A Categorical-Radiometric Method for Forest Land-Cover Change Detection in Russia Using Hybrid Landsat MSS, TM and ETM+ Data

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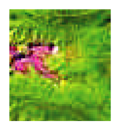
SCIENTIFIC MOTIVATION

To compare boreal forest land-cover and carbon change trends in Russia prior to and subsequent to the dissolution of the Soviet Union in 1991, time-series remote sensing data comprised of MSS, TM, and ETM+ is needed to quantify forest and land-cover transition rates. At minimum three dates are needed 1) at present, 2) at the time of the changeover (1991), and 3) before the changeover. Landsat data is the appropriate resolution to investigate change due to logging; however due to persistent cloud cover and consistent gaps in Landsat data recording over Russia in the 1990s, research by the authors has shown that many areas of Siberia are covered by usable Landsat multi-date imagery from approximately 1975, 1990, and 2000, but rarely more frequently. Because of the considerable value of the Landsat dataset for quantifying trends in land-cover change and carbon over the past 25 years in Russia, we have developed a 3-date categorical change procedure within one study area of this region. The use of radiometric change information to further refine the change product was assessed, but due to scene characteristics it was not found to improve the final product. The implementation of this hybrid procedure is discussed due to it's potential benefits with a more suitable dataset.

GOAL

THE GOAL OF THE ANALYSIS IS TO ASSESS THE POTENTIAL OF 3-DATE LANDSAT HYBRID (MSS, TM, ETM+) TIME SERIES IMAGERY FOR DETECTING, MAPPING, AND QUANTIFYING CHANGE IN FORESTED LAND COVER IN SIBERIAN RUSSIA



Study Site and Landsat Time-Series Datasets over Central Siberia

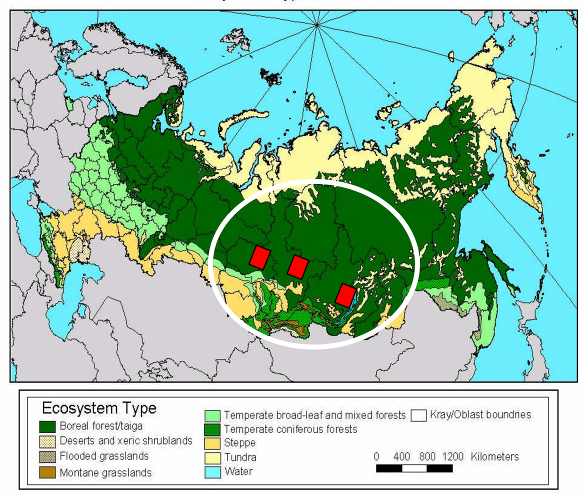
Landsat MSS and TM Mixed History:

The history of Landsat over Central Siberian Russia is mixed due to periods with incomplete scenes and systematic errors in the data, onboard tape recorder failures, and clouds.

Landsat-7 Archive is Excellent

Our new research to date shows that the Landsat-7 archive for our study region is excellent. Frequent repeat passes and consistent collection mean approximately 50% of possible path/rows (potential case study sites) have growing season data available at < 10% cloud cover, and 50% of those have virtually no cloud cover.

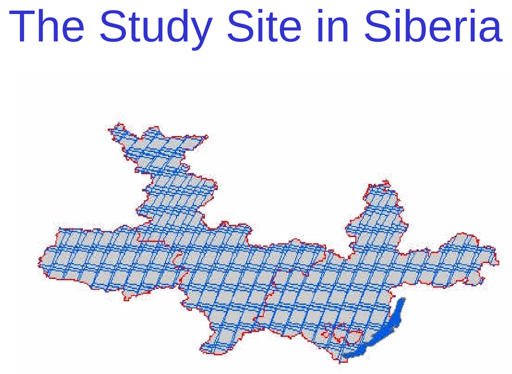
Ecosystem Types of Russia



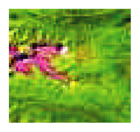
Landsat-7 Data Availability

	1999	2000	2001
Total N of WRS-2 Path/Row Scenes in Study Area	128	128	128
Total N of Scenes With <10% Cloud Cover	36	67	59
Total Usable Scenes at < 10% Cloud Cover	16	29	23

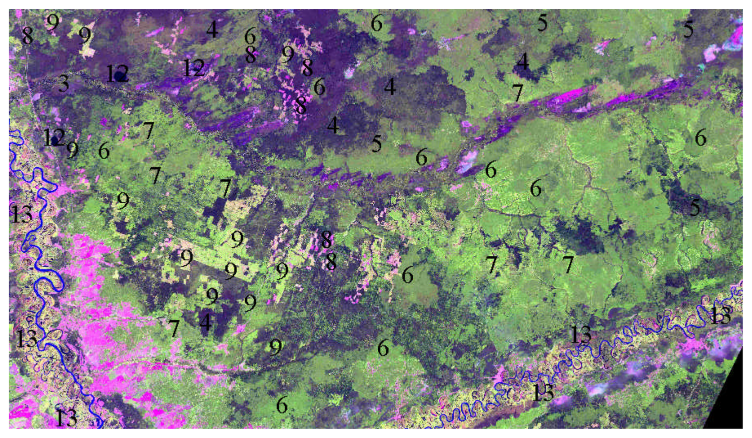
The Study Site in Siberia



Landsat WRS-2 Path/Rows in Study Site. Shown in Geographic Projection



Forests and Disturbance in The Study Site



LEGEND (potential classes)

1 – coniferous stands (100-200 years) ("dark- needle" dominant)
2 – spruce, fir (+ S. pine) dominant stands ("dark needle" forest on flood-lands)
3 – pine dominant stands
4 – mixed coniferous/deciduous stands
5 – mature deciduous stands (>60 years)
6 – pre-mature deciduous stands (< 60 years)
7 –old cuts (~ >10-15 yr.)
8 – cuts (5-15 years age) with deciduous (birch, aspen) regeneration.
9 – fresh cuts
10 – built-up areas
11 – fresh fire scars
12 – bogs
13 – agriculture (fields, hay lands, pasture)
14 – flood-lands vegetation
15 – water

LOGGING

Managed forest region in Krasnoyarsk Krai. (Photo by Slava Kharuk, Sukachev Forest Research Institute).

FIRE

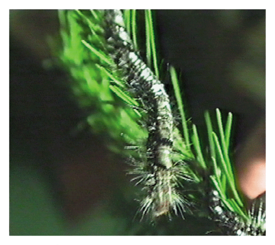


Fig. V-EI, 1999.

INSECTS

Forest Stand damage resulting from Siberian silkworm in Krasnoyarsk Krai (Photos: EWG)

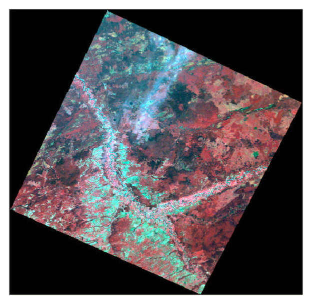
Change Analysis Using Hybrid Landsat Imagery

PROCEDURAL STEPS

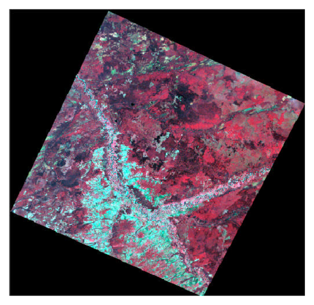
- Determine method to accurately georeference Landsat MSS,TM, and ETM+ imagery
- Decide on method to make different spatial and spectral resolutions as comparable as possible
- Address atmospheric haze limitations
- Assess potential to radiometrically balance time-series imagery
- Determine land-cover and disturbance classes present in the imagery and that can be accurately separated by their reflectance characteristics captured by the Landsat sensors
- Categorize (classify) ETM+, TM, and MSS imagery
- Categorical change detection
- Radiometric change analysis on areas of suspected significant change

I. DATA: LANDSAT MSS, TM, ETM+ TIME SERIES

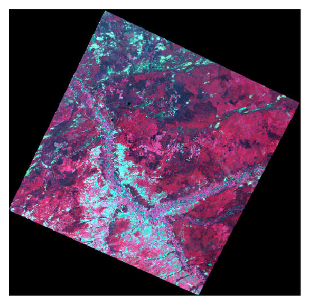
Landsat WRS-2 Path 147 Row 20



Landsat 2 Multi Spectral Scanner (MSS)
Acquisition: August 30, 1975
Spatial Resolution: 80 m
Radiometric Resolution: 6-bit
Spectral Resolution:
band 1: 0.5-0.6
band 2: 0.6-0.7
band 3: 0.7-0.8
band 4: 0.8-1.1



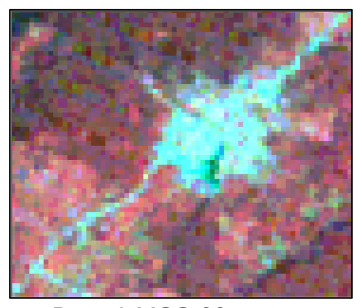
Landsat 5 Thematic Mapper (TM)
Acquisition: September 7, 1989
Spatial Resolution:
28.5 m (reflective)
120.0 m (thermal)
Radiometric Resolution: 8-bit
Spectral resolution:
band 1: 0.45-0.52
band 2: 0.52-0.6
band 3: 0.63-0.69
band 4: 0.76-0.9
band 5: 1.55-1.75
Band 6: 10.3-12.2
Band 7: 2.08-2.35



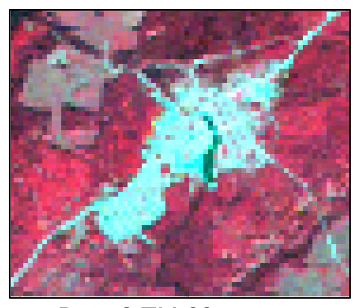
Landsat 7 Enhanced Thematic Mapper Plus (ETM+)
Acquisition: July 9, 1999
Spatial Resolution:
15 m (panchromatic)
30 m (reflective)
60 m (thermal)
Radiometric resolution: best 8 of 9 bits
Spectral Resolution:
band 1: 0.450 - 0.515 band 5: 1.550 - 1.750
band 2: 0.525 - 0.605 band 6:10.400 -12.500
band 3: 0.630 - 0.690 band 7: 2.090 - 2.350
band 4: 0.750 - 0.900 band 8: 0.520 - 0.900

II. GEOMETRIC CORRECTION AND REGISTRATION

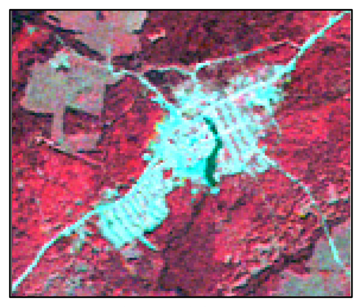
Landsat 7 imagery processed with definitive ephemeris can achieve geometric accuracies of 30-50 meters, excluding terrain effects (USGS). This becomes a valuable resource in remote regions where accurate and/or high resolution maps are not available. Since definitive ephemeris was available for this Landsat 7 acquisition, it was used to produce the base map for the project area. Images were received in satellite path orientation. The ephemeris geographic Lat/Long coordinates where obtained from the ETM+ image header and used with the Landsat 7 geometric Model in ERDAS Imagine 8.5. The data was resampled to the Albers Equal Area projection with a principal meridian in the center of the study region using the Krasovsky spheriod and Pulkovo datum. Image to image registration was used to register the TM image to the ETM+ base map and the MSS scene to the registered TM image. To maintain the higher spatial information available in the TM and ETM+ data and still make the TM data comparable to the lower resolution of the MSS data, the resampled 30-meter TM scene was degraded to 60-meters. Landcover change information was then calculated at 60-meters in the first time interval and at 30-meters in the second time interval. The results from the first time interval were multiplied by 2 before merging with the results from the second time interval.



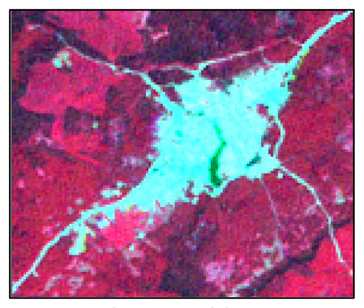
Date 1 MSS 60 meters



Date 2 TM 60 meters



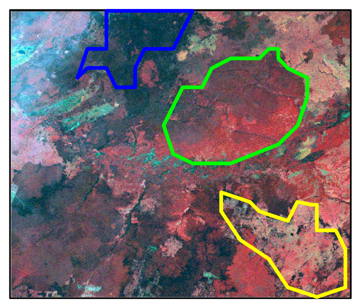
Date 2 TM 30 meters



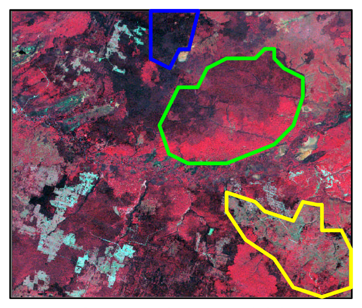
Date 3 ETM+ 30 meters

III. ATMOSPHERIC HAZE and PHENOLOGIC PROBLEMS, RADIOMETRIC PROPERTIES

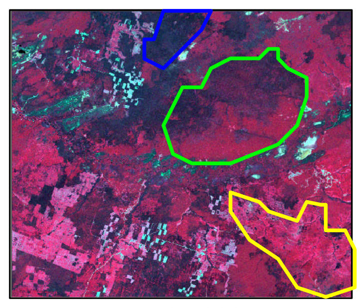
Although images chosen have few clouds, atmospheric scattering is present in all three dates. Several haze reduction algorithms were implemented on the three separate images but none produced satisfactory results. Differences in red and blue band DN values of pure coniferous forest with and without haze produced values that varied by only a couple of counts. This suggests that the atmosphere is scattering equally across the visible wavelengths. This type of scattering is not correctable because there is no way to quantify the haze contribution. In addition, the images where acquired during a seasonal period where vegetation is changing. So even though the three dates fall within 3 sequential months, phenological differences in vegetation are apparent. Since pixels representing the same landcover and having different spectral properties can be grouped (clustered) and labeled in the same category, these factors are less of a problem with categorical change than they are with radiometric change detection.



August 30 1975



September 7 1989

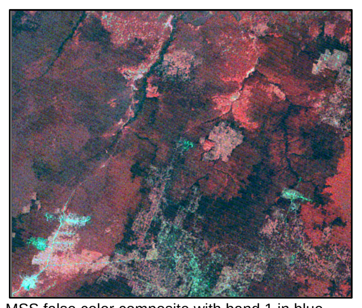


July 9 1999

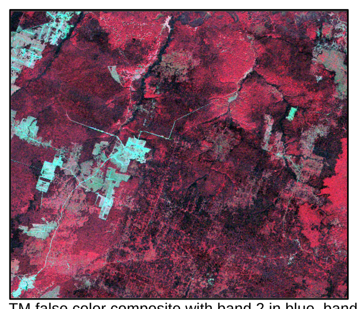
- (yellow) Phenological differences: This area is changing in its appearance although its landcover has not changed. Note that the July scene is overall greener, some if this vegetation is starting to senesce in August, and even more by September.
- (green) Phenological differences: The top portion of this area is mature conifer forest and the bottom half is mature deciduous forest. Note how the tones are different in appearance in the different months of acquisition.
- (blue) Atmospheric affects: The contribution of atmospheric reflectance make these regions of coniferous forest appear brighter than they would under clear sky.

IV. CATEGORIZATION OF LAND COVER AND DISTURBANCE IN STUDY SITE FOR THREE DATES

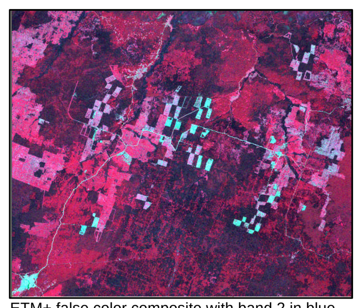
The imagery was clustered using an unsupervised maximum likelihood algorithm. The clusters were labeled into 6 broad categories using ground truth data from our Russian colleagues transmitted via an interpreted image. A neighborhood majority filter was used on the final recoded classified data to obtain greater continuity within landcover patches.



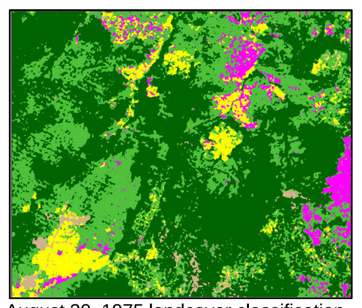
MSS false color composite with band 1 in blue, band 2 in green, and band 4 in red



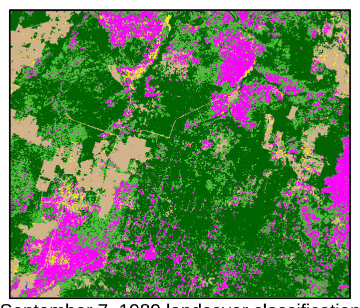
TM false color composite with band 2 in blue, band 3 in green, and band 4 in red.



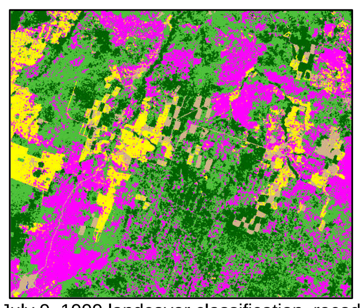
ETM+ false color composite with band 2 in blue, band 3 in green, and band 4 in red.



August 30, 1975 landcover classification, recoded and filtered.



September 7, 1989 landcover classification, recoded and filtered



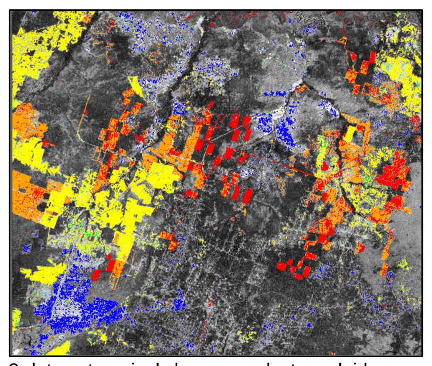
July 9, 1999 landcover classification, recoded and filtered

Water
Mature Conifer
Mature Mixed
Mature Deciduous
Pasture/Crop/Regeneration
Bare/Cleared

V. CATEGORICAL CHANGE ANALYSIS

A 3-date categorical change trajectory approach was developed that attempts to only extract landcover change information that is due to logging activity. In order for a pixel to be labeled as one of these categories of change it must pass a decision rule which takes into consideration how the change in terrain would appear in the 3 image dates. These change signatures help to refine the changes of interest and obtain more accurate change categories than would be possible with only 2-date categorical change. For example, pixels classified as cleared on first date and regenerating on the second date could occur in areas where there are phenological differences or mis-classification in either date. Refining this type of logging class to also be mature deciduous on the third date eliminates many of these changes that are not of interest from the final product.

Change Category	1975 Landcover	1989 Landcover	1999 Landcover
Logged before 1975	Pasture/crop/regen	Mature deciduous Pasture/crop/regen	Mature deciduous
Logged in 1975	Bare/cleared	Pasture/crop/regen	Mature deciduous Pasture/crop/regen
Logged 1975-1989	Mature conifer Mature mixed Mature deciduous	Pasture/crop/regen	Mature deciduous Pasture/crop/regen
Logged in ~1989	Mature conifer Mature mixed Mature deciduous	Bare/cleared	Mature deciduous Pasture/crop/regen
Logged 1989 – 1999	Mature conifer Mature mixed Mature deciduous	Mature conifer Mature mixed Mature deciduous	Pasture/crop/regen
Logged in ~1999	Mature conifer Mature mixed Mature deciduous	Mature conifer Mature mixed Mature deciduous	Bare/cleared



3-date categorical change product overlaid on 1999 ETM+ red band.

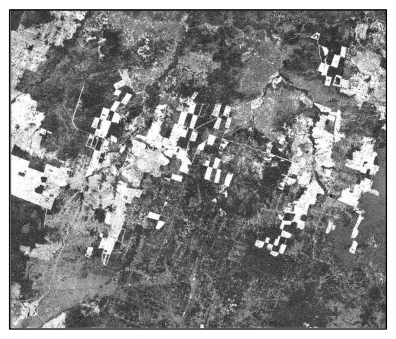
Logged before 1975
Logged close to 1975
Logged between 1975 and 1989
Logged close to 1989
Logged between 1989 and 1999
Logged close to 1999

VI. RADIOMETRIC CHANGE INFORMATION: CHANGE VECTOR ANALYSIS (CVA)

A hybrid change detection approach can be used which combines radiometric and categorical change information so that actual areas of change must occur in both. CVA captures the location and characteristics of radiometric change between two dates in multiple spectral bands. Advantages are that you get labels from categorization and reduction in false categorical change from CVA. Change direction information can be used to describe and separate features of interest with predictable change trajectories. Change magnitude information can be used to threshold out noise inherent in the data processing by only allowing large differences in values between the two dates to be seen.

Sector Code	TM Band 2	TM Band 3	TM band 4
0	-	-	-
1	-	-	+
2	-	+	-
3	-	+	+
4	+	-	-
5	+	-	+
6	+	+	-
7	+	+	+

Change direction represented as sector codes. Each code describes whether a pixel increased or decreased in brightness between a combination of spectral bands in two dates of imagery



Change magnitude channel computed as the Euclidean distance between multispectral channels in two dates. Bright areas represent large radiometric changes.