Annual Report for Period: 09/2006 - 08/2007 **Submitted on:** 07/15/2007

Principal Investigator: Walker, Donald A. **Award ID:** 0531180

Organization: U of Alaska Fairbanks

Title:

Collaborative Research: Greening of the Arctic - Synthesis and Models to Examine the Effects of Climate, Sea-ice, and Terrain on Circumpolar Vegetation Change

Project Participants

Senior Personnel

Name: Walker, Donald
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Bhatt, Uma
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Jia, Gensu
Worked for more than 160 Hours: Yes
Contribution to Project:
Developing time series of NDVI for the Arctic.

Name: Epstein, Howard
Worked for more than 160 Hours: Yes
Contribution to Project:
Developing vegetation change models. PI on collaborative proposal at U Virginia.

Name: Comiso, Joey
Worked for more than 160 Hours: Yes
Contribution to Project:
Developing time series of sea ice and land surface temperatures for the Arctic.

Name: Kaplan, Jed
Worked for more than 160 Hours: Yes
Contribution to Project:
Devoloping global vegetation change models.

Post-doc

Graduate Student

Name: Raynolds, Martha
Worked for more than 160 Hours: Yes
Contribution to Project:
Ph.D. studned examining pan-Arctic geobotanical GIS database and analysis of vegetation-terrain-temperature- NDVI relationships

Name: Munger, Corinne
Worked for more than 160 Hours: Yes
Contribution to Project:
MS student. Vegetation and NDVI change at Toolik Lake in relationship to glacial history.

Name: Cook, Benjamin

Worked for more than 160 Hours: Yes

Contribution to Project:

Ph.D. Graduate student. Disseration Title ôRegional Climate Change, Ecosystem Responses, and Climate Feedbacksö

Name: Yu, Qin

Worked for more than 160 Hours: Yes

Contribution to Project:

Ph.D. Student

Undergraduate Student

Technician, Programmer

Name: Maier, Hilmar

Worked for more than 160 Hours: Yes

Contribution to Project:

GIS, remote sensing, and system analyst

Name: Barbour, Edie

Worked for more than 160 Hours: Yes

Contribution to Project:

Web-site developer

Other Participant

Research Experience for Undergraduates

Organizational Partners

Other Collaborators or Contacts

Activities and Findings

Research and Education Activities:

INTRODUCTION

One, often overlooked, feature of the Arctic terrestial tundra is its intimate relationship with the Arctic Ocean and sea ice. Eighty percent of the Arctic tundra (3.2 million km2) is within 100 km of perennially or seasonally frozen seawaters that provide the cool summer temperatures necessary for tundraÆs presence. Since 1975, the September sea-ice extent has declined nearly nine percent per decade, with a total reduction of 21%. Forty percent of the models predict complete loss of Arctic late-summer sea ice by 2100. Changes to the sea-ice boundaries will likely affect a wide variety of other changes to the Arctic System including northward migration of extratropical cyclones, general warming of the land surfaces, and reduction in the extent of the tundra biome. These changes will have major implications for the permafrost, snow, hydrology, soils, wildlife, and people who live in the Arctic. They also have global implications because of albedo and trace-gas feedbacks to the climate system. Consequently, one of the major questions facing Arctic terrestrial ecologists at the moment is, ôWhat will happen to the tundra regions if the Arctic Ocean becomes seasonally ice free as indicated by current trends in sea ice?ö The Greening of the Arctic initiative examines the sea-ice, climate and vegetation

interrelationships and the relevance to people living in the Arctic. Linkages between sea ice and terrestrial vegetation are indirect û through albedo/climate feedbacks to the atmosphere. Several new circumpolar databases offer a fresh perspective to view and study changes to the vegetation of the whole Arctic. New circumpolar maps and remote sensing data provide tools to examine the underlying causes of pan-Arctic vegetation change. A synthesis of these circumpolar data sets is especially appropriate now during the International Polar Year planned for 2007-2008.
We are examining how the vegetation of the circumpolar Arctic is responding to recent changes in climate and sea ice, and how these changes are modified by terrain variables, such as soils, topography, and bedrock. We are using observed information from GIS and remote-sensing data sources to help predict future response of arctic vegetation.
Traditionally, the Arctic system has been studied by separate groups of scientists studying the ocean, atmosphere, land, and ice components of the system. Our team consists of experts in geobotany, sea ice, climatology, soils, permafrost, remote sensing, and vegetation modeling, who will address the central question of how pan-Arctic vegetation has responded to climate change and how it will change in the future. The project also has strong linkages to projects studying other components of the total Arctic System including the geophysical environment, carbon budgets, wildlife, and humans. Our project is divided into four main research components and a management component: Component I: Climate, sea-ice, land-surface temperatures: trends and interreltionships (Bhatt, Comiso, Jia, Raynolds); Component II: Spatial patterns of circumpolar vegetation and NDVI (Jia, Raynolds, Walker); Component III: Temporal patterns of circumpolar NDVI (Jia, Bhatt, Comiso, Markon, Epstein); Component IV: Simulation Modeling (Epstein, Kaplan, Lischke);Component V: Project management (Walker, Raynolds, Maier).
ACTIVITIES:
Meetings attended with one or more presentations regarding the Greening of the Arctic initiative (oral talk or poster):
1. ICARP II meeting, Copenhagen, Denmark, 10-12 Nov 2005
2. NOAA State of the Arctic Workshop, Woods Hole, MA, 24-26 Oct 2005
3. ARCSS SASS Investigators Meeting, Seattle, WA, 26-27 Mar 2006
4. NEESPI CLAC meeting, Fairbanks, AK, 6-8 Apr 2006
5. Bi-Annual Circumpolar Remote Sensing Symposium, Seward, AK, 16-19 May 2006
5. The Arctic Forum, Washington DC, 25-26 May 2006
6. Arctic AAAS Meeting, Fairbanks, AK, 2-4 Oct 2006,
7. NASA LCLUC Meeting, University of Maryland, 10-12 Oct 2006
8. 7th International Conference on Global Change, Fairbanks, AK, 19-20 Feb 2007
8. NASA LCLUC Meeting, University of Maryland, 4-6 Apr 2007
9. IS/CGU/AMS Congress Meeting, St. Johns, New Foundland, 28 May-1 Jun 2007
Project meetings
1. AGU Fall Meeting, San Francisco, CA, Dec 2005
2. AGU Fall Meeting, San Francisco, CA, Dec 2006
3. NASA LCLUC Meeting, University of Maryland, 13 Oct 2006
4. GOA meeting, Copenhagen, Denmark, 8-11 Feb 2007

Publications
1. Cook, B.I., G.B. Bonan, S. Levis, and H.E. Epstein. Dynamic vegetation amplifies climate model response to snow cover changes. Climate Dynamics in press.
2. Cook, B.I., G.B. Bonan, S. Levis, and H.E. Epstein. The thermal insulative effect of snow in the climate system. Submitted to Climate Dynamics.
3. Cook, B.I., H.E. Epstein, T.M. Smith, and J.O. Kaplan. Artic Oscillation and El Ni±o Southern Oscillation induced climate impacts and terrestrial ecosystem responses. Submitted to Global Biogeochemical Cycles.
4. Epstein, H.E., J.O. Kaplan, H. Lischke, and Q. Yu. 2007. Simulating future changes in arctic and sub-arctic vegetation. Computing in Science and Engineering 9:12-23.
5. Epstein, H.E., D.A. Walker, M.K. Raynolds, G.J. Jia, and A.M. Kelley. Phytomass of patterned-ground ecosystems across the full temperature gradient of the arctic tundra. Submitted to Journal of Geophysical Research-Biogeosciences.

6. Jia, G. J., H. E. Epstein, and D. A. Walker. 2006. Spatial heterogeneity of tundra vegetation response to recent temperature changes. Global Change Biology, 42-55.
7. Jia, G.J., H.E. Epstein, and D.A. Walker. Vegetation greening in the Canadian Arctic related to warming and sea-ice decline. Submitted to Journal of Geophysical Research-Biogeosciences.
8. Richter-Menge, J., Overland, J., Proshutinsky, A., Romanovsky, V., Bengtsson, L., Brigham, L., Dyurgerov, M., Gascard, J.C., Gerland, S., Graversen, R., Hass, C., Karcher, M., Kuhry, P., Maslanik, J., Melling, H., Maslowski, W., Morison, J., Perovich, D., Przybylak, R., Rachold, V., Rigor, I., Shiklomanov, A., Stoeve, J., Walker, D., Walsh, J. 2006. State of the Arctic Report, 36 pp, NOAA/OAR/PMEL, Seattle, WA.
9. Raynolds, M. K., J. J. Comiso, D. A. Walker, D. Verbyla. (under revision 2007). Relationship between satellite-derived land surface temperatures, arctic vegetation types, and NDVI. Remote Sensing of Environment.
10. Raynolds, M.K., D,A, Walker, and H.A. Maier. 2006. NDVI patterns and phytomass dirtribution in the circumpolar Arctic. Remote Sensing of the Environment, 102: 271-281.
11. Raynolds, M. K., C. A. Munger, D. A.Walker, C. M. Vonlanthen, A. N. Kade. (submitted 2007).Vegetation, biomass, thaw depth and snow depth maps along the North American Arctic Transect. Journal of Geophysical Research Biogeosciences.
12. Walker, D. A., H. E. Epstein, W. A. Gould, C. L. Ping, V. E. Romanovsky, Y. Shur, C. T. Tarnocai, R. P. Daanen, G. Gonzalez, A. N. Kade, A. M. Kelley, W. B. Drantz, P. Kuss, N. V. Matveyeva, G. J. Miochaelson, C. A. Munger, D. J. Nickolsky, R. A. Peterson, M. K. Raynolds, and C. M. Vonlanthen. 2007 submitted. Biocomplexity of msall patterned-ground features along the North American Arctic Transect. Journal of Geophysical Research û Biogeosciences.

Presentations

1. Bhatt, U.S., D.A. Walker, M.K. Raynolds, and J.C. Comiso. 2007. Influence of Regional Sea Ice Variability on Arctic Tundra. Pages 76-78 in Seventh International Conference on Global Change: Connection to the Arctic (GCCA-7), 19-20 February, 2007, Fairbanks, Alaska,
2. Bhatt, U. D. Walker, M. Raynolds, J. Comiso. 2007. Influence of Regional Sea Ice Variability on Arctic Tundra. CMOS/CGU/AMS 2007 Congress Meeting, St John's, Newfoundland Canada, 31 May 2007 (poster date). Canadian Meteorological and Oceanographic Society, Canadian Geophysical Union, American Meteorological Society
3. Epstein, H.E., D.A. Walker, G.J. Jia, A.M. Kelley and M.K. Raynolds. Climate, plant biomass, and NDVI relationships along the full arctic bioclimate gradient. Arctic Forum May 2006, Washington, D.C.
4. Epstein, H.E. Greening of the Arctic: Assessing tundra dynamics with remote sensing and modeling. Earth System Science Partnership Open Science Conference, Beijing, China, November 2006.
5. Cook, B.I., G.B. Bonan, S. Levis, H.E. Epstein, and T.M. Smith. Amplification of climate model response to snow cover fraction parameterization through dynamic vegetation. American Geophysical Union Fall Meeting, San Francisco, CA, December 2006.
6. Epstein, H.E., A.M. Kelley, D.A. Walker, G.J. Jia, and M.K. Raynolds. Regional-scale vegetation dynamics in patterned-ground ecosystems of arctic tundra. American Geophysical Union Fall Meeting, San Francisco, CA, December 2006.
7. Jia, G.J. H.E. Epstein, and D.A. Walker. Decadal changes of vegetation greenness in the Canadian Arctic. American Geophysical Union Fall Meeting, San Francisco, CA, December 2006.
8. Raynolds, M. K and D. A. Walker. 2006. Satellite land surface temperatures and tundra vegetation. Presentation at Arctic Science Conference. Fairbanks AK, 2-4 October 2006. p 55.
9. Raynolds, M. K. and D. A. Walker. 2006. Arctic Patterned Ground. Poster at American Geophysical Union conference, San Francisco, 11-15 December 2006.
10. Raynolds, M. K. 2007. Arctic vegetation: its distribution and characteristics. GLOBE Teachers. 23 March 2007, Fairbanks Alaska.
11. Raynolds, M. K. 2007. Searching for the effects of climate change on arctic vegetation. Science CafÚ, 29 May 2007, Fairbanks Alaska.

Graduate Students
Ben Cook (Ph.D. 2007) û Dissertation Title ôRegional Climate Change, Ecosystem Responses, and Climate Feedbacksö (Major advisor û Epstein)
Corinne Munger (M.S. 2007) û Dissertation title ôSpatial and temporal patterns of vegetation, terrain, and greenness in the Toolik Lake and Upper Kuparuk River region, Alaskaö (Major advisor û Walker)
Martha Raynolds (Ph.D. Candidate) (Major advisor û Walker)
Qin Yu (Ph.D. Candidate) (Major advisor û Epstein)

Findings:

SUMMARIES OF RESEARCH RESULTS
Component I: Climate, sea-ice, land-surface temperatures: trends and interreltionships (Bhatt, Comiso, Raynolds)
For this analysis we use 25 km resolution passive microwave sea ice concentration (Comiso 1999) and AVHRR land surface temperatures (Comiso 2006, 2003) covering the 24-year period from January 1982 to December 2005. The spatial variations of the climate-tundra relationships are examined by performing analysis regionally as defined by bioclimate subzones (CAVM 2003). We developed FORTRAN programs, to construct indices of ice area and surface temperature in 100-km buffer zones along the coast over the ocean and land, respectively. Other standard climate analysis programs were adapted for this data set and the research questions of this project. An analysis of the monthly records of ice concentration and land surface temperaure indicates that the land surface temperatures are cooler when ice is more extensive. This statement appears to be true for the pan-arctic region. A subsequent analysis has been performed of the evolution of this relationship using weekly ice concentration and land surface temperaure. We have focused our detailed analysis over two regions so far, the Beaufort Sea and Kara Sea regions, in order to better understand the relationships between climate parameters before developing the pan-arctic view. The relationships with the larger scale climate is being examined. Thus far, our analysis has not directly linked sea ice and NDVI (skipping the intermediate component of land surface temperature), but alternate ways of looking at the data are being pursued.
Major findings
- There is a decreasing trend in sea ice area in the Arctic Ocean and increasing trends of Summer Warmth Index (SWI) on land.
- Sea ice opening up earlier is correlated with a warmer summer and this is likely due in part to large scale climate circulation from previous winter as well as local effects.
- There are notable regional variations in details of the climate relationships in the Arctic, warranting analysis on regional scales.
- Kara-Yamal is more closely associated with the NAO/NAM while the Beaufort (large amplitude during 1998) with ENSO.

Component II: Spatial patterns of circumpolar vegetation and NDVI (Raynolds, Munger, Walker)
Major findings
Biomass:
ò There is a five-fold increase in total biomass on the zonal 10 x 10 m grids from Subzones A and B, to Subzone E ranging from from 0.4 kg/100 m2 to 74.6 kg/100 m2 (Figure 1).

Figure 1. Above-ground plant biomass on 10 x 10 m zonal grids based on relevÚ biomass of vegetation types multiplied by proportion of vegetation types within each grid.

Spatial distribution of NDVI and relationship to temperature:
ò There is a 5 oC increase in SWI along the climate gradient corresponding to an increase in NDVI of approximately 0. 7 (Figure 2).

Figure 2. Regression analysis of Normalized Difference Vegetation Index (NDVI) as a function Summer Warmth Index (SWI, ?C), regression line (solid) ? 1 s.d. (dotted lines). The NDVI values are maximum NDVI from AVHRR data from 1993 and 1995. The SWI values are mean AVHRR land surface temperatures 1982-2003, buffered from coasts and excluding lakes and ice.

ò The satellite-derived land-surface temperataures were used to calculate the long-term mean land-surface summer warmth index (Figure 3). The long-term max NDVI values were compared to the land-surface SWI values. The strongest positive r

elationship
between NDVI and SWI occurred in partially vegetated and graminoid vegetation types. Recently de-glaciated areas, areas with many water bodies, carbonate soil areas, and high mountains had lower NDVI values than predicted by SWI Analysis of the max NDVI in relationship to surface SWI values

Figure 3. Map of twenty-two-year mean of land-surface summer warmth index (SWI) of arctic tundra, based on AVHRR land surface temperature data 1982-2003 (inset - arctic bioclimate subzones according to the Circumpolar Arctic Vegetation Map).

Training and Development:

The project has four students involved in graduate studies (Yu, Cook, Munger, Raynolds). ò Bhatt was the instructor for Climate Journal Club the spring semester (Jan-May 2007) each every Friday from 3:30-4:30. This is an informal forum for discussing current research results and some of the research results from this project were discussed during the semester.

Outreach Activities:

Uma Bhatt is co-editing the special IPY series of six articles for the journal Computing in Science and Engineering continues. In addition to editorial duties, this project entails preparing sidebars for each of the special IPY articles, which Bhatt has done with co-guest editor D. Newman.

Skip Walker is developing the Dalton Highway Field Trip for the Ninth International Conference on Permafrost. This is a major conference and field trip that will introduce participanat to the climate gradient in northern Alaska and the greening that is occurring.

Martha Raynolds presented a talk for local community science forum, ôScience CafÚö, titled 'Searching for the Effects of Climate Change on Arctic Vegetation'. She also presented a talk to 45 GLOBE teachers, 23 March, Fairbanks titled ôArctic vegetation: its distribution and characteristicsö.

Journal Publications

Cook, B.I., G.B. Bonan, S. Levis, and H.E. Epstein., "Dynamic vegetation amplifies climate model response to snow cover changes.", Climate Dynamics, p. , vol. , (2007). Accepted,

Cook, B.I., G.B. Bonan, S. Levis, and H.E. Epstein., "The thermal insulative effect of snow in the climate system", Climate Dynamics, p. , vol. , (2007). Submitted,

Cook, B.I., H.E. Epstein, T.M. Smith, and J.O. Kaplan, "Arctic Oscillation and El Niño Southern Oscillation induced climate impacts and terrestrial ecosystem responses", Global Biogeochemical Cycles, p. , vol. , (2007). Submitted,

Epstein, H.E., J.O. Kaplan, H. Lischke, and Q. Yu, "Simulating future changes in arctic and sub-arctic vegetation", Computing in Science and Engineering, p. 12, vol. 9, (2007). Published,

Epstein, H.E., D.A. Walker, M.K. Raynolds, G.J. Jia, and A.M. Kelley, "Phytomass of patterned-ground ecosystems across the full temperature gradient of the arctic tundra", Journal of Geophysical Research-Biogeosciences, p. , vol. , (2007). Submitted,

Jia, G. J., H. E. Epstein, and D. A. Walker, "Spatial heterogeneity of tundra vegetation response to recent temperature changes", Global Change Biology, p. 42, vol. 12, (2006). Published,

Jia, G.J., H.E. Epstein, and D.A. Walker, "Vegetation greening in the Canadian Arctic related to warming and sea-ice decline", Journal of Geophysical Research-Biogeosciences, p. , vol. , (2007). Submitted,

8. Richter-Menge, J., Overland, J., Proshutinsky, A., Romanovsky, V., Bengtsson, L., Brigham, L., Dyurgerov, M., Gascard, J.C., Gerland, S., Graversen, R., Hass, C., Karcher, M., Kuhry, P., Maslanik, J., Melling, H., Maslowski, W., Morison, J., Perovich,, "State of the Arctic Report", NOAA/OAR/PMEL, Seattle, WA, p. , vol. , (2006). Published,

Raynolds, M. K., J. J. Comiso, D. A. Walker, D. Verbyla, "Relationship between satellite-derived land surface temperatures, arctic vegetation types, and NDVI", Remote Sensing of Environment, p. , vol. , (2007). Submitted,

Raynolds, M.K., D,A, Walker, and H.A. Maier, "NDVI patterns and phytomass dirtribution in the circumpolar Arctic", Remote Sensing of the Environment, p. 271, vol. 102, (2006). Published,

Raynolds, M. K., C. A. Munger, D. A.Walker, C. M. Vonlanthen, A. N. Kade, "Vegetation, biomass, thaw depth and snow depth maps along the North American Arctic Transect", Journal of Geophysical Research Biogeosciences, p. , vol. , (2007). Submitted,

12. Walker, D. A., H. E. Epstein, W. A. Gould, C. L. Ping, V. E. Romanovsky, Y. Shur, C. T. Tarnocai, R. P. Daanen, G. Gonzalez, A. N. Kade, A. M. Kelley, W. B. Drantz, P. Kuss, N. V. Matveyeva, G. J. Miochaelson, C. A. Munger, D. J. Nickolsky, R. A. Pete, "Biocomplexity of small patterned-ground features along the North American Arctic Transect", Journal of Geophysical Research ? Biogeosciences, p. , vol. , (2007). Submitted,

Books or Other One-time Publications

Web/Internet Site

Other Specific Products

Contributions

Contributions within Discipline:

The Greening of the Arctic project is contributing to our understanding of how the climate

warming in the Arctic is affecting the circumpolar patterns of biomass and NDVI. These studies are highly relevant to our understanding of carbon distribution and expected changes to above- and below-ground carbon reserves in the Arctic.

Contributions to Other Disciplines:

This broad interdisciplinary study is making contributions to understanding the linkages between arctic sea-ice patterns, synoptic cilmate patterns, land-surface temperatures, and terrestrial vegetation.

The pan-arctic GIS studies are also increasing our knowledge of the linkages between vegetation, climate, geology, and a variety of other terrain variables that affect vegetation patterns at the global scale. Understanding these relationships is important for detecting and understanding the changes in NDVI that are occuring across the Arctic.

Contributions to Human Resource Development:

The project is training 4 graduate students (Qi Yu, Ben Cook, Corinne Munger, and Martha Raynolds) and has contributed to the training of two post-doctoral students (Corinne Vonlanthen, and Patrick Kuss)

Contributions to Resources for Research and Education:

Contributions Beyond Science and Engineering:

The project is developing a better understanding of the effects of climate change on Arctic Systems and should contribute to developing sound policies regarding resource developoment, and human response to change in the Arctic.

Special Requirements

Special reporting requirements: None

Change in Objectives or Scope: None

Unobligated funds: $ 0.00

Animal, Human Subjects, Biohazards: None

Categories for which nothing is reported:

Organizational Partners

Any Book

Any Web/Internet Site

Any Product

Contributions: To Any Resources for Research and Education