The Role of Land-Cover Change in High Latitude Ecosystems:
Implications for Carbon Budgets in Northern North America

Annual Report for First Year of NASA-LCLUC Project (NAF-11142)
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Abstract

In our previous NASA LCLUC Project (NAG5-6275), we conducted change-detection studies of land-cover change in the Alaska region, and we developed a prototype spatially explicit modeling framework capable of using satellite-derived data on land-cover change to estimate how changes in land cover cause changes in ecosystem carbon storage. Our goals in our current NASA LCLUC Project are (1) to evaluate a key question about land-cover change that emerged from our previous project, and (2) to extend the application of our modeling framework to the entire Alaska-Canada region.

A key question that emerged from our previous studies pertains to whether lakes and wetlands are drying up in the Alaska region, which may be indicative of large-scale decreases in soil moisture across Alaska. We hypothesize that there has been a significant decrease in the number of lakes and ponds in regions of discontinuous permafrost. We proposed to test this hypothesis by comparing Digital Raster Graphics (DRGs) from the 1950's, Landsat TM imagery from the 1980's, and Landsat-7 ETM+ imagery from 2000. The comparisons will be made across an east-west and north-south climate gradient in Alaska. The areas we chose range from maritime to continental climate regimes: Kenai Peninsula, Copper River Basin, Seward Peninsula, Innoko Flats, Tanana Flats, Forty Mile Flats, and the Yukon Flats.

Our modeling framework is based on the Terrestrial Ecosystem Model (TEM), and in this study we will apply TEM to the entire Alaska-Canada region. In comparison to Alaska, a greater array of disturbances, which include fire, insects, agricultural land use, and timber harvest play a role in the carbon dynamics of Canada. Also, other factors besides disturbance such as increasing atmospheric CO_2, climate change, warming permafrost, and nitrogen deposition may be affecting carbon storage in both Alaska and Canada. Thus, the extension of our modeling efforts to simulate carbon dynamics for the Alaska-Canada region involves further development of TEM to consider multiple disturbances in the context of other multiple environmental changes and further development of spatially explicit data sets on land cover change in the Alaska-Canada region. We will evaluate our application of TEM to the Alaska-Canada region in the context of well-founded atmospheric inversion estimates, and in the context of other regional analyses of changes in carbon storage based on satellite-derived data (AVHRR) and forest inventory approaches.

Achievement of the objectives in the proposed study will improve our understanding of processes responsible for historical changes in carbon storage in high latitudes, will give us greater confidence in our ability to model those changes, and will give us the capability to evaluate how land-cover changes may affect carbon storage in high latitude regions in the future.

Key Words

Research Fields: Remote Sensing, Ecosystem Dynamics, Atmospheric Chemistry
Geographic Area/Biome: Alaska-Canada, Tundra, Boreal Forest
Remote Sensing: Change Detection, TM/ETM+, AVHRR
Methods/Scales: Ecological Modeling, Inversion Modeling, Forest Inventory Analysis

Questions, Goals, and Approaches

Relevance to NASA ESE Questions.

Our study is relevant to two NASA ESE questions: (1) What are the changes in land cover and land use change (LCLUC)?; and (2) What are the consequences of LCLUC? Our change detection study to evaluate whether lakes and wetlands are drying up in the Alaska region is directly related to the first question, while the application of our modeling framework to the entire Alaska-Canada region to evaluate the mechanisms responsible for changes in regional carbon storage is directly related to the second question. In our original proposal we did have a component of the study (approximately 25%) to evaluate whether human suppression of fire has affected the fire regime in Alaska, a component that is related to the NASA ESE question on the causes of LCLUC. This component was eliminated from the study when we cut the budget, and we are currently attempting to leverage off of other funds to support this analysis. Thus, at this time we do not have a human dimensions component in our NASA LCLUC Project. Themes covered in our project include carbon/nutrients (50%), water (25%), and GOFC (25%).

Overall Goals, Timeline, and First Year Objectives for the Project.

We have two overall goals for this project: (1) to evaluate whether lakes and wetlands are generally drying up in the Alaska region, and (2) to extend the application of our modeling framework to the entire Alaska-Canada region for the purpose of elucidating the mechanisms responsible for changes in regional carbon storage. Our timeline for the first goal is to refine methodology by September 2002 by focusing our efforts on the Kenai Peninsula and Copper River Basin focus areas, to complete analyses on all focus areas (Kenai Peninsula, Copper River Basin, Seward Peninsula, Innoko Flats, Tanana Flats, Forty Mile Flats, and the Yukon Flats) by September 2003, and to write and submit manuscripts during the final year of the project. Our timeline for the second goal is to make progress in model development and to obtain data sets during the first year of the project, to fully develop the spatially explicit data sets required for model application and to apply the fully developed model during the second year of the project, and to evaluate model simulations and to write manuscripts during the third year of the project.

With respect to the first goal, our specific objectives for the first year of the project (performance period of August 1, 2001 - July 31, 2002) were (1) to recruit a graduate student to conduct the change detection study, (2) to obtain the imagery needed to conduct the change detection study, and (3) to refine methodology and make preliminary progress by concentrating change detection analysis on the Kenai Peninsula and Copper River Basin focus areas. We have recruited Mr. Brian Riordan, who is a M.S. graduate student in Forest Science at the University of Alaska Fairbanks, to conduct the change detection analysis as part of his thesis research. We have ordered and obtained the following imagery: DRGs for the Kenai Peninsula and Copper River Basin, and Landsat 5 TM and Landsat 7 ETM+ images for all of the focus areas. In addition, we have begun to acquire aerial photography from 1978 to 1984 for the Kenai Peninsula and Copper River Basin focus areas. Mr. Riordan has begun the change detection analysis and has made significant progress in refining methods for the Kenai Peninsula and Copper River Basin focus areas. Preliminary results suggest that there has been a significant decrease (approximately 50% during the last half of the 20^{th} Century) in water surface area in both the Kenai Peninsula and the Copper River Basin (Figure 1). We believe that the research directed at our first goal is right on track with respect to our three-year timeline as we are meeting the specific objectives for the first year of the project.

With respect to the second goal, our specific objectives for the first year of the project were (1) to make progress in development of the modeling framework, (2) to conduct simulations for the Alaska-Canada region with data sets that we have already organized, (3) to recruit a graduate student at Boston University who would assist us in comparing the results of our simulations with analyses of changes in carbon storage based on remote sensing and forest inventory data, and (4) to obtain data sets that we need for developing and organizing the spatially explicit data sets required by the modeling framework for the full array of disturbances and other factors.

We have made substantial progress in developing the modeling framework. First, we have developed a version of the Terrestrial Ecosystem Model (TEM) that fully considers soil thermal dynamics (Zhuang et al., 2001), and have used the model in a study of carbon dynamics along a fire chronosequence in interior Alaska (Zhuang et al., 2002) and in a study of the role of soil thermal in carbon dynamics of northern terrestrial ecosystems (Zhuang et al., submitted). The application of the model for northern terrestrial ecosystems provided the capability to consider how decadal scale warming influences freeze-thaw dynamics of northern terrestrial ecosystems affects the start of the growing season to influence carbon storage. The results of these simulations, which indicate that carbon storage is increasing, in part, because thaw is occurring earlier in northern hemisphere ecosystems to cause an earlier start to the growing season, are consistent with analyses based on atmospheric and remote sensing data. We are currently in the process of conducting simulations for the Alaska-Canada region that also the effects of fire disturbance (including fire severity with data from our collaborator Dr. Kasischke) based on data sets that we currently have available. The preliminary results of these simulations indicate that changes in carbon storage simulated for the Alaska-Canada region are similar to those from analyses based on atmospheric inversions (e.g., Dargaville et al., 2002; see Figure 2) and analyses based on remote sensing and inventory data (Zhuang et al., submitted). A graduate student on the project from Boston University has been helping us to compare our simulations with an analysis of changes in carbon storage based on remote sensing and inventory data (e.g., see Myneni et al., 2002, *PNAS* 98:14784-14789). We have also made progress in developing a version of TEM that considers multiple disturbances, and we are evaluating the performance of this version for spatial data sets on agriculture and forest harvest that we already have organized for the conterminous U.S. We held a meeting among project personnel and collaborators at the 2001 Fall AGU meeting, which was well attended. Spatial data sets on insect disturbance and forest harvest have been delivered to us by two of our Canadian collaborators (Drs. Kurz and Apps), and a data set on the central location and sizes of fire in Canada from 1960 to 1995 has been provided to us by another of our Canadian collaborators, Dr. Brian Stocks, who has agreed to provide us with the polygonal data set of fire timing and extent once it is ready for release. We have received polygonal data sets of fire in Canada for provincial contacts in the Yukon and in the Northwest Territories. We have combined the Canadian data on fire history with our Alaska data set on fire scars to produce a data sets of the history of fire in northern North America (e.g., see Figure 3). We believe that we will have acquired the key data sets that we need for developing the spatial data sets that will be required for TEM to consider the full array of disturbances that affect carbon storage in the Alaska- Canada region. We believe that the research directed at our second goal is right on track with respect to our three-year timeline as we are meeting the specific objectives for the first year of the project.

Approaches/Methods

The research directed at our first goal is focused on detecting changes in the area of ponds and water bodies that have no inlet or outlet. We have acquired the majority of the images that we need to perform this study. Digital Raster Graphics will be used to generate our base image. This provides us with the oldest possible visual record of the presence of ponds. We will then co-register each Landsat image or aerial photograph to the DRG. By toggling between the images we can visually detect the presence or absence of a water body. We will then create separate polygon themes, which will be composed of ponds, for each image. These polygon themes can then be compared in order to calculate surface water loss or gain. We will then determine whether seasonal variability can account for changes in water area by evaluating variability in precipitation and temperature records between the years associated with the images. We have started our analysis by concentrating research on the Kenai Peninsula and Copper River Basin focus areas and will continue to move north and west as the project progresses.

In comparison to Alaska, a greater array of disturbances, which include fire, insects, agricultural land use, and timber harvest play a role in the carbon dynamics of Canada. Also, other factors such as increasing atmospheric CO_2, climate change, warming permafrost, and nitrogen deposition may be affecting carbon storage in Canada. Thus, the extension of our modeling efforts to simulate carbon dynamics for the Alaska-Canada region involves further development of TEM to consider multiple disturbances in the context of other multiple environmental changes and further development of spatially explicit data sets on land cover change in the Alaska-Canada region. A key focus of our modeling development efforts is to provide the model with the capability to consider the effects of interactions between soil thermal dynamics, climate variability, and disturbance. We have a number of data sets that are available to support application of the modeling framework to the Alaska-Canada region. In addition, access to some recently developed data sets will allow us to better address the effects of spatial and temporal variations in the distribution of plant functional types, forest harvest and regrowth, and atmospheric nitrogen deposition across the globe on terrestrial carbon, nitrogen and water dynamics. Similar to other studies we have conducted with the modeling framework, we will conduct simulations in a factorial fashion to identify the role of various factors that we are considering (atmospheric CO_2, climate, nitrogen deposition, and disturbance) on the historical carbon dynamics simulated for the Alaska-Canada region. With respect to disturbance regimes, we will conduct analyses that identify how simulated carbon dynamics varies with respect to uncertainty in assumptions made in the modeling framework, particularly assumptions about the severity of disturbance and about the frequency of disturbance prior to the availability of historical information on the frequency of disturbance. We will evaluate our application of TEM to the Alaska-Canada region in the context of well-founded atmospheric inversion estimates (e.g., Dargaville et al., 2002; Schimel et al., 2001, *Nature* 414:169-172), and in the context of other regional analyses of changes in carbon storage based on satellite-derived data (AVHRR) and forest inventory approaches (e.g., Myneni et al., 2001, *PNAS* 98:14784-14789; Goodale et al., 2002, *Ecological Applications* 12:891-899).

Progress During the First Year

We are meeting the first-year objectives for both goals of the project. With respect objectives related to the first goal to test whether the areas of ponds and lakes in Alaska are shrinking, we have recruited a graduate student to conduct the change detection analysis, we have obtained imagery for the change detection analysis, and we have made progress in refining methodology for two of our focus areas, the Kenai Peninsula and the Copper River Basin. Preliminary results of the change detection analysis for these areas suggests that the area of ponds and lakes have shrunk by approximately 50% during the latter half of the 20th Century. With respect to the objective related to the second goal to extend the model framework to the Alaska Canada region, we have made substantial progress in model development, we have conducted preliminary simulations with data sets that we have available, we have recruited a graduate student at Boston University to help with comparison of simulation results with changes in carbon storage estimated by remote sensing and forest inventory data, and we have obtained the additional data sets we need for developing and organizing the spatially explicit data sets required by the modeling framework for the full array of disturbances and other factors. We have added new capability to TEM to consider how responses of freeze-thaw dynamics to warming affect carbon storage in northern terrestrial ecosystems. The application of the model for northern terrestrial ecosystems provides the capability to consider how decadal scale warming influences freeze-thaw dynamics of northern terrestrial ecosystems affects the start of the growing season to influence carbon storage. We believe that our progress in the providing the capability to consider how freeze-thaw dynamics explicitly affects ecosystem carbon storage represents a new capability among global biogeochemical models. We are currently in the process of conducting simulations for the Alaska-Canada region that also the effects of fire disturbance based on data sets that we currently have available. The preliminary results of these simulations indicate that changes in carbon storage simulated for the Alaska-Canada region are similar to those from analyses based on atmospheric inversions and analyses based on remote sensing and inventory data.

New Findings

- **Preliminary results of the change detection analysis for these areas suggests that the area of ponds and lakes have shrunk by approximately 50% during the latter half of the 20th Century.**
- **The results of our simulations for northern hemisphere ecosystems indicate that carbon storage is increasing, in part, because thaw is occurring earlier in northern hemisphere ecosystems to cause an earlier start to the growing season. These results are consistent with analyses based on atmospheric and remote sensing data.**

New Potential

- **The capability to consider how freeze-thaw dynamics explicitly affects ecosystem carbon storage represents a new capability among global biogeochemical models.**

New Products

We have no new products at this time. We will be making spatial data sets available as we organize and develop new data sets through the course of this project.

Conclusions

The progress during the first year of our study indicates that we are on track with respect to achieving the two goals of the study. Preliminary results of the change detection study indicate that water surface area has been decreasing during the latter half of the 20th Century in Alaska. We have added a new capability to consider how responses of freeze thaw dynamics influence carbon storage, a capability that we believe represents new progress in modeling global biogeochemical cycles. For the Alaska-Canada region, the results of our simulations appear to be generally consistent with analyses based on atmospheric, remote sensing, and forest inventory data.

Publications

(includes submitted manuscripts and publications from our previous NASA LCLUC Project)

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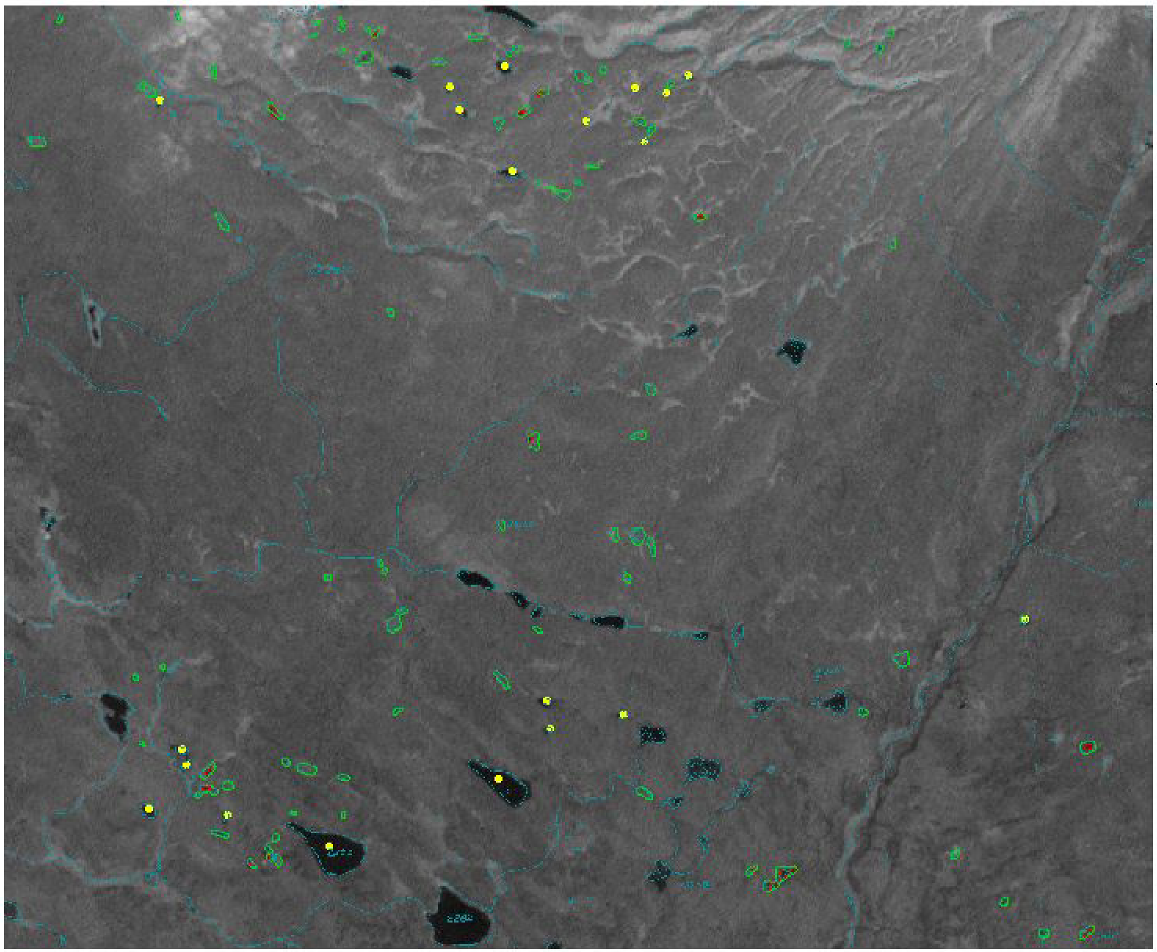
Figure 1:

Copper River Basin water body loss shown with Landsat7 ETM+ imagery and Digital Raster Graphics



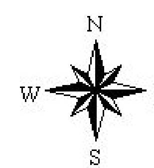
Legend

Water bodies present in 1958

New water body shape ETM+ 2000

Static ponds

Background is a Landsat7 ETM+ image displayed in band 8, the panchromatic band with (15-m spatial resolution). The darker colored areas are water releated.



Alaska and Canada Carbon Flux Variability from TEM

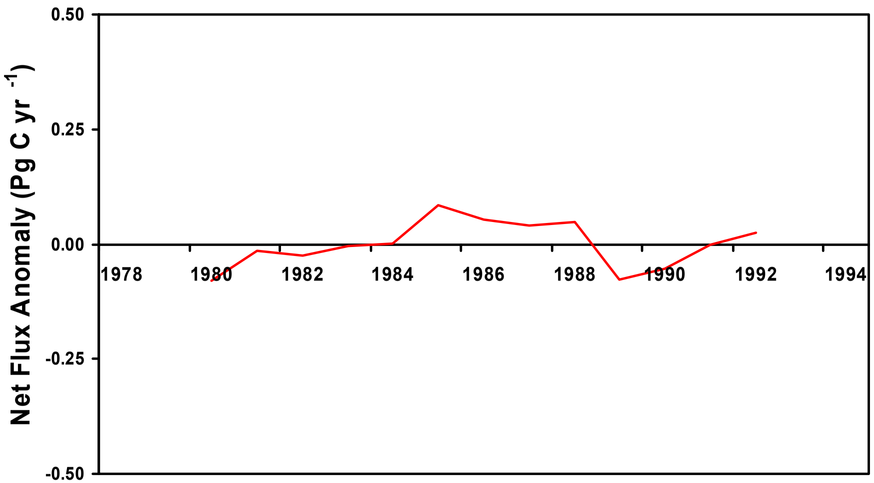


Figure 2: Comparison of variability in net carbon exchange simulated by TEM from 1980 – 1992 with estimates from an atmospheric inversion (Dargaville et al., 2002).

Alaska and Canada Carbon Flux Variability from an Atmospheric Inversion - R. Dargaville

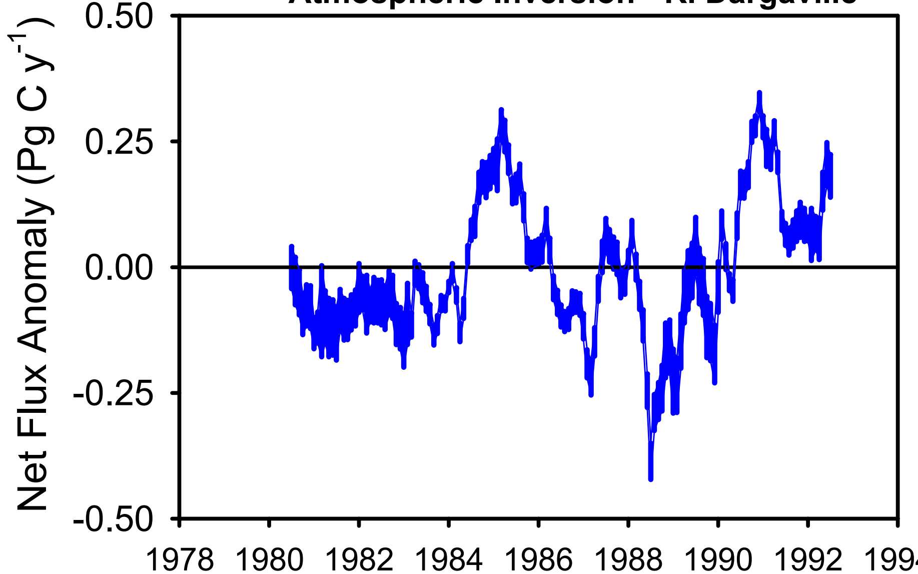


Figure 3: Historical Fire Scars for Alaska (1950 – 1999) and Canada (1959 – 1999)