Monitoring Boreal Landcover and Ecosystem Dynamics at Regional Scales using Integrated Spaceborne Radar Remote Sensing and Ecological Modeling

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Abstract

This investigation combines mapping and monitoring of boreal landcover with ecological modeling for assessment of regional and continental scale carbon flux dynamics. We are utilizing imagery from the JERS Synthetic Aperture Radar (SAR) to develop a landscape segmentation map for use in an ecosystem process model. The segmentation map is coupled with landscape freeze/thaw dynamics derived using temporally dense spaceborne scatterometer data. These combined features allow determination of the timing of seasonal transitions for all regions of the land cover classification. Integration of an ecosystem model with the remote sensing-derived products will allow improved quantification of carbon flux dynamics on regional and continental scales. Each element in this suite of products will be assessed using existing data sets and *in situ* biophysical data collected under other activities. Integrating the suite of monitoring tools within a common framework will allow assessment of landcover change, making possible evaluation of landcover changes on carbon flux dynamics and regional and local scale ecological processes in general. Our development and validation efforts are first focused on intensive study regions in Alaska and the Boreal Ecosystem-Atmosphere Study (BOREAS) region of Canada. The methods developed will be extrapolated to other North American boreal regions and will be applicable to Eurasian boreal regions as well, with our intent being to apply these techniques to derive contiguous products for the circumpolar boreal and arctic regions.

Keywords:

(1) Research Fields: carbon cycle, freeze/thaw, vegetation structure
(2) Geographic Areas/Biome: North America, boreal forest
(3) Remote Sensing: SAR, scatterometer, radars
(4) Methods/scales: regional scale, time series analysis, land cover classification

Questions, Goals and Approaches

This investigation focuses on development of forest monitoring techniques. We integrate a landscape mapping with scatterometer-based spatio-temporal estimates of freeze/thaw dynamics and an ecosystem process model to combine mapping and monitoring of boreal landcover for assessment of regional and continental scale carbon flux dynamics. The proportion of social science is 0 %. We estimate the theme breakdown to be 50% carbon and 50% GOFC.

Major tasks include acquisition and processing of spaceborne scatterometer data into freeze/thaw phenology products, processing of JERS SAR imagery into landcover maps, acquisition of ancillary data products for product validation, parameterization of the ecological process model for application to the boreal landcover classes, and integration of the landcover product, the freeze/thaw product and the process model in an common framework. Our original approach has not been modified.

Our goals continue to address each of the key elements of this investigation, as well as the integration of these elements into an analysis structure. Our second year goals have been:

(1) Improvement of freeze-thaw products through investigation of alternative freeze-thaw detection algorithms and comparison with higher resolution SAR-based products.

(2) Linking of spaceborne scatterometer-based freeze-thaw products of North America to biophysical processes related to the initiation and termination of growing season at site-specific scales.

(3) Initiation of hierarchical classification of JERS SAR imagery for BOREAS and Alaska sites utilizing North American mosaic products from the Global Boreal Forest Mapping (GBFM) Project.

(4) Integrate the landcover mapping and phenology products with the ecosystem process model into a test-bed structure for analysis of the intensive sites.

Narrative Statement of Progress

Progress during the second year has proceeded along all elements of our investigation. We have assembled two full growing seasons of pan-boreal scatterometer data from the SeaWinds instrument on-board QuikScat. The SeaWinds data stream was initiated in June 1999 and is presently on-going. We have staged and assembled data through 2001, and are presently assembling data through spring 2002. Time series freeze-thaw status has been derived across the boreal North American domain. Derivation of these freeze-thaw map products has utilized time-series threshold detection algorithms, classifying freeze-thaw transitions through comparison of the time series backscatter to either a frozen or thawed reference state or to thresholds derived from statistics based on a moving window average.

Validation and interpretation efforts have been on-going and have primarily involved testing, validation and improvement of freeze/thaw classification algorithms at local (25 km) scales utilizing in situ data collected at a series of ground measurement stations in Alaska, Thompson Manitoba, Fraiser and Niwot Ridge CO. Emphasis has been on development of improved freeze-thaw maps for application across the continental scale. For local scale testing, we have assembled ecosystem biophysical data from eight in situ measurements stations extending along a north-south transect across Alaska, and 3 other sites in central Canada and Colorado. Measurements used for validation at these sites include vegetation tissue and soil temperatures, snow depth and snow water equivalent, and net CO_2 flux. These data have been used to validate the freeze-thaw status and biophysical functioning of the trees and soil at each site. We have also assembled multi temporal imagery from the JERS and ERS SARs for cross-sensor validation of freeze-thaw detection schemes (Figures1 and 2).

We have begun hierarchical classification of Alaskan and BOREAS sites from the Alaskan and Canadian JERS-1 mosaics (Figures 3 and 4). These include classifications supervised with respect to physiographic region, vegetation, biomass, and wetlands. With preliminary Alaskan and Canadian mosaics we are evaluating algorithms for both regional and local classifications. We are integrating JERS imagery with TM, ERS, and X-band radar imagery, and with thematic coverages of Alaskan and Canadian Regions for validation. We expect greater discrimination of vegetation structure and ecosystem types, particularly in wetlands to emerge from these combined datasets.

Having examined the link between freeze-thaw detection and biophysical function at specific sites, our next effort will be to expand this capability to a mapping across regional scales. This mapping will be linked to the hierarchical land cover classification in a framework with an ecosystem process model.

Validation and interpretation of the scatterometer-based data products will be on-going. We will continue to develop scatterometer-based phenology products indicating dates of major thaw events estimated at regional scales across selected boreal regions. We will compare results derived using various freeze-thaw detection algorithms to quantify improvement in mapping of landscape thaw.

Summary of Findings:

For our analyses of phenological processes, we have examined springtime and autumn relationships between xylem sap flow, carbon shift and biophysical measurements. We have found that growing season initiation is primarily responding to the timing of seasonal snow melt and the influx of melt water into surface soil layers (< 10cm). In autumn, termination of the growing season is responding mainly to decreasing air, vegetation and soil temperatures below a threshold of approximately 1-5C. Examination of the Ku-band scatterometer products and comparison of these products to radar scattering models and to L- and C-band JERS and ERS SAR products demonstrate that Ku band backscatter is highly responsive to snow melt processes more so than the lower frequency radars. Ku-band freeze-thaw classifications thus correspond closely with the timing of growing season initiation. In fall, however, Ku-band backscatter generally defines seasonal freeze-up, which can occur up to several weeks following termination of the growing season. In terms of annual carbon exchange, it is most important that we correctly identify the growing season onset rather than termination, since the bulk of annual production is accumulated in spring and early summer.

Land cover detail within seemingly uniform coniferous regions of AVHRR classifications (Figure 4) differentiates high biomass forests free of permafrost, low biomass black spruce forests mostly underlain by permafrost, ponds, inundated wetlands, and flowing water wetlands (without permafrost). The ecological differences among these land cover types are crucial. The responses of these ecosystems to climatic change are distinctly different, and the responses are important for modeling of fluxes and land cover changes. Most dramatic of these changes will be transitions of forest to wetlands. Inundated areas are areas of greater carbon efflux, and are typically underlain by peat deposits which represent potential efflux. At 1 km AVHRR scale inundation disappears entirely from classifications. However, these ecosystem types differ predictably in their seasonal changes, within single AVHRR pixels.

Conclusions

We have made critical progress in our understanding of the link between our freeze-thaw products and biophysical function of boreal forest. Having established this at site-specific locations, we next proceed to derivation of a regional-scale phenology mapping and integration of this information within an ecosystem process model.

Publications

Kimball, J., K. C. McDonald, A. R. Keyser, S. Frolking, and S. W. Running, 2000. "Application of the NASA Scatterometer (NSCAT) for Classifying the Daily Frozen and Non-Frozen Landscape of Alaska," *Remote Sensing of Environment*, 75:113-126.

Kimball, J.S., K.C. McDonald, S. Frolking and S.W. Running. 2001. Radar remote sensing of the spring thaw transition across a boreal landscape. *Remote Sensing of Environment*, BOREAS Special Issue (submitted).

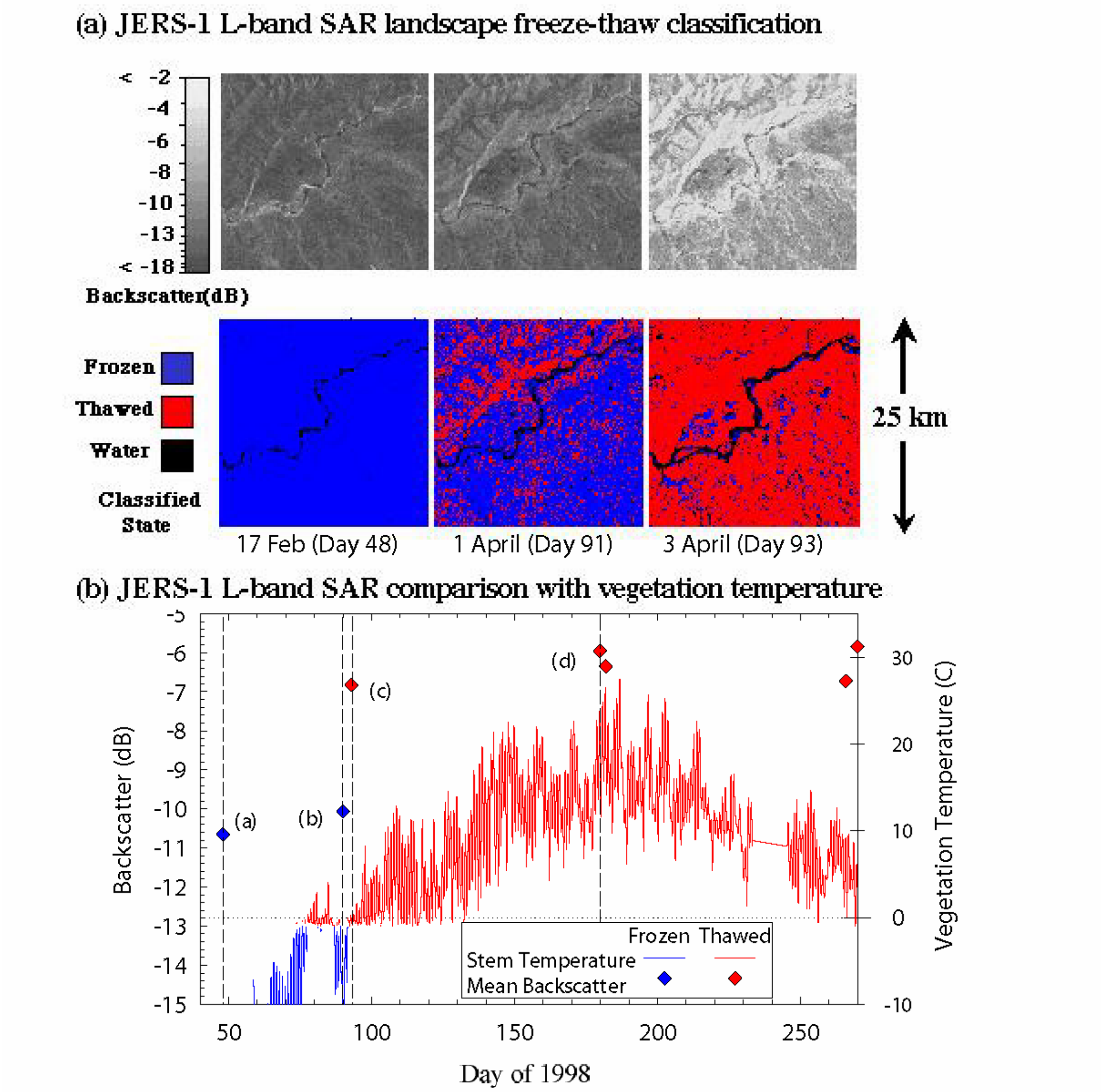

Figure 1. (a) The series of JERS L-band SAR images from central Alaska show the spring thaw transition along the Tanana River floodplain and adjacent regions. The 25 km square region corresponds to the approximate size of a QuikScat pixel. The heterogeneity of the thaw transition is largely driven by the complex land cover composition (e.g. forests, wetlands, topography.) The lower panel (b) compares vegetation tissue temperature to backscatter for forested regions within the floodplain. The L-band radar, while less sensitive to snow processes than the Ku-band radar, responds to the bulk landscape thaw status, representative of the integrated vegetation - soil surface continuum.

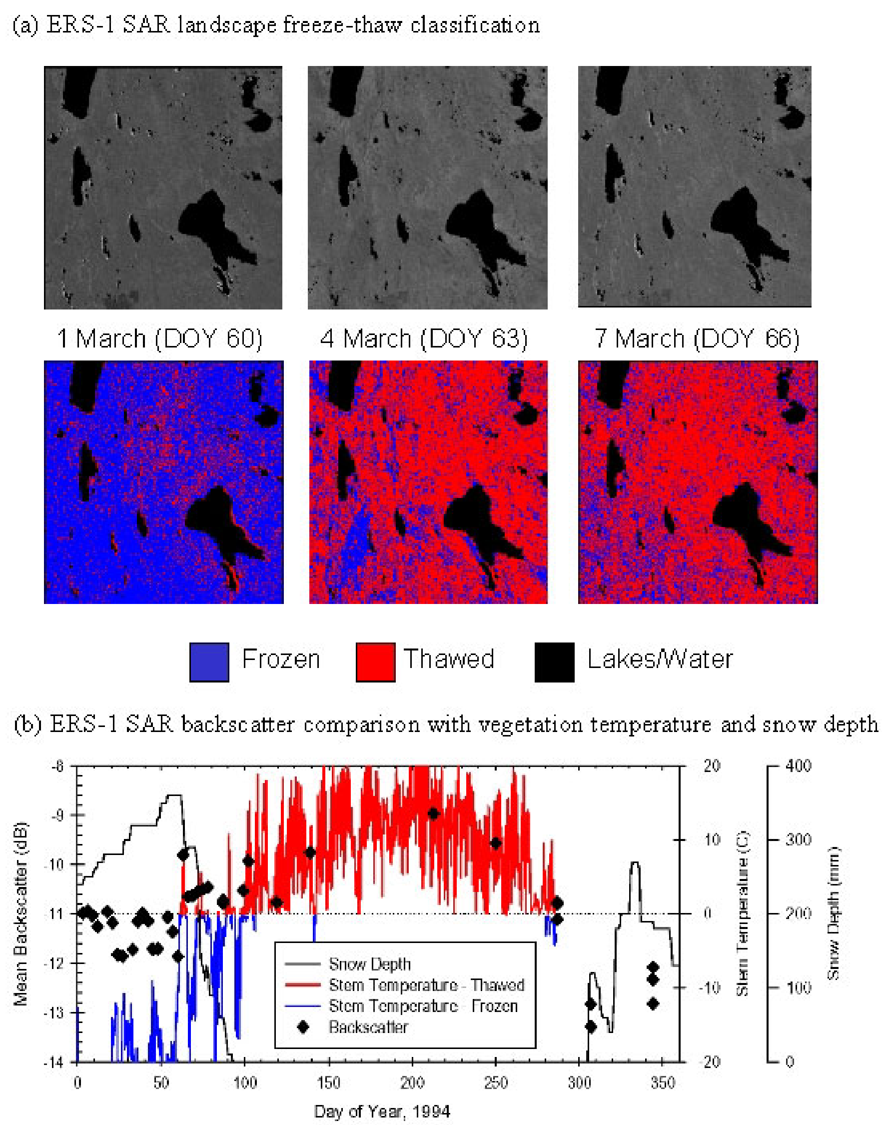

Figure 2: (a) This series of ERS Synthetic Aperture Radar images of the BOREAS Southern Study Area region show the response of the C-band radar to seasonal dynamics in a boreal landscape. The series of three backscatter images (top) were used to derive the corresponding landscape freeze-thaw state classification maps. (b) compares backscatter from the SSA Old Black Spruce site with tree stem temperature and snow depth. C-band backscatter exhibits less dynamic range in response to springtime forest thaw processes than that observed at L-band.

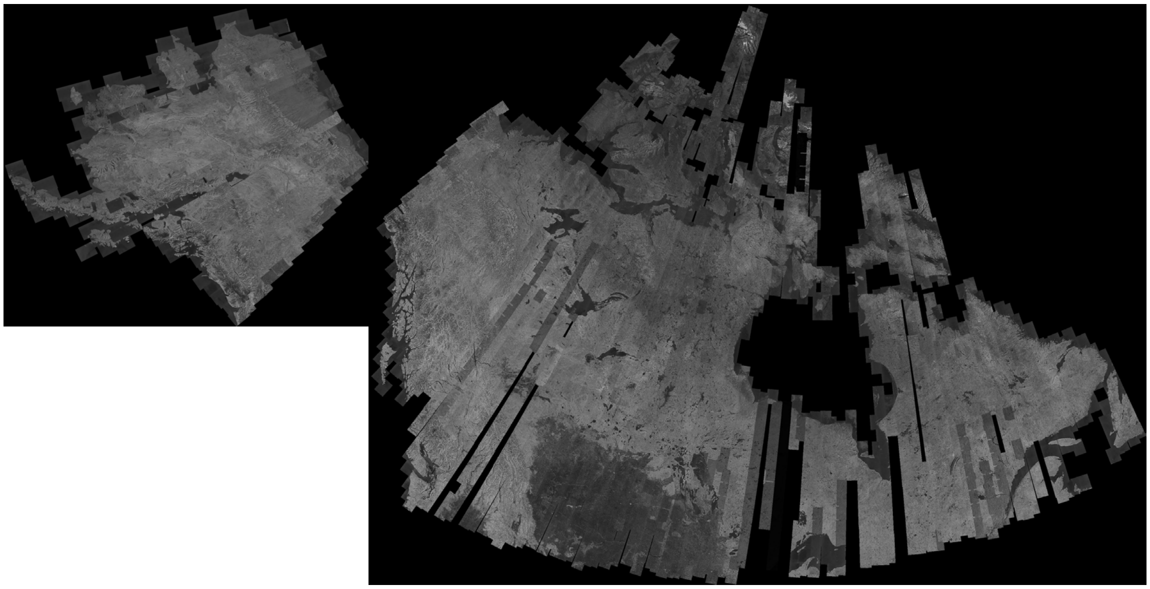

Figure 3: JERS-1 L-band SAR backscatter mosaics of Canada and Alaska. These new 100 meter resolution mosaics provide nearly complete coverage of the North American boreal forest. The contiguous coverage will allow extrapolation of landcover products across large regions of boreal North America.

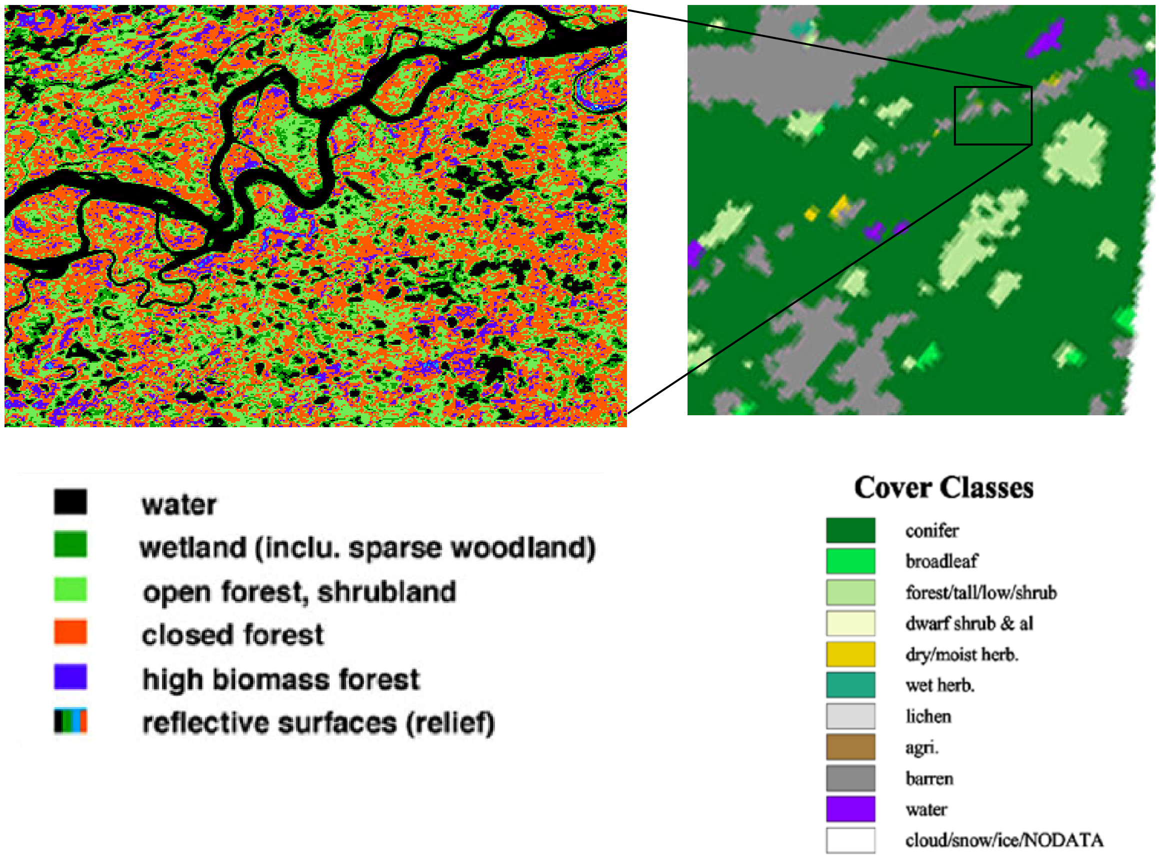

Figure 4. Land cover detail (left) within seemingly uniform coniferous regions of AVHRR classifications (right) differentiates high biomass forests free of permafrost, low biomass black spruce forests mostly underlain by permafrost, ponds, inundated wetlands, and flowing water wetlands (without permafrost).