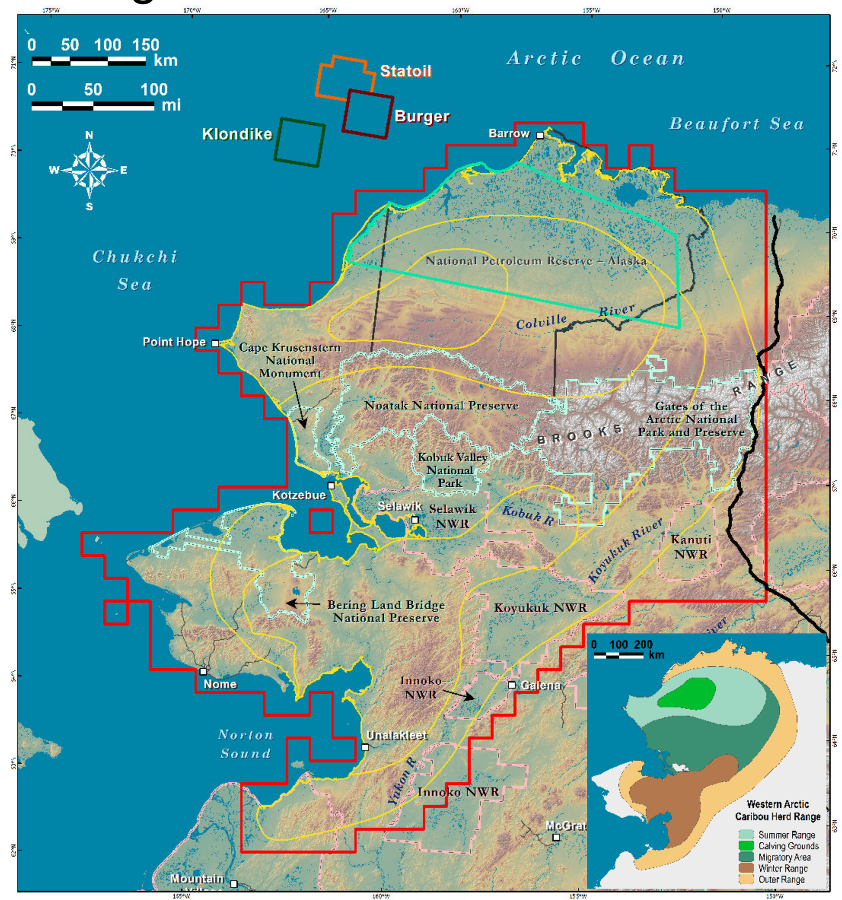
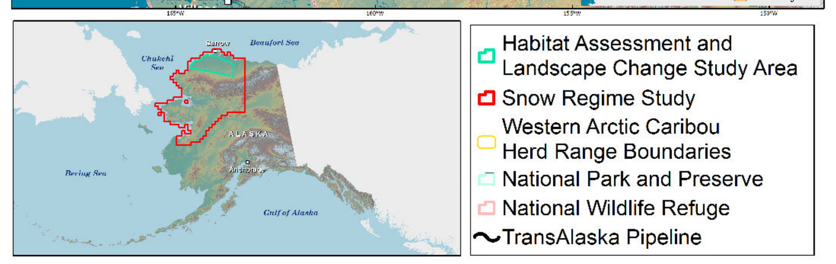
Assessment of Snow Regime Patterns and Vegetation Greenness Trends in Northern Alaska using Landsat Time-Series Data, 1985–2011

Matthew J. Macander[1,2]
Martha K. Raynolds[3,1]
Gerald V. Frost[4,1]
Mark A. Winterstein[3,1]
1. Corresponding author. Box 80410, Fairbanks, Alaska, 99708. (907) 455-6777x112. mmacander@abrinc.com
2. ABR Inc.—Environmental Research & Services. Fairbanks, Alaska, United States.
3. Institute of Arctic Biology, University of Alaska Fairbanks, Fairbanks, Alaska, United States.
4. Environmental Sciences, University of Virginia, Charlottesville, Virginia, United States.

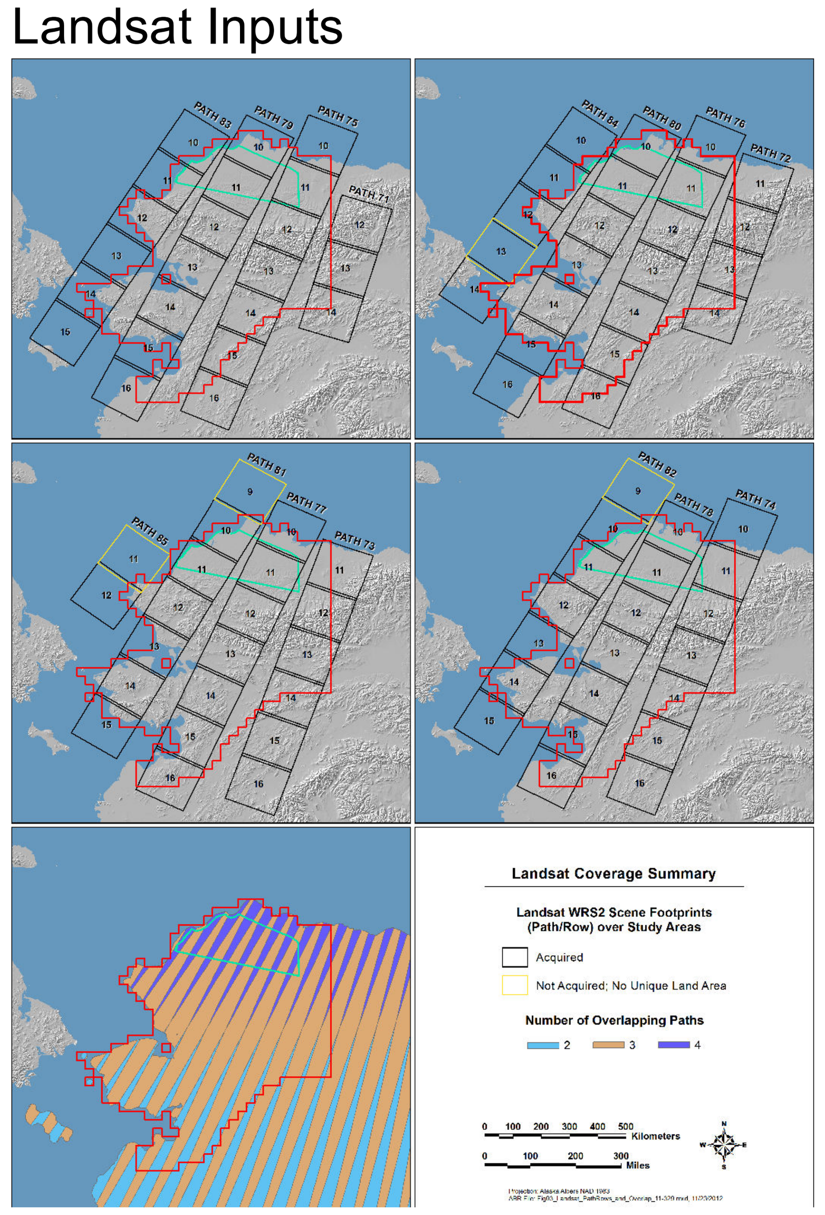
AGU Fall Meeting 2012, Poster ID GC21A-0941

Background





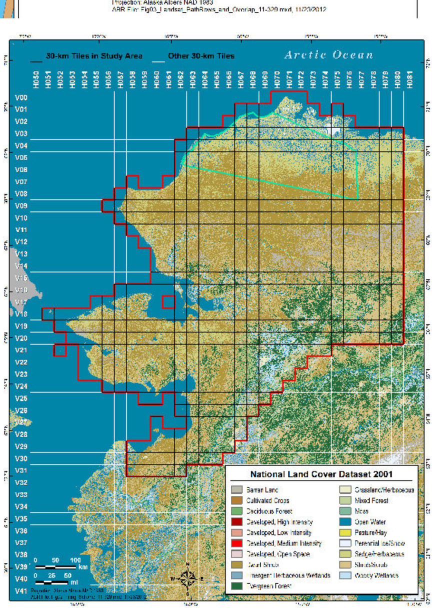
Landsat Inputs



Landsat Stack Pre-Processing

Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS)
- Masek (2006)
- Calibration to Top-of-Atmosphere Reflectance
- Atmospheric Correction (Landscape Change inputs only)
- Preliminary Cloud Mask

Reprojection and Tiling
- Alaska Albers (NAD1983)
- 30km x 30km Tiles (1000x1000 pixels)



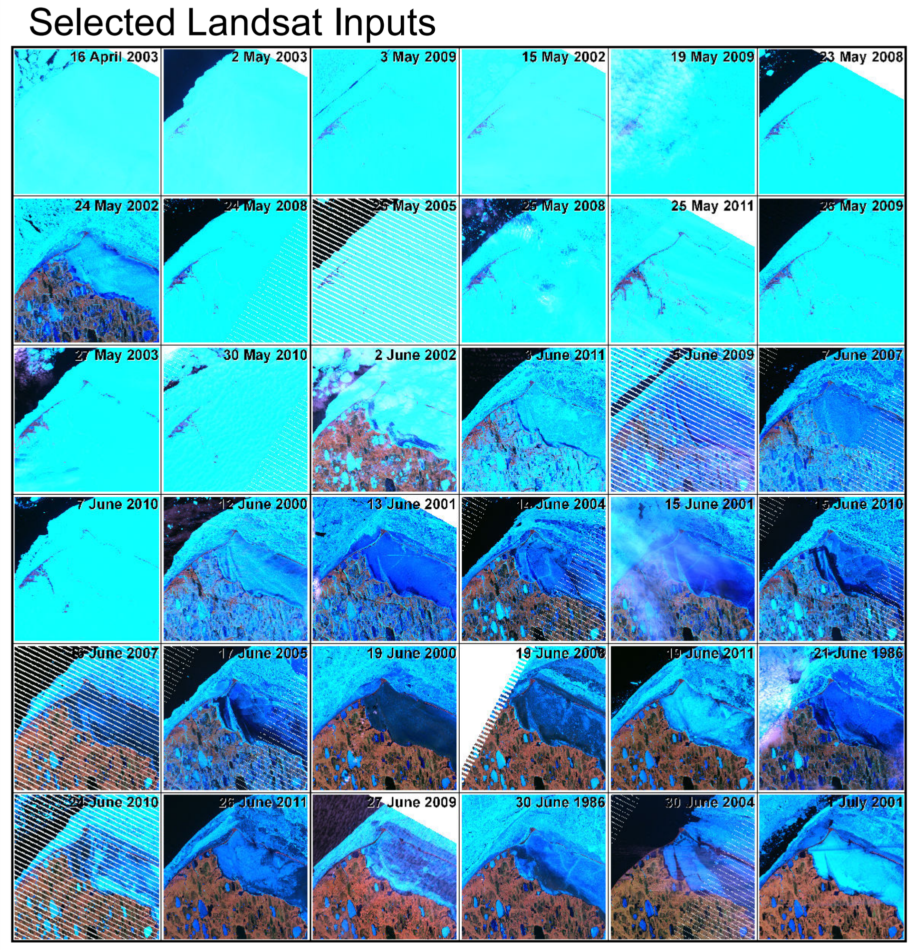
Snow Regime

ABR worked with the National Park Service to produce accurate and detailed models of snow cover within the range of the Western Arctic Caribou Herd, to provide important context to help understand movement patterns and timing of caribou migrations. Snow depth influences caribou winter distribution and habitat availability by impacting the costs of locomotion and cratering for forage plants and lichens. Snow depth patterns on the landscape also influence plant communities, affecting the distribution of preferred forage species. Physical modeling techniques (e.g. Liston and Hiemstra 2011) and remote sensing methods (e.g. Hall et al. 2001, Brodzik et al. 2007) have been used to provide information on snow cover and snow depth data at daily to weekly timescales, and at spatial resolutions of 500–25,000 m. However, much of the variability in snow cover happens at much finer spatial scales, particularly for mountain and tundra snowpacks (Sturm 1995). To help characterize winter and spring habitat conditions related to snow depth for the Western Arctic Caribou Herd, we used a combination of image interpretation and statistical modeling to describe patterns of snow persistence on the landscape at fine spatial resolution (30-m pixels). To accomplish this we compiled and analyzed an extensive time series of over 10,000 Landsat images (1985–2011) that covered the caribou range.

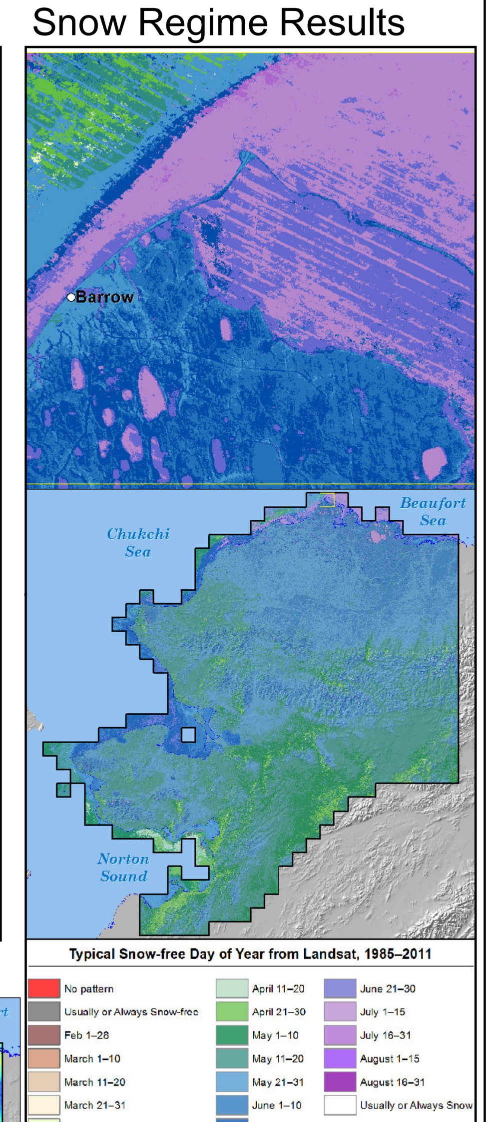
Methods

A terrain shadow map was generated for each Landsat tile based on the solar azimuth and zenith from the scene metadata, combined with a hillshade and illumination model using the ASTER G-DEM2 (a product of METI and NASA). The Snowmap algorithm was applied to the cloud-free pixels for each tile (the dark reflectance tests were skipped for modeled shadow pixels). The snow state and julian date were extracted for every cloud-free pixel in the time-series stack and a binary classification tree selected the julian date that best separated the snow-covered from the snow-free day of year. The results from the Landsat snow-free date algorithm were compared to long-term average snowmelt dates from SNOTEL sites in the study area.

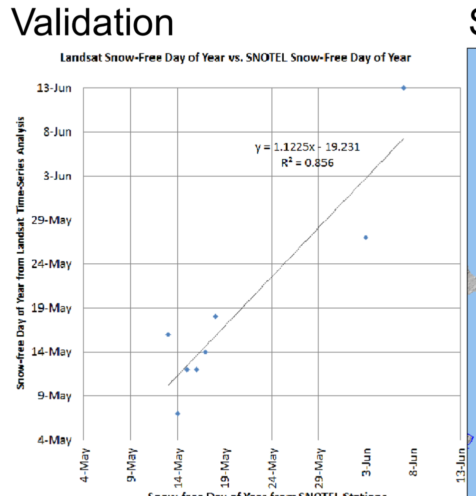
Selected Landsat Inputs



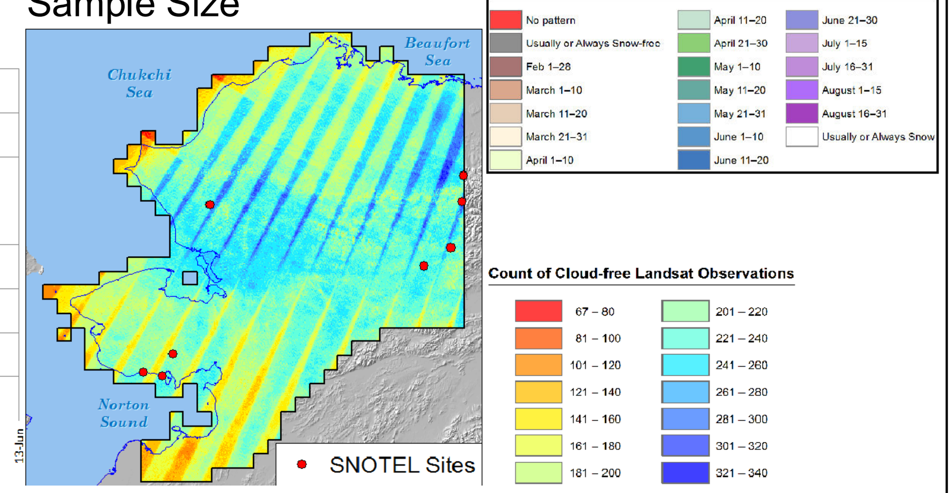
Snow Regime Results



Validation



Sample Size



Landsat TM and ETM+ Acquisitions, Snow Regime Study Area

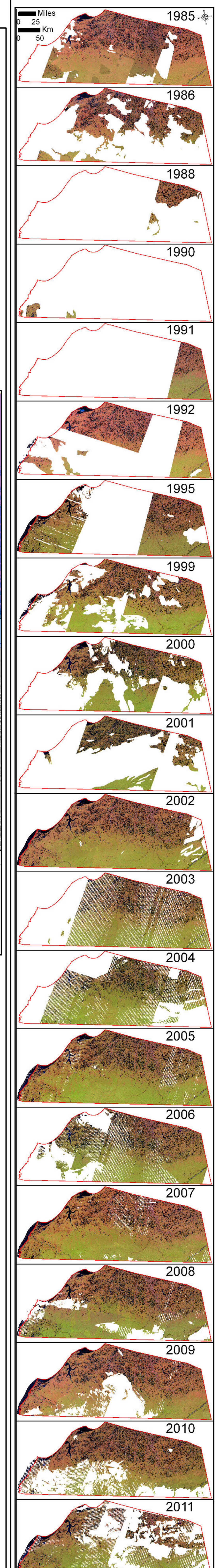
Year	January	February	March	April	May	June	July	August	September	October	November	December	Total
1984									1				1
1985				10	9	22	48	30	32	25	40		216
1986			3		16	69	50	55	35	52	25	2	307
1987							6	4	4		6		20
1988					3	6	9	11					29
1989							7	8		3			18
1990						2	3	6	1				12
1991						8	9	19					36
1992						49	57	32	2				140
1995						1	22	39	58	27			147
1999						14	40	87	81	89	34		345
2000	9	30	78	101	100	121	84	51	63	70	16		723
2001			108	109	108	123	70	70	73	72	39		772
2002	11	66	117	101	119	109	95	89	71	33			811
2003		2	121	98	73		47	69	45	20			475
2004		3	107	116	78	107	71	80	58	21			641
2005		5	70	91	84	157	141	102	91	69			810
2006		8	94	107	121	143	144	127	105	15			864
2007		9	99	74	116	105	131	185	91	30			840
2008		9	71	63	151	163	153	168	123	27			928
2009		1	109	126	175	177	174	145	81	26			1014
2010		3	97	69	121	152	94	125	181	45			887
2011		7	119	124	218	175	113	78	43				877
Total	20	143	1193	1189	1492	1703	1568	1580	1239	624	160	2	10913
% of scenes:2000-2011	100%	100%	100%	99%	98%	90%	84%	82%	83%	69%	34%	0%	88%

Vegetation Greenness Trends and Landscape Change

Shell Exploration and Production Alaska and ABR, Inc. are evaluating environmental issues associated with potential pipeline corridors for transporting oil and gas from offshore prospects in the Chukchi Sea to the Trans-Alaska Pipeline System (TAPS). Broad scale vegetation and habitat assessment work, including categorical habitat type mapping, is being conducted. Wildlife habitats are not static, however, and they change over time in two primary ways that are important to understanding and characterizing wildlife use. The first habitat change dynamic is seasonal changes, which are pronounced during the short growing season. The second important habitat change dynamic is landscape change, which can be punctuated or gradual, occurring over a period of years to decades.

Several studies of coarse-resolution satellite images have observed widespread increases in vegetation greenness since the 1980s (e.g., Myneni et al. 1997). Ground studies and repeat photography have identified shrub expansion as one major mechanism of landscape greening (e.g., Tape 2006), though graminoid expansion could be more important at colder sites (Elmendorf 2012). Gradual and abrupt changes in vegetation affect wildlife use and will continue to affect wildlife habitats in the future.

Landsat Time-Series

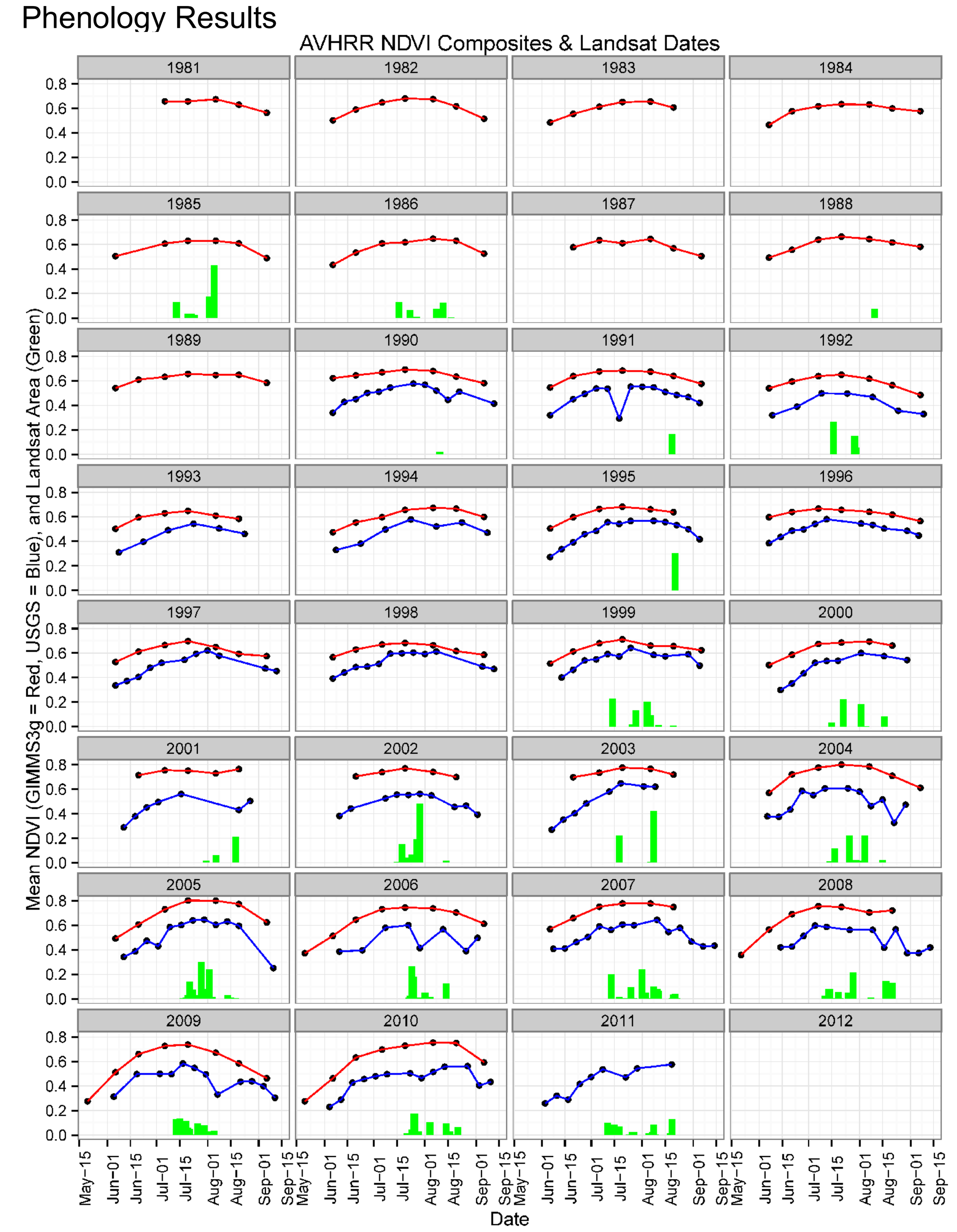


Methods

We are characterizing landscape change at a relatively fine, 30-m resolution using data from both satellite imagery time-series and systematic field sampling of vegetation structure, composition, and spectra. We assessed NDVI trends over the 1985–2011 time period for a 56,984 square kilometer study area including the Arctic Coastal Plain and Brooks Range Foothills. Landsat scenes from peak summer (July 15–August 21) for each available year were calibrated to surface reflectance, cleared of shadows and clouds using a combination of automated algorithms and manual delineation, then composited based on acquisition date, with scenes closest to August 1 preferred. Linear regression was applied to calculate the slope of NDVI change for pixels with a significant ($p \le 0.05$) trend.

Data from two coarse-resolution AVHRR time-series covering the study area were analyzed to assess the phenological timing of the Landsat scenes used for the fine-scale change analysis. In addition, the NDVI trend was assessed using maximum value annual composites of each AVHRR time-series. The new Global Inventory Modeling and Mapping Studies 3rd generation (GIMMS3g) covers 1981–2010 with circumarctic extent at 12.4 km resolution (Pinzon 2007). The USGS has produced a 1-km time-series covering Alaska from 1990–present (http://ivm.cr.usgs.gov/index.php).

Phenology Results



The July 15–August 21 window used for the Landsat composites mostly falls within the period of peak phenology during each year. The occasional mid-summer dips in the USGS AVHRR are most likely caused by cloud contamination.

Conclusions

The Landsat archive is a very valuable asset for characterizing seasonal habitat phenology and landscape changes that affect wildlife habitats. The irregular acquisition schedule in the Alaskan archive present challenges, but utilizing all scenes with useful information and performing preprocessing including calibration, cloud-screenign and tiling allows the time-series products to be used for many different applications.

The snow regime analysis results will be used to characterize winter habitat conditions for caribou and can also be used to characterize subgrid heterogeneity for snow cover in climate models and for monitoring with coarser spatial resolution satellite imagery.

The Landsat time-series landscape change analysis was successful at identifying both abrupt and gradual transitions. Ongoing analysis of the *in situ* vegetation cover and structure data and field spectra, supported by analysis of high-resolution (0.1–2.5 m pixels) photography and satellite imagery will quantify the vegetation changes associated with observed spectral trends. Understanding the spatial distribution and extent, and the mechanisms of landscape change in northern Alaska will aid in sustainable development of resources and infrastructure.

Acknowledgments

The habitat assessment and landscape change analysis are supported by Olgoonik Fairweather and Shell Exploration & Production Company. Weston Howe with Olgoonik and Erling Westlien with Shell provided logistical and scientific support, respectively. Kyle Joly and the National Park Service supported the snow regime analysis. Chris Swingley with ABR provides invaluable scientific programming support for these efforts.

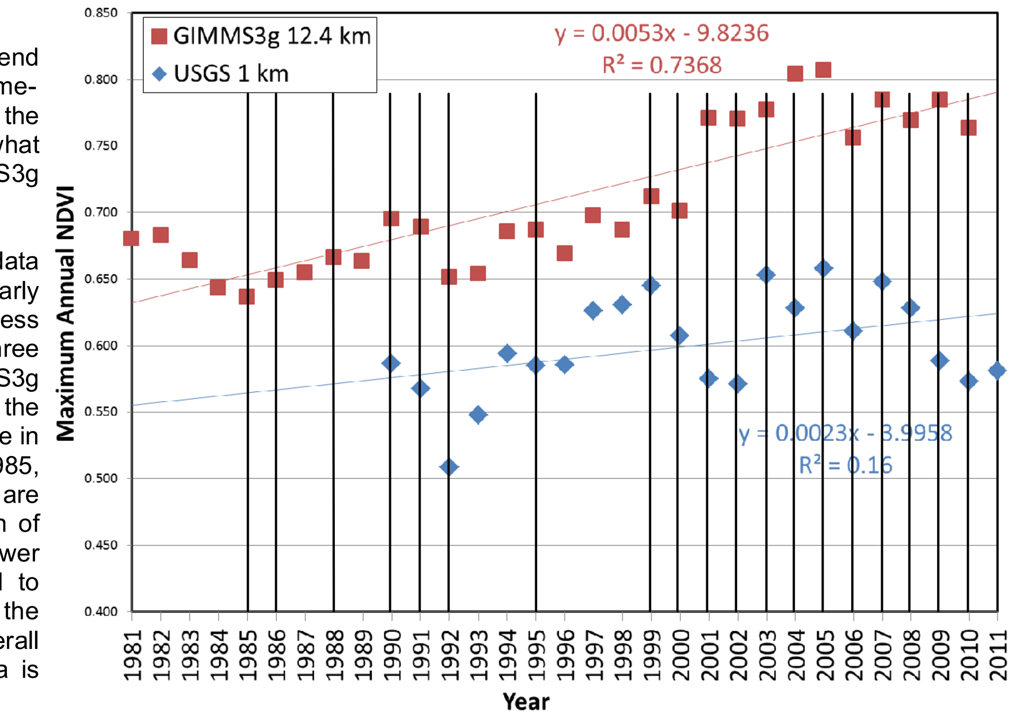
References

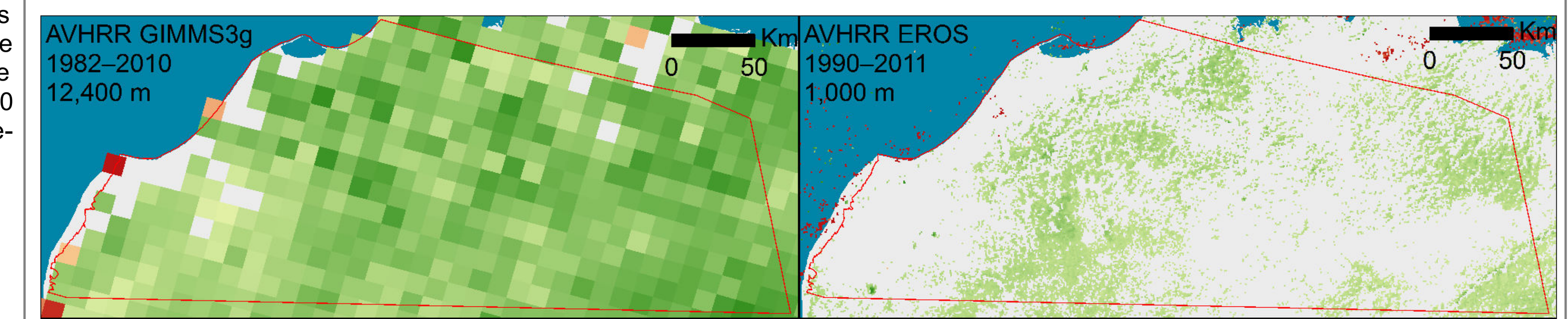
Brodzik, M. J., R. L. Armstrong, and M. Savoie. 2007. Global EASE-Grid 8-day Blended SSM/I and MODIS Snow Cover. Boulder, CO, USA: National Snow and Ice Data Center.
Elmendorf, S., et al. 2012. Global assessment of experimental climate warming on tundra vegetation: heterogeneity over space and time. Ecology Letters, 15, 164–175.
Hall, D.K., G.A. Riggs, and V.V. Salomonson. 2001. Algorithm Theoretical Basis Document (ATBD) for the MODIS Snow and Sea Ice-mapping Algorithms, September 2001. MODIS Snow and Sea Ice Global Mapping Project, Goddard Space Flight Center, Greenbelt, MD. http://modis-snow-ice.gsfc.nasa.gov/atbd.html (January 20, 2006).
Liston, G. E., & Hiemstra, C. A. 2011. The changing cryosphere: Pan-Arctic snow trends (1979-2009). Journal of Climate, 24(21), 5691-5712.
Masek, J. G., E. F. Vermote, N. E. Saleous, R. Wolfe, F. G. Hall, F. Huemmrich, F. Gao, J. Kutler, and T. K. Lim. 2006. A Landsat surface reflectance data set for North America, 1990-2000, IEEE Geoscience and Remote Sensing Letters, 3 (1): 69–72.
Myneni, R.B., Keeling, C.D., Tucker, C.J., Asrar, G., & Nemani, R.R. (1997). Increased plant growth in the northern high latitudes from 1981 to 1991. Nature, 386, 698-702.
Pinzon, J.E., Brown, M.E., & Tucker, C.J. (2007). Global Inventory Modeling and Mapping Studies (GIMMS) satellite drift corrected and NOAA-16 incorporated Normalized Difference Vegetation Index (NDVI), monthly 1981–2006.
Sturm, M., J. Holmgren, and G. E. Liston. 1995. "A Seasonal Snow Cover Classification for Local to Global Applications." Journal of Climate. Vol. 8. Pp. 1,261–1,283.
Tape, K., Sturm, M., & Racine, C.H. 2006. The evidence for shrub expansion in Northern Alaska and the Pan-Arctic. Global Change Biology, 12, 686-702.

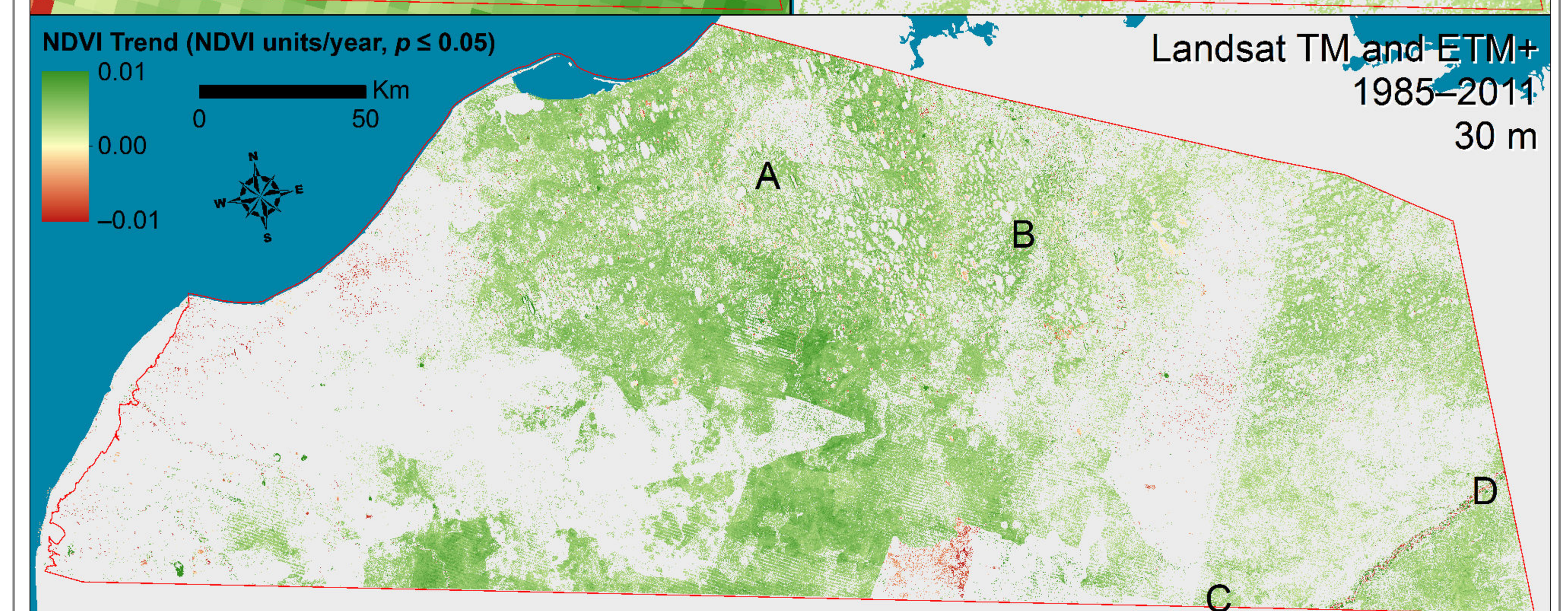
Trend Analysis Results

For the full study area, there is a greening trend in both the GIMMS3g and USGS AVHRR time-series with a much stronger trend in the GIMMS3g. Much of this may be due to what appears to be an artifical increase in GIMMS3g NDVI for 2001–present.

The longer time period of the GIMMS3g data does allow an assessment of how the early Landsat data fit into the long-term greenness trend. 1985 and 1986 represent two of the three lowest annual NDVI values in the GIMMS3g time-series. 1992 has the lowest value in the USGS time-series and the fourth lowest value in the longer GIMMS3g time-series. Since 1985, 1986 and 1992 happen to be the years that are major contributors to the 1985–1992 portion of the Landsat time-series, their somewhat lower than average greenness values compared to other years in the long-term time-series may affect the long-term Landsat trend results, but the overall increase in NDVI values for the study area is well supported.







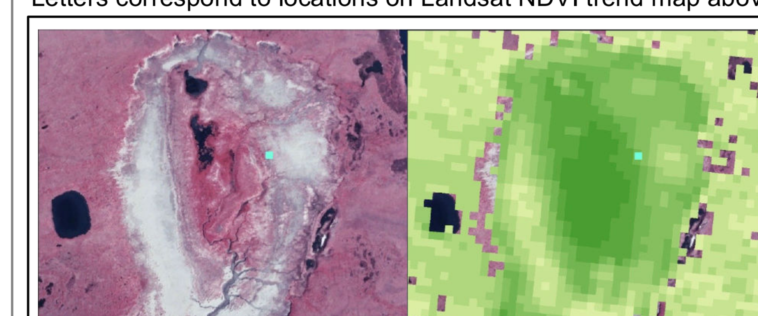
Linear regression using the Landsat time-series identified widespread significant spectral change: 19,516 square kilometers, or 31.4% of the study area, experienced a significant increase in NDVI ($p<0.05$). 677 square kilometers (1.2% of the study area) experienced a significant decrease in NDVI. Widespread decreases were seen only in areas that did not have Landsat imagery in the 1980s or early 1990s. Smaller areas with decreasing NDVI were sites of erosion or other disturbance.

NDVI increases covered virtually the entire study area based on the GIMMS3g data. The patterns of increase between the USGS AVHRR NDVI and Landsat NDVI were very similar.

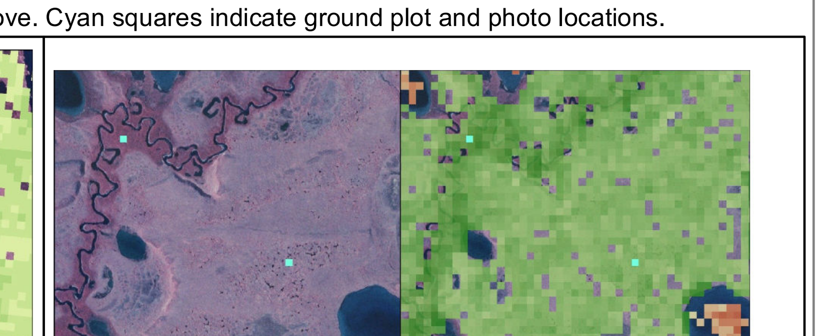
The finer spatial resolution of the Landsat analysis allowed us to target vegetation sampling in individual patches of vegetation experiencing greening and improves our ability to explain mechanisms of landscape change. Line point intercept sampling of vegetation cover and structure over 110-m diameter plots was conducted during summer 2012. Visible and near-infrared field spectra

Mechanisms of Landscape Change

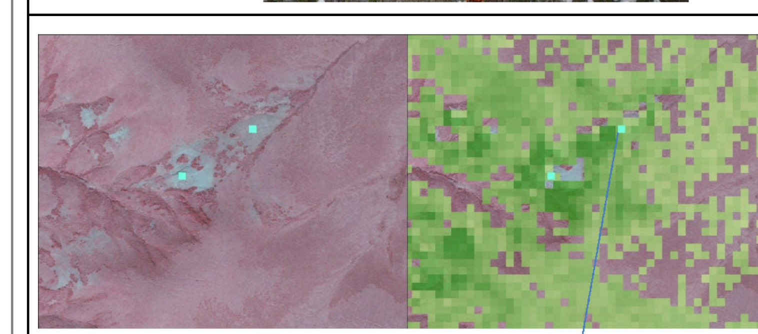
Letters correspond to locations on Landsat NDVI trend map above. Cyan squares indicate ground plot and photo locations.



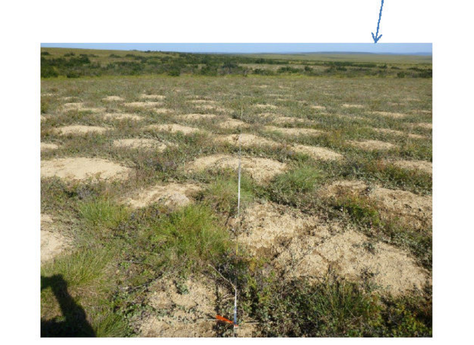
(A) Successional processes in drained lake basins.

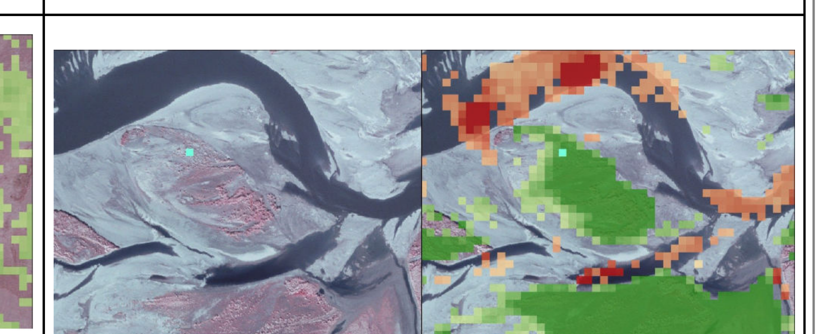


(B) Vegetation greening along shrubby drainage and on degrading ice-wedges.



(C) Vegetation establishment in strongly cryoturbated, patterned-ground areas (circles and stripes).





(D) Successional processes on floodplains.