SUMMARY

The Arctic is experiencing the Earth's most rapid climate change and extensive oil and gas development. As climate warms and roads and pipeline networks are expanding, Arctic people are responding and adapting, but with concern about their voice in future land-use decisions that affect their livelihoods. ***The goal of our project is to use remote-sensing tools combined with interview data and socioeconomic information collected from local people to study the history of climate change and industrial development in northern Alaska and Russia. We will use this information to develop predictive models to achieve a holistic understanding of Arctic social-ecological systems (SESs) and develop methods to anticipate and adapt to the impending changes.*** Our proposed work is a broad integrative study that is a wrap-up and synthesis of earlier LCLUC/NEESPI research, a portion of which focused on the cumulative effects of climate change and gas-field development on the social-ecological systems of the Yamal Peninsula region of Russia and the Nenets reindeer herders. A new aspect of our proposed work is a comparative study of the Prudhoe Bay oil field and Iñupiat people in northern Alaska. This will update a previous study by the National Research Council. It will also be a collaboration with the NSF-LTER Maps and Locals (MALS) initiative. We will use data from interviews of local Iñupiat people and oil-industry personnel to determine their perceptions of the effects of LCLUC that are evident on remote-sensing products. We will use a detailed GIS database recently obtained from the oil industry to trace the history of development at Prudhoe Bay, AK. To place the change in the oil fields in a global context, we will synthesize climate, sea-ice, vegetation and ecological information from the circumpolar Arctic and two long arctic transects. We will use a hierarchy of remote sensing products, including a 30-yr+ Advanced Very High Resolution Radiometer (AVHRR) time series, Global Land Survey (GLS) decadal products, and a variety of Very High Resolution (VHR) products. In accordance with the call, our project has a strong social-science component; several of our team members are leaders in the field of Arctic SES analysis. We will do a thorough comparison of the SES effects of climate change and expanding road and pipeline networks in the Prudhoe Bay and Bovanenkovo oil/gas fields. Another new aspect, as specified in the call, is a focus on wetland systems. Both industrial complexes are in vast tundra wetlands. We will use previously obtained wetland data from northern Alaska to classify and improve models of tundra vegetation and permafrost response to changing water regimes, and link variation in wetland systems to satellite-derived spectral data. The models will also address issues related to increased reindeer grazing. The linkages between our work and methane fluxes will be explored through a collaborative link with a University of Washington LCLUC study in Siberian wetlands. The project has six major tasks:

Task 1: Organizing workshop.

Task 2: Synthesis of field data and remote-sensing information for the circumpolar Arctic, northern Alaska, the Yamal Peninsula and the two arctic transects.

Task 3: Models of vegetation and permafrost change in response to different scenarios of climate, soil moisture, grazing, and surface disturbance.

Task 4: Update and analyze historical image and map data from Prudhoe Bay and Bovanenkovo oil and gas fields to trace the history of LCLUC.

Task 5: Use findings from our ecological analyses with available socio-economic information and interviews with local subsistence hunters and herders to assess the responses and vulnerabilities of Iñupiat and Nenets livelihoods to change.

Task 6: Workshop at the conclusion of the project that will involve project investigators, indigenous leaders from each region, and industry representatives.

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VULNERABILITY, IMPACTS AND ADAPTATIONS OF ARCTIC SOCIAL-ECOLOGICAL SYSTEMS

OVERVIEW

Much current international attention is focused on the Arctic's vulnerability to the combined impacts of climate change and widespread resource development. Two principle concerns are: 1) the response of arctic terrestrial ecosystems, including the vegetation and permafrost, to the expected changes and 2) the effects on the livelihoods of Indigenous Peoples of the Arctic (ACIA 2004, Callaghan et al. 2005, Huntington et al. 2005, Chapin et al. 2006, Larsen et al 2010). Our project will focus in the oil and gas fields of Prudhoe Bay, Alaska, and Bovanenkovo, Russia, where industrial development activity has been the greatest. We first review the past six years of relevant research funded by the NASA LCLUC Program that is part of the Northern Eurasia Science Partnership Initiative (NEESPI). We then describe the proposed research, organized according the two themes and six tasks shown in Fig. 1. Each task is directed at answering a set of specific questions. We then describe the education and outreach component, data management, overall project management and collaborations, proposed deliverables, and schedule.

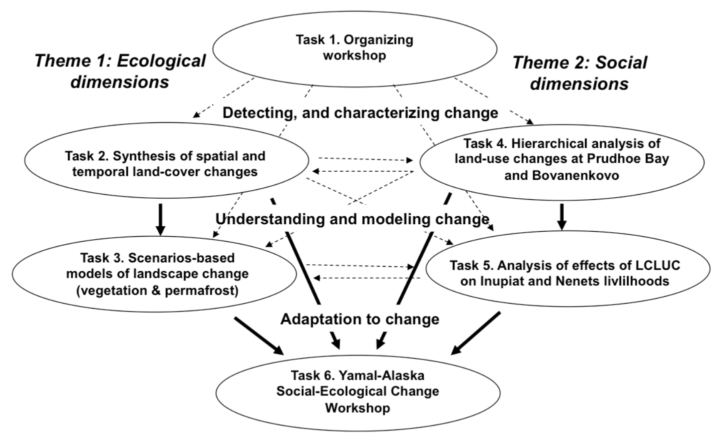

Fig. 1. *Overview of the project's research themes and major tasks. Bold arrows show direct data and information flow between tasks. Dashed arrows are places where information from one task might be helpful in informing or interpreting the results of another task.*

We will first place the history of LCLUC in northern Alaska and the Yamal within a global context using circumpolar and regional analyses of changes to climate, sea-ice, land temperatures, vegetation and permafrost. The project includes a Eurasia Arctic Transect (EAT) that stretches from tree line near Nadym, Russia (65˚ 32' N to Franz Josef Land (80˚ 37' N). We will combine ground-based and remote-sensing information from the EAT with information from other studies including a similar long transect in North America to determine how the terrestrial ecological and social systems in both regions responded during the past 40 years of heightened climate change and resource development. We will use this information in vegetation and permafrost models along with information provided by local people to help predict how these systems will change during the next century. The goal is to develop a whole-system understanding of Arctic SESs so that the local people, land managers, and policy makers can anticipate and adapt to impending changes.

PREVIOUS RELEVANT LCLUC RESEARCH

Two prior LCLUC/NEESPI projects in 2005-2011 addressed issues related to resource development and climate change and their relevance to the indigenous Nenets people in northwest Siberia. Both projects included investigators from the University of Alaska Fairbanks, the University of Virginia, NASA Goddard, the Earth Cryosphere Institute (ECI) in Tyumen and Moscow, Russia, and the Arctic Centre (AC) in Rovaniemi, Finland. There were four major findings and sets of observations derived from these projects: 1) Climate-change studies found strong correlations between coastal summer sea-ice trends, land-surface-temperatures (LST), and vegetation greenness (using the Normalized Difference Vegetation Index, NDVI) for most Arctic regions and the circumpolar Arctic as a whole (Bhatt et al. 2010a, Forbes et al. 2010, Goetz et al. 2011, Walker et al. 2009a). 2) Four expeditions to seven locations along the EAT resulted in an archive of ground-based measurements of vegetation, soil, active layer, permafrost temperature, and spectral information (Walker et al. 2008, 2009b, 2009c, 2011a). Remote-sensing studies examined the regional effects of climate, terrain, permafrost, soil, and disturbances on the EAT land surface (Epstein et al. 2010, Walker et al. 2009, Raynolds et al. 2008, 2009, 2010, 2011submitted). 3) The field observations from the transect were used to improve the parameterization of the ArcVeg model so it is suitable for vegetation-change studies in tundra regions. Specifically, it models changes in the biomass and productivity of different plant functional types using different scenarios of changing summer warmth, soil substrates, and reindeer foraging (Epstein et al. 2007, Goetz et al. 2011, Yu et al. 2009). 4) Several papers addressed the cumulative effects of resource development and climate change on the local Nenets people (Forbes et al. 2009, 2010, Kumpula et al. 2010, 2011, Stammler et al. 2009; Walker et al. 2011a) and permafrost (e.g., Leibman et al 2008, Khomutov 2009, 2010). These and other results were presented at the First and Second Yamal Land-Cover Land-Use Change Workshops and numerous conferences related to the International Polar Year. The project web site http://www.geobotany.uaf.edu/yamal/index has complete results from the previous rounds of funding, including pdfs of past proposals, publications, posters and talks at conferences and workshops, annual data reports, annual reports to NASA, and list of participants.

PROJECT DESCRIPTION

Task 1. Organizing Workshop

We will conduct a workshop in Moscow during the first month of the project that will evaluate the data and products produced during the earlier phases of research and coordinate their use for the modeling and synthesis efforts. We will bring team members, key stakeholders and outside advisors together to address Tasks 2-5 (Fig. 1). Several new remote sensing, GIS, and modeling products have either been generated or are planned for both the Prudhoe Bay and Bovanenkovo regions (see Task 2.1, 2.2). We will coordinate the synthesis and use of these products in the modeling efforts. We will also coordinate the Russian and Alaska human-dimension components of the project.

Task 2. Synthesis of Arctic spatial and temporal land-cover changes

Subtask 2.1. Circumpolar syntheses

We will synthesize spatial and temporal information for the circumpolar Arctic to answer the following questions:

1. What are the primary causes of the spatial patterns and temporal changes of circumpolar NDVI?
2. What are the climate drivers of the circumpolar temporal patterns of sea-ice, land temperature and NDVI change?
3. What have been the historical circumpolar patterns of change in permafrost temperatures, and active layer thickness?

Circumpolar remote sensing and GIS information:

Examination of the circumpolar changes in vegetation, climate and permafrost will be aided by new circumpolar data sets, including new vegetation and bioclimate maps that we will produce. An improved vegetation map is needed to provide better land-cover information for the Arctic at a scale similar to other environmental model inputs (Krankina et al. 2011). The vegetation map will improve the spatial resolution of the current Circumpolar Arctic Vegetation Map (CAVM Team 2003, Walker et al. 2005), which is a polygonal map that mainly displays dominant zonal vegetation for relatively large areas of the Arctic. We will produce a fine-scale (1-km raster) circumpolar vegetation map based on the CAVM and 1-km AVHRR NDVI data (Markon et al. 1995). We will also create a finer resolution, pixel-based map of the bioclimate zonation of the Arctic. The existing bioclimate subzone map (Walker et al. 2005) is based on known zonal vegetation distribution and weather station data from widely spaced stations that are mostly located along the coast. It is now possible to derive a better approximation of the bioclimate subzone boundaries based on the summer warmth index (SWI) for land surface for the entire Arctic derived from AVHRR data (Comiso 2003, Raynolds et al. 2008) (Fig. 2, top). SWI is the sum of monthly average surface temperature above freezing. It gives an indication of both the length and warmth of the summer and correlates well with the variation in arctic vegetation distribution (Edlund and Alt 1989, Raynolds et al. 2009). These long-term data can be used to calculate a 30-year average (1982-2011) summer warmth for all points in the Arctic (Comiso 2003, Bhatt et al. 2010).

To answer our first question in Task 2.1 we will use these new products in combination with a Circumpolar GIS database (Raynolds 2009) to analyze the controls on spatial and temporal patterns of circumpolar NDVI. These maps and analyses will provide input for the permafrost (GIPL) and vegetation (ArcVeg) models (Task 3) and other circumpolar analyses, and will also be useful for examining future shifts in the zonal climate and vegetation.

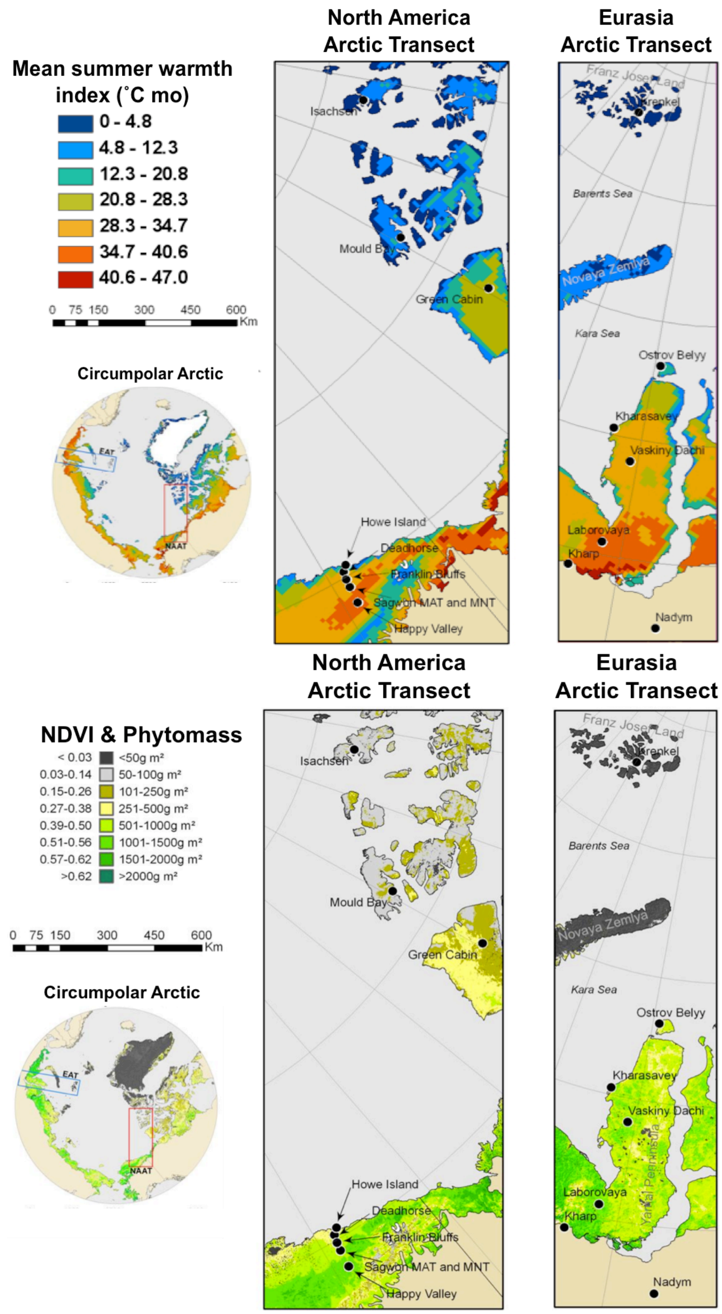

Fig. 2. *Summer warmth index and NDVI maps of the circumpolar Arctic, the North America Arctic Transect (NAAT) and Eurasia Arctic Transect (EAT) regions, based on 1982-2010 AVHRR data.*

<u>Circumpolar synthesis of climate, sea-ice, land temperature and NDVI:</u>

From 1982 to 2010, Arctic tundra areas had an overall 12% increase in vegetation productivity (based on remotely sensed NDVI), a concurrent 32% increase of near-coastal open water, and 12% increase in SWI (Bhatt et al. 2010a, b) (Fig. 3). Linearly detrended correlations between NDVI, sea ice and land temperatures display a consistent and statistically significant relationship throughout the Arctic. In the Yamal for example, decreased springtime sea ice is correlated with warming temperatures (R=-0.39, 95% sig. level) and higher time-integrated NDVI (TI-NDVI) (R=-0.34, 90%). However, there is notable regional heterogeneity. For example, the W. Kara/Yamal region showed a 36% decrease in summer coastal sea ice, a slight (3.3%) decrease in SWI and a small 4.5% increase in NDVI; whereas, in the Beaufort/Northern Alaska region the coastal ice decreased 41%, land temperature warmed 15% and maximum NDVI (MaxNDVI) increased by 26% (Fig. 4).

The seasonal breakdown of the NDVI trends indicates that the largest changes have happened late in the growing season with sea-ice decreases indicating a delayed freeze-up concurrent with land temperature warming and bi-weekly MaxNDVI increases (not shown). This picture of the seasonal progression of anomalies displays striking regional variation, suggesting that regional processes (e.g., local winds and cloud cover, snow cover) play important regional roles in determining trends of the seasonal patterns.

At the circumpolar scale, the key objective is to better understand the impact of the large-scale atmospheric circulation in driving the state of the cryosphere in terms of both near coastal sea ice and snow conditions on the tundra. This analysis will characterize atmospheric circulation patterns in sea level pressure (Atmospheric Reanalysis data sets) and associated storm track statistics (Zhang et al. 2004) that precede late and early sea ice break up and snow melt. The ice and snow conditions in late spring set the stage for how quickly the land surface can warm and allow the vegetation to begin to photosynthesize. This analysis will employ the NCEP/NCAR reanalysis data set to characterize the atmospheric conditions. Reliable high-resolution snow data over the Arctic began in the late 1990's (IMS Daily Northern Hemisphere Snow Analysis or MODIS products), which will limit the full ice-snow analysis to the last 15 years.

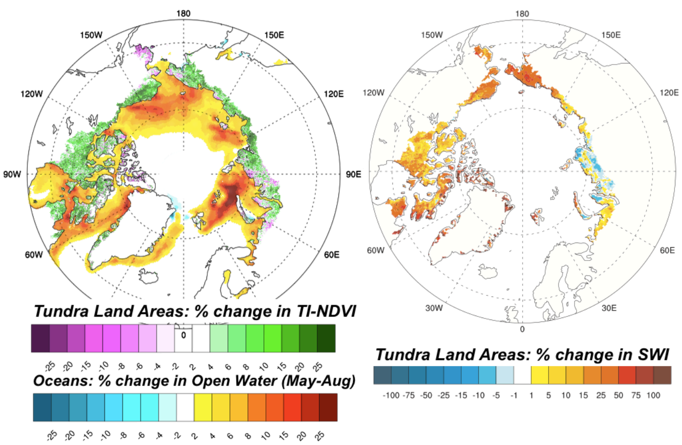

Fig. 3. *Percent change in 1982-2010 Time-integrated NDVI (TI-NDVI) (left, land), Aug-May open water (left, ocean), and Summer Warmth Index (sum of monthly mean temperatures >0 ˚C. (right, land).*

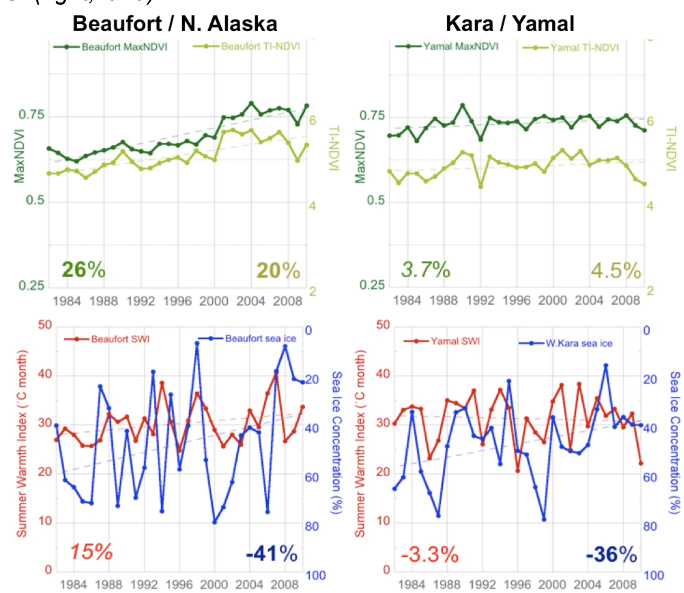

Fig. 4. *Time series of MaxNDVI and TI-NDVI (top). Time series of SWI and Spring sea ice concentration (bottom). The Beaufort region is shown in the left column and the Yamal on the right. The percent change is identified in each plot in the color matching the line. Statistical significance at the 90% level or greater is shown in italic and for the 95% level or greater in*

<u>*Circumpolar permafrost synthesis:*</u>

To answer the third question of Task 2, we will use the trends in permafrost temperatures derived from the boreholes of the Thermal State of Permafrost (TSP) IPY project (Romanovsky et al. 2010). We also will use new remote sensing datasets on vegetation and surface temperatures described above as an input for the Geophysical Institute Permafrost Laboratory (GIPL) permafrost-dynamics model in order to assess the permafrost and active-layer dynamics for the circumpolar domain (see Task 3.1).

Subtask 2.2 Regional syntheses

For the regional analyses we will address the following questions:

1. What are the primary vegetation, soil and site-factor controls of NDVI and plant productivity on zonal sites along the North America and Eurasia arctic transects (Fig. 2)?

2. What climate drivers are most responsible for climate variability and change over Northern Alaska and the Yamal during the summer? What is the relative importance of the circumpolar- versus regional-scale circulation for summertime climate anomalies over the Yamal?
3. How have the changes in climate and land cover affected the stability of ice-rich permafrost landscapes of northern Alaska and the Yamal?

Regional remote sensing and GIS information:

For the analyses of changes in the Alaska North Slope and Yamal regions we will need landscape-level resolution remote-sensing information, which is available with MODIS data at 250-m and 500-m pixel sizes; and Landsat GLS data with 30-m resolution (Gutman et al. 2008). The GLS data are required for monitoring changes in infrastructure (see Task 4) and for major shifts in vegetation and landscape boundaries. The GLS data are less useful for monitoring temporal dynamics of NDVI over large areas because of the highly variable acquisition dates of the individual scenes. We will use the GLS data for our time series analyses if the scenes that include our NAAT and EAT study locations were acquired during the "peak-season" period of maximum NDVI (usually 20 July- Aug 10). A circumpolar cloud and snow-free polar projection of MODIS data displaying maxNDVI for each pixel is currently under development as part of the Circumboreal Forest Mapping initiative (Talbot et al. 2010) and should be available in time for our project. For each of the digital vegetation maps we will create biomass distribution maps. These maps will be based on a modeled NDVI-biomass relationship using biomass data from the EAT sites and maxNDVI values derived from the 30-m GLS data at the same sites.

Synthesis of information from two Arctic transects:

To answer the first question of Task 2.2, we will synthesize the data collected from 69 relevés (vegetation study plots) along the Eurasia Arctic Transect (EAT) during earlier LCLUC research. These data are currently in data reports that were produced for four Yamal expeditions in 2007-2010 (Walker et al. 2009b, c, 2011a). We will then combine these data with information from the 1800-km North America Arctic Transect (NAAT) (Kade et al. 2005, Vonlanthen et al. 2008, Walker et al. 2011 in press). An analysis of the zonal vegetation patterns along the North American transect has recently been completed and a similar analysis of the Eurasian transect is in progress (Walker et al. 2011b, c). Both projects used similar methods to collect ground-based observations of vegetation, soils, permafrost temperatures, active-layer depths, and spectral properties, which make them suitable for a comparative synthesis of spatial and temporal changes along the complete Arctic bioclimate gradient. An example of a comparison of data from both transects shows that a consistent NDVI-biomass relationship exists for both transects (Fig. 5) despite major structural differences of the vegetation and differences in the biomass-climate relationships.

Despite the strong correspondence in the biomass-NDVI relationships along the transects, the transects are different in other respects. For example, the biomass of zonal vegetation is strongly correlated with summer air temperature along the North America transect ($r^2 > 0.8$), whereas there is a nearly flat relationship on the Yamal Peninsula, Russia, especially in the central part of the EAT (bioclimate subzones B, C, & D) (not shown). This same trend is noted in the ground- and satellite-based measurements of the NDVI. The more

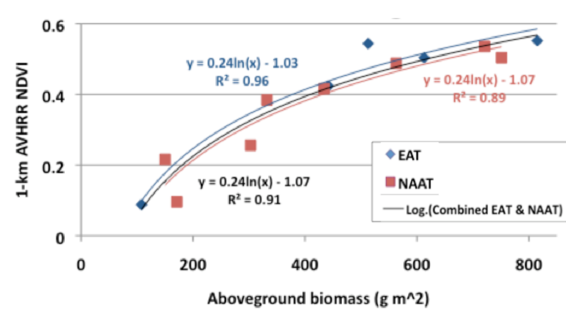

Fig. 5. 1-km AVHRR NDVI vs. aboveground biomass. *The three regression lines show the relationship along the Eurasian transect (blue), North American transect (red) and the combined data set (black). Nearly identical relationships were found for both transects. The regressions compare aboveground phytomass sampled at zonal sites along the Eurasia and North America Arctic transects to AVHRR maximum NDVI data from 1993 and 1995 (CAVM Team 2003, Raynolds et al. 2011 submitted.)*

homogeneous nature of the Russian transect is likely caused by more consistent soil conditions, warmer than expected temperatures along the central part of the Russian transect, and the homogenizing effect of landscape-scale disturbances related to reindeer grazing and landslides (Walker et al. 2009a). This has major implications for disturbance-modulated vegetation change throughout the Arctic in response to climate change.

Regional climate analysis:

Ecological changes and extreme weather events, consistent with warming summer and winter climates, have been reported by the local people in both regions of this study. For example, on the Yamal, rain-on-snow events have caused Nenets reindeer-herd losses up to 25% (Bartsch et al. 2010). The nomadic tundra Nenets have also reported early thawing of lakes and rivers in spring, late freeze-up in autumn, and warmer summers with increased insect harassment (Forbes et al. 2009). To address these issues, the role of large-scale climate on thaw/freeze of lakes and on summer temperatures and NDVI in the observational record will be investigated. At the regional scale of northern Alaska and the Yamal (Figure 4), we will highlight the regional differences in spring-time snow and sea-ice conditions as the starting point and then characterize the progression of local atmospheric conditions in conjunction with land surface temperature and NDVI. This analysis requires reliable wind data to evaluate the impact of the local circulation (e.g. sea-breeze circulation) on land surface temperatures. The ERA Interim reanalysis (Jan 1989 – present), though shorter than desired, will be used to evaluate local conditions as they are considered the best available near-surface wind dataset for Northern Alaska (J. Zhang, personal communication) and have been shown to simulate surface air temperatures over the Arctic well (Dee and Uppala 2009). Cloud conditions likely play an important role in regional climate anomalies and will be included if the new Arctic cloud product from U. Wisconsin is available in time for this study (Y. Liu, personal communication). The data for this regional synthesis will be augmented with meteorological station data for the Yamal and Northern Alaska where available.

In another study of regional climate, we will compare the annual growth-ring chronologies from two *Salix lanata* populations on sandy and clayey soils in the vicinity of Bovanenkovo (planned for summer of 2011) with local station data from across the northwest Eurasian Arctic and with summer warmth index (SWI) and NDVI derived from satellite sensors. Changes in the height and extent of willow thickets have both immediate and long-term implications for the livelihoods of the Nenets including the availability of firewood and the consequences to the migrating herds of reindeer (Forbes et al. 2009). Forbes et al. (2010) have shown very strong correlations between summer warming, annual growth rings of *Salix lanata* and decadal trends in NDVI since 1981.

Regional permafrost analysis:

To answer the third question of Subtask 2.2, we will use the trends in permafrost temperatures derived from the boreholes of the Thermal State of Permafrost (TSP) IPY project (Romanovsky et al., 2010), along with data on vegetation, active-layer and permafrost and landslide dynamics collected by the Earth Cryosphere Institute (ECI) (e.g. Drozdov et al. 2010; Liebman et al. 1998). We are particularly interested the relationships among soil texture, grazing activity and NDVI, and how these variables in turn affect the soil temperatures, active-layer thickness, and permafrost. These relationships have been extensively studied on the Yamal Peninsula and elsewhere in Russia (e.g. Yershov and Williams 1998). Vulnerability of the land cover to cryogenic disturbances depends on the ice content in the upper layers of permafrost. Cryogenic landslides are the most widely observed natural disturbance that have an impact on the land cover of the Yamal. The mechanisms of arctic landslides are rather well understood (French 2007, Lewkowicz 1990, Leibman and Egorov 1996, Leibman et al. 2003), and their interactions with vegetation are described in a series of publications (Ukraintseva and Leibman 2000, Ukraintseva et al. 2000). Ancient and contemporary landslides clearly seen on the aerial photos can be linked to specific landforms and vegetation types (Drozdov et al. 2010, Khomutov and Leibman 2009, 2010). This allows us to use remote sensing in risk assessment of the landslide hazard in the areas of human activities, which in the Yamal region includes gas production and reindeer herding, both of which may trigger landslides regardless of climate fluctuations. We will also use this knowledge base in combination with a recently completed GIS for the region and a newly acquired GeoEye scene to help predict land-surface process activation and its impact on land use using the GIPL model (see Task 3). In order to better understand the linkages between permafrost and vegetation, we have placed soil temperature loggers in each of our EAT and NAAT vegetation study plots at the surface and at the base of the soil organic layer. The data from the NAAT logger have already been analyzed (Kade et al. 2006, Walker et al. 2011 in press). The EAT loggers will be collected in summer 2011. The data will be used to determine the *n*-factor, which is the ratio of seasonal thawing or freezing degree-day sums at the soil surface to that in the air (Carlson 1952). The value integrates the effects of all surface factors of the soil thermal regime and is a simple indicator of the energy balance at the ground surface, developed in arctic engineering studies to estimate temperatures of homogeneous artificial surfaces from air temperatures. These data will be compared with similar data from North America (Kade et al. 2006) to develop trends in the *n*-factor that can be applied to the whole Arctic.

Task 3. Models of landscape change

Subtask 3.1. Arctic wetland vegetation-permafrost interactions

This portion of the project will focus on three questions:

1. How do changes associated with altered tundra soil moisture regimes influence vegetation response?
2. How do changes in soil moisture and associated vegetation changes affect permafrost?
3. Can the properties of vegetation important for modeling permafrost response to altered soil-moisture regimes be inferred from remotely sensed data?

The LCLUC call for proposals asked for a new emphasis on wetlands and how they will respond to land cover and land-use changes. Most soils in the Low Arctic are saturated with water because of thick moss mats, cold soil temperatures, and shallow active layers. The largest fen in the world is on the Arctic Coastal Plain of northern Alaska, and exists largely because of near surface permafrost that prevents the downward drainage of water. The response of Arctic wetland permafrost regimes to climate change is a primary concern because these areas could become relatively well drained if soils warm and active layers thicken, with major consequences to many ecosystem processes, including soil organic-matter decomposition and trace-gas fluxes. The insulation of soils by surface vegetation is a key control on the dynamics of the soil thermal regime (Yershov and Williams 1998, Daanen et al. 2008, Nikolsky et al. 2009). Mosses, for example, can have high thermal resistance that strongly affect soil temperatures, active-layer thickness, and permafrost stability, and their dynamics are strongly affected by changing moisture regimes and other disturbances (Chapin et al. 2008, Kade et al. 2008, Blok et al. 2009).

To address the need for more information from Arctic wetlands, we will use a modeling approach (Fig. 6) and data from a variety of sources including a detailed study that monitored the response of vegetation to variable levels of flooding that were created along a road that was constructed at Prudhoe Bay in 1982-1983 (Klinger et al. 1983). Plant species, biomass, LAI, and soil chemical and physical data were collected from experimental and control study plots associated with the Prudhoe Bay Waterflood project (Klinger et al. 1983m Meehan, no date). We also have vegetation and soil data from many other wet vegetation study plots along the NAAT including plots at Isachsen, Green Cabin, Prudhoe Bay, Franklin Bluffs, Happy Valley, Toolik Lake and Imnaviat Creek. Most of these plots have GPS coordinates. Those that predate GPS are permanently marked and will be relocated to obtain their coordinates so their spectral properties on remote sensing images can be analyzed. We will use a variety of statistical approaches to define recurring vegetation communities and relationships among environmental variables, the distribution of plant communities and satellite-derived spectral information (McCune et al. 2002, Tichy 2002, Tichy et al. 2009 in press). Additionally, in 2012 we will invite Klaus Dierssen, and Fred Daniëls, experts in circumpolar wetlands and classification of arctic vegetation (Dierssen 1996, Dierssen and Dierssen 2005, Daniëls et al. 2005), to visit the North Slope and help in the classification and analysis of these areas.

The information from these analyses will provide input to vegetation and permafrost models to predict responses to changes in summer temperatures, soil texture and soil moisture. We will also use regional climate scenarios and remote sensing data developed by UAF's Scenarios Network for Alaska and Arctic Planning (SNAP) program (Rupp et al. 2000, Murphy et al. 2010) as driving data for the permafrost and productivity models (Fig. 6).

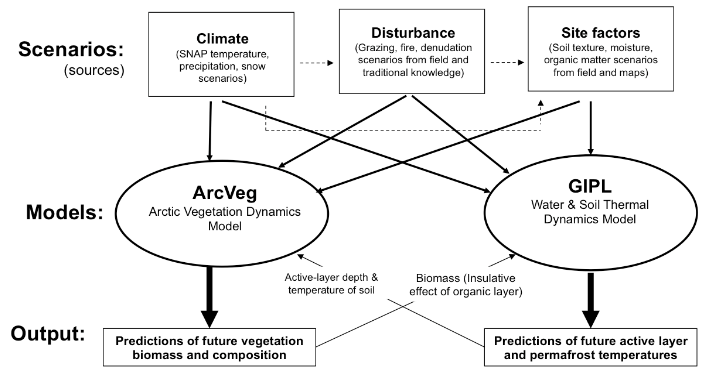

Fig. 6. *Scenarios and models for Task 3. Bold solid arrows are scenario inputs for each of the models. Dashed lines represent places where changes in one scenario may affect other scenarios. Light solid arrows represent examples where output from one model could inform the other.*

We will use the GIPL permafrost model, which was developed specifically to assess the effect of changing climate on permafrost. It is a spatially distributed physically based transient model that calculates active-layer thickness dynamics and soil temperatures down to 500 m (Sazanova and Romanovsky 2003, Marchenko et al. 2009, Nicolsky et al. 2009). This model also robustly accounts for the effects of snow cover, vegetation, soil moisture, and soil thermal properties. Input parameters to the model are spatial datasets of mean monthly air temperature and precipitation, prescribed vegetation, soil thermal properties and water content, which are specific for each vegetation and soil type and geographical location. Recently the model was applied for simulatuions of permafrost distribution for the entire pan-arctic permafrost domain using remote-sensing data (Marchenko et al., 2008a, b, 2009) (Fig. 7). The monthly satellite-derived snow-water equivalent (SWE) climatologies from 1978 through 2003 also were used to perform this simulation. Global SWE data are gridded to the Northern and Southern 25 km Equal-Area Scalable Earth Grids (EASE-Grids). Global snow water equivalent is derived from Scanning Multichannel Microwave Radiometer (SMMR) and Special Sensor Microwave/Imagers (SSM/I) (Armstrong & Brodzik, 2001). The GIPL model will be used in this project to focus on the interactions between vegetation, permafrost and soil moisture.

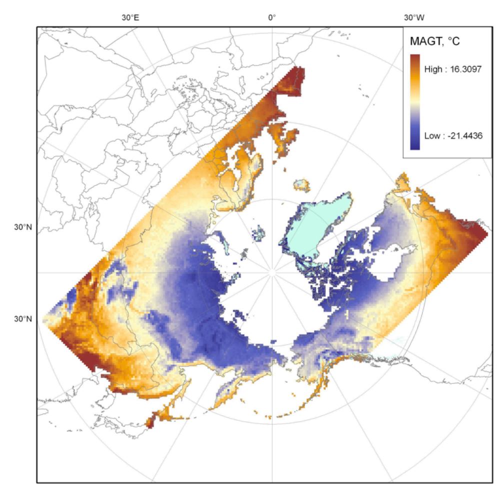

Fig. 7. *Mean annual ground temperatures at 1 m depth using AVHRR surface temperature data as a climate forcing. The data were averaged for the 1980-2003 period and simulated by the GIPL Model.*

Tundra vegetation dynamics will be simulated by the ArcVeg model. Currently, vegetation in the GIPL model is static. ArcVeg will be used to assess and project tundra vegetation dynamics across different high-latitude regions with varying climate, grazing, and soil scenarios (Epstein et al. 2000, 2001, 2004, 2007; Kruse et al. 2004, Daanen et al. 2008, Yu et al. 2009, Goetz et al.

2011). ArcVeg computes the inter-annual dynamics of tundra biomass, net primary productivity, and plant-community composition of twelve different plant functional types. The model is essentially driven by nitrogen mass balance (assuming that N is a key limiting factor for tundra vegetation), moving nitrogen among soil organic nitrogen, soil inorganic nitrogen, and plant pools. The key forcing factors in the model are climate (temperature), disturbances such as grazing and freeze-thaw processes, and the soil organic nitrogen quantities in the active layer. The model currently operates on an annual time step; however, a daily version of the model is presently being developed.In order to determine how vegetation change could affect future permafrost we will "couple" (offline) the ArcVeg model with the GIPL model. On an annual time step, ArcVeg will provide data to GIPL on the biomass of different plant functional types, for the parameterization of thermal conductivity by the surface vegetation. In turn, GIPL will provide ArcVeg with the depth of the active layer and the mean active layer temperatures, to determine the quantity of organic nitrogen available for active-layer decomposers and the rate of the mineralization process (controlled by temperature). Since the ArcVeg model is currently driven by dynamics of temperature and soil nitrogen, our first task will be to add soil moisture and surface water as controls in the model. This will involve constructing a set of water balance equations that include precipitation, snowmelt, runoff – run-on, transpiration, and evaporation; we will work closely with GIPL to develop this functionality. Resulting soil and surface water will be an additional control on vegetation and microbial activity.

Subtask 3.2. Vegetation-grazing interactions

The specific disciplinary questions that we will answer are:

1. What are the projections for changes in tundra vegetation for the North Slope and the Yamal over the next century?
2. How do climate change and the present grazing regimes interact to influence these dynamics? How sensitive are these systems to varying degrees of warming and grazing intensities?
3. What are the key mechanisms by which grazing influences vegetation dynamics in these systems (nutrient cycling acceleration, trampling, plant resistance-resilience to foraging)?

Managed reindeer (*Rangifer tarandus*) herding has large effects on land cover in many arctic tundra regions and has been a major focus of our LCLUC project (Forbes and Kumpula 2009, Forbes et al. 2009). The effects of managed reindeer and wild caribou grazing and trampling on plant species have been studied relatively extensively (e.g., Forbes and Kumpula 2009, Moen and Danell 2003, Olofsson et al. 2004, Bråthen et al. 2007, Gough et al. 2007, Pajunen et al. 2008, Kitti et al. 2009). However, the interactions between reindeer or caribou grazing and climate change, and their effects on plant community structure and land cover have received less attention (e.g., Klein and Shulski 2009, Post and Pedersen 2008, Olofsson et al. 2009). Post and Pedersen (2008) found that grazing mitigated long-term warming effects on plant communities, as was also suggested by Olofsson et al. (2009) in an herbivore-shrub interaction study where herbivores were found to inhibit shrub expansion. These results are consistent with one of our recent modeling studies that found that grazing decreased tundra biomass and buffered plant responses to warming (Yu et al. 2009). Managed reindeer grazing also appears to cause relative increases in deciduous shrub cover compared to evergreen shrubs over much of the Yamal Peninsula (Walker et al. 2011b). Since many deciduous shrubs are also preferred forage for reindeer and caribou (e.g. Pajunen et al. 2008, Pajunen 2009, Kitti et al. 2009, Olofsson et al. 2009), the mechanisms by which the preferentially eaten deciduous shrubs increase in abundance with grazing is unclear. There are several potential mechanisms, including 1) accelerated nitrogen cycling with a positive feedback for the nutrient-rich, forage species, and 2) trampling of the plant community as a whole, followed by regrowth of the more resilient deciduous forage species. Yet, these and other possible explanations have not been teased apart. Further investigation of grazing effects on tundra vegetation at the level of the major plant functional types (PFTs) is needed for a better understanding of warming and herbivore interactions on tundra plant community structure and composition.

To answer questions 1 to 3 of Subtask 3.2, we will use the vegetation, biomass, and remote-sensing data from the NAAT and EAT (see Task 2.2), along with General Circulation Model (GCM), SNAP climate scenarios (Murphy et al. 2010) and information from the Nenets on grazing practices (see Task 5.2) to examine the interacting effects of climate and grazing on the land cover of the Yamal. A specific focus will be on changes in production and composition of plant-functional-types (e.g. deciduous and evergreen shrubs, graminoids, mosses, lichens). Varying climate change scenarios (i.e. different degrees of warming and cooling) and different grazing regimes (with respect to return interval and forage consumed) can be simulated in order to conduct sensitivity analyses of these systems to climate, grazing, and their interaction. During the last two rounds of funding, our project collaborated with researchers in Finland on reindeer effects on LCLUC. We will continue this collaboration to examine several decades of increasing deciduous shrubs within wetlands, their relationship to increasing temperatures and NDVI, and the implications for Nenets reindeer herding (Forbes et al. 2010). This new proposed study will synthesize the results from two widespread wetland species (*Salix lanata*, *Alnus fruticosa*). *S. lanata* data will be derived from three different latitudes along the Yamal transect and from both sandy and clayey soils at the Bovanenkovo gas field. Also Johan Olofsson and his graduate student Elina Kaarlejärvi from Umeå University, Sweden, have a long time series (12 years) of reindeer exclosure data (Olofsson et al. 2009) that will allow us to compare some controlled effects of grazing on vegetation from field data with the ArcVeg simulation output.

To help explain the anomalously high amount of deciduous shrubs and low amount of evergreen shrubs on the Yamal Peninsula relative to the North Slope of AK, we will conduct sensitivity analyses on various model parameters related to grazing and vegetation response in ArcVeg. We will specifically alter the following two parameters: 1) the nitrogen-cycling acceleration rate related to grazing (i.e. the percentage of organic nitrogen eaten that gets returned to the site as inorganic nitrogen through animal waste); and 2) the resilience (i.e. growth rate) of the different plant functional types in response to being eaten. From some preliminary model runs, we find that small changes in the resilience parameter for evergreen shrubs can determine whether this plant type responds positively or negatively to grazing. Presently, the vegetation in ArcVeg is affected by grazing solely through foraging; however, trampling clearly is also an important process in grazed systems (Olofsson et al. 2009), and we will add a trampling function to ArcVeg. While foraging by reindeer and caribou is largely a selective process controlled by plant nutrition, trampling is either a more general process that affects all plant types, or it may affect some of the shorter plant types to a greater extent than taller shrubs. Our objective here is to understand how actual changes in grazing regimes alter the land cover. We will use available literature on wild caribou grazing (e.g. White et al. 1975, 1983, White and Trudell 1980a,b) on the North Slope of AK and reindeer grazing/trampling in northern Fennoscandian wetlands (Kitti et al. 2009). We will also use our information from observations and interviews with Nenets, regarding any ways in which they may have altered their herding practices in response to gas development on the Yamal and/or climate change. These new grazing scenarios will be used as parameters in ArcVeg to determine how climate change and one aspect of land use change (energy development) can affect another aspect of land use (wild and managed grazing), which in turn affects the land cover (vegetation). To examine the potential for further feedbacks to grazers, we can use ArcVeg to track the forage consumed over time in these scenarios.

Task 4. Hierarchical analysis of land-use changes at Prudhoe Bay and Bovanenkovo

We will address the following questions:

1. How has the infrastructure (roads, borrow pits, pipelines, construction pads, etc.) changed since the discovery of oil at Prudhoe Bay in 1968, and the discovery of gas at Bovanenkovo in 1971?

2. Can Landsat GLS data be used to reliably detect major changes in infrastructure?
3. What have been the long-term indirect effects of the infrastructure changes (e.g. roadside flooding, roadside thermokarst, dust, roadside etc.)? Can these be reliably detected using very high-resolution (VHR) imagery (e.g. Quickbird-2, GeoEye, etc.)

There are three main goals of this comparative analysis: 1) To produce an updated inventory of the extent of infrastructure within the North Slope and Bovanenkovo fields. 2) To determine if there are aspects of development that go beyond simple accumulation of impacts to include impacts that have nonlinear (e.g., exponential) effects related to environmental feedbacks. 3) To develop a set of remote-sensing products that we can use in our interviews of the subsistence users and oil field workers to document their perceptions of the landscape changes (see Task 5).

During the last two rounds of funding, our project collaborated with researchers in Finland and Russia to examine the cumulative effects of numerous agents of change on the indigenous Nenets people of the Yamal Peninsula region (Forbes et al. 2009, Kumpula et al. 2010, 2011, Stammler et al. 2009, Walker et al. 2011b). A portion of this study examined the consequences of infrastructure change in the Bovanenkovo gas field (BGF) during the exploration phase of development using high-resolution Quickbird imagery (1980s-2005) (Forbes et al. 2009, Kumpula et al. 2010, 2011). A new railroad linking the Bovanenkovo field to the rest of Russia was completed in 2010. The infrastructure network will expand greatly after 2012 when the main pipeline to the south is completed and the Bovanenkovo field begins operation. We will use a variety of remote-sensing products including, SPOT, ASTER and other available VHR imagery to fill gaps in the Landsat time series to build a comprehensive chronology of BGF industrial development.

For the northern Alaska oil fields, we will update a previous analysis of historical (1968-2001) infrastructure changes (NRC 2003). Oilfield infrastructure affects a large area of the Alaska North Slope. The oil industry has an archive of annual aerial photographs of the entire oil field and maintains a GIS database that shows the extent of all infrastructure including roads, gravel construction pads, power lines, culverts, bridges, etc. The database is described in Appendix E of the National Research Council's report of cumulative effects of oil development on the Alaska North Slope (NRC 2003). This database is updated annually and has recently been made available to us for this analysis. As of 2001, about 11,200 ha, including the oilfields, Trans-Alaska Pipeline and Dalton Highway, had been covered by gravel or mined, and about 2600 km^2 were enclosed by the perimeter of the oil fields (NRC 2003). Documenting and monitoring changes over such a large area is a challenge. Only the Landsat GLS products with 30-m pixels offer full coverage of the entire region at regular intervals and with a resolution that can detect the major (but not all) changes. GLS data could offer a quick inexpensive way to monitor changes if the results are comparable to the detailed GIS analysis of the oil industry. We will use the 2005 GLS data to delineate the extent of North Slope infrastructure and compare the results with a time-series area analysis of infrastructure changes that used high-resolution aerial photographs (NRC 2003). Changes in different landscapes (floodplains, flat thaw lake plains and hilly plains, sandy and loess regions) will be compared. We will also compare the changes in different vegetation/land-cover types (Muller et al. 1999, Jorgenson and Heiner 2003). We are interested in what percentage of the changes are detectable using GLS data, what types of infrastructure are detectable, and how this varies according to terrain and vegetation type.

Much of the impact on ecosystems from oil and gas development occurs at much finer scales than is detectable with GLS and coarser scale satellite imagery (Kumpula et al. 2010, 2011, Walker et al. 1986a, b). We are particularly interested in the effect of development on wetland habitats and on permafrost-related features, The earlier studies suggested that some impacts may be nonlinear. For example, changes in the extent of thermokarst pits and flooding of ice-wedge polygon troughs appeared to be increasing exponentially because of thermal feedbacks related to increased amounts of heat absorbing water bodies (Walker et al. 1986b, 1987). Such impacts are common along roads and within village road networks such as the one at Nuiqsut in the Colville River delta near Prudhoe Bay. We will use available Quickbird images to do a fine-scale (1:6000-scale) analysis of three 25-km^2 areas of intensive development that were previously mapped but have not been updated since 1983 (Walker et al. 1980, 1987). We will also examine the road network in Nuiqsut, a nearby Iñupiat village, to compare the present extent of thermokarst features to those in 1949 aerial photographs taken by the U.S. Navy. The mapping will provide detailed time series of a variety of indirect impacts, such as off-road vehicle trails, road-side flooding and areas of dust-covered tundra, thermokarst and flooding. This information will be used in interviews with villagers and oil field workers (see Task 5).

Task 5. Analysis of the effects of LCLUC on livelihoods of Inupiat and Nenets.

The research questions for this portion of the project will be:

1. How do Iñupiat hunters and Nenets reindeer herders perceive cumulative effects related to LCLUC?
2. How are changes affecting ecosystems services important to Iñupiat and Nenets indigenous economies at the community and brigade levels?
3. How do strategies for responding to change compare between the Yamal and the North Slope?
4. How do Iñupiat and Nenets evaluate their capacities to respond to change, given the projections for future industrial development with climate change?

These questions follow from the assumption that the interactions of Nenets and Iñupiat with oil and gas development and climate change share similarities and differences that can be instructive in understanding human adaptation in conditions of rapid change, and that local knowledge can contribute to the findings of science. We will address these questions with information from past and ongoing social-ecological studies in northern Alaska and Russia to understand social responses to LCLUC and their related feedbacks. As found in previous research, Nenets and Iñupiat have demonstrated significant adaptive capacity in the face of these forces of change (Forbes et al 2009, Haley 2004), in spite of significant differences in material assets and standards of living.

Our method integrates the findings from this project's other analyses (Tasks 1-4) with documentation of local ecological knowledge and past responses to change. We use an "emic" approach (i.e. behavior or a belief in terms meaningful to the actor) (Bernard 2006) for comparative studies to complete the synthesis investigate social-ecological dynamics and implications of cumulative effects to indigenous livelihoods. Our framework examines 1) local perceptions of change, 2) strategies for responding to change 3) the implications to local livelihoods and 4) an evaluation of the capacity to adaptive in the face of future changes.

In the case of Yamal, the Arctic Centre in Finland has used remote-sensing products extensively with studies of the herders' perceptions of the land-cover and land-use changes (Forbes et al. 2009, 2010, Stammler 2005, Kumpula et al. 2010, 2011). We will focus on quantitative and qualitative data concerning social-ecological changes in the vicinity of Bovanenkovo gas field that have taken place since 2005 at the conclusion of a major study funded by the Academy of Finland (Environmental and Social Impacts of Industrialization in Northern Russia, ENSINOR). We will use newly acquired remote sensing products that have been ground-truthed (summer 2011) using ecological field sampling techniques (vegetation composition, cover, structure, leaf area index). Socio-economic data will derive from our active migration with three brigades whose territories are now directly affected by the Bovanenkovo gas field. We will also have new information from Nenets reindeer brigades 4 and 8 from extensive follow-up of the ENSINOR interviews (Forbes et al. 2009, Kumpula et al. 2010, 2011). Since 2005 industrial development has spread north and east onto the territory of brigade 5, so it will be included as well. Special emphasis will be placed on the socio-economic implications of both infrastructure development (Task 4) and changing environmental conditions related to changes in NDVI patterns, increased shrubs, and local areas of increases in grasses (see tasks 2.2 and 3.2).

In Alaska the products of Task 4 and summarized findings from social data (economic data and land-use data) will be used as prompts in group interviews with North Slope residents and with oil field workers to document perceptions of change and the implications of change to ecosystem services. The integration of local knowledge and spatial analysis will be completed as iterative group interviews with residents of Nuiqsut, the Iñupiat Alaska community in closest proximity to oil infrastructure. The Nuiqusit Subsistence Advisory Board will serve as our advisory group for this work. Methods previously developed for documenting oil-field workers' local knowledge have proven valuable in understanding ecological change (Backensto 2009) and will be employed. The Alaska focus is on the implications of LCLUC to the mixed cash-subsistence economies of North Slope villages, and draws on census data, findings of the Survey of Living Conditions (SLICA), and the detailed socio-economic household data recently gathered through the "The Study of Sharing Networks to Assess the Vulnerabilities of Oil and Gas Development Impacts in Arctic Alaska" (Kofinas, PI / MMS M07AC13028). Task 5 contributes to the NSF Arctic Long-Term Ecological Research's (ARC- LTER) participation in the Maps and Locals project, a cross-site collaborative study of 11 LTER sites (http://www.lter.uaf.edu/bnz_MALS.cfm), which is focused on methods for integrating local knowledge with spatial analysis in coupled social-ecological systems research.

Forbes, Kofinas, and Stammler will collaborate with local residents to complete a comparative analysis of Yamal and North Slope to identify the relative vulnerability of these indigenous peoples to oil and gas development and climate change, with the goal of generating generalized propositions about LCLUC effects on arctic indigenous livelihoods.

Task 6. Yamal-Alaska workshop

An workshop involving scientists, indigenous hunters and herders, and policy makers from Alaska and Yamal will be convened to present the results of our research and to develop an international approach to the analysis of cumulative effects of resource development and climate change on Arctic social-ecological systems. The goals will be to (1) compare social-ecological interactions of oil and gas development with climate change in the two regions, (2) consider frameworks for the cumulative effects that are applicable in a circum-Arctic context, (3) identify strategies for mitigation, adaptation, and transformation in the face of these interacting forces of change, and 4) generate a list of barriers and facilitating conditions for scientists, local knowledge holders, and decision makers to implement adaptive co-management research in the future. Adaptive co-management practices call for close collaboration and integration of management, research, and monitoring practices through explicit feedback mechanisms to refine and improve future management decisions (Armitage et al. 2007, Kofinas et al. 2007). These might include among other things comprehensive region-wide planning, a focus on ecosystem-level research, approaches to defining the true area affected by the industrial development (rather than reporting only the footprint of gravel placement and mining), social-ecological approaches that involve closer analysis of the effects on human communities, and how to deal with the uncertainties of the interactions between different types of perturbations. The proposed workshop will lay the ground work for a larger future workshop involving scientists and indigenous participants from across the Arctic who would work to develop an Arctic-wide approach to the analysis of cumulative effects of climate change and industrial development on social-ecological systems.

EDUCATION AND OUTREACH

Findings from this project, if appropriately communicated to local residents and industry representatives, may help both groups adapt more effectively to impending changes. They could also influence the way in which the oil industry and local populations interact. The indigenous people in both regions feel that they can adapt to the changes occurring if they are involved and can influence decisions that affect their ability to use the land and their resources

(Forbes and Stammler 2009). A major element of our human-dimension studies is adaptive co-management and active engagement of the local populations in the science (see Task 5). In this project we also will actively engage industry. Dr. Bill Streever, environmental studies leader for BP Exploration (Alaska) Inc., will lead the Alaska industry and village outreach part of the project. He will aid in involving oil-industry employees and North Slope residents in Barrow, Alaska in the project and informing them about scientific results relevant to their interests while also showing appropriate follow-through to individuals interviewed as part of Task 4. Industry employees will be reached through briefings in Anchorage and in the North Slope oilfields. Initially, Anchorage briefings will be managed through the Alaska Oil and Gas Association (the regional industry trade association) to capture representatives from all of the companies working in northern Alaska. Secondarily, follow-up briefings may be offered to individual companies as opportunities arise. On the North Slope, briefings will be offered to staff based in the oilfields during weekly safety and planning meetings. North Slope residents will be reached through public presentations in Barrow managed through Ilisagvik College (the two-year tribal college in Barrow) and the Barrow Arctic Science Consortium. The presentation and/or a question-and-answer session will be transmitted over the North Slope public radio station, KBRW, which is received by all of the North Slope villages. Also, one or more articles will be written in nontechnical language describing the project and its outcomes for publication in the North Slope's newspaper, *The Arctic Sounder*. Throughout the outreach effort in both the oilfields and in the Yamal and North Slope villages, remote sensing products developed as part of Task 4 and interview responses obtained as part of Task 5 will help nonspecialists understand both the methods and the relevance of this project. Additional outreach will be via publications, presentations, and a web page that is maintained by Edie Barbour http://www.geobotany.uaf.edu/yamal/. Other outreach efforts include our continued participation in the production of the State of the Climate (e.g., Walker et al. 2010, Romanovsky et al. 2010) and the Arctic Report Card (http://www.arctic.noaa.gov/reportcard/index.html) which are produced annually by NOAA to update the scientific community and the public about the ongoing changes in global and Arctic systems.

DATA MANAGEMENT

The project will have a data manager and web site developer. Each of the research teams at UVA, ECI, UAF, and the Arctic Centre will be responsible for the data within their individual tasks. Overall, project data management will be coordinated through the Alaska Geobotanical Center (AGC). A part-time data manager will coordinate the development of the remote-sensing data archive for the project and insure that metadata is written for each data set following national protocols. Datasets will be made available to the wider science community through the Joint Office for Science Support (JOSS) as soon as they become available and are quality checked. Final archiving will be done through the Arctic Data Coordination Center and Geographic Information Network of Alaska (GINA) at UAF. All project data will be made available through the AGC web site http://www.geobotany.uaf.edu/. The current web site http://www.geobotany.uaf.edu/yamal/ focuses on the LCLUC issues on the Yamal Peninsula. This will be expanded to address the cumulative effects of climate change and resource development in Northern Alaska and the Yamal Peninsula.

OVERALL PROJECT MANAGEMENT AND COLLABORATIONS

The project will have a science management team composed of the Co-Is, Bhatt, Comiso, Epstein, Forbes, Kofinas, Leibman, Marchenko, Pinzon, Raynolds, Romanovsky, Streever and 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-Is. The project will be coordinated with other LCLUC projects. Most relevant, the permafrost modeling effort will strengthen its ties to the LCLUC project at the University of Washington because of the linkages between permafrost thawing and changes in arctic trace-gas fluxes. At the organizing workshop, we will explore the ways in which the two modeling efforts can be more strongly connected. We have also developed a strong collaboration with NSF Arctic Long-Term Ecological Research's (ARC-LTER) Maps and Locals project, a cross-site collaborative study of 11 LTER sites (http://www.lter.uaf.edu/bnz_MALS.cfm), which is integrating local knowledge with spatial analysis in coupled social-ecological systems. Furthermore, we have added Dr. Bill Streever, Environmental Studies Program Director for BP Exploration (Alaska) Inc. and current Chair of the Science and Technical Advisory Panel for the North Slope Science Initiative. Dr. Streever will develop the industry and community outreach portions of the project.

EXPECTED OUTCOMES, DELIVERABLES, AND SCHEDULE

The deliverables for the six tasks include: **Task 1 (Organizing workshop):** A summary of the results of the workshop will be prepared and posted on the project web site. The document will lay the foundation for the synthesis, modeling and human dimension aspects of the project. **Task 2 (Synthesis of spatial and temporal land cover change):** New raster based maps of vegetation (1-km pixels) and surface temperature (8-km pixels) will be prepared and published. A synthesis of information from the Eurasian and North America Arctic transects will be completed. A specially designed landscape map of the key areas of the Vaskiny Dachi site near Bovanenkovo will be prepared. A series of papers will be directed at a whole-ecosystem understanding of the mechanisms and linkages among arctic climate, coastal sea-ice concentrations, summer land-surface temperature, snow dynamics, permafrost temperatures, soil physical properties (water regimes and texture), active-layer dynamics, vegetation properties, and key disturbances (primarily infrastructure impacts, grazing by reindeer, and landslides). The papers will be presented at an AGU session in Fall 2014 and submitted to an appropriate journal such as *Permafrost and Periglacial Processes, Environmental Research Letters,* or *Geophysical Research Letters* by Spring 2015. **Task 3:** A whole-system modeling framework will involve interactive GIPL and ArcVeg models. The ArcVeg modeling results will be the subject of a Post-doctoral project by Qin Yu, University of Virginia. The GIPL model is being developed by Sergei Marchenko and Vladimir Romanovsky and will be presented in a series of papers at future conferences and submitted to appropriate journals. **Task 4:** The hierarchical remote-sensing analysis comparing change in the Prudhoe Bay and Bovanenkovo areas will be conducted during the first two years of the project. A paper comparing the Prudhoe Bay and Yamal regions will be presented at the Yamal-Alaska Workshop in 2014 and submitted to a major international journal by Spring 2015. **Task 5:** A paper that compares and contrasts the perceptions of change among the indigenous Nenets and Inupiat people will be presented at the Yamal-Alaska Workshop in 2014 and submitted to a major international journal by Spring 2015. **Task 6:** The Yamal-Alaska Workshop will be held in the final year of the project and will be a synthesis of the ecological and sociological changes along the two transects. We will solicit several journals for a special issue devoted to the results from this workshop.

HOW THE RESEARCH FITS WITHIN NASA AND THE LCLUC PROGRAM RESEARCH OBJECTIVES

The project addresses the five major elements of the LCLUC program's call for proposals: 1) **Synthesis**: Our entire project is organized around the synthesis of prior LCLUC research combined with other relevant information. 2) **VIA:** We will study the ecological and social changes to the two most strongly impacted groups of indigenous people in the Arctic. Several of our team members are leaders in the field of Arctic SES analysis, and a major element of the project is linked to the NSF-sponsored Maps and Locals (MALS) project. 3) **Wetlands:** We will use previously obtained wetland data to classify and model tundra wetland vegetation and permafrost response to changing water regimes. 4) **Remote sensing:** The project will utilize a wide variety of remote-sensing and GIS products in its modeling and synthesis to help project future responses of arctic SESs to climate change and other disturbances. **5) Cross LCLUC linkages:** We will collaborate with Dennis Lettenmiar's LCLUC wetland modeling effort at U. of Washington to develop holistic models of arctic wetland response to climate warming that include changes to permafrost regimes, soil water, vegetation, and trace gas fluxes.

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