Towards Global Monitoring of Forest Cover

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Abstract – The open Landsat archive offers the opportunity to employ a global, moderate spatial resolution for monitoring forest change. A method for systematically processing Landsat imagery was implemented for four test areas: Indonesia, the Democratic Republic of the Congo, European Russia and Quebec. All Landsat imagery with metadata less than 50% cloud cover was used as inputs. For Indonesia and the Democratic Republic of the Congo, forest extent and loss were mapped from 2000 to 2010. For European Russia and Quebec, forest extent and loss were mapped from 2000 to 2005. All results were compared with samples of expert-interpreted Landsat samples, chosen within a probability-based sample framework. The method can be implemented generically at the biome scale with results illustrating a capability for large-scale processing of Landsat imagery for global forest extent and change assessments.

Key words: Landsat; MODIS; forest cover; change detection; global change.

1. INTRODUCTION

Methods developed for characterizing global land cover using coarse resolution data sets such as AVHRR and MODIS can now be applied to Landsat data. Since December 2009, the Landsat image archive has been made freely available, enabling the application of lessons learned using AVHRR and MODIS. While global-scale forest change indicator maps have been produced using MODIS data (Hansen et al. 2010), Landsat offer a medium spatial resolution more suitable for area estimation of forest cover change. The primary difference between Landsat and heritage coarse spatial resolution data sets in terms of processing is the comparative infrequency of Landsat acquisitions. To the credit of the Landsat Science Team, a global acquisition for the Landsat Enhanced Mapper Plus instrument was put in place, assuring global coverage. However, the number of acquisitions varies from region to region, and when combined with cloud cover limitations, scene overlap and the scan-line corrector malfunction, the number of viable observations for any portion of the land surface can be highly variable.

A standardized method, insensitive to the vagaries of the acquisition strategy and able to apply per pixel quality assessment flags, is a pre-requisite for global forest cover monitoring. While a number of national-scale earth observation-based forest monitoring programs exist, including those of Australia, Brazil and India, most rely on a method incorporating interpreter interaction. It is posited here that a global forest monitoring endeavor would not have the luxury of such an approach. To perform annual, or even 5-year global updates of forest change, a highly automated procedure would be needed. This paper presents examples of such a method in moving towards global forest cover monitoring.

2. DATA AND METHODS

All Landsat ETM+ data under 50% metadata cloud cover between epochal anniversary dates were used. For example, forest cover extent and loss products for Indonesia and the Democratic Republic of the Congo from 2000 to 2010 represented 15,692 and 8,881 ETM+ images respectively. For European Russia and Quebec, image inputs from 2000 to 2005 obtained and constrained by a MODIS phenology-defined growing season per Landsat path/row and consisted of 7,592 and 3,456 images respectively.

Each image was converted to top of atmosphere reflectance. For Indonesia and the Democratic Republic of the Congo, an across track anisotropy correction was also applied (Hansen et al. 2008). Subsequently, standard cloud, haze, shadow and water models were applied to each pixel. Pools of good quality observations were then used as inputs to forest cover extent and loss models. All models employed decision tree algorithms (Hansen et al. 1996). Forest extent was mapped for the initial year of each study period. Forest loss was derived separately using inputs from all years and subtracted from the initial forest cover extent layer. Forests were defined as 30% or greater tree cover at the Landsat pixel scale. Trees were defined as 5 meter or taller woody vegetation. Change was limited to stand replacement disturbances at the Landsat pixel scale, or a forest to non-forest conversion. Degradation was not assessed.

3. RESULTS

For Indonesia, the method revealed an overall reduction in forest cover loss as compared to reported rates for the 1990's (FWI/GFW 2002). However, the rate of change from 2005 to 2010 was higher than that of 2000 to 2005. Forest disturbance is found predominantly in the Sumatra and Kalimantan island groups and was estimated at nearly 1Mha per year. However, only roughly half of this change is estimated to be of intact forests. The remaining half is related to agroforestry and the harvesting of timber plantations or removal of palm estates. Persistent cloud cover limited the development of annual cloud-free composites, but did not preclude the estimation of forest cover loss (Broich 2011). Figure 1 depicts the Indonesia results.

For the Democratic Republic of the Congo, forest cover loss was likewise greater for the 2005 to 2010 epoch. However, overall total forest cover loss was just over one-third of that of Indonesia, at approximately 0.37Mha per year. Forest cover loss for the Democratic Republic of the Congo is not related to agro-industrial activities as in Indonesia. For the Congo, small-scale subsistence farming is the primary driver of change and is found in close proximity to settlements and along trunk roads. Roughly 30% of Democratic Republic of the Congo forest exists as dry tropical woodland, largely in the south of the county. For mapping forest extent and change within this

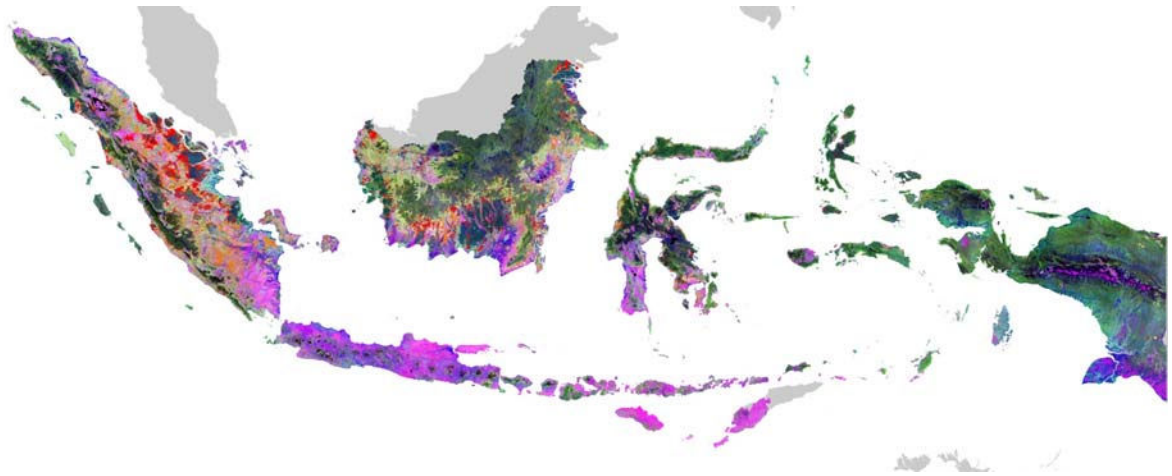

Figure 1. Landsat ETM+ image composite in 5-4-3 false color. Red overlay is primary forest loss from 2000 to 2010, orange is other forest loss from 2000 to 2010.

region, a growing season was defined using MODIS data and used to select input images in order to avoid confounding change with seasonality. Data from this study are available for download at http://carpe.umd.edu (OSFAC 2010).

For the boreal/temperate study areas of European Russian and Quebec, Canada, a seasonal filter was also used. Figure 2 shows the per path/row definition of growing season start and end dates using MODIS data. For European Russia, forest cover loss totaled over 2Mha for the period from 2000 to 2005 (Potapov et al. 2010). Compared to studies of prior epochs, relatively more forest cover loss was found in proximity to major cities, including Moscow and St. Petersburg, and less in the far northeast, the site of extensive logging in Soviet times. In addition to logging, forest fires were a significant driver of forest cover loss. For Quebec, fire was indicated as a primary driver in the northern part of the province, with logging predominating in the south.

Figure 2. Per path/row start-end dates for boreal biome growing season inclusion of Landsat imagery.

The method was implemented in four test areas containing portions of the major treed biomes of the earth. Quebec and European Russia are principally boreal, but have large areas of temperate forest. While Indonesia is largely humid tropical, the Democratic Republic of the Congo has a considerable land surface in both humid tropical and dry tropical biomes. Comparisons were made with samples from a global assessment of forest cover loss (Hansen et al. 2010). Blocks of Landsat imagery were expert-interpreted for forest extent and loss and compared with the systematic regional-scale mapping procedure. Results reflected the robustness of the wall-to-wall systematic mapping method (Broich et al. 2011; Potapov 2010 et al.).

4. CONCLUSION

The combination of the open Landsat archive, expertise in forest cover characterization, and high-performance computing offers an unprecedented capability for forest monitoring. Of these three factors, the Landsat data policy is the most critical. Landsat data are acquired seasonally for the entire terrestrial land surface, feature robust radiometric calibration and orthorectification, and can be accessed free of charge. Without such a progressive data policy, large area monitoring of forest cover would not be possible for many parts of the world.

In this study, a generic approach was applied to mapping forest cover extent and loss at regional/national scales for four very different environments. Indonesia features a rapidly changing agroforestry dynamic where true deforestation does not occur. Clearings are quickly replanted, requiring a rapid return rate for observing disturbance dynamics, especially given the persistence of cloud cover over the country. The Democratic Republic of the Congo exhibits a spatially pervasive but small-scale change dynamic, also within a cloud-affected environment. The large extent of dry tropical woodlands require a seasonal filtering of input imagery in quantifying forest extent and change. The examples of European Russia and Canada also required a seasonal adjustment in selecting growing season observations with a low of around two months for obtaining viable imagery at high latitudes. Methods implemented for the four test areas indicate the viability of a generic approach to forest cover extent and change mapping that could be implemented at the global scale. The method relies on a robust radiometric normalization, per pixel quality assessment flags, and hard-wired models for characterizing forest extent and change.

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