

**MODELING SIBERIAN BOREAL FOREST LAND-COVER CHANGE AND CARBON
UNDER CHANGING ECONOMIC PARADIGMS**

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3 BACKGROUND

3.1 Abstract

While change in political and economic structures is occurring in a number of countries worldwide, nowhere else recently has this occurred at the scale of the break-up of the state-controlled Soviet Union and its transition towards a more market economy. This event stands out in the magnitude of the change; its rapid transition period, and the geographic extent and global impact of the potential effect, including its effect on the Siberian boreal forest. We hypothesized that these two different economic paradigms – state-controlled and market economy – may leave significantly different imprints on the land, and we propose to develop a case-study landscape model of the contrasting economic drivers and of their past, present, and potential future consequences for land-cover land-use change and carbon in Siberia. **Goals and Objectives:** The goal of the proposed project was to develop a model of Siberian boreal forest land-cover land-use change and carbon that accounts for changing economic paradigms and that is informed by remote sensing-derived analyses of change. To achieve this goal we addressed four objectives: 1) develop an economic statistical models of the factors affecting forests in Siberia over the past 70 years; 2) use time-series Landsat-derived datasets to develop land-cover land-use classifications, change matrices and transition probabilities, including their human and spatial dependency; 3) add the carbon content to these land cover states through application of an ecosystems dynamics and carbon model; 4) combine these into an integrated landscape model of land-cover land-use change in Siberia based on extension of the different economic paradigms. **Approach:** This project builds on previous work in remote sensing and modeling of Siberian forests specifically using time-series analyses and ecosystem models. We used new Landsat-7 dataset for three test sites in three of the most important administrative units in the Siberian forest sector: Tomsk Oblast, Krasnoyarsk Krai, and Irkutsk Oblast. We derived land-cover transitions from time series remote sensing and linked results to carbon content. We developed statistical representations of the economic paradigms over time. Land-cover/use transition probabilities and associated carbon contents were coded into a Markov-based simulation model and this model was applied to create future land-use and carbon scenarios based on different economic paradigms. **Results:** We constructed a time-series Landsat-7 dataset and classified different land-cover states at each time period. We applied change analysis to classified images. We developed landscape change models and future scenarios through Markov models and cellular automata. We analyzed the dependence of land-cover change on natural and socio-economic variables. We linked these change data with carbon contents. We examined the model output in terms of land-cover land-use impacts of the different economic paradigms. We investigated and explained trends in the age structure, composition, and carbon of study region Siberian boreal forests. This work will be useful for further understanding the relationships between land-cover land-use change and carbon, and economic trends in Siberia.

Keywords

Research Fields: Carbon Cycle, Change Detection, Forest Management
Geographic Area/Biome: Siberia, Russia, Boreal Forest
Remote Sensing: Landsat
Methods: Regional Scale, Time Series Analysis, GIS

4 ACCOMPLISHMENTS

4.1 NASA Context and Contributions

NASA ESE Scientific Questions our project addresses all three of the following:

- 1) Changes in LCLUC, 2) Causes of LCLUC, 3) Consequences of LCLUC

Social Science Component:

25% of the project is directed at socioeconomic statistics and drivers of change in Central Siberian forests.

Themes Components:

Carbon – 20%, Water – 5% (part of study site contiguous to Lake Baikal), Nutrients – 0%, LCLUC Forest and Land-Cover Change – 50%, Socio-economic – 25%

4.2 Goals and Timelines

Goals and Timeline for Year 1: (U. of Michigan responsibility unless otherwise noted)

1. Remotely Sensed Data

- a. Identify and acquire time-series Landsat data for 3 case study sites. *Completed 1/02*
- b. Pre-process Landsat data. *Completed 4/02*
- c. Develop and perform classifications and forest land-cover change detection. *75% Completed 7/02; Completed 7/04*

2. GIS Database for Spatial Analysis

- a. Digitize comprehensive GIS database for 3 case study sites from Russian 1:200,000 topographic maps: transportation, settlements, and hydrology. *Completed 7/02*
- b. Translate and attribute. *90% Completed 7/02; Completed 7/03*
- c. Overlay accurately on satellite data. *Completed 7/02*

3. Socio-Economic Database

- a. Acquire socio-economic data for 3 case study sites. Acquire data from University of Michigan and Institute for Economics, Novosibirsk Akademgorodok. *Completed 8/02*
- b. Develop a database. *75% Completed 8/02; Completed 6/05*

4. Carbon

- a. Re-parameterize carbon models for Central Siberia (Shugart responsibility). *Completed*

Goals and Timeline for Year 2 plus Supplement:

1. Remotely Sensed Data

- a. Complete classifications of Landsat time-series data for 3 case study sites (3 sites X 3 scenes/times per site). *Completed 8/03*
- b. Develop classification accuracy assessment dataset. Acquire validation data from Russian colleagues and process for ERDAS Imagine. *Completed 8/03*
- c. Complete accuracy assessments for all scenes. *Completed 8/03*
- d. Complete land-cover change analysis and derive land-cover change statistics for the 3 case study sites. *Completed 8/03*
- e. Acquire MODIS data for the 3 case study sites. *50% complete 7/03*
- f. Analyze scaling issues between Landsat and MODIS for the 3 case study sites. *50% complete 7/03; Completed research 8/04, Ph.D. Thesis in process.*

2. GIS Database for Spatial Analysis

- a. Finish all digitized GIS database layers and check all for accuracy. Includes: roads, hydrology, DEM, settlements. *Completed 6/03*
- b. Begin to use GIS data with model development for spatial analysis of change patterns. *Begun April 2003; completed 8/05.*

3. Socio-Economic Database

- a. Translate and process all data acquired summer 2002 and complete database of socio-economic data. *Complete 1/03*
 - b. Analyze data in database for: i. National level, ii. Oblast level, iii. Raion level. *Complete 1/03*
 - c. Generate plots and graphs and statistical models showing statistical trends of drivers of land-cover/use change. *Complete 3/03*
- 4. Modeling**
- a. Parameterize and run model for different economic paradigms (pre-1989 and post 1989) for the first case study sites. *Completed 8/04*
- 5. Carbon**
- a. Re-parameterize carbon models for Central Siberia (Shugart responsibility). *Completed*

Goals and Timeline for Year 3 plus Year 4 No-Cost Extension

1. Modeling

- a. Parameterize and run model for different economic paradigms for the remaining case study sites (pre-1989 and post 1989). *Completed 1/-4 - 8/05*
- b. Assess final model strengths, limitations, accuracies. *Completed 8/05*
- c. Complete additional investigation of spatial relationships of LCLUC in Siberia to improve models. *Completed 8/05*
- d. Synthesize UM LCLUC results with UVA Carbon results. *Completed 8/05, Journal publications in process*

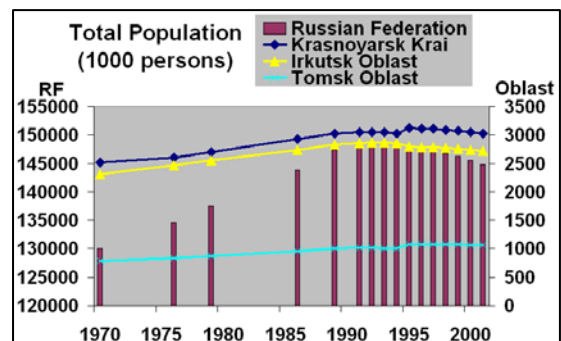
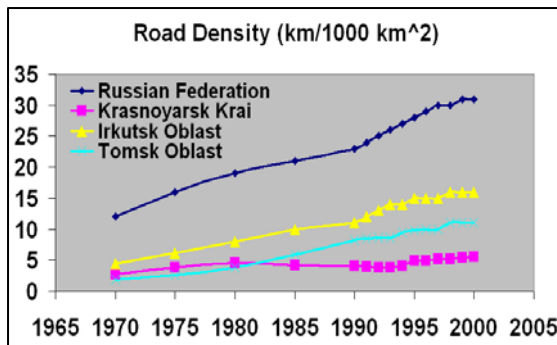
2. Reporting

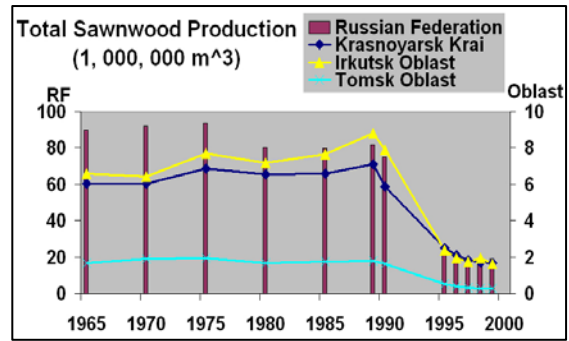
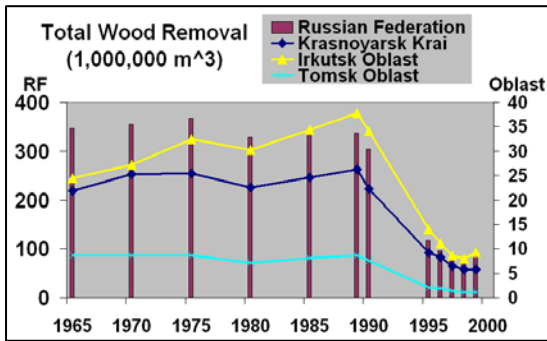
- e. Prepare Final Report *Complete 11/12/05*
- f. Prepare Papers for publication *Ongoing, see publications section*
- g. Student Thesis *One M.S. thesis completed 4/04; One Ph.D. thesis in process*

5 SELECTED RESULTS SUMMARY

5.1 Land-Cover & Socio-Economic Change

- Logging decreased significantly after 1989 and has not significantly increased.
- Forest harvest decreased 1990-2000; however it had already been decreasing in the study sites 1975-1990
- Agricultural abandonment underway by 1990, and continues to 2000. Result of change in policy away from collective farms.
- Urban, wetland, bare categories are not as dynamic (e.g. urbanization not a major issue)
- Major insect damage seen in one site
- Fire - need more (annual) data to more fully assess impact
- Overall – we do see the footprint of economic change on the landscape when we analyze Landsat data from Soviet Union and post-Soviet Union times.





5.2 Forest Type and Age

- This change is most pronounced with respect to the forest and agricultural land covers. In the case of forest:
- Previous primary forest had a much greater proportion of “light & dark coniferous” (pine or spruce/fir/Siberian pine)
- Forest harvest currently occurs primarily in mature conifer forest or mixed forests. In some areas there was significant cutting prior to 1975.
- The late 20th century forest is dominated by pine-mixed (*Pinus sylvestris*) or deciduous forest types and deciduous appears at present to be increasing
- After fire or logging the deciduous component remains dominant up to 70-100 years, then the stand begins to succeed to conifer
- The areal percentage of coniferous and mixed forests is declining 1975-2000 while the areal percentage of deciduous is increasing. Possible reasons:
 - New regrowth from prior logging moving into more mature deciduous
 - Continuing agricultural abandonment
 - Reduced but continued logging in conifer forest type
 - Fire occurrence in pine-mixed forests
- Interesting Question: How will this trend interact with climate change?

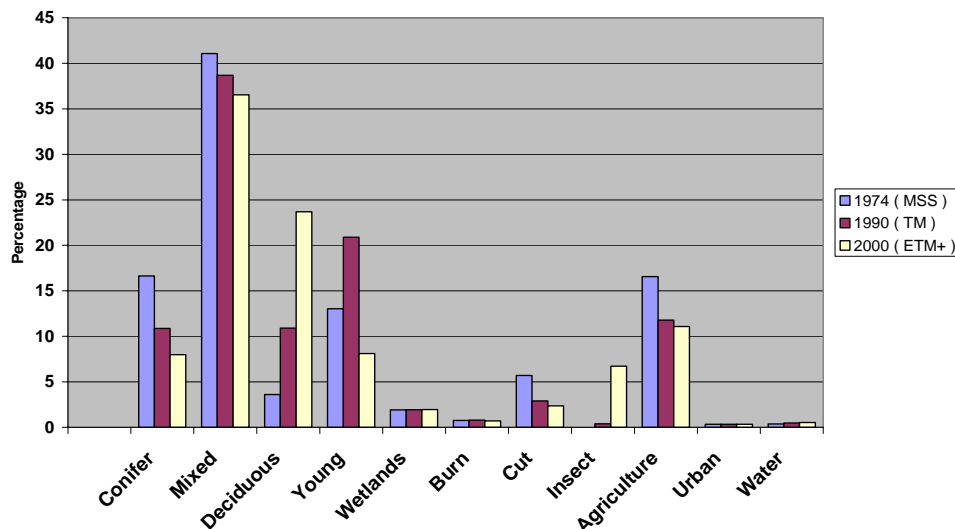


Figure. Landsat-derived statistics 1975-2000 in case study sites show that significantly reduced forest harvest, increased collective farm abandonment, growing deciduous forests, and insects/fire are changing the *amount*, *age*, and *type* of forest on the landscape with implications for carbon storage.

Carbon

- UVA models of productivity for Eastern Siberia boreal forests: Annual productivity is high up to ~100 years, then declines significantly. Younger (< 100 years) forests have a greater *rate* of carbon accumulation. Older forests store more
- Carbon stored appears to be increasing in the deciduous type and decreasing in the other forest types
- Increasing carbon stored in deciduous is probably the result of land-cover change and disturbance, from abandoned agriculture and logging (human activities) and from fire.
- Region probably is a carbon sink at this time. Carbon sink may be from reduced logging and new and maturing re-growth

6 PUBLICATIONS, PRESENTATIONS, AND REPORTING

6.1 Publications

Krankina, O., K. M. Bergen, G. Sun, H. H. Shugart, V. I. Kharuk, J. G. Masek, W. B. Cohen, M. Duane and E. Kasischke. 2004. Northern Eurasia. Chapter 5 in *Land Change Science: Observing, Monitoring, and Understanding Trajectories of Change on the Earth's Surface*. Dordrecht, Netherlands, Kluwer.

Yan, X. and H.H. Shugart. 2005. A forest gap model to simulate dynamics and patterns of Eastern Eurasian forests. *Journal of Biogeography* 32:1641-1658.

Bergen, K., S. G. Conard, R. A. Houghton, E. S. Kasischke, S. Kharuk, O. Krankina, J. Ranson, H. H. Shugart, A. Sukhinin and R. F. Treyfeld. 2003. NASA and Russian scientists observe land-cover/land-use change and carbon in Russian forests. *Journal of Forestry*, June Special Issue on Technologies in Forestry, 34-41.

Bergen, K. M., E. Vaganov, G. Gutman and C. Justice. 2002. GOFCC/GOLD Regional Workshop: GOFCC/GOLD Information Products for Forest and Land Management in Siberia/Far East. *The Earth Observer* 14(6): 19-21.

Bergen, K.M., Zhao, T.T., Peterson, L., Kharuk, V. Observing Forested Land-Cover Change 1975-2000 in Central Siberian Russia from Landsat. (in progress).

Bergen, K.M., Brown, D.G., Shugart, H.H., Peterson, L., Zhao, T., Miller, N., Kharuk, V., Blam, Y. Siberian Boreal Forest Landscape Dynamics and Carbon under Changing Socio-Economic Paradigms, 1975-2000. (in progress)

Peterson, L., Bergen, K., Brown, D., Olenik. Boreal Forest Land-Cover Change Scenarios Using Landsat and Spatial Models: A Case Study in the Baikal Region of Siberian Russia. (in progress)

Zhao, T., Bergen, K.M., Brown, D.G. and Kharuk, V. Scales of Land-Cover and Disturbance in Siberian Russia: Landscapes Identified at Landsat and MODIS Resolutions. (in progress)

Education. Bondur, V.G. and K. Bergen, chapter authors. 2004. Chapter 7 of *NEESPI Science Plan* (Northern Eurasia Earth Science Partnership Initiative). Washington, D.C.: NASA. (<http://neespi.gsfc.nasa.gov/science/science.html>).

Multi-Dimensional Forested Ecosystem Structure: Requirements for Remote Sensing Observations. 2005. K. Bergen, R. Knox, and S. Saatchi, Editors. 2005. Final Report of the NASA Workshop held June 23-25, Annapolis, MD.

6.2 Presentations

Bergen, K.M., Zhao, T., Peterson, L., Kharuk, S., Brown, D. 2005. Changing Trends in Forest Type and Age in Central Siberian Russia, 1975-2000. *Association of American Geographers Annual Conference*, Denver, CO, April 6-10. Presenter and Session Chair.

Zhao, T., Bergen, K.M., Brown, D. 2005. Scales of Land-Cover and Disturbance in Siberian Russia: Landscapes Identified at Landsat and MODIS Resolutions. *Association of American Geographers Annual Conference*, Denver, CO, April 6-10.

Hitztaler, S. and K. Bergen. 2005. Spatial Analysis of Siberian Boreal Forest Land-Cover Change and Case Study in Kamchatka. *International Conference on Land-Cover and Land-Use Change Processes in Far East Asia Region*. Harbin, China, Feb. 2-5.

Bergen, K.M. et al. Modeling Siberian Boreal Forest Land-Cover Change and Carbon under Changing Economic Paradigms. Invited presentation for *Annual NASA LCLUC Meeting - Boreal Section*, College Park, MD., Jan. 20-22.

Bergen, K.M. InSAR & Land-Cover. 2004. Vegetation/Land-Cover Section Leader and Speaker. *NASA and Interagency workshop on Interferometric SAR*. Reported in: Standing Room Only Signals Zeal for Earth Imaging, *Nature*, Nov. 4.

Bergen, K.M. 2004. Forest Structure and Disturbance. Invited speaker at the *NASA Terrestrial Ecology Program annual Focus Area Review*. NASA Headquarters, Washington, D.C.

Bergen, K.M. and T. Zhao. 2004. Land-Cover Classification and Change Detection in the Siberian Boreal Forest. *NASA MODIS Validation Workshop*. Boston University, Boston, MA. February 2-4.

Bergen, K.M. 2004. Pioneering NASA LCLUC Research Projects Mature 1997-2004. Invited Keynote research results presentation for *Annual NASA LCLUC Meeting - Boreal Section*, College Park, MD., Jan. 20-22.

Bergen, K.M., Peterson, L. 2003. Linking Research and Education in the Study of the Boreal Forest. *Northern Eurasia Earth Science Partnership Initiative (NEESPI) Meeting*, Suzdal, Russia, April 21-25.

Bergen, K. M., T. Zhao, L. Peterson, K. V. I., A. Soja, H. H. Shugart and Y. Blam. 2003. Forest Dynamics in the East Siberian Boreal Forest: Analysis using Time-Series Statistical and Satellite Data. *18th Annual Symposium of the International Association for Landscape Ecology-US Chapter*, Banff, Alberta, CA.

Peterson, L., K. M. Bergen, L. Vaschuk, V. Olenik and W. A. Kurz. 2003. Modeling forest land-cover change in the Irkutsk Region of Siberia. *18th Annual Symposium of the International Association for Landscape Ecology-US Chapter*, Banff, Alberta, CA.

NASA Land-Cover Land-Use Change Annual Meeting, College Park, invited poster (with D. Brown, H. Shugart, N. Miller, S. Kharuk, E. Kasischke), October 2002.

Bergen, K. M., N. Miller and J. E. Colwell. 2002. A Categorical-Radiometric Method for Forest Land-Cover Change Detection in Russia Using Hybrid Landsat MSS, TM and ETM+ Data.

GOFC/GOLD Regional Workshop: GOFC/GOLD Information Products for Forest and Land Management in Siberia/Far East, Krasnoyarsk, Russia.

NASA- Russian Academy of Sciences Northern Eurasian Earth Science Planning Initiative (NEESPI), Moscow, Russia, invited speaker and participant, February 2002.

NASA Land-Cover Land-Use Change Annual Meeting, College Park, invited poster (with D. Brown, H. Shugart, S. Kharuk, E. Kasischke), October 2001.

GOFC Regional Workshop, Center for International Environmental Cooperation of Russian Academy of Sciences, St. Petersburg, Russia, invited poster, June 2001.

European Commission. Joint Research Center, Ispra, Italy, invited seminar, May 2001.

NASA Earth Sciences Joint Working Group (ESJWG) Meeting, Washington, D.C., invited speaker and participant, April 2001.

GOFC Global Boreal Forest Workshop, North America Working Group, invited rapporteur, August 2000.

NASA Land-Cover Land-Use Change Annual Meeting, Reston, paper (with E. Kasischke, H. Shugart, A. Soja, and D. Clark), April 2000.

7 GRANTS

Land Dynamics, Social Vulnerability, and Ecological Effects of Flooding Under Policy and Environmental Change Around Poyang Lake, China. Co-I with PI Dan Brown (Michigan SNRE) and Shuming Bao (UM International Center). 2005. (\$586,000).

Supplement to NASA Grant Modeling Boreal Forests Land-Cover Land-Use Change Under Changing Economic Paradigms (PI). *NASA LCLUC*. 2004. (\$50,000).

A Workshop Planning Proposal for a Regional GOFC Workshop: GOFC Satellite Information Products for Forest and Land Management in Siberia/Far East. *NASA LCLUC* (\$28,000)

Support for Foreign Scientists to Attend GOFC Workshop. *START*. 2002. (\$8,000).