# Application of space-based technologies and models to address land-cover/land-use change problems on the Yamal Peninsula, Russia

**Research Topic: Impacts** **Proposed start and end dates: 6/1/06-5/31/09**

**Short title: Yamal Land-Cover Change** **Internat'nl and U.S. Govt. Agency participation: Yes**

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## Summary of Proposal:

*The overarching goal of our proposed research is to use remote-sensing technologies to examine how the terrain and anthropogenic factors of reindeer herding and resource development, combined with the climate variations on the Yamal Peninsula, affect the spatial and temporal patterns of vegetation change and how those changes are in turn affecting traditional herding by indigenous people of the region.* The Yamal Peninsula in northern Russia has been identified as a "hot spot" for both Arctic climate change and land-use change. The Yamal has undergone extensive anthropogenic disturbance and transformation of vegetation cover over the past 20 years due to gas and oil development and overgrazing by the Nenets reindeer herds. We propose to establish a transect of eight sites across the Yamal to investigate the combined effects of climate change and anthropogenic influences. We will investigate how vegetation changes in this heavily impacted region on poor sandy soils compares with other areas in the Arctic, especially a similar transect on loess soils with less grazing impact in North America. We will use a combination of ground-based studies, remote-sensing studies, and studies of Nenets land-use activities to help develop vegetation-change models that can be used to predict future states of the tundra. This research is in response to the Northern Eurasia Earth Science Partnership Initiative (NEESPI). It principally addresses the NEESPI science questions regarding the local and hemispheric effects of anthropogenic changes to land use and climate. Furthermore, it will use and contribute to NASA's global-change observations, particularly work exploring the consequences of the dramatic decline in the Arctic sea ice and the greening of terrestrial vegetation that is occurring in the northern latitudes. The project will combine the long-term record available through AVHRR and MODIS sensors with the most recent sensors that provide very detailed spatial and spectral information regarding land-cover/land-use change in the Arctic. The project is also the intersection of three International Polar Year (IPY) initiatives: (1) "Greening of the Arctic" (GOA), (2) "Cold Land Processes in NEESPI" (CLPN) and (3) "CircumArctic Rangifer Monitoring and Assessment" (CARMA).

## BUDGET SUMMARY

**Justification for budget items:**

***Direct labor:*** The role and commitment of each of the project team members is summarized in the section: "Summary of Personnel and Work Efforts".

***Other direct costs:***

***Subcontracts:*** Descriptions of the subcontracts are contained in the "Summary of Personnel and Work Efforts" and summarized as follows:

**NASA-Goddard ($40K):** Provide the sea-ice and land-surface temperature data. Joey Comiso will improve the LST data for the Yamal region by calibrating the satellite information to the available met-station data, and work closely with the team of Bhatt, Jia, and Comiso to examine the dynamics of terrestrial NDVI in relationship to LST and sea-ice distribution patterns.

**Bern University, Switzerland ($20K):** Provide model output from the BIOME4 model to examine vegetation-change scenarios on the Yamal Peninsula using improved parameter data from the project. Jed Kaplan, developer of the BIOME4 model, will work closely with the team on adapting BIOME4 to the Yamal vegetation-change scenarios, but will not receive salary from the project.

**University of Virginia ($60K):** Provide one mo/yr salary support for Howie Epstien and partial support for a Ph.D. graduate student who will work on adapting the ArcVeg model to the Yamal transect.

**Arctic Centre, Rovaniemi ($60K):** Coordinate the field aspects of the study of the Nenets reindeer herding practices and provide logistic support for a graduate student to accompany the Nenets people during their annual migrations and to erect exclosures to study the effects of reindeer on the forage of the region. Bruce Forbes will work closely with the team to integrate the human dimensions aspect of the project based on his extensive field experience on the Yamal Peninsula, but will receive no salary from the project.

**Earth Cryosphere Institute, Moscow ($100K):** Coordinate the field logistics and provide data collection and distribution services for the field work at the 7 sites along the Yamal transect. The subcontract will cover the helicopter logistics, costs of establishing the field camps, and collecting the climate, soil, and vegetation information at each of the sites. The contract will also cover the costs of updating the GIS coverages of the region and providing these data to the project.

***Equipment:*** We request $24K for 4 climate stations at four of the sites along the Yamal transect. (Three of the sites already have adequate climate measurements. The $6K per station cost is based on the price of identical stations that have been built at sites along the North American Arctic Transect.

***Supplies:*** We request $3K/yr in years 2 and 3 to cover incidental field costs incurred during the field work on the Yamal Peninsula.

***Travel:***

An organizing meeting held in year 1 at a site on the East Coast to finalize the field plans on the Yamal Peninsula. We are requesting funds for 15 investigators and graduate students to attend the meeting @ $2K per person for travel and per diem. Total $30K

Field work on the Yamal Peninsula and project workshop in Moscow in years 2 and 3. We are requesting funds for 10 people to travel to Moscow and Nadym @ $3K per person for travel and per diem. Total $60K

***Other:*** We request: (1) $2K/yr in years 2 and 3 to cover publication page charges. (2) $2K/yr for computer support in the Alaska Geobotany Center. These costs are for technical support, repair and maintenance of the computers, and annual software fees that are not covered by the University. (3) $2K/yr for communication, copies, and preparation of reports associated with management of the project.

***Facilities and administrative costs:*** Overhead is set at 25% of total modified direct costs as specified by NASA. (**Leah: please provide the correct legal verbage here).**

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## SUMMARY OF PERSONNEL AND WORK EFFORT

**Donald. A. (Skip) Walker (UAF)** will serve as project PI and coordinate the ground based studies of vegetation biomass. He is on a 9 mo university appointment and is requesting 1 mo/yr salary support in years 2 and 3 of the project.

**Uma Bhatt (UAF)** will perform the climate modeling aspects of the project, linking climate dynamics to sea-ice distribution, land-surface temperatures, and terrestrial NDVI. She is on a 6 mo university appointment and is requesting 1 mo/yr salary support in years 2 and 3 of the project.

**Gary Kofinas (UAF)** will coordinate the human dimensions aspects of the project in the study of Nenets reindeer-herding patterns. He is on a 9 mo university appointment and is requesting 1 mo/yr salary support in years 2 and 3 of the project.

**Vladimir Romanovsky (UAF)** will be responsible for establishing the climate stations at each field site and coordinating the climate/permafrost dynamics portion of the study. He is on a 9 mo university appointment and is requesting 1 mo/yr salary support in years 2 and 3 of the project.

**Gensuo Jia (UAF)** will be responsible for the analysis of the terrestrial NDVI data and coordination of the other remote-sensing aspects of the project. He is currently at Colorado State University and will be a Visiting Fellow on a 6 mo/yr appointment to UAF in years 2 and 3 of the project.

**Howie Espstein (U Va)** will coordinate the vegetation modeling aspects of the project. He will work under a subcontract to the University of Virginia ($30K/yr in years 2 and 3) which will provide one mo/yr salary support and partial support for a Ph.D. graduate student who will work on adapting the ArcVeg model to the Yamal transect.

**Joey Comiso (NASA-Goddard)** will provide the sea-ice and land-surface temperature data. He will improve the LST data for the Yamal region by calibrating the satellite information to the available met-station data, and work closely with the team of Bhatt, Jia, and Comiso to examine the dynamics of terrestrial NDVI in relationship to LST and sea-ice distribution patterns. He will work under a full-cost-accounting subcontract to NASA-Goddard for $20K/yr in years 2 and 3 of the project.

**Jed Kaplan (University of Bern, Switzerland)** will provide model output from the BIOME4 model to examine vegetation-change scenarios on the Yamal Peninsula using improved parameter data from the project. He will not receive salary from the project. A subcontract of $10K/yr in years 2 and 3 is for services to provide the model output data for the Yamal Peninsula and the circumpolar region.

**Bruce Forbes (Arctic Centre, Rovaniemi, Finland)** will coordinate the field aspects of the study of the Nenets reindeer herding practices. A subcontract to the Arctic Centre of $30K/yr in years 2 and 3 of the project will provide logistic support for a graduate student to accompany the Nenets people during their annual migrations and to erect exclosures to study the effects of reindeer on the forage of the region.

**Marina Liebman and Natalya Moskalenko (Earth Cryosphere Institute, Moscow)** will be responsible for coordinating the field logistics and providing data collection and distribution services for the field work at the 7 sites along the Yamal transect. A $100K subcontract to the Earth Cryosphere Institute will cover the helicopter logistics, costs of establishing the field camps, and collecting the climate, soil, and vegetation information at each of the sites. The contract will also cover the costs of updating the GIS coverages of the region and providing these data to the project.

**Hilmar Maier (UAF)** is the GIS/Remote Sensing and Computer Systems Administrator for the Alaska Geobotany Center. He will help in all aspects of the remote sensing and GIS analyses and provide system support. We are requesting 2 mo/yr of salary support for him in years 2 and 3 of the project.

## WHY THE YAMAL?

Fig. 1. Nenets woman drives her sled across an eroding road in the gas field at Bovonenkova that obstruct their migration on the Yamal Peninsula,West Siberia. Photo Credit: © Bryan and Cherry Alexander/ www.arctic photo.co.uk.

Two of the major questions facing Arctic terrestrial ecologists at the moment are what will happen to the tundra regions as the global climate warms (ACIA 2004) and what will happen as rapid industrial development and land-use changes proceed (Nellemann et al. 2001)? The Yamal region in northwest Siberia has been identified as a "hot spot" for both of these forces of change (Forbes 1999a). Large-scale oil and gas development is interacting with a sensitive landscape and nomadic reindeer herds to produce extensive land-cover changes (Fig. 1) (Vilchek and Bykova 1992, Forbes 1995, Forbes 1997b, Vilchek 1997) and changes to the wildlife of the region (Dobrinskii 1997). At the same time the region has experienced an overall warming during the past 30-40 years comparable to that documented for northern Alaska and northwest Canada (IPCC 2001, Comiso 2003).

The Nenets, the indigenous people of the Yamal, and their large reindeer herds migrate across the peninsula annually. Their activities are strongly affected by the ongoing resource development, changes to the distribution of vegetation in the region, and a difficult socio-economic atmosphere (Pika and Bogoyavlensky 1995; Zen'ko 2004). Overgrazing by their reindeer herds also affect the vegetation of the region. In the early 1980s the conflict between oil

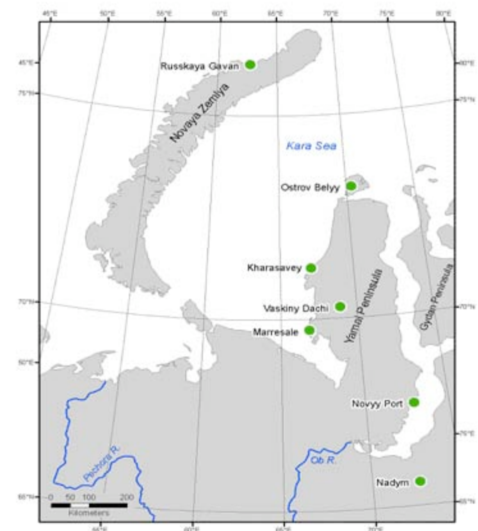


Fig. 2. Map of Yamal region and proposed research locations.

development and indigenous populations of the Yamal became apparent and was the subject of several Soviet government studies and later reports in the open literature (Prokhorov 1988, Prokhovor 1989, Pika 1992). A short article appeared in the *Wall Street Journal* in 1988 (Gambel 1988), and a few other articles in western journals and the popular press brought the conflict to the attention of concerned parties outside of Russia (Vitebsky 1990, Vilchek and Bykova 1992, Pika and Bogoyavlensky 1995, Khitun 1997, Vilchek 1997, Vilchek and Tishkov 1997, Forbes 1999b). For the most part, however, the general public in the West is still nearly totally unaware of the scale of the issue.

The Yamal Peninsula (Fig. 2) is also one of the best places in the Arctic to examine the effects of climate change on tundra vegetation because it encompasses nearly the full Arctic climate gradient. It has a distinct pattern of vegetation zonation that includes four bioclimate subzones (subzones B to E in Fig. 3 and Fig. 7). The zonal vegetation ranges from dominantly low-shrub tundra in the south to prostrate dwarf-shrub tundra on Bely Island off the northern coast. The

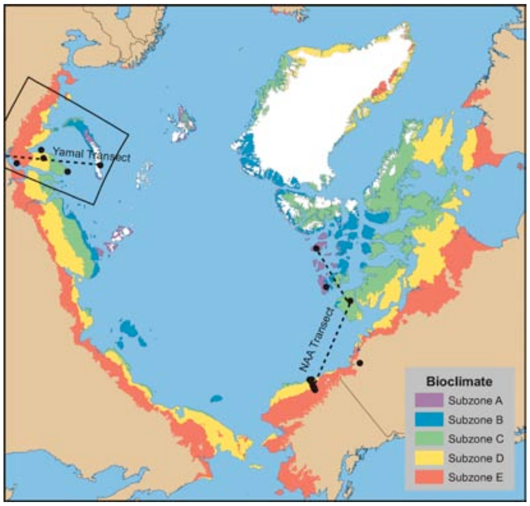

Fig. 3. Arctic bioclimate subzones. (CAVM Team 2003). The locations of the NAA and Yamal transect are shown.

combination of clear zonation patterns, an extremely sensitive landscape, and intensive impacts from resource development and reindeer make this an ideal area of study for the USDA-NASA Land-Cover/Land-Use Change (LCLUC) initiative.

*The overarching goal of our proposed research is to use remote-sensing technologies to examine how reindeer herding and resource development, combined with the climate trends on the Yamal Peninsula, affect the spatial and temporal patterns of vegetation change and how those changes are in turn affecting traditional herding by indigenous people of the region.* The use of space-based observing systems linked with ground-based studies of the landscape and the Nenets reindeer-herding patterns will help to quantify shifts in land-use/land-cover and will be used to improve circumpolar vegetation-change models for regional and circumpolar planning (Kaplan et al. 2003).

*Key elements of the study include: (1) ground-based observations of vegetation and key terrain variables; (2) a spatial and temporal analysis of images from space-based sensors of greening trends on the Yamal and how these are linked to historical climate and land-use; (3) a study of the Nenets reindeer herding patterns in relationship to changes in the vegetation, and (4)modeling studies that will compare the Yamal to a similar but less impacted transect in North America.*

### RELEVANCE TO NASA, USDA, AND NEESPI

Both NASA's Land-Cover/Land-Use Change (LCLUC) and USDA's Cooperative State Research, Education, and Extension Service (CSREES) programs are interested in studies of land cover and land use that are coupled to climate variability and global change as they relate to resources for society. The reindeer rangelands of the Yamal Peninsula are threatened resources that support an indigenous population of about 9000 people, 4500 of which are nomadic reindeer herders, on a landmass of 122,000 km$^2$ (Pika and Bogoyavlensky 1995). The oil and gas development on the Yamal Peninsula started in the early 1980's and created major disturbances to the land that greatly reduced the available range for reindeer, resulting in severe overgrazing of much of the peninsula.

Of particular relevance to NASA are our studies of greening (i.e., increase in vegetation growth) across all five bioclimate subzones on the Yamal Peninsula, Belyy Ostrov, and Novaya Zemlya. This will improve our understanding of how primary drivers of climate and sea-ice distribution have affected the regional patterns of biomass production and in turn how this might affect the local indigenous people and their way of life. Our study addresses NASA's National Objective number 5 " *Study the Earth system from space and develop new space-based and related capabilities for this purpose",* and Strategic Objective 13. It will use and contribute to NASA's global-change observations, particularly work exploring the consequences of the dramatic decline in the Arctic sea ice and the greening that is occurring in the northern latitudes. This proposal focuses on the topical area of LCLUC Drivers and Environmental Impacts (short title "Impacts") and the question, "*What are the primary drivers of land-use and land-cover change on the Yamal Peninsula, and what will be the environmental, social, and economic consequences of current and potential land-use and land-cover change over the next 5 to 50 years?*"

This research is also in response to the Northern Eurasia Earth Science Partnership Initiative (NEESPI), which focuses on issues in northern

Eurasia that are relevant to regional and global scientific and decision-making communities. It principally addresses the NEESPI science questions regarding the local and hemispheric effects of anthropogenic changes to land use and climate. The study is fully complementary to the NEESPI research strategy, which capitalizes on a variety of remote sensing tools to help parameterize the arctic portion of BIOME4, a global vegetation change model, and ArcVeg, a model of transitory vegetation change that will be used to address the key research questions within northern Eurasia. We will address the following NEESPI-related questions that are especially relevant to the NASA LCLUC program: *(1) From empirical data, what has been the integrated role of anthropogenic impacts, including those related to climate change and land-use changes, on producing the current status of ecosystems on the Yamal Peninsula? (2) Using the BIOME4 and ArcVeg models, in addition to grazing exclosures, what are the differential impacts of climate and reindeer herding on the Yamal ecosystems? (3) Using the BIOME4 and ArcVeg models to project future dynamics, how will anticipated vegetation changes affect the Yamal ecosystems? (4) What will be the consequences of regional and global changes for the Yamal environment, the economy, and the quality of life for the Nenets people?* While the focus of this effort is on the Yamal Peninsula, the results can potentially be extrapolated to other reindeer management regions throughout the circumpolar north.

## CLIMATE CHANGE AND ARCTIC VEGETATION: IS THE YAMAL BECOMING GREENER?

General circulation models (GCMs) predict that the Arctic will warm on an area average of between 3.2 and 6.6 ˚C when $CO_2$ in the atmosphere is double that of preindustrial levels (Holland and Bitz 2003), which is predicted to occur within the next 26 to 60 years (New 2005). As the climate warms, changes to tundra vegetation are expected to occur with major consequences for the permafrost, snow, hydrology, soils, wildlife, and people who live in the Arctic. Vegetation changes will also have global implications because of albedo and trace-gas feedbacks to Earth's climate system (Beringer et al. 2001; Chapin III, 2000). Summaries of system-wide changes in the Arctic are reported in several references (Serreze et al. 2000, Morison et al. 2001, Overland et al. 2004, Hinzman et al. 2005 in press). Predictions of vegetation change are based on greenhouse warming experiments (Shaver et al. 2000), modeling studies (Gilmanov 1997, Williams et al. 2000; Epstein et al. 2004), observations of recent shrub increases in northern Alaska (Sturm et al. 2001; Silapaswan et al. 2001), and studies of patterns of biomass along natural arctic temperature gradients (Jia et al. 2002, Lucht et al. 2002).

Direct evidence of widespread change, however, has been more difficult to document. A general pattern of increased greening has been observed globally north of 55˚N (Myneni et al. 1997, Zhou et al. 2001, Lucht et al. 2002), and at least part of the Arctic tundra is getting greener (Fig. 4). The greenness of the entire Arctic Slope of Alaska (200,000 $km^2$) increased an average of 17% from 1981 to 2001, as measured by the normalized difference vegetation index (NDVI)[1], an index of vegetation greenness, (AVHRR) sensor (Fig. 4) (Jia et al. 2003). The increase in NDVI occurred during a period when the summer warmth index (SWI) measured at ground stations across northern Alaska increased by 0.16-0.34˚C $yr^{-1}$. (The SWI is equivalent to thawing degree months or the sum of the mean monthly temperatures greater than 0˚C.) Correlations between biomass and NDVI along the climate gradient suggest that the 17% increase in NDVI corresponds to an average biomass increase of about 100-150 g $m^{-2}$ over northern Alaska during the past 20 years. This would be a surprisingly large change and needs to be confirmed with more detailed studies of

[1] The index is given by: NDVI = (NIR – R)/(NIR +R), where NIR is the spectral reflectance in the near-infrared band (0.725-1.1 μm), dominated by light scatter from the plant canopy, and R is reflectance in the red (0.58-0.68μm), chlorophyll-absorbing portion of the spectrum. The values can theoretically vary from 0 (no green vegetation) to 1.0 (very high cover of green vegetation).The index has been used extensively in tundra vegetation of northern Alaska as an indicator of biomass and other ecosystem properties such as $CO_2$ flux (Stow et al. 2004). Jia et al. 2002 and Walker et al. 2003 provide details of the most relevant NDVI studies in northern Alaska.

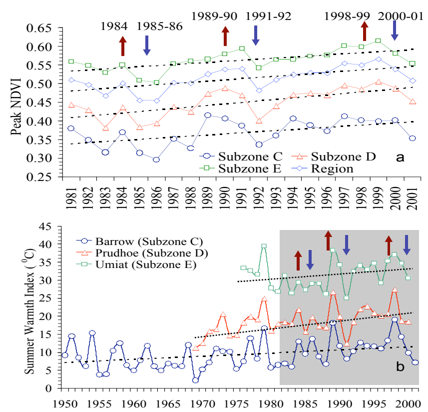


Fig. 4 (a) Time series of peak NDVI derived from 8-km resolution AVHRR data from 1981 to 2001 among the bioclimate subzones and for the Arctic Slope, Alaska. (b) Summer warmth index (SWI) over the past 22-50 years at meteorological stations in each bioclimate subzone. Dashed lines are linear regressions. The shaded area in (b) highlights the period of SWI covered by the NDVI data in (a). The arrows show years of corresponding increases (red) and decreases (blue) in NDVI and SWI. SWI is equivalent to the thawing degree months or the sum of mean monthly temperatures greater than 0 ˚C. From Jia et al. (2003).

actual measured long-term biomass change in the Arctic.

Jia et al. (2003) also showed that the time series of NDVI varies considerably with vegetation type, and soil substrate (Fig. 5). Other studies

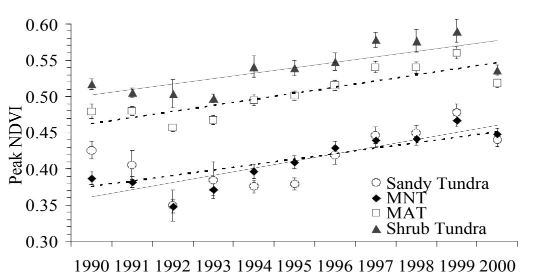


Fig. 5. Time series of Peak NDVI based on 1-km resolution AVHRR data among sandy tundra, moist nonacidic tundra (MNT), moist acidic tundra (MAT, and shrub tundra. From Jia et al. (2003).

have shown that landscape age (Walker et al. 1995) and substrate pH strongly affect patterns of NDVI and a host of ecosystem properties including trace-gas fluxes and energy budgets (Walker et al. 1998). One of the objectives of the proposed work is to determine if similar patterns of greening have occurred on the Yamal Peninsula despite very different substrate and disturbance regimes and examine what these changes may mean to the local Nenet's people.

The Arctic Ocean is currently undergoing a rapid reduction in its perennial sea-ice cover that will likely lead to major changes in tundra ecosystems (Morison et al. 2001). In a separate proposal to NSF, we have proposed a detailed analysis of the linkages between sea-ice patterns and greening trends along the NAA transect in Fig. 2 (Walker et al. 2005). A portion of this LCLUC study will examine vegetation changes in relationship to climate and sea-ice changes in parallel study along the Yamal Peninsula transect.

### HOW VEGETATION CHANGE AFFECTS THE NENETS PEOPLE

Tundra shrubs and graminoids are among the most important species for reindeer on the Yamal in terms of fodder reserves, nutritive value, and digestibility. Climate change is enhancing shrub growth in many areas of the Arctic ('shrubification') (Sturm et al. 2001). Areas of dense shrub cover can create problems for herding animals, and herders tend to avoid these areas. Another concern occurs on dry well drained uplands, where trampling is a problem when animals are concentrated in these areas, causing local desertification (Forbes 1997; Khitun 1997). Upland habitats can become dominated by graminoids through trampling and enhanced nutrient cycling a process referred to as 'grassification' (Zimov et al. 1995). At the same time, natural regeneration of anthropogenically disturbed sites is generally slower in the Yamal region than in comparable habitats in the European Russian North due to the Yamal's colder climate and poorer, sandier soils. There is a critical need to understand the mechanisms behind and the balance among shrubification desertification and grassification; how they are related to changing climate and patterns of greening; and to what extent Nenets people are contributing to and/or affected by these trends.

### THE YAMAL'S UNUSUALLY SENSITIVE LANDSCAPES

The Yamal, like most of the Arctic terrestrial biome, is sensitive to global climate change, but unique permafrost conditions and soils make it particularly vulnerable to catastrophic change. One reason the landscape is so sensitive is that nearly pure ground ice, up to dozens of meters thick, lies at shallow depths on much of the peninsula and is subject to thaw, thermokarst, and extensive mass wasting if disturbed (Leibman and Egorov 1996; Melnikov et al. 2004). It is a relatively flat region, with low-elevation sandy ice-rich uplands and finer-grained sediments in the broad valleys (Khitun 1997). Much of the landscape is rapidly eroding as the ice-rich permafrost melts out of the uplands. Sandy sediments that overlay the ice are difficult to utilize and rehabilitate when constructing roads and other components of infrastructure for the extensive oil and gas resources on the peninsula (Forbes 1997a, Khitun 1997). The arctic climate and poor soils further hamper rehabilitation of disturbed lands (Khitun 1997, Sumina, 1997, Tishkov 1997).

## RESEARCH QUESTIONS

The major research questions are as follows:

**Vegetation and landscape change:**

*1. What have been the quantitative changes to the vegetation and landforms on the Yamal Peninsula over the period of satellite-based observations?*

*2. Do the annual variations in greening correspond to changes in the local sea-ice and land-surface-temperature patterns?*

*3. Has there been a general greening similar to that documented in northern Alaska (Jia et al. 2003)? More specifically, how do the greening patterns) magnitude, distribution, and temporal patterns) on the sandy, nutrient-poor soils of the Yamal Peninsula compare with those on the loess soils of northern Alaska?*

*4. What do the trends in NDVI correspond to in terms of changes to the amount of plant biomass?*

*5. Has the greening occurred evenly across broad landscapes, or has it been confined to local areas of greater warmth, moisture or nutrient availability, such as on south-facing slopes, finer-grained soils, water tracks, or near streams?*

**The Nenets people and reindeer**

*1. How has the extensive grazing disturbance across the peninsula affected the greening trends?*

*2. How has vegetation change to date affected Nenets herding?*

*3. How will future vegetation change likely affect Nenets herding patterns?*

*4. How has the industrial infrastructure on the Yamal affected the herding patterns?*

## RESEARCH APPROACH

To answer these questions we will use a combination of (1) ground-based studies of the vegetation biomass, geophysical variables, and geomorphic disturbance; (2) remote sensing studies of sea-ice, land-surface temperatures, vegetation greenness and distribution, and extent of industrial development; (3) involvement of the Nenets people in this research; and (4) vegetation-change models to help predict future change in the region.

### *Ground-based studies along the Yamal transect (Epstein, Forbes, Leibman, Moskalenkso, Romanovsky, Walker)*

Ground-based studies are essential to quantify regional changes to permafrost, geomorphological processes, and plant biomass. Surprisingly, there are no long-term repeated measures of biomass in the Arctic that can be used to compare with temporal trends of NDVI. In a separate proposal to NSF, we proposed analyzing NDVI along the route of an 1800-km North American Arctic transect that was established as part of a study of the biocomplexity of patterned ground (NAA Transect in Fig. 3) (Walker et al. 2004). In that study, we collected a set of biomass and leaf-area index (LAI) data and a wide variety of other biological and geophysical data from 10 zonal locations spanning the five arctic bioclimate subzones. The intent is that these data will form a legacy data set, whereby biomass and other key variables would be sampled at regular intervals in the future for comparison with long-term trends in the NDVI.

The Yamal transect would be a Eurasian equivalent of the NAA transect. We will study seven locations (Fig. 2). These locations will be established with the intent that they be monitored at regular 3-5 year intervals and used to establish relationships between the spectral information and biophysical parameters. We also include the cryptogam-barren site in Subzone A at Russkaya Gavan on Novaya Zemlya so that the full bioclimate gradient is represented. We consider the analysis of Subzone A to be a high priority item because of the possible high sensitivity of this subzone to change and even to possible elimination within the next 100 years due to strong warming in the extreme High Arctic. We will study the temporal trends of spectral data at this site and others in Subzone A on the Russian arctic islands. The Russian Haven site, however, is only accessible by ship, and requires a two-week journey. Because of the high ship board costs and time required for the journey, and the greater relevance of the sites on the Yamal Peninsula to the issues related to the Nenets people, field work in Subzone A is not budgeted in this proposal and will be accomplished only if an opportunity presents itself at Russian Haven or another Subzone A site.

We will use the same sampling methods as those used along the NAA Transect (Walker et al. 2003a, Walker et al. 2004). The sites will be selected outside the areas of major industrial development so they can be used as a baseline against which to measure changes in greenness caused by the development. It will not be possible to select large areas that are not impacted by reindeer, so these sites will be studied at finer scales with the use of 10x10-m exclosures to exclude reindeer. We will attempt to relocate exclosures established by Amoco Inc. in the 1990s and build new ones in each bioclimate subzone.

A team of scientists from the Earth Cryosphere Institute SB RAS, Moscow Department, will be primarily responsible for the data collections and analysis along the transect. We will select zonal study areas at each location and measure key biological and physical properties (biomass, leaf-area index, plant community composition, climate, soil properties, active layer, permafrost conditions) to see how differences in biomass are affected by climate and other properties of the system. Three sites along the proposed transect have already been established and monitored since their establishment: Nadym (northern Tiaga, est. 1970), Marre-Sale (subzone D, est. 1978), Vaskiny Dachi, subzone D, central Yamal, est. 1988). Thaw layer, permafrost and vegetation mapping have been done at each site and biomass meaurement have been collected on 0.5 x 0.5-m plots (Melnikov 2004, Moskalenko, 2003, Ukraintseva, 2000).

We are proposing in addition to construct 10 x 10-m grids to monitor thaw-layer and snow depth and to map the vegetation in at least three representative zonal sites at each location. Air temperatures and soil temperatures at 10-cm depth intervals will be collected at each location using MRC temperature probes and Campbell data loggers. Aerial photographs will be taken of each grid from a helicopter at approximately 50-m altitude for use in mapping the vegetation at fine scales. Soil pits will be dug with shovels and a gas-powered jackhammer to 1-m depth and sampled using the protocols of the US Soil Conservation Service (Soil Survey Staff 1993).Vegetation will be sampled in the grids and in nearby replicate plots using the Braun-Blanquet approach (Westhoff and van der Maarel 1978).

Biomass, leaf-area index (LAI), and the normalized difference vegetation index (NDVI) data will be collected at each site along two 50-m transects located adjacent to the grids.

### *Remote-Sensing studies*

#### Remote sensing of vegetation change (Jia, Epstein)

The AVHRR-NDVI record is long enough now to detect meaningful trends with respect to the vegetation greenness and phenology records (NCEROS, 2005; Tucker et al., 2004; Stow, 2004). This part of the project will combine available remote-sensing data for sea-ice, land-surface temperatures, and the normalized difference vegetation index (NDVI, Fig. 6) with a group of recently available terrain GIS databases to examine how the vegetation of the Yamal is responding to global climate change and local anthropogenic impacts. Greenness will

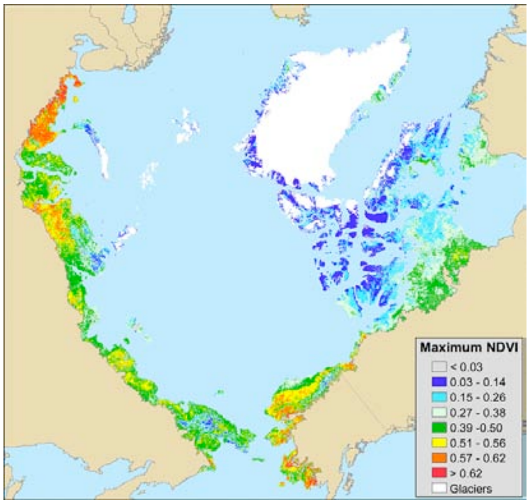


Fig. 6. Maximum NDVI of the Arctic. From Walker et al. (2003)

be measured using a time series of weekly Index (NDVI). Also, it has been shown that the enhanced vegetation index (EVI) derived from MODIS datasets is more capable of contrasting vegetation greenness than NDVI, so we will also examine EVI time series and compare the results against NDVI.

The NDVI data for the Yamal region will be stratified by bioclimate subzone, land-surface temperature regimes and a host of vegetation and terrain variables in the GIS data base (soil type, geomorphic features, vegetation type) to see how these factors affect the NDVI trends. Processing will consist of spectral analysis and supervised classification along with hand-editing to accurately map land cover classes that in our

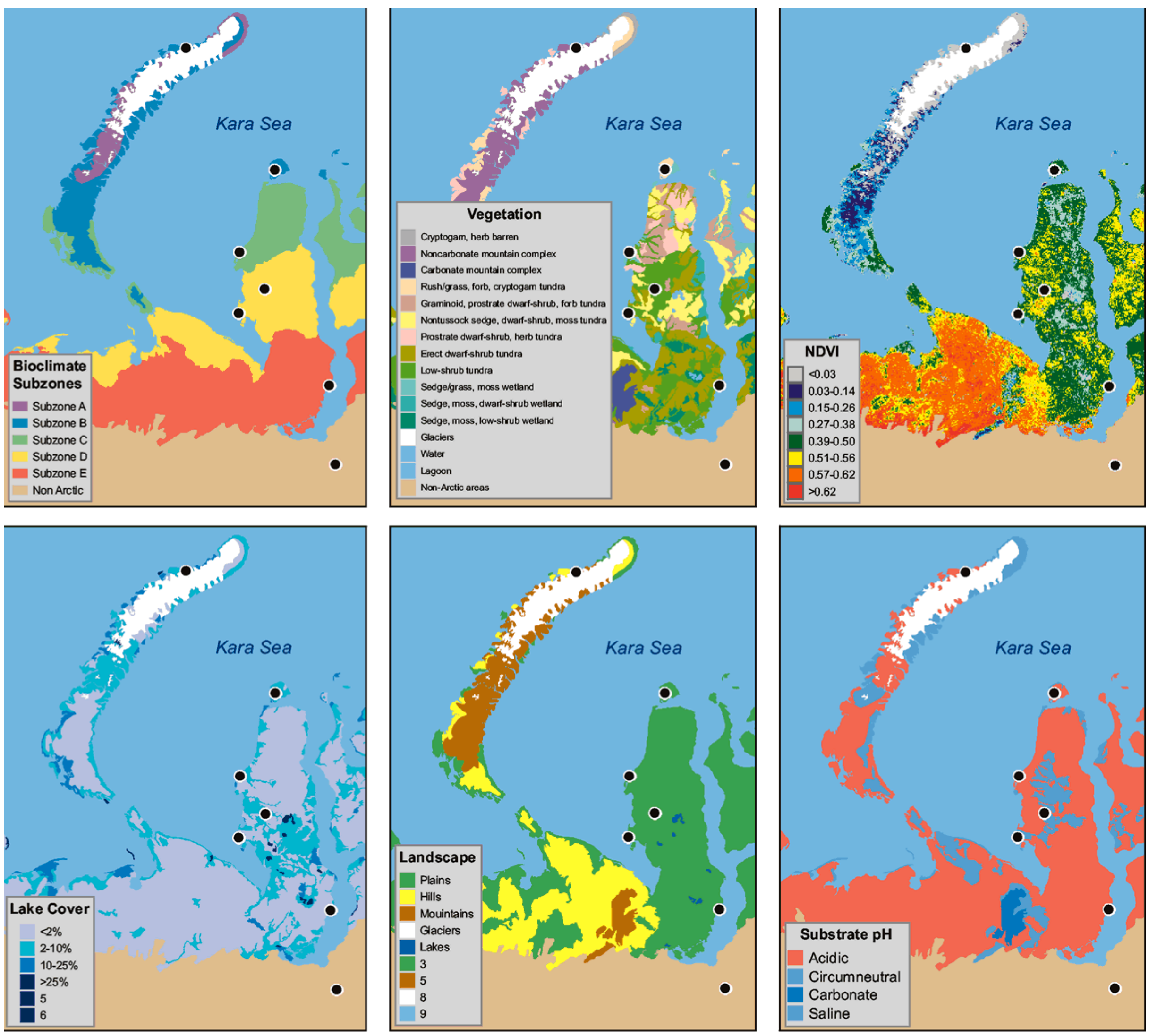


Fig. 7. Geobotanical variables of the Yamal region derived from the Circumpolar Arctic Vegetation Map (Walker et al. 2003). Dots are the proposed study-site locations.

experience cannot be detected accurately by automated means. This process will be aided by integrated landscape maps of the region in GIS format that have been produced by the Earth Cryosphere Institute. These maps will provide the basic information for the extension of the vegetation and terrain dynamics measurements in the field to the entire Yamal region.

We will analyze the 23+ yr circumpolar AVHRR GAC (8-km) dataset across the five bioclimate subzones over the Yamal region (Fig. for inter-annual fluctuations and trends of NDVI using the methods of Jia et al. (2003). At present, it is not known with certainty that the magnitude of the trend detected by Jia et al. (2003) in Alaska is due entirely to changes in the vegetation or if it is partially due to sensor calibration error or trends in the transparency of the atmosphere (Stow et al. 2003, Hope et al. 1995). We will reanalyze the new dataset of both GAC and LAC data with higher temporal resolution and longer time coverage to obtain a more confident magnitude of greening and more accurate estimates of possible earlier onset and lengthening of the growing season. We will also check the results from the NOAA Advanced Very High Resolution Radiometer (AVHRR) NDVI values against other sensors such as MODIS, the Landsat Thematic Mapper (TM), and SPOT. The trend observed in Alaska occurred in a region with pronounced warming over the period of the NDVI record, so we will expect to find a similar trend for the Yamal. We will use image differencing among several representative time periods and time series auto-regression to calculate absolute values and rates of changes. Then, using the field data of biomass, leaf-area index (LAI), NDVI, thaw depth, soil moisture, and other variables measured in different subzones and vegetation types, we will be able to establish regression models between AVHRR-NDVI and those variables. If significant relationships are found, we will use the equations to interpret NDVI in terms of the biophysical variables, creating new map data layers.

We will analyze the 15+ yr AVHRR LAC (1-km) datasets in the regions where data are available with a similar approach to that described for the GAC data, and then compare the results with AVHRR GAC-derived maps. In this finer resolution approach, we will examine changes of vegetation greenness among vegetation types and terrain types, and find out how the differences in vegetation composition are reflected in NDVI dynamics.

By examining the NDVI time series with fine temporal resolution (7-day), we expect to have a more accurate and better understanding of heterogeneous changes of two important vegetation phenological characteristics, onset of greenness and length of growing season, and to be able to detect possible earlier onset and lengthening of growing season across bioclimate gradients.

The broader climatic issues related to the persistence of sea ice from winter to summer and from late-summer to winter will be investigated. Is freeze-up delayed when ice is severely reduced during the summer in the Yamal region? This has been observed in parts of the Arctic (McPhee et al., 1998; Comiso et al. 2003), and here we propose to examine this phenomenon with special emphasis on the Yamal region. The availability of high temporal resolution (weekly) data will enable a detailed analysis of this persistence. The mechanisms behind such persistence are critical for understanding and predicting sea-ice response to and influence on climate. Joey Comiso at NASA-Goddard will provide spatial maps and better estimates of land-surface temperatures for the Yamal region along with temporal images of sea-ice patterns for the last 20 years. The team of Jia, Bhatt, and Comiso will examine the linkages between arctic climate patterns, sea-ice distribution, land-surface temperatures, and terrestrial NDVI patterns along the Yamal bioclimate gradient.

To determine where in the landscapes NDVI is changing most rapidly, we will compare a series of MODIS images that cover areas of detailed mapping by the Earth Cryosphere Institute where we have imagery and GIS information at 1:25,000 scale and finer (Table 1). In this way, we will examine sub-pixel heterogeneity of AVHRR data against MODIS data. We will then use data fusion techniques among AVHRR GAC, LAC and MODIS to see if we can take advantage of both the long time series of AVHRR and the higher spatial resolution of MODIS. At this finer resolution, we will examine changes of vegetation greenness among vegetation types, different soil and ground ice conditions, and effects related to development and reindeer herding.

***Data sources.*** This project will use the Circumpolar 23+ yr record of monthly AVHRR GAC (8-km) data assembled by the NASA Goddard Space Center (Tucker et al, 2004; 2005). The AVHRR GAC data is the longest complete remote sensing time series (1981-present) available to cover the peninsula, with 8-km pixel resolution and 30-day spatial resolution. The AVHRR LAC data with finer spatial (1-km) and temporal (7-day) resolution since the early 1990s provides us the opportunity to monitor ecosystem changes in more detail in the lower portion of the Arctic. The 5+ yr record of 10-day Moderate Resolution Imaging Spectroradiometer (MODIS) (500-m and 36 bands ranging from visible to short wave infrared (SWIR)) dataset processed and provided by the NASA MODIS Vegetation Team (Carroll et al., 2005). MODIS enables us to examine even more detailed patterns of NDVI within each AVHRR pixel with a particular focus on specific vegetation types. Its SWIR bands have the capacity to estimate soil moisture, snow cover and sea ice, while its thermal bands can be used to derive land surface temperature. Major parameters of the remote sensing datasets used in this proposed study are listed in Table 1.

Table 1. Remote sensing data that will be utilized in this study.

| Satellite | Spatial resolution | Spectral Bands | Temporal Frequency | Availability | Capacity |
|---|---|---|---|---|---|
| AVHRR GAC | 8km | 6 | 30 days | 1981- | Large scale monitoring of vegetation greenness and growing season |
| AVHRR LAC | 1km | 6 | 7 days | 1990- | Greenness, moisture, and spatial transitions |
| MODIS | 250/500/ 1000m | 36 | 10 days | 1999- | Greenness, moisture, and spatial transitions |
| Landsat | 15/30m | 7 | 5 yr | 1972- | Vegetation types, transitional zones |
| DEM | 10m, 1km | 1 | NA | 2003-2004 | Measurements of elevation, slope, aspect, and 3-D view |
| QuickBird | 0.6/2.8m | 5 | 6 days | 2002- | Canopy cover, vegetation type, frost scars, polygon patterns |
| IKONOS | 1/4m | 5 | 6 days | 2001- | Canopy cover, vegetation type, frost scars, polygon patterns |

**AVHRR**: Advance Very-High Resolution Radiometer
**MODIS**: Moderate Resolution Imaging Spectroradiometer
**QuickBird**: high resolution satellite data by DigitalGlobe Inc.
**DEM**: Digital Elevation Model

The key source of historical surface temperature data is the Advanced Very High Resolution Radiometer (AVHRR) (Comiso 2003). These sensors have monitored the Arctic daily for 23+ years, and provide a superb geospatially and temporally registered record of changes to the sea-ice, land-surface temperatures, and vegetation (Comiso & Parkinson 2004). Sea-ice concentration is available from the earlier part of the record (1978-) from the SMMR instrument and since 1987 from the SSMI instrument. Ice conditions from these two sensors have been combined into one data set by and will be used in conjunction with remote sensing information about the age of the ice (Comiso 2002).

Gridded monthly temperature data based on in situ measurements compiled by the Climate Research Unit (CRU) at the University of East Anglia will complement the higher spatial and temporal resolution remote sensing data. The NCEP daily reanalysis (Kalnay et al. 1996) will provide information about the large-scale atmospheric circulation (e.g. hemispheric sea level pressure) on monthly, weekly, and daily time scales. Key northern hemispheric climate indices (e.g. North Atlantic Oscillation, Arctic Oscillation, and Pacific Decadal Oscillation), will serve to relate high latitude climate anomalies to larger scale climate patterns. The LST data will be further improved with high resolution validation data sets from a variety of other sources including ground station data, and other satellites (e.g., MODIS, ASTER).

At several of the study sites, detailed landscape maps have been developed by the Earth Cryosphere Institute, and these will be used to examine how the terrain affects patterns of greening. In addition, landslides, thermal-erosion, and thermokarst features have strongly affected the vegetation patterns over large areas. A hierarchy of remote-sensing imagery (aerial photos (Table 2), AVHRR, Landsat, MODIS, SPOT, Corona, Quickbird) will be used to quantify these features from the 1960s to the present.

Table 2. Available Russian imagery from the study locations.

| Location | Type | Scale | Dates |
|---|---|---|---|
| Nadym | Air photos, bw, glossy | 1:25,000 | 1970 |
| | | 1:12,000 | 1971 |
| | | 1:5,000 1:2000 | 1977 |
| | | 1:1,000 | 1982, 1986 |
| Novy Port | Air photos, bw, glossy | 1:35,000 | 1982 |
| | | 1:12,000 | 1949 |
| | | 1:15,000 | 1966 |
| Vaskiny Dachi | Air photos, bw, glossy | 1:12,000 | 1978, others r |
| Marre-Sale | Air photos, bw, mat | 1:10,000 | 1985, 1990 |
| Northwest Siberia | Satellite image, mat print | 1:200,000 | 1980 |

***Anticipated products.*** (1) Identification of key climate variables, both concurrent and from previous seasons, which play a role in determining the amount of summer sea ice in the Yamal region and therefore the vegetation conditions. (2) NDVI predictive capability. Based on the climate-vegetation relationships we identify in the proposed study, we can develop a framework that could be used to estimate future NDVI in the Yamal region based on sea ice conditions from climate change scenario simulations. (3) Empirical and remote-sensing-based estimates of the trends and rates of vegetation greenness/biomass changes across the Yamal region over the past 23+ years. (4) Comparison of the patterns of greenness on the sandy heavily grazed soils of the Yamal with the less disturbed North American transect. (5) Maps of vegetation biomass/LAI change rates over past 23+ years.

### *Modeling vegetation patterns*

Numerous modeling approaches have been used to help predict the consequences of climate change to arctic vegetation at regional and circumpolar scales (Kittel et al. 2000, Rastetter et al. 2003). One recent approach used climate data from the last 100 years to determine how Köppen classification boundaries have shifted (Wang and Overland 2004). The authors determined that climate has already changed sufficiently to potentially eliminate about 20% of the present distribution of tundra and that the changes have been strongest during the 1990s. The most sophisticated model that addresses both changes in the composition and spatial patterns of global vegetation is BIOME4, a recent iteration of the BIOME model (Prentice et al. 1992, Kaplan 2005). Another model called ArcVeg (Epstein et al. 2000) has been used to predict the dynamic transient response of plant species and vegetation types to various disturbances. We will use the BIOME4 model to help predict changes in the Yamal region due to climate change and use ArcVeg to predict the transient conditions of the tundra.

#### The BIOME4 model

The BIOME series of global vegetation models are coupled carbon and water-flux models that predict steady-state vegetation distribution, structure, and biogeochemistry (Prentice et al. 1992). They have been applied to a wide variety of studies of biogeography, biogeochemistry, and climate dynamics. The BIOME4 model has recently been used to simulate paleo-Arctic environments, present-day ecosystems, and future changes in these systems (Bigelow et al. 2003, Kaplan et al. 2003, Kaplan 2005). In a simulation to recreate present-day vegetation with climate and substrate as the drivers, BIOME4 recreated the general distribution of five broad tundra physiognomic types that are displayed on the CAVM (Fig. 8), but there was considerably less correspondence between the simulated tundra map and the observed map than there was in forested portions of the simulations (Kaplan 2005). Kaplan attributed the relatively low correspondence in the Arctic to the following factors: (1) The simulated map did not take into account large areas of exposed bedrock, particularly in the Canadian Shield. (2) There is a lack of good temperature data in the High Arctic, particularly in the coldest parts of the Arctic (Subzone A). (3) Hyper-maritime area such as southwestern Alaska and Chukotka are not properly represented because of the

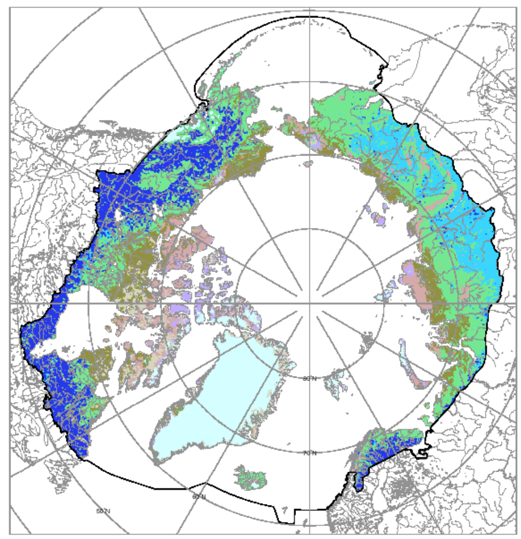

Fig. 8. Simulated present-day vegetation from the BIOME4 model. The southern boundary of the map combines the Arctic as defined by the Arctic Monitoring and Assessment Program (AMAP) and the Conservation of Arctic Flora and Fauna (CAFF). The legend is not included to save space. The general zonal patterns in the Arctic are comparable to those on the CAVM (Fig. 1). From Kaplan (2005).

influence of water-logged soils, and cool summer temperatures. Other very important factors are the age of landscapes, the distribution of ice-rich permafrost, and soils with special properties such as very sandy or very gravelly soils. In this project, we will incorporate information from the ground-based studies (soil, improved climate, permafrost, vegetation plant functional types and NDVI) to improve parameterization of the drivers in the model. A question for this portion of the research: *Given better climate and terrain information, how will the composition and distribution of zonal plant communities on the Yaml Peninsula change under future climate scenarios?*

***BIOME4 Simulations.*** Our main objective for BIOME4 is to simulate the changes in the distribution of vegetation types on the Yamal Peninsula based on general circulation model projections of climate change. BIOME4 represents five extant tundra vegetation types and two boreal forest types within its current structure; it is generally used at continental and global scales with resolutions on the order of 10-km square grid cells. In another related proposal (Walker et al. 2005) we will improve the current BIOME4 simulation of the tundra region by including information from recent global mapping efforts. Newly developed circumpolar datasets should dramatically improve the utility of the BIOME4 model and generate more accurate projections of vegetation change. In this project, we will focus the BIOME4 modelling specifically on the Yamal peninsula. Surface temperatures since the 1970s, derived from AVHRR infrared data (Comiso 2003), will be used as a new temperature dataset. In addition, the GIS data sets developed for this project, including permafrost distribution and soil characteristics, will provide additional information and constraints for the BIOME4 simulations.

**The ArcVeg Model**

A major challenge in vegetation change studies is to determine the rates of change as governed by biogeochemical processes that strongly limit vegetation production in arctic tundra ecosystems (Shaver et al. 2000, Shaver et al. 2001). Patterns of change as inferred from output of the BIOME4 model provide a picture of the region once it has stabilized under a climate change scenario, but it does not provide information on the transient dynamics of vegetation nor the intermediate states, which are likely to exist over many decades until the vegetation approaches an equilibrium with a new climate. The ArcVeg model was developed to examine the soil nutrient effects on inter-annual changes in tundra vegetation structure and function, and will be used to directly link the processes of biogeochemical cycling with species and vegetation change (Epstein et al. 2000, 2001, 2004b). ArcVeg simulates tundra vegetation changes from year-to-year at the structural level of plant functional types (PFTs) or species; currently twenty arctic tundra and boreal forest plant types are parameterized within the model. While simulating vegetation change is the ultimate product of the model, the general framework is one of nutrient mass balance, with nitrogen being the key nutrient limiting the vegetation of arctic tundra. Climate change scenarios within the model alter the available nitrogen for plants in addition to the length of the growing season, driving dynamics of vegetation. Dynamics of the zonal vegetation at the functional type level can be extrapolated to the extent of bioclimate subzones. Models that operate at the level of plant functional types or species provide a better picture of regional scale vegetation dynamics and nutrient cycling than more lumped vegetation models (Epstein et al. 2001). In previous analyses, the model has shown that the transient dynamics of arctic tundra vegetation in response to warming and grazing produce compositions of plant functional types that differ from any typical zonal vegetation community (Epstein et al. 2000). Vegetation changes occur not just as changes in the mean values of PFT biomass, but also as changes in the spatial variance of PFT biomass (Epstein et al. 2004b). One of our chief goals now is to derive a sub-model that links predictions of NPP for each tundra type with NDVI.

***ArcVeg Simulations.*** Our major questions here are: *How will the plant production and NDVI patterns on the Yamal change as the climate and* *disturbance regimes change? And how will these differ from the patterns on the NAA transect?*

***Response to climate change.*** The conceptual framework for the ArcVeg model is based on the premise that the arctic tundra is in general a nitrogen-limited ecosystem, whereby plant productivity is constrained by the availability of forms of nitrogen for plant uptake (i.e. ammonium, nitrate, dissolved amino acids). Air and soil temperature increases would increase decomposer activity, making more nitrogen available for plant growth. Warming would additionally increase the length of the growing season, which would make conditions more suitable for the growth and sustainability of plant types with a greater component of woody tissue, such as deciduous and evergreen shrubs. These are the general conditions under which the ArcVeg model simulates the dynamics of vegetation in response to climate change. Our plan is to simulate the dynamics of plant biomass and functional type composition for the zonal vegetation in each of the arctic Subzones (A-E). The warming scenarios used will be a 3 °C and 6 °C increases ramped linearly over a 50-year period, which is consistent with GCM scenarios for the region (New 2005). A 3 °C increase essentially represents a climate shift from a given arctic Subzone to the adjacent southern Subzone. However, because of the transient nature of the ArcVeg model the output will not just shift the subzones northward, but will describe the process of change in plant functional types and species composition.

***Response to different substrate and grazing regimes.*** Furthermore, the NAA and Yamal transects (Fig. 3) are on two very different substrates and have different disturbance regimes. The NAA transect is relatively undisturbed and on fine-grained, relatively nutrient-rich soils; whereas the Yamal transect is heavily grazed and on predominantly sandy nutrient-poor soils. We will use ArcVeg to address how the tundra will vary under these two very different nutrient and grazing regimes. Fig. 9 illustrates several hypotheses of predicted response of zonal vegetation along the bioclimate gradients of the NAA and Yamal transects: (1) Aboveground biomass / NDVI on the Yamal is substantially less than that in the NAA given lower soil organic matter and overgrazing. (2) Absolute responses (g/m2 or NDVI) to warming will increase with mean annual temperature, i.e. the southern subzones will respond more to warming, since the vegetation is already in place, including already substantial shrub biomass. (3) The relative responses (% change in biomass or NDVI) may be greatest at intermediate levels of mean annual temperature (i.e. subzone D), given that the middle subzones have a mix of plant functional types, and warming might initiate a shift from graminoid-moss dominated tundra to more shrub dominated tundra. (4) The responses to warming in the NAA will be greater than those on the Yamal because the low soil organic matter and overgrazing will constrain vegetation dynamics. Information from the ground-based studies will

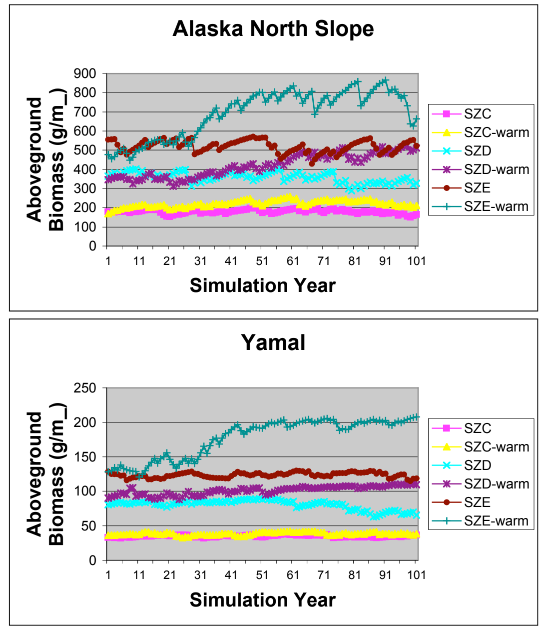


Fig. 9. ArcVeg model simulations of the response of zonal vegetation in subzones C, D, and E (SZC to SZE) to existing and warming climate scenarios for the next 100 years. The model indicates much lower biomass on the Yamal Peninsula in all three subzones. Assumptions of the model: 1) The Yamal has 25-50% less organic matter than the NAA at each subzone. 2) The Yamal landscape is essentially grazed every year, and 25% of the total biomass is removed by grazing. Whereas the NAA landscape sees a caribou herd about once every 10 years, and 25% of the total biomass is removed. 3) The current version of the model has grazers preferentially feeding on the plant types with the greatest N concentrations. These assumptions will modified once field information is available for the Yamal.

be used to improve the parameters for the Yamal transect and these will be compared with similar simulations from the NAA transect.

***Predicting NDVI response.*** Existing relationships between plant biomass and NDVI developed on the Arctic Slope of Alaska (Jia et al. 2003, Riedel et al. 2005) and from the ground-based studies in this proposal will be used to transpose the ArcVeg simulations of biomass over time for each Subzone into time-series of NDVI. These simulated NDVI time-series will be compared to the observed NDVI time-series from the AVHRR dataset; we will use the ~25 year NDVI record (since 1981) at an 8 x 8 km resolution and the ~15 year record at 1 x 1 km resolution. The ArcVeg model was initially parameterized and validated with data largely collected before 1990 (Epstein et al. 2000); therefore it is a rather good representation of the baseline conditions. The biomass-NDVI relationships are being improved upon for the Low Arctic and developed for the High Arctic as part of a currently-funded NSF Biocomplexity Project (Walker et al. 2003c, Kelley et al. 2004) and a proposed project through NSF {Walker, 2005 #14026}. These relationships will facilitate the simulation of NDVI dynamics for all five arctic Subzones for comparison with satellite data.

***Model enhancements and future projections using data on vegetation changes that have already occurred.*** Differences in the comparisons between simulated vegetation patterns and observed vegetation patterns for both the BIOME4 model and the ArcVeg model should reveal key pieces of information regarding the applicability of our conceptual model of tundra vegetation. Do the BIOME 4 and ArcVeg models reasonably project vegetation patterns? Which of the two models has the best correspondence with the observed data? Do we over- or underestimate the presence of tundra vegetation types? Do we over- or underestimate the degree of NDVI changes in response to warming across the five arctic Subzones? The answers to these questions will inform us as to what potential aspects of our models need further refinement. Enhancement of the models based on these findings will allow for more accurate projections of future vegetation dynamics. In addition, the heterogeneity of greening over the past several decades on the Yamal will dictate which particular areas have experienced the greatest changes (increases or decreases) in vegetation. One hypothesis is that the changes should be greater on the finer grained soils and in areas lacking intensive grazing pressure (Epstein et al. 2004). The spatial patterns of NDVI time-series will allow us to answer these questions. Are vegetation changes in the Arctic occurring largely due to changes in plant functional type composition, or are they more due to increases in biomass of all existing plant functional types? How do substrate differences and grazing regimes affect these patterns? Finally, the observed changes in vegetation will provide new baseline data for additional modeling simulations and projections of future vegetation dynamics.

***Anticipated products.*** (1) Circumpolar maps of predicted tundra vegetation changes in response to climate dynamics over the next several decades. (2) Descriptions of expected changes in PFT and species composition of arctic vegetation types in response to climate change. (3) Enhanced understanding and models of arctic vegetation change dynamics.

***Nenets land-use studies***

Since 1991, the collapse of the Soviet Union has brought drastic socio-economic changes to the North that have far exceeded climate as a force for change on the daily livelihoods of herders. After a lull in the early 1990s, the oil and gas industry has been reinvigorated and the pace of development has quickened considerably in the past several years. The Yamal region is considered a priority resource development area; its natural gas fields are expected to come on line for supplying both Russian and European markets within the next several years. Already during the exploration phase, large amounts of territory were affected directly and indirectly in the vicinity of Bovanenkovo, the largest gas field on the Yamal Peninsula. The result is that, in the space of about 20 years, herders whose summer pastures overlap with Bovanenkovo have experienced extensive anthropogenically mediated changes in the quantity and quality of the available vegetation. At the same time, both climate and permafrost for the region have warmed considerably since the 1950s and are projected to warm much more in the coming decades.

The Nenets are affected by large-scale changes due to climate and industrialization of the Yamal and are also the cause of large-scale changes because of their reindeer herds, which have affected ecosystem structure and function for at least a millennium. The intensity and extent of the use of the Yamal tundra as pasture increased in recent centuries, with reports of heavy use or 'overgrazing' of certain areas already in the early 20$^{th}$ century (Krupnik 1993; Golovnev and Osherenko 1999). Population numbers dropped precipitously during World War II as herds were slaughtered to feed Soviet troops. However, they have risen steadily since then and now number about 600,000 in the whole okrug (region), with about 200,000 animals on the Yamal Peninsula (WRH 1999). As such, the Nenets and their herds have been and continue to be critical components of the Yamal ecosystems. They are also important drivers of ecosystem change that must be accounted for in any assessment of climate warming and implications for greening. Fortunately, migration routes have changed little over time and many of the same campsites have been in more or less constant use for centuries (Fedorova 1998). It is known from studies in other reindeer herding regions that the concentrations of animals are relatively higher around campsites than in habitats further away (Karpov 1991). This has implications for graminoid and shrub growth along the migration routes and is being investigated in a separate project funded by the Academy of Finland during 2004-2007, coordinated by Bruce Forbes.

We will study the mechanisms behind and the balance between shrubification desertification and grassification, how they are related to patterns of greening, and to what extent Nenets are contributing to and/or affected by these trends.

Nenets reindeer herders whose migration routes intersect the most intensive areas of infrastructure development have agreed to participate in a study pertaining to land cover changes that have occurred over the past 30+ years. Their participation in the project will be through group and individual interviews with members of three herding brigades to document local knowledge. *This part of the project will be a detailed case study of plant-animal-climate interactions in the vicinity of Bovanenkovo, where both petroleum-related activities and reindeer grazing/trampling exert important controls over vegetation. Herders will be actively engaged in the field via participant observation and interviews along the course of the northern Yamal migration. Fenced exclosures will be constructed to keep reindeer out of representative habitats as a baseline against which to weigh future changes with and without grazing/trampling. Interviews will serve to document herders knowledge of local conditions and herders' migration routes, which is essential for interpreting time series satellite imagery and aerial photography employed for change-detection analyses. Interviews will also include presentation of a set of "what if" scenarios of projected changes, leading to discussions of the implications of these changes to land cover and land-use changes, reindeer herding and traditional ways of life for the Nenets.*

**MANAGEMENT APPROACH**

This proposal is considered a contribution to the Interntional Polar Year (IPY) 2007-2008. Initiatives submitted to the International Polar Year (IPY) Joint Committee for endorsement are encouraged to develop linkages with other IPY initiatives. For example, this particular project is conceived as an intersection of three IPY initiatives: (1) "Greening of the Arctic" (GOA), (2) "Cold Land Processes in NEESPI" (CLPN) and (3) "CircumArctic *Rangifer* Monitoring and Assessment" (CARMA) (Fig. 10). GOA is a pan-Arctic plan

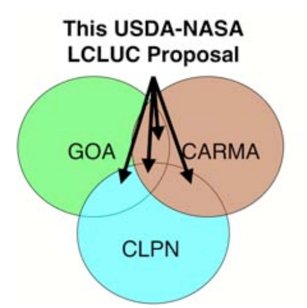


Fig. 10. This project is the intersection of the Greening of the Arctic (GOA, D.A. Walker, PI), Cold Land Processes in NEESPI (CLPN, V.E. Romanovsky), and CircumArctic *Rangifer* Monitoring Assessment (CARMA, G.P. Kofinas) IPY initiatives.

to examine the rates and causes of changes in vegetation biomass and productivity across the Arctic using remote sensing and ground-based studies (Walker et al. 2005). CLPN is a monitoring, data assimilation, and modeling program that will enhance the predictive capability of Earth System models to account for environmental changes over Northern Eurasia **(Vlad reference?)**. CARMA is a monitoring and assessment program for human-*Rangifer* (reindeer and caribou) systems across the Arctic in response to ongoing global change, including changes to caribou and reindeer habitat (Kofinas and Russell 2004). GOA, CLPN, and CARMA each have separate management structures.

### *Project organization and data flow*

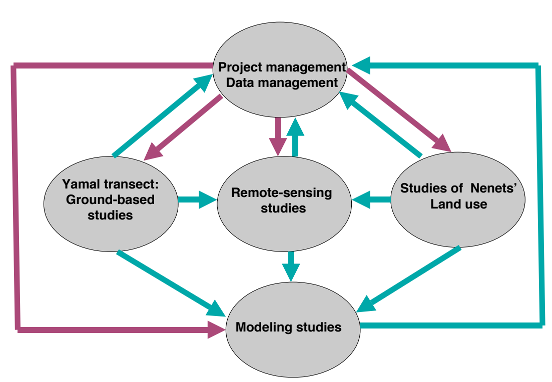


Fig. 11. Project management and data flow. Red arrows indicate organization/coordination activities; green arrows indicate data flow

The project has five major components discussed in the technical section of this proposal: (1) Ground-based studies, (2) Remote sensing studies, (3) Modeling, (4) studies of the Nenets people, and (5) Project management/data management. The five components are linked by coordination and data flow activities as shown in Fig. 11. The Yamal LCLUC will have a science management team composed of the collaborators (Bhatt, Comiso, Epstein, Forbes, Jia, Kofinas, Leibman, Moskalenko, Romanovsky, Walker). For purposes of this submittal, Dr. D.A. Walker will serve as Principal Investigator of the project, but decisions will be made with the consensus of the co-PIs The project will be coordinated with other NEESPI projects, other IPY projects, and ongoing circumpolar mapping and modeling studies such as the BIOME4 modeling project (Kaplan 2005) and the GLOBIO project (Nelleman et al. 2001).

### *Data management and outreach*

Data will be centrally managed at the Alaska Geobotanical Center (AGC), University of Alaska Fairbanks. Hilmar Maier will facilitate day-to-day activities and be the data manager of the project. Annual hard-copy data reports will be prepared for each of the field locations. Metadata will be written for each data set following national protocols and made available to the wider science community through the Joint Office for Science Support (JOSS) as soon as it becomes available and is quality checked. Final archiving will be done through the Arctic Data Coordination Center and Geographic Information Network of Alaska (GINA) at UAF. A web page will be developed and highlighted as part of the Arctic Geobotanical Atlas, which is a web-based hierarchic geographic information system currently under development at AGC.

### *Schedule*

An organizing meeting will be held in spring of the first year. The ground-based studies of the Yamal transect will be conducted during 3-week field campaigns in years 2-3 at 2-3 locations per summer (Fig. 10). Data analysis and modeling will also be conducted during these years.

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# FACILITIES AND EQUIPMENT

### ALASKA GEOBOTANY CENTER

The mission of AGC is to explore and understand global tundra ecosystems and to foster responsible land use and conservation of these systems. The Center is dedicated to excellence in field research, teaching and making our teaching and research relevant to societal issues and concerns. Interdisciplinary geobotanical research involves the cooperation among vegetation scientists, soil scientists, hydrologists, geologists, geographers, permafrost specialists, and other involved in Earth system research. Our primary areas of interest are climate change, paleoecology, vegetation classification and analysis, geobotanical mapping, snow ecology, and disturbance ecology in northern regions. AGC is located in the Institute of Arctic Biology (IAB) at the University of Alaska Fairbanks. The facilities of the Institute include a well-staffed administrative office, and a library specializing in northern topics.

AGC's lab facilities include equipment to support vegetation and soil field research and computer equipment to support GIS and remote-sensing work. AGC's current computing resources include a total of 14 GIS workstations, personal workstations, portable notebook computers, file servers and web servers. The AGC maintains a full complement of high-end software and peripheral devices to support our GIS and remote-sensing environment, allowing us to perform advanced GIS analysis, image processing and graphic layout on the Unix, Macintosh and Intel platforms. The major software packages currently used at AGC include ARC/Info Workstation, ArcView and ArcGIS (Environmental Research Systems, Inc.) for geographic information system analysis and cartographic design, ENVI (Research Systems, Inc.) and Land Analysis System (USGS) for manipulation and analysis of multi-spectral remote sensing data, Photoshop (Adobe Systems, Inc.) for editing graphic images and Studio MX (Macromedia, Inc.) for website development and graphic production. We will also utilize TerraExplorer, a 3-D “full motion flight” simulator developed by Skyline Software, which is being developed as a user interface for the web site for the Arctic Atlas.

### THE GEOPHYSICAL INSTITUTE

The Geophysical Institute has an extensive collection of high latitude climate library resources. Some of the arctic specific information is available nowhere else. Additionally, what is not available locally, such as more exotic interdisciplinary materials, can be obtained efficiently using the elctronic document delivery services covering both stocked and unstocked journals.

A sufficient amount of computer resources, including Macintosh and LINUX workstations, are available for the climate analysis. These machines are used for running the numerical codes and analysis of the data and presentation preparation. Additionally, and very importantly, the group access to significant super-computer resources in the form a Cray X1 and several IBM SP and Regatta systems at the Arctic Region Supercomputing Center (ARSC) located at UAF. The supercomputer facility is already used extensively by Uma Bhatt in running the GCMs and doing data analysis and can provide resource to facilitate the use of high-resolution remote sensing data. A high-end visualization facility (including a CAVE) is available to the group at ARSC.

# CURRICULUM VITAE

**DONALD A. (SKIP) WALKER**

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**Education:** U.S. Air Force Academy (1964-1967)- Mechanical Engineering, Astronautics; University of Colorado Boulder, Environmental Biology, B.A. (1972), M.A. (1977), Ph.D. (1981).

**Areas of Specialization:** Tundra Ecology, Vegetation Mapping, Landscape Ecology, Quantitative Ecology Methods, Vegetation of Northern Alaska and the Arctic, Snow-Ecosystem Interactions, Landscape Response to Climate Change, Geographic Information Systems and Remote Sensing, Disturbance and Recovery of Arctic Ecosystems.

**Statement of relevant background**: I have worked in the Arctic for 35 years and written extensively on the topics of cumulative impacts of oil field development and disturbance and recovery in arctic ecosystems. I served on the National Research Council Committee on Cumulative Environmental Effects of Alaskan North Slope Oil and Gas Activities (2000-2003). I have directed several large interdisciplinary and international projects, including the recent Circumpolar Arctic Vegetation Map project and a Biocomplexity in the Environment project that examines interactions between climate, patterned-ground forms, soils, and vegetation along an 1800 km transect in Alaska and Canada. I written numerous papers regarding tundra and landscape ecology; application of remote sensing for vegetation classification; and the use of NDVI to examine landscape change, greening in Alaska, and estimating circumpolar biomass. Finally, I have worked on the Yamal Peninsula and the Kolyma River area in Siberia, and collaborated extensively with the researchers at the Earth Cryosphere Institute in Moscow.

**Professional Experience:**
University of Alaska Fairbanks
- Director Alaska Geobotany Center, 1999 to present,
- Professor, Department of Biology and Wildlife, 1999 to present.

University of Colorado Boulder
- Assistant Professor Attendant Rank 1989-93,
- Associate Professor Attendant Rank 1996-1998,
- Professor Attendant Rank 1998-1999, University of Colorado Boulder
- Fellow, 1985-1999, Institute of Arctic and Alpine Research (INSTAAR, University of Colorado
- Senior Research Associate, 1998-1999, INSTAAR
- Co-Director, Tundra Ecosystem Analysis and Mapping Laboratory, 1989-1999, INSTAAR
- Research Associate, University of Colorado : Herbarium, 1990-1999

**Publications:** 135 refereed publications: 4 books and major edited publications, 9 book chapters, 79 journal articles, 43 government publications and maps and published abstracts. Plus 162 unrefereed works, including: 9 book reviews, 63 unpublished conference papers and lectures (14 invited), 42 conference posters without published abstracts, 48 other reports and maps to government agencies and consulting firms, and 2 theses.

**Most relevant publications:**

National Research Council, Committee on Cumulative Environmental Effects of Oil and Gas Activities on Alaska's North Slope (Orians, G., T. Albert,, G. Brown, R. Cameron,, P. Cochran, S.C. Gerlach, G. Gryc, D. Hite, M. Kennicott, A. Lachenbruch,, L. Lowry, J. Sedinger, L. Speer, **D. Walker**). 2003. *Cumulative Environmental Effects of Oil and Gas Activities on Alaska's North Slope.* National Academies Press, Washington, D.C. 288 pp.

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Ecosystem and plant community ecology; climate-plant-soil interactions; tundra, grassland, and shrubland ecosystems; field studies, remote sensing and simulation modeling.

**Statement of Relevant Background:**

I have worked in the Arctic for almost 10 years, since 1996, on four different government-sponsored projects. These projects include: the Sustainability of Arctic Communities, Arctic Transitions in the Land-Atmosphere System (ATLAS), the International Tundra Experiment (ITEX), and Biocomplexity of Arctic Frost-Boil Ecosystems. I am also a PI on a Greening of the Arctic (GOA) proposal and International Polar Year (IPY) initiative. Throughout these projects, I have conducted a variety of field, remote sensing and modeling studies, which included the development of the ArcVeg transient vegetation dynamics model. I have supervised one postdoc (Dr. Jiong Jia – Co-PI on this proposal), five graduate students (Dr. Monika Calef, Alexia Kelly, Sebastian Riedel, Ben Cook, and David Richardson), and three undergraduate students on arctic research over the course of these projects. I have been first- or co-author on 21 publications deriving from these studies, with three more submitted and several others in preparation.

**Professional Experience:**

2004-present*Associate Professor*, Department of Environmental Sciences, University of
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1998-2004*Assistant Professor*, Department of Environmental Sciences, University of
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1997-1998*Post-Doctoral Research Associate*, Institute of Arctic and Alpine Research,

1992-1997*Graduate Research Assistant*, Departments of Rangeland Ecosystem Science and

**Publications:**

I have 41 refereed publications: 37 journal articles and 4 book chapters. I have given 10 invited lectures and have 79 conference abstracts.

**Most Relevant Publications:**

Jia, G.J., H.E. Epstein and D.A. Walker. Spatial heterogeneity of tundra vegetation in response to recent temperature changes. **Global Change Biology**: in revision.
Walker, M., H. Wahren, L. Ahlquist, J. Alatolo, S. Bret-Harte, M. Calef, T. Callaghan, A. Carroll, C. Copass, H. Epstein, G. Henry, R. Hollister, I.S. Jonsdottír, J. Klein, B. Magnusson, U. Molau, S. Oberbauer, S. Rewa, C. Robinson, G. Shaver, K. Suding, A. Tolvanen, Ø. Totland, P.L. Turner, C. Tweedie, P. Webber, P. Wookey. Tundra plant community response to experimental warming: sensitivity in a rapidly changing environment. **Proceedings of the National Academy of Sciences:** in revision.
Calef, M.P., H.E. Epstein, A.D. McGuire, T.S. Rupp and H.H. Shugart. 2005. Analysis of vegetation distribution in Interior Alaska and sensitivity to climate change using a logistic regression approach. **Journal of Biogeography** 32:863-878.
Riedel, S.M. H.E Epstein and D.A. Walker. 2005. Biotic controls over spectral indices of arctic tundra vegetation. **International Journal of Remote Sensing** in press.
Riedel, S.M., H.E. Epstein, D.A. Walker, D.L. Richardson, M.P. Calef, E.J. Edwards, and A. Moody. 2005. Spatial and temporal heterogeneity of LAI, NDVI and aboveground net primary production for four tundra types in northern Alaska. **Arctic, Antarctic and Alpine Research** 37:35-42.
Epstein, H.E., J. Beringer, C. Copass, W. Gould, A. Lloyd, F.S. Chapin III, C.L. Ping, G. Michaelson, S. Rupp and D.A. Walker. 2004. The nature of spatial transitions in arctic ecosystems. **Journal of Biogeography** 31:1917-1933.
Epstein, H.E., M.P. Calef, M.D. Walker, F.S. Chapin III, A.M. Starfield. 2004. Detecting changes in arctic plant communities in response to warming over decadal time scales. **Global Change Biology** 10:1325-1334.
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Kruse, J., B. White, H. Epstein, B. Archie, M. Berman, S. Braund, F. Chapin III, J. Charlie Sr., J. Eamer, N. Flanders, B. Griffith, S. Haley, L. Huskey, D. Klein, G. Kofinas, S. Martin, S. Murphy, W. Nebesky, C. Nicolson, K. Peter, D. Russell, A. Starfield, J. Tetlichi, A. Tussing, M. Walker, O. Young. 2004. Sustainability of arctic communities: an interdisciplinary collaboration of researchers and local knowledge holders. **Ecosystems** 8:815-828.
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Yu, M., J. E. Ellis, and H. E. Epstein. 2004. Regional analysis of climate, primary production and livestock density in Inner Mongolia. **Journal of Environmental Quality** 33:1675-1681.
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Epstein, H.E., R.A. Gill, J.M. Paruelo, W.K. Lauenroth, G.J. Jia, and I.C. Burke. 2002. The relative abundance of three plant functional types in temperate zone grasslands and shrublands of North and South America: effects of projected climate change. **Journal of Biogeography** 29:875-888.
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### Areas of Specialization

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### Positions

Research Scientist, Department of Forest, Rangeland, and Watershed Stewardship, Colorado State University 2003- present

Research Associate, Department of Environmental Sciences, University of Virginia 1999-2002

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### Publications:

Jia, G.J., H.E. Epstein and D.A. Walker, 2005, Spatial heterogeneity of tundra vegetation response to recent temperature changes, Global Change Biology (submitted).

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McGill University, Montreal, Canada; **Ph.D. (**Ecological Biogeography), 1993
Vermont College of Norwich University, Montpelier, Vermont and The Center for Northern Studies (CNS), Wolcott, Vermont; **M.A.** (Northern Studies), 1987
University of Vermont, Burlington; **B.A.** (Environmental Studies), 1984
Positions held:
Research Professor in Global Change, Arctic Centre, University of Lapland, Rovaniemi, Finland
Docent in Plant Ecology/Biogeography, Faculty of Science, University of Oulu, Oulu, Finland

Duties as scientific expert:
Member, Board of Directors, Arctic Research Consortium of the United States (ARCUS)
Member, Editorial Board of *Polar Geography*
Member, Steering Committee for the IASC Human Role in Reindeer/Caribou Systems Project
Member, Advisory Board of Finland's 'Arctic Graduate School' (ARKTIS)
Member, Working Group Circumpolar Arctic Environmental Studies (CAES) Ph.D Network

Previously received research funding (last five years only):
2004-2007 – Grant from the Academy of Finland's Russia in Flux Programme to fund the project 'Social and Environmental Impacts of Industrial Development in Northern Russia' (ENSINOR). 460 000 euro over four years beginning January 2004. I am the Project Coordinator.
2001-2004 - Grant from the European Commission's 5$^{th}$ Framework Programme to fund the project 'The Challenges of Modernity for Reindeer Management: Integration and Sustainable Development in Europe´s Subarctic And Boreal Regions' (RENMAN). 1.97 million euro over three years beginning February 2001. I was the Project Coordinator.
2000-2003 – Grant from the European Commission's 5$^{th}$ Framework Programme to fund the project 'Human Interactions in the Mountain Birch Forest Ecosystem: Implications for Sustainable Development'. 1.65 million euro over three years beginning April 2000. Project Coordinator: Docent Kari Laine, Department of Biology, University of Oulu, Finland. I was a subcontractor to the project for 48 000 euro.
1999-2002 – Grant from the Nordic Academy for Advanced Study (NorFA) (with Päivi Soppela) to fund the Circumpolar Ph.D. Network in Arctic Environmental Studies (CAES Network) – 400 000 NOK/year for three years beginning January 1999.
2000-2001 - Grant from The National Geographic Society's Research and Exploration Committee (U.S.A.) to fund the project 'Determining Responses of Forest-Tundra Vegetation to Disturbance in Northeast Siberia (Russia)'. $17,000 USD for two years.

Relevant peer-reviewed publications (last five years only):
Forbes, B.C., N. Fresco, A. Shvidenko, K. Danell and F.S. Chapin III (2004) Geographic variations in anthropogenic drivers that influence the vulnerability and resilience of high latitude social-ecological systems. *Ambio* 33:377-382.
Whiteman, G., B.C. Forbes, J. Niemelä and F.S. Chapin III (2004) Bringing high-latitude feedback and resilience into the corporate boardroom. *Ambio* 33:371-376.
Chapin, F.S. III, P. Angelstam, M. Apps, F. Berkes, C. Folke, B.C. Forbes, G. Juday and O. Peterson (2004). Vulnerability and resilience of high-latitude ecosystems to environmental and social change. *Ambio* 33:344-349.

Mascia, M., J.P. Brosius, T. Dobson, B.C. Forbes, G. Nabhan and M. Tomforde (2003) Conservation and the social sciences. *Conservation Biology* 17:649-650.

Weladji, R. and B.C. Forbes (2002) Disturbance effects of human activities on *Rangifer tarandus* habitat: implications for life history and population dynamics. *Polar Geography* 26:171-186.
Forbes, B.C., J.J. Ebersole and B. Strandberg (2001) Anthropogenic disturbance and patch dynamics in circumpolar arctic ecosystems. *Conservation Biology* 15:954-969.
Kofinas, G., G. Osherenko, D. Klein and B. Forbes (2000) Research planning in the face of change: the human role in reindeer/caribou systems. *Polar Research* 19(1):3-21.

<u>Relevant edited publications (last five years only)</u>:

Chapin, F.S., III, M. Berman, T.V. Callaghan, A.-S. Crepin, K. Danell, B.C. Forbes, G. Kofinas, D. McGuire, M. Nuttall, C. Pungowiyi, O. Young, and S. Zimov (MS) Polar Systems. In: R. Scholes (ed.) *Millennium Assessment*. Island Press, Washington, D.C. (in press).

Nuttall, M., F. Berkes, B.C. Forbes, G. Kofinas, T. Vlassova and G. Wenzel (2005) Hunting, Herding, Fishing and Gathering. In: R. Corell (ed.) *Arctic Climate Impact Assessment*, Cambridge University Press, Cambridge (in press).

Forbes, B.C., A. Tolvanen, K. Laine and F.-E. Wielgolaski (2005) Rates and processes of natural regeneration in disturbed habitats. In: F.-E. Wielgolaski (ed.) *Plant ecology, herbivory and human impact in northern mountain birch forests*. Ecological Studies 180, Springer-Verlag, Berlin, pp. 193-202.

Tolvanen, A., Y. Norokorpi and B.C. Forbes (2005) Recreation activities at treeline and interactions with other land use. In: F.-E. Wielgolaski (ed.) *Plant ecology, herbivory and human impact in northern mountain birch forests*. Ecological Studies 180, Springer-Verlag, Berlin,pp. 203-217.

Forbes, B.C. (2005) Conservation; Environmental problems; Habitat loss; Polar steppe; Reindeer; Sedge meadows; Tundra; Vegetation distribution; Wet tundra, Wilderness. Yamal-Nenets Autonomous Okrug. In: M. Nuttall (ed.) *Encyclopedia of the Arctic*. Routledge, New York.

Forbes, B.C., C. Monz and A. Tolvanen (2004) Tourism ecological impacts in terrestrial polar ecosystems. In: R. Buckley (ed.) *Environmental Impacts of Ecotourism*. CAB International. pp. 155-170.

Forbes, B.C. (2004) Impacts of energy development in polar regions. In: C.J. Cleveland (ed.) *Encyclopedia of Energy*. Academic Press, San Diego, pp. 93-105.

Forbes, B.C. (2004) Flax in flux: the waxing and waning of 'people plants' in Finland and beyond. In: G. Kearsley and B. Fitzharris (eds.) *Glimpses of a Gaian world*. School of Social Science, University of Otago, pp. 17-38.

Sumina, O.I. and B.C. Forbes (2003) Vegetation responses to anthropogenic disturbance: a useful indicator for global change assessment? In: R.O. Rasmussen and N. Koroleva (eds.) *Social and Environmental Impacts in the North*. Kluwer Academic Publishers, Dordrecht, pp. 207-223.

Forbes, B.C. and J.D. McKendrick (2002) Polar tundra. In: A.J. Davy and M. Perrow (eds.) Handbook of Ecological Restoration. Cambridge University Press, Cambridge, pp. 355-375.

Forbes, B.C. (2002) Rendrift og olieudvinding på Poluostrov Jamal: Bæredygtighed eller gensidig uforenelig praksis (Reindeer herding and petroleum development on Poluostrov Yamal: sustainable or mutually incompatible uses)? In: C. Oreskov (ed.) Tundraens og tajgaens folk. INFONOR, Copenhagen, pp. 23-29.

Forbes, B.C. (2002) Small-scale disturbances have significant effects on arctic tundra. *WWF Arctic Bulletin* No. 1.02, p. 14.

Nellemann, C., L. Kullerud, I. Vistnes, B. Forbes et al. (2001) GLOBIO Global methodology for mapping human impacts on the biosphere: the Arctic 2050 scenario and global application. UNEP/DEWA Technical Report 3, 47 pp.

Tolvanen, A., B.C. Forbes, K.E. Rytkönen, and K. Laine (2001) Regeneration of dominant plants after short-term pedestrian trampling in sub-arctic plant communities. In: F.E. Wielgolaski (ed.) Nordic Mountain Birch Ecosystems. UNESCO, Paris, pp. 359-368.

Forbes, B.C. (2001) Changes in permafrost landscapes under global change: ecological responses to variations in land use and climate. In: R.R. Paepe and V. Melnikov (eds.) Permafrost Response on Economic Development, Environmental Security and Natural Resource Potential. Kluwer Academic Publishers, Dordrecht, pp. 333-339.

Saarikivi, J. and B. Forbes (2000) Maakaasu tuhoaa elämää pohjoisessa (Gas destroys life in the North). *Ylioppilaslehti* 87(15):16-17.

Forbes, B.C. (2000) Preface. In: O.I. Sumina (ed.) Research on Anthropogenic Impacts in the Russian Arctic. Arctic Centre Reports 29, University of Lapland, Rovaniemi, pp. 4-7.

<u>Relevant edited volumes (last five years only)</u>:

Forbes, B.C., M. Bölter, N. Gunslay, J. Hukkinen, Y. Konstantinov, F. Müller and L. Müller-Wille (eds.) Reindeer management in northernmost Europe: linking practical and scientific knowledge in social-ecological systems. Ecological Studies 184. Springer-Verlag, Berlin (in press).

Forbes, B.C. (ed.) (2004) RENMAN Final Report: The challenges of modernity for reindeer management. Arctic Centre Reports 41, University of Lapland, Rovaniemi, 100 pp.

Soppela, P., B. Forbes and R.E. Haugerud.(eds.) (2002) Proceedings of the 1st CAES Workshop 'Reindeer 2000', Tromsoe, Norway, 9-16th August 1999. *Rangifer*, Special Issue, 13.

Forbes, B.C. and G. Kofinas (eds.) (2000) The human role in reindeer and caribou grazing systems. Proceedings of an International Arctic Science Committee Workshop held 10-14 February 1999 in Rovaniemi, Finland. *Polar Research* 19(1):1-142.

Serving as a referee for international journals:
American Journal of Botany; Arctic; Arctic, Antarctic and Alpine Research; Biodiversity and Conservation; Canadian Journal of Botany; Ecography; Ecosystems; Journal of Applied Ecology; Journal of Environmental Management; Journal of Wildlife Management; Oecologia; Permafrost and Periglacial Processes; Polar Biology; Polarforschung; Polar Geography; Polar Research; Rangifer; Restoration Ecology.

# CURRENT AND PENDING SUPPORT

## CO-INVESTIGATOR LETTERS OF COMMITMENT

From: "Howard Epstein" <hee2b@virginia.edu>

To: <ffdaw@uaf.edu>

Cc: "'Leah Swasey'" <fnlts@uaf.edu>

Subject: RE: Revised Letter of commitment for USDA-NASA LCLUC proposal

Date: Mon, 27 Jun 2005 16:48:16 -0400

Organization: University of Virginia

X-Priority: 3 (Normal)

Importance: Normal

X-Proofpoint-Spam-Details: rule=notspam policy= score=0 mlx=0 adultscore=0 adjust=0 engine=2.5.0-05062402 definitions=2.5.0-05062701

X-Proofpoint-Spam-Score: 0

Status:

Dear Skip,

I acknowledge that I am identified by name as a collaborator to the investigation entitled "Application of space-based technologies and models to address land-cover/land-use change problems on the Yamal Peninsula, Russia" that is submitted by Dr. Donald A. Walker to the NASA Research Announcement NNH05ZDA001N-LCLUC, and that I intend to carry out all responsibilities identified for me in this proposal. I understand that the extent and justification of my participation as stated in this proposal will be considered during peer review in determining in part the merits of this proposal.

Sincerely,

Howard Epstein

Dept. of Environmental Sciences

University of Virginia

P.O. Box 400123

Charlottesville, VA 22904-4123

hee2b@virginia.edu

(434) 924-4308

X-Sender: ffver@ffver.email.uaf.edu

Date: Fri, 24 Jun 2005 09:10:02 -0800

To: ffdaw@uaf.edu

From: Vladimir Romanovsky <ffver@uaf.edu>

Subject: Re: Revised Letter of commitment for USDA-NASA LCLUC proposal

X-Proofpoint-Spam-Details: rule=notspam policy= score=0 mlx=0 adultscore=0 adjust=0 engine=2.5.0-05061701 definitions=2.5.0-05062303

X-Proofpoint-Spam-Score: 0

Status:

Dear Skip,

I acknowledge that I am identified by name as a collaborator to the investigation entitled "Application of space-based technologies and models to address land-cover/land-use change problems on the Yamal Peninsula, Russia" that is submitted by Dr. Donald A. Walker to the NASA Research Announcement NNH05ZDA001N-LCLUC, and that I intend to carry out all responsibilities identified for me in this proposal, i understand that the extent and justification of my participation as stated in this proposal will be considered during peer review in determining in part the merits of this proposal.

Best regards, Vladimir Romanovsky

At 05:32 AM 6/24/2005 -0800, you wrote:

****************************************************************

Vladimir E. Romanovsky

Associate Professor

Geophysical Institute UAF      tel.: (907)474-7459

903 Koyukuk Drive              FAX : (907)474-7290

P.O.Box 757320

Fairbanks, AK 99775-7320    e-mail: ffver@uaf.edu

www.gi.alaska.edu/snowice/Permafrost-lab

****************************************************************

Reply-To: "Jiong Jia" <jiong@colostate.edu>

From: "Jiong Jia" <jiong@colostate.edu>

To: "Skip Walker" <ffdaw@uaf.edu>

Subject: Letter of commitment

Date: Fri, 24 Jun 2005 14:18:13 +0800

X-Priority: 3

X-Virus-Scanned: by amavisd-new at mail.iap.ac.cn

X-Proofpoint-Spam-Details: rule=notspam policy= score=0 mlx=0 adultscore=0 adjust=0 engine=2.5.0-05061701 definitions=2.5.0-05062303

X-Proofpoint-Spam-Score: 0

Status:

I acknowledge that I am identified by name as a collaborator to the investigation entitled "Application of space-based technologies and models to address land-cover/land-use change problems on the Yamal Peninsula, Russia" that is submitted by Dr. Donald A. Walker to the NASA Research Announcement NNH05ZDA001N-LCLUC, and that I intend to carry out all responsibilities identified for me in this proposal, i understand that the extent and justification of my participation as statted in this proposal will be conseered during peer review in determining in part the merits of this proposal.

--------------------------------------

Gensuo (Jiong) Jia, Ph.D.

Research Scientist

FRWS, Colorado State University

Fort Collins, CO 80523-1472

Phone: (970) 491-0495

Fax: (970) 491-2339

Email: <mailto:jiongjia@cnr.colostate.edu>jiongjia@cnr.colostate.edu

<http://www.cnr.colostate.edu/~jiongjia>http://www.cnr.colostate.edu/~jiongjia

To: Skip Walker <ffdaw@aurora.uaf.edu>

From: Bruce Forbes <bforbes@ulapland.fi>

Date: Tue, 28 Jun 2005 13:35:37 +0300

X-University-of-Lapland-Mail-Protection: Found to be clean

Subject: letter of commitment

X-Proofpoint-Spam-Details: rule=notspam policy= score=0 mlx=0 adultscore=0 adjust=0 engine=2.5.0-05062402 definitions=2.5.0-05062703

X-Proofpoint-Spam-Score: 0

Status:

To Whom it May Concern:

I acknowledge that I am identified by name as a collaborator to the investigation entitled "Application of space-based technologies and models to address land-cover/land-use change problems on the Yamal Peninsula, Russia" that is submitted by Dr. Donald A. Walker to the NASA Research Announcement NNH05ZDA001N-LCLUC, and that I intend to carry out all responsibilities identified for me in this proposal, i understand that the extent and justification of my participation as statted in this proposal will be conseered during peer review in determining in part the merits of this proposal.

Sincerely,

Bruce C. Forbes

*********************************************

Bruce Forbes, Research Professor

Arctic Centre, University of Lapland

Box 122

FIN-96101 Rovaniemi, Finland

Phone: +358-16-341-2710

Fax: +358-16-341-2777

Mobile: +358-40-8479202

E-mail: bforbes@ulapland.fi

http://www.ulapland.fi/home/arktinen/bforbes/

*********************************************

Date: Fri, 24 Jun 2005 17:40:55 +0200

From: "Jed O. Kaplan" <jed.kaplan@ips.unibe.ch>

Subject: Letter of commitment for USDA-NASA LCLUC proposal

To: ffdaw@uaf.edu

X-Virus-checked: by University of Berne

X-Proofpoint-Spam-Details: rule=notspam policy= score=0 mlx=0 adultscore=0 adjust=0 engine=2.5.0-05061701 definitions=2.5.0-05062303

X-Proofpoint-Spam-Score: 0

Status:

Dear Skip,

I acknowledge that I am identified by name as a collaborator to the investigation entitled "Application of space-based technologies and models to address land-cover/land-use change problems on the Yamal Peninsula, Russia" that is submitted by Dr. Donald A. Walker to the NASA Research Announcement NNH05ZDA001N-LCLUC, and that I intend to carry out all responsibilities identified for me in this proposal, i understand that the extent and justification of my participation as stated in this proposal will be considered during peer review in determining in part the merits of this proposal.

Sincerely,

Jed Kaplan

Jed O. Kaplan, Ph.D.

Institute of Plant Sciences

University of Bern

Altenbergrain 21

3013 Bern

Switzerland

http://www.ips.unibe.ch/index.php

Phone: +41 31 631 4992

Fax: +41 31 631 4942

Email: jed.kaplan@ips.unibe.ch

29 June 2005

To: Donald A. “Skip” Walker

University of Alaska, Fairbanks

PO Box 757000

Fairbanks, Alaska 99775-7000 USA

From: Bruce C. Forbes

Arctic Centre

University of Lapland

FIN-96101 Rovaniemi, Finland

Letter of Commitment

To Whom it May Concern:

I acknowledge that I am identified by name as a collaborator to the investigation entitled "Application of space-based technologies and models to address land-cover/land-use change problems on the Yamal Peninsula, Russia" that is submitted by Dr. Donald A. Walker to the NASA Research Announcement NNH05ZDA001N-LCLUC, and that I intend to carry out all responsibilities identified for me in this proposal, I understand that the extent and justification of my participation as stated in this proposal will be considered during peer review in determining in part the merits of this proposal.

I also understand that there needs to be a matching contribution from my institute for this research. I would therefore like to stress that Arctic Centre will cover all salaries and research expenses (i.e., intellectual efforts), and overhead expenses (facilities and administration) of the research. I am currently coordinating another project funded for 460 000 EUR by the Academy of Finland during 2004-2007 that will provide the majority funds for the intellectual effort.

Yours sincerely,

Bruce C. Forbes

Research Professor in Global Change

## BUDGET DETAILS