Maximum NDVI/biomass for the circumpolar Arctic, the NAAT and EAT derived from a data set first developed for the Circumpolar Arctic Vegetation Map (Raynolds et al. 2001) with biomass data from the NAAT and EAT transects (Walker et al. 2011 in press).

The two transects have important differences in precipitation, soil pH, floristic composition, vegetation structure, and AVHRR-MaxNDVI.

Physical Environment

- The NAAT and EAT display a similar trend in summer temperatures, but the NAAT has a more continental Arctic climate with considerably less precipitation (mainly in winter) due to the presence of perennial sea ice in much of the Beaufort Sea, whereas the EAT has a more maritime climate, strongly influenced by the North Atlantic current. Summer temperatures are much colder in subzone A of the EAT and subzone B of the NAAT. Winter precipitation is much greater along the EAT.
- The NAAT has more varied geology and soils. Soil pH along the NAAT is circumneutral to basic, while EAT is predominantly acidic. Patterned ground (non-sorted circles) is more abundant along the NAAT.
- The EAT is more homogeneous than the NAAT in the central part of the the gradient because of similar habitats along the length of the Yamal Peninsula.
- Reindeer grazing and extensive land sliding and thermal erosion (not shown, Walker et al. 2011) are important disturbance factors along the EAT.

Bioclimate subzone	Transect: location	Latitude Longitude	Summer Warmth Index (˚C mo)		Precipitation (mm)			Soil texture pH
			Air (SWIa)	Surface (SWIs)	Total	Summer JJA	Winter S-May	
A	NAAT: Isachsen	78.7˚ N 103.6˚ W	3	6.8	114	53	61	Clay 5.8
	EAT: Krenkel	80.6˚ N 57.9˚ E	1	1.9	282	56	211	Sandy loam 6.2
B	NAAT: Mould Bay	76.2˚ N 119.3˚ W	4.6	6.5	104	47	66	Sandy loam 7.8
	EAT: Ostrov Belyy	73.3˚ N 70.1˚ E	11.5	11.5	234	74	154	Loam 4.6
C	NAAT: Green Cabin	73.2˚ N 119.6˚ W	16.6	22.7	156	63	91	Sandy loam 7.7
	EAT: Kharasavey	71.2˚ N 67.0˚ E	15.5	28.7	298	89	192	Silt loam 4.5
D	NAAT: Franklin Bluffs	69.7˚ N 148.7˚ W	24.2	32.7	179	61	86	Loam 7.4
	EAT: Vaskiny Dachi	70.3˚ N 68.90˚ E	na	29.6	277	100	186	Silt loam 4.5
E	NAAT: Happy Valley	69.147˚ N 148.8˚ W	29.5	36.2	198	72	99	Silty clay loam 5.1
	EAT: Laborovaya	67.7˚ N 68.0˚ E	na	36.4	664	224	443	Clay loam 4.6

Table 1. Descriptions of zonal Arctic tundra study sites along the NAAT and EAT. Bioclimate subzones according to CAVM Team (2003). SWI is the sum of monthly mean air temperatures above freezing. Air values (SWIa) are at 2-m height derived from station data (varying lengths of record) and Walker et al. (2008a); surface values (SWIs) are means (1982-2003) at top of the plant canopy in 12.5-km pixels derived from AVHRR satellite data (Raynolds et al. 2008a). Precipitation derived from Global Precipitation Climatology Centre (Beck et al. 2004) (Modified from Walker et al. 2011 in press.) Soils data are from field surveys (Walker et al. 2011 et al, in press.)

Floristic Composition

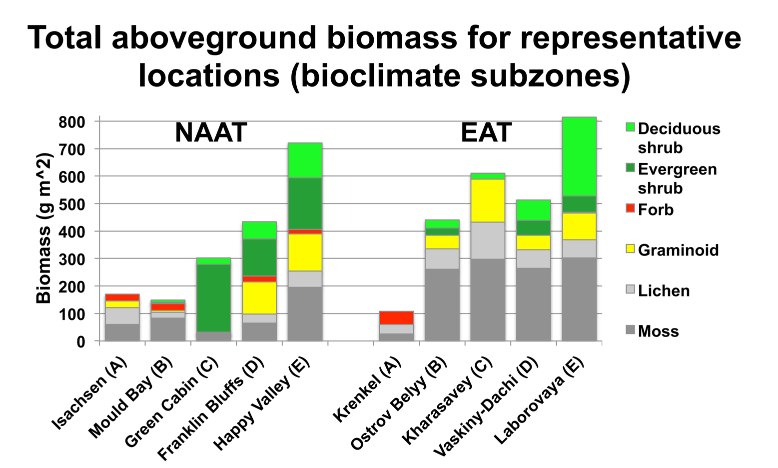
- The NAAT and EAT relevés (study plots) were floristically most similar to each other in subzone E (42% similar, see red cells in Table 2), somewhat similar at the northern end (subzone A, 21%), and least similar in the middle part of the transects (B, 13%; C, 5%; and D, 12%). A contributing factor to the relatively high between-transect similarities in subzones A and E is the high percentage of circumpolar species in both subzones.
- In the middle and southern parts of the transects (subzones B, C, D & E) the NAAT subzones had relatively low floristic similarity to each other (4-18%, see dark gray cells in columns B, C, and D) because of their varied locations on the mainland and scattered islands with different substrates. In contrast, EAT subzones B, C, D, and E (light gray cells in columns B, C, D, and E) all have relatively high similarity to each other (34-52%), which was caused by relatively homogeneous substrates and similar local floras along the length of the Yamal Peninsula.

Sub-zone	Transect	A NAAT	A EAT	B NAAT	B EAT	C NAAT	C EAT	D NAAT	D EAT	E NAAT	E EAT
A	NAAT	49*									
	EAT	21	71*								
B	NAAT	38	27	41*							
	EAT	9	10	13	44*						
C	NAAT	10	13	18	6	25*					
	EAT	13	12	16	40	5	66*				
D	NAAT	8	16	14	10	16	12	41*			
	EAT	10	12	13	38	5	50	12	56*		
E	NAAT	5	7	7	22	4	35	12	38	54*	
	EAT	6	9	10	34	4	46	11	52	42	65*

Table 2. Floristic-similarity matrix. Analysis of 202 relevés (133 from the NAAT and 69 from the EAT) and 556 species. Top value within each column (*) is the within-group similarity (mean similarity of all pairs of relevés within the given transect and subzone). Other values are between-group similarities (mean similarity of all pairs of relevés), with one of the pair coming from the column group and one from the row group. Red colored cells are between-transect similarities within subzones. Dark gray cells are within-transect similarities of subzone relevé-groups of the NAAT, and light gray cells are within-transect similarities of subzone relevé groups of the EAT. All values are significant at p<0.01. (Walker et al. 2011, in press.)

Vegetation Structure

- The NAAT and EAT have similar tundra vegetation physiognomy to each other in most bioclimate subzones, but with important differences in the details (Fig. 4, Top). For example, EAT moss biomass is 1.6-11.5 times greater than NAAT biomass in subzones B, C, D & E.
- The greater moss and total biomass of the EAT at comparable summer temperatures (Fig. 4, Bottom) is attributed to the much higher precipitation along the EAT (Table 1).
- Differences in the soils and grazing regimes also affect the structural differences. For example, the NAAT has greater evergreen-shrub biomass in subzones C, D, & E, which is attributed to the abundance of the prostrate evergreen shrub *Dryas integrifolia*, which is common on the high-pH soils of the NAAT. In subzone E, the acidiophilus evergreen shrub *Ledum decumbens* is less common along the EAT, likely due to its sensitivity to reindeer trampling.



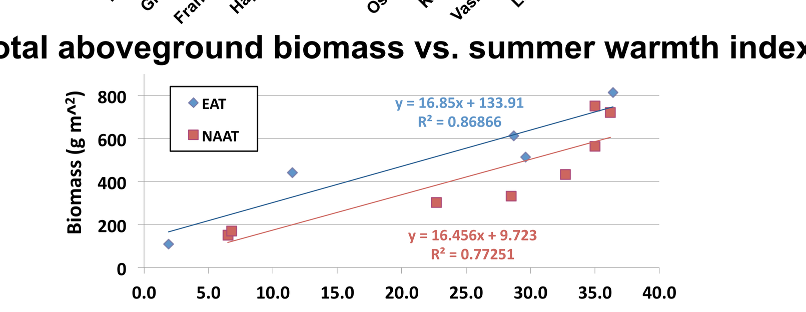
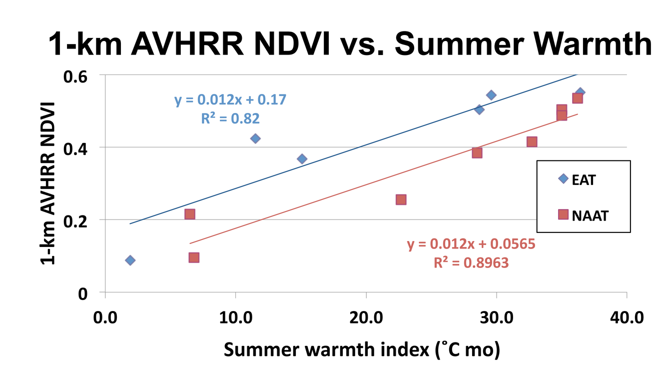


Figure 4. (Top) Total aboveground biomass by plant functional type for the NAAT and the EAT locations. (Bottom) *Total aboveground biomass vs. Summer Warmth Index along the NAAT and the EAT.*

NDVI

- The spatial patterns of MaxNDVI (Fig. 5, Top) follow the same general trend as biomass (Fig. 4 bottom), with generally higher values along the EAT at comparable summer-warmth-index levels.
- The temporal trend of NDVI of the land areas adjacent to the Beaufort Sea near the NAAT has increased 26% whereas in the vicinity of the EAT, the NDVI has declined about 2% (Fig. 5, Bottom). Bhatt et al. (2010 updated) showed that these trends correspond to about a 16% increase in the SWI along the NAAT vs. a 4% decline in the SWI along the EAT.
- The causes of the differences in temperature and NDVI responses along the two transects are not known, but differences in trends of the snow-free period along the two transects may be one factor (Bhatt & Bieneck, unpubl.)



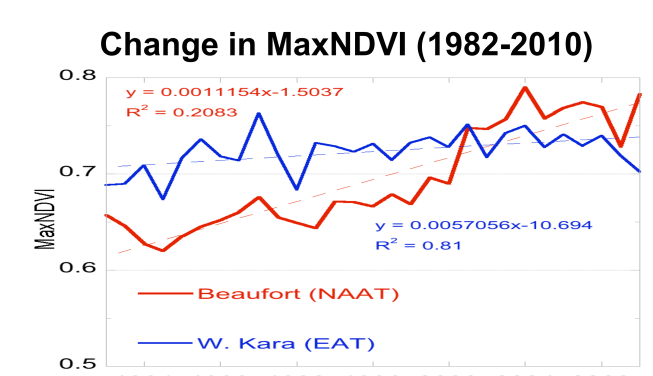


Figure 5. (Top) 1-km AVHRR NDVI vs. SWI along the NAAT and the EAT (Walker et al. 2011, in press).
(Bottom) AVHRR-NDVI trends (1982-2010) for the Beaufort Sea (NAAT) and West Kara Sea (EAT) regions (Bhatt et al. 2010, updated).

Despite the environmental and vegetation differences, the two transects have nearly identical relationships between AVHRR-MaxNDVI & biomass.

- The MaxNDVI has a similar logarithmic relationship to biomass along both transects (Fig. 6), which is useful for mapping patterns of biomass and monitoring changes in tundra biomass — if the relationship holds in other areas of the Arctic.
- Additional data from a third transect or from other under-sampled zonal areas of the Arctic would give us greater confidence in the predictive power of the relationship.

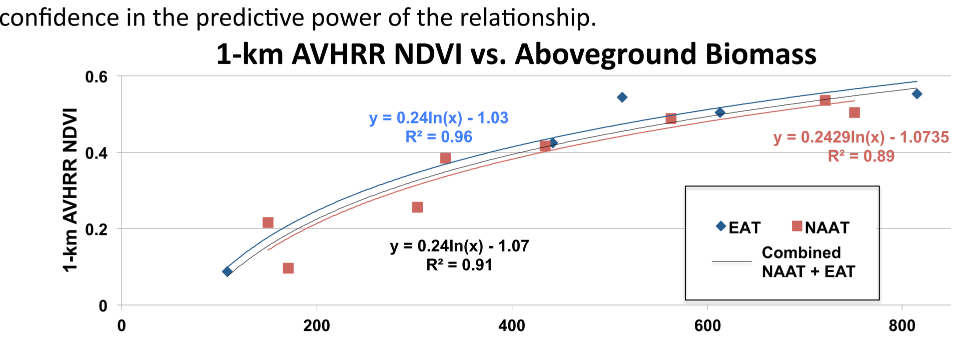


Figure 6. 1-km AVHRR NDVI vs. aboveground biomass along the North America Arctic Transect (NAAT), the Eurasia Arctic Transect (EAT) and the combined data set. (Modified from Raynolds et al. 2012).

Conclusions

- **Although the two transects have broadly similar summer-temperature regimes and overall vegetation physiognomy, there are differences in the soil pH, disturbance regimes, and precipitation (especially winter precipitation) that cause important differences in the relative abundance of the major plant functional types and total aboveground plant biomass.**
- **The transects are floristically and structurally most similar at the ends of the transects (bioclimate subzones A and E), where they share similar soil pH and a large groups of circumpolar plant species. They are most different in the middle subzones (B, C & D), where there are a strong contrasts in soil pH and basiphilous vs. acidophilus floras.**
- **Much of the difference in biomass and NDVI of the two transects appear to be caused by differences in the biomass of the moss layer, which is much greater along the more maritime EAT, and evergreen shrubs, which are more abundant along the NAAT.**
- **During the past 28 years the maximum NDVI of the more continental NAAT region has increased about 17%, whereas that of the more maritime EAT region has declined about 4%. The cause of these differences might be due to differences in precipitation trends associated with more and later open water in the Barents and Kara seas adjacent to the EAT.**
- **The results indicate that there are important differences in productivity and NDVI associated with acidic vs. nonacidic tundra regions and relatively maritime vs. more continental portions of the Arctic. These differences have important implications for terrestrial ecosystem response to a warmer and more maritime Arctic.**

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