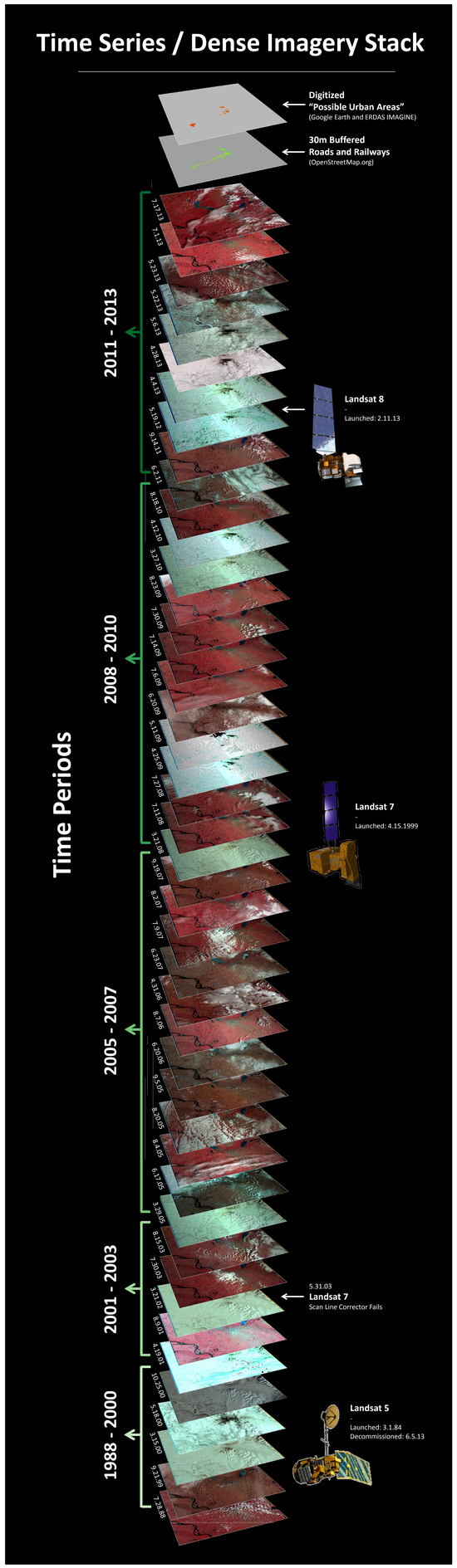
Land Cover Change Detection in Urban Siberia: Arctic Application of Landsat Dense Time Stacks using Decision Trees

Kelsey E. Nyland, Ryan N. Engstrom, Nikolay I. Shiklomanov - The George Washington University, Department of Geography, Washington, DC

THE GEORGE WASHINGTON UNIVERSITY
WASHINGTON, DC

Time Series / Dense Imagery Stack



Abstract

The Arctic is warming significantly faster than the rest of the globe and has garnered the attention of many as to the environmental, social, and economic concerns and possibilities surrounding arctic communities. A number of communities in the Russian Arctic are large urban centers – a product of soviet planned development. Assessing the environmental and urban sustainability of these communities is particularly difficult owning to their remote locations and the strict government controls on access. Remote sensing using satellite imagery presents a much easier and cost effective means of evaluation. However, using satellite imagery in the Arctic has been known to be extremely challenging due to consistent cloud cover, data gaps, landscape heterogeneity, and the small and scattered nature of these cities. A relatively new method known as dense time stack analysis has successfully dealt with similar issues in other regions of the world enabling them to map urban morphology. This methodology uses all available Landsat scenes for a given study area regardless of the season, cloud cover or data gaps. By including all available data, gaps are largely compensated for producing a more complete dataset for land cover and land use classification over time. The work presented here applied this "brute force" method of data compilation and classification to the two Siberian cities Dudinka and Noril'sk that are visited by the GW Geography Department's summer field course in coordination with the Moscow State University. Examining these two cities from the 1980's to 2013 through Landsat imagery allows us to examine the general development trends and identify areas and specific infrastructure types changing fastest. These areas identified will be further investigated with high resolution imagery in order to assess their local environmental impacts.

Research Questions

- Is the Landsat dense time stack methodology an effective and accurate means for detecting land cover and land use change in urbanized areas of the Arctic?
- Can spatial analysis of land cover and land use change be used to assess a community's urban morphology and infrastructure sustainability?

Study Areas

Dudinka

Dudinka is a port city on the Yenisei River providing access to the Kara Sea and Arctic Ocean via the Northern Sea Route. Founded in 1667 this settlement is much older and has served as an administrative seat. Today the port primarily serves Norilsk Nickel for receiving fuel and supplies and for shipping their metal and coal products.

Figure 3. An Alaska Express ship docked at the port of Dudinka loading a shipment of Nickel from Noril'sk.

Figure 2. Nori'sk skyline looking over the smelters toward the nearby plateau.

Noril'sk

Noril'sk was originally established in the 1920's as a fossil fuel (coal) and mineral extraction center. It was a GULAG labor camp from 1935 – 1956 and remains essentially a "company town" where almost the entire populous is employed by the Norilsk Nickel mining or smelting operations. After the fall of the Soviet Union and the loss of the large government subsidies for Siberian communities Noril'sk did lose significant population but was buoyed by private investors.

The cities were selected based on their proximity to each other and prior experience in both locations. Located in Central Siberia between the Yenisei River and the Central Siberian Plateau approximately 75 km apart places them both within the same Landsat scene extent (shown in faded gray in figure 1). Both cities have been visited twice on the international summer field course on permafrost conducted jointly by the GW Geography Department and the Moscow State University's Glaciology and Geocryology Faculty.

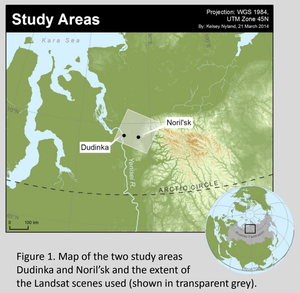


Figure 1. Map of the two study areas Dudinka and Noril'sk and the extent of the Landsat scenes used (shown in transparent grey).

Methodology

The methodology followed was largely based on a recent publication that addressed similar issues to remote sensing in the Arctic in China (excessive cloud cover, data gaps etc.) (Schneider, 2012). All of the freely available level one Landsat products available for the scene containing Dudinka and Noril'sk were acquired from the US Geological Survey's Glovis website (see time series/dense imagery stack panel). The scenes were visually scrutinized using ERDAS Imagine software for excessive cloud cover and geometric accuracy. Scenes found completely obscuring both cities were removed from the time series and none were found needing georectification. Several year time periods were established and the bands composing each were stacked. Training sites for the classes of interest; built up (excluding earthen works such as mines and tallings), soil, vegetation, water and change between these, were created with the aid of Google Earth's high resolution imagery. The training sites created were applied to the See5 classification algorithm which created decision trees to classify the time period stacks. Cross-validation was performed to evaluate the decision tree created.

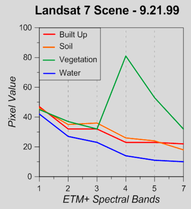
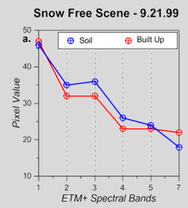


Figure 4. Spectral plot for the four primary classes used. Note how the classes "built up" and "soil" are nearly indistinguishable in all 6 bands used.



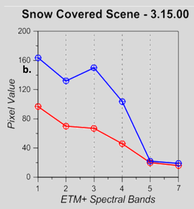
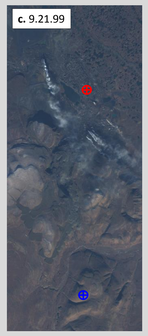


Figure 5. Spectral plots for the soil and built up classes in snow free (a) and snow covered (b) scenes. Locations of the corresponding pixels to the spectral signatures in the snow free (c) and snow covered (d) scenes. On the ground photos of the built up pixel location (e) and soil pixel's (f) locations in July 2013.



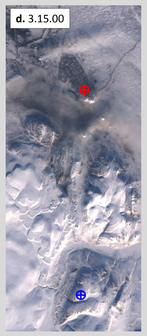


Figure 5. e. Leninskiy Street in the urban core of Noril'sk.

Figure 5.f. View of the plateau on the edge of the urban core of Noril'sk.

Results

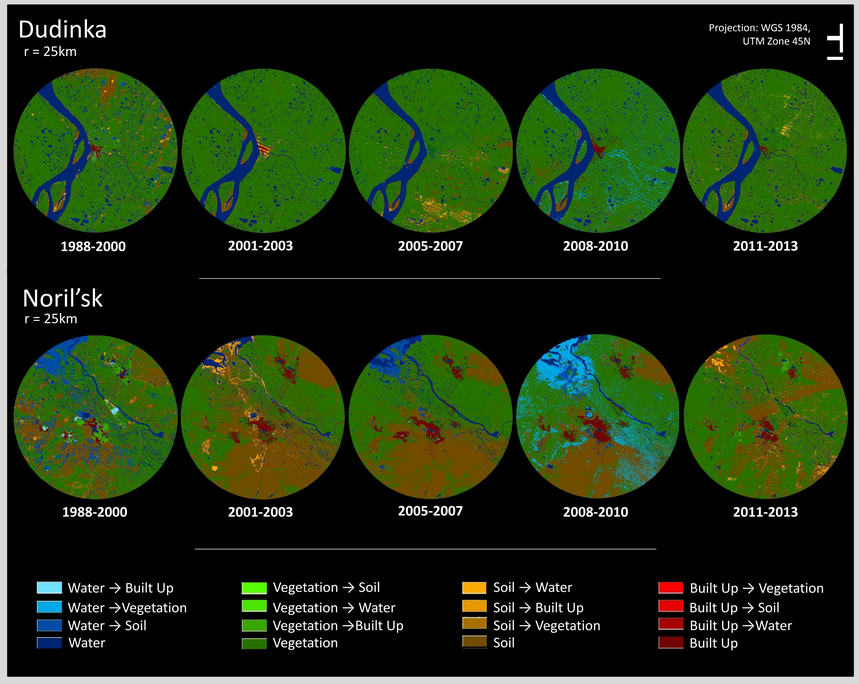


Figure 6. Classified images of the imagery stacks for each time period. Centered over each of the respective cities, Dudinka and Noril'sk, the circular study areas are equal in size at 50 km in diameter. The classes shown represent the steady state features for the given time period (water, vegetation, soil, and built up areas) and all of the possible changes that could have been observed between these. Training sites were only made for those classes that could be positively identified through visual inspection of the imagery, historical knowledge of the areas gained through field experience, or through Google Earth high resolution imagery. Striping or confusion of classes such as in the 1988-2000 images are due to excessive cloud cover in multiple images in the stack or multiple scan line gaps lining up. In these cases there was not enough imager included in the stack to compensate for the areas omitted or obscured.

Accuracy Assessment

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
(1) Water	14572	2	1						1							
(2) Water→Soil	5	1157	2	1		1										
(3) Water→Vegetation	2	1	344								4					
(4) Water→Built-Up				6												
(5) Soil→Water	1				472	2						1				3
(6) Soil	1					3060					6					
(7) Soil→Vegetation							23				2					
(8) Soil→Built-Up								X								
(9) Vegetation→Water	1								23							
(10) Vegetation→Soil										X						
(11) Vegetation	2		3			10					4615	1				5
(12) Vegetation→Built-Up												81				2
(13) Built-Up→Water													9			
(14) Built-Up Soil														X		
(15) Built-Up→Vegetation															X	
(16) Built-Up											7	1	1			656

Figure 7. Summary confusion matrix for all decision trees created. The total number of pixels correctly (black numbers) classified within an image based on 20% of the training data reserved for validation verses the total number of pixels incorrectly assigned (red numbers in the column that they were assigned to). An "X" indicates a class not found within the scene and therefore not trained.

The decision trees were very successful at classifying pixels based on the training data provided to it. The over all error for each of the five trees constructed (one for each time period) were very low (in consecutive order, 0.4%, 0.3%, 0.2%, 0.5%, and 0.2%). Of the minimal amount of misclassified pixels, figure 7 shows the average and which classes they were misclassified as.

Unfortunately accuracy assessment statistics could not be performed on the classified images as compared to what can be identified on the ground through higher resolution imagery since there is none immediately available such as on Google Earth. However, through a visual assessment and intimate knowledge of the two study areas it is apparent that the Noril'sk area was much more difficult due to the close proximity of the exposed soil on the plateau and from the large scale mining operations which lead to some over estimation of built up area. In addition, a large swath of dead vegetation moving SE from Noril'sk due to the pollution carried by the predominant wind direction was largely classified as soil in the different time periods. There is also noticeable striping in several of the classified images for both Dudinka and Noril'sk due to the majority of images in the given stack had scan line corrector issues from the Landsat 7 sensor and these data gaps overlapped . Striping was generally misclassified as area of change to or from water.

Conclusions

- The Landsat dense time stack methodology shows promise for application in arctic environments with additional ancillary data.
- This approach in conjunction with mathematical modeling can potentially be used to assess complex interactions between natural and anthropogenic factors affecting arctic urban sustainability.
- The unique characteristics of Russian Arctic cities complicate the evaluation of the urban morphology remotely. Consequently, additional field work in the two cities is required for a more thorough evaluation and will be conducted in July 2014.

Figure 8. A block of soviet era buildings partially constructed and never inhabited (a), foundation of an unfinished building where funding ran out being used as the platform for a public playground (b), and the recycling of a former building's foundation for a new building made of lighter materials (c). Recycling foundations has been a common engineering practice in this region since foundations on permafrost typically constitute 10 – 40% of the total construction cost for a given building.

Acknowledgements

This research was supported by the U.S. National Science Foundation (NSF) grants ARC – 1231294 and ARC-1002119 and by the National Research Council of Norway grant 34306/1/ECNS21015N awarded to The George Washington University. Critical to this work was the on the ground experience afforded by the International Permafrost Field School organized jointly by Moscow State University's Glaciology and Geocryology Faculty and the George Washington University's Geography Department, specifically by Professors Valeriy I. Grebenets and Dmitry A. Streletskiy.

Reference

Schneider, A. 2012. Monitoring land cover change in urban and peri-urban areas using dense time stacks of Landsat satellite data and a data mining approach. *Remote Sensing of Environment*, 124, 689-704.