IMPROVING AUTOMATED DISTURBANCE MAPS USING SNOW-COVERED LANDSAT TIME SERIES STACKS

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Abstract.—Snow-covered winter Landsat time series stacks are used to develop a nonforest mask to enhance automated disturbance maps produced by the Vegetation Change Tracker (VCT). This method exploits the enhanced spectral separability between forested and nonforested areas that occurs with sufficient snow cover. This method resulted in significant improvements in Vegetation Change Tracker outputs at the 95 percent confidence interval. An estimated 34 percent of the world's forests receive sufficient snowfall to use this method.

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INTRODUCTION

The extensive Landsat archive is increasingly being leveraged to gain an understanding of land cover/land use change dynamics by offering insight into the spatial and temporal aspects of forest disturbances. The Vegetation Change Tracker (VCT) is an automated change detection method that uses growing season Landsat time series stacks (LTSSs) to detect forest disturbances (Huang et al. 2010a). Its efficacy is highly dependent on forest density, abruptness of the onset of disturbance, and presence of agricultural and wetland areas (Thomas et al. 2011).

STUDY AREA

VCT was applied to quantify landscape-level patterns of forest disturbances from 1985 to 2008 in the Lake Michigan and Lake Superior basins. This study area was chosen to gain an understanding of the impacts of forest disturbances on the water quality of the Great Lakes. These basins are primarily composed of forests (intact and disturbed), cropland, pastureland, wetlands, and urban areas. The level of forest fragmentation generally decreases along a south-to-north gradient. A variety of anthropogenic as well as natural disturbances occur throughout the study area. These disturbances include harvest, urban development, insect mortality, storm damage, and fire (Schulte et al. 2007, Stueve et al. 2011).

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METHODS

In the course of this study, it was observed that VCT often incorrectly classified nonforested wetlands and agricultural areas as disturbances due to their dense vegetation cover and high inter-annual variability. To mitigate this error, a modified VCT workflow was developed and employed that incorporates winter Landsat imagery. This version of VCT is referred to as VCTw due to its utilization of snow-covered winter Landsat time series stacks (LTSSw) for the creation of a nonforest mask. The VCTw approach uses the VCT cloud masking method (Huang et al. 2010b). Due to similarities of clouds and snow cover in the spectral/temperature data space, the VCT cloud masking method consistently identifies nonforested snow-covered areas as clouds (Fig. 1). Areas that are consistently identified as clouds and that do not show a long-term recovery trend throughout an LTSSw are included in a nonforest mask. Forested and disturbed pixels from the standard VCT product that fall within the nonforest mask are recoded to nonforest (Fig. 2). The full VCTw flowchart can be found in Figure 3.

We produced standard VCT and VCTw change products for nearly 25 million hectares within the Lake Superior and Lake Michigan drainage basins. An accuracy assessment of the VCT and VCTw change products was conducted through a two-stage sampling design across three geographic regions using techniques discussed by Nusser and Klass (2003), as well as Stehman et al. (2003). Due to the variability in typical disturbance type and size throughout the basins, the study area was divided into three regions. The three accuracy assessment regions were the lower Lake Michigan basin (LLMB), upper Lake Michigan basin (ULMB), and the lower Lake Superior basin (LLSB). (The upper Lake Superior basin (ULSB) made up the Canadian portion of the Lake Superior basin. The ULSB could not be included in this validation due to a lack of consistent aerial reference imagery.) Aerial photography spanning the analysis period served as the reference imagery. The standard VCT year of disturbance classes were binned into two disturbance classes to match the temporal resolution of the reference imagery. These classes were disturbed early (1985-1999) (D1) and disturbed late (2000-2008) (D2). The remaining classes were persisting forest (PF), nonforest (PNF), and water (PW).

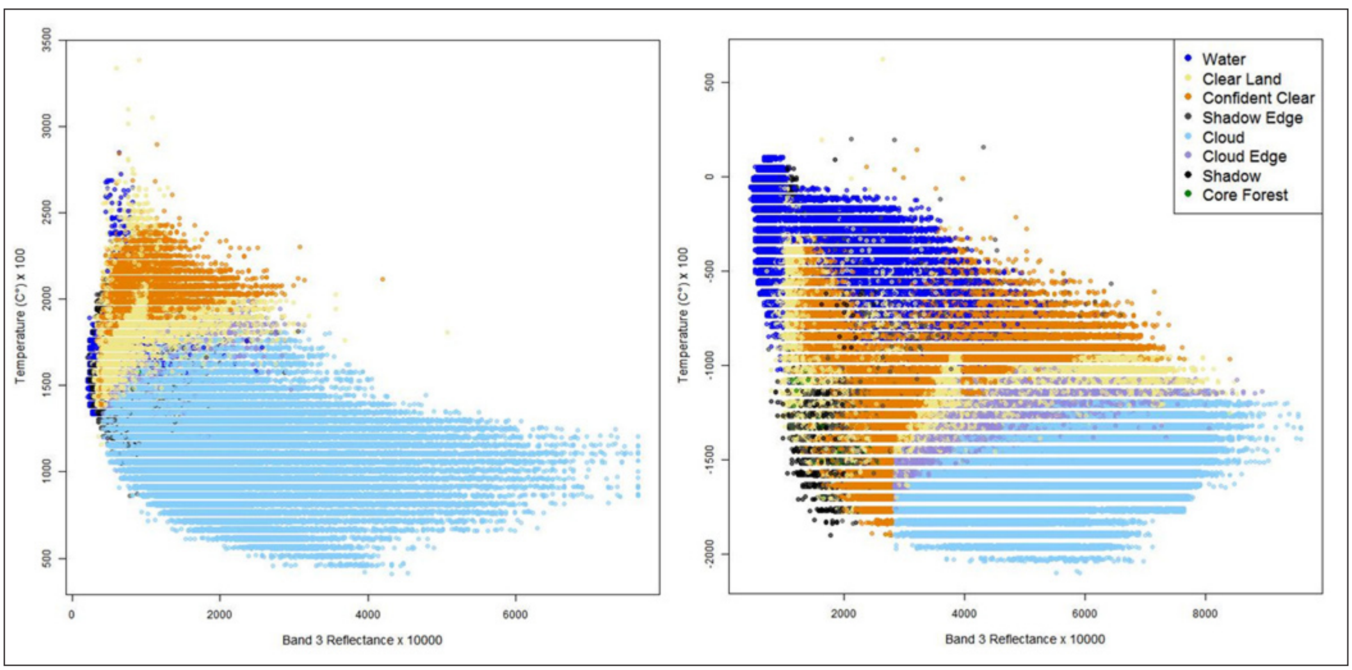

Figure 1.—Spectral-temperature space for a summer Landsat TM scene with clouds (left plot), and a cloud-free snow-covered winter scene (right plot). The cloud masking model misclassifies snow as clouds due to their similar bright/cold spectral/thermal signature.

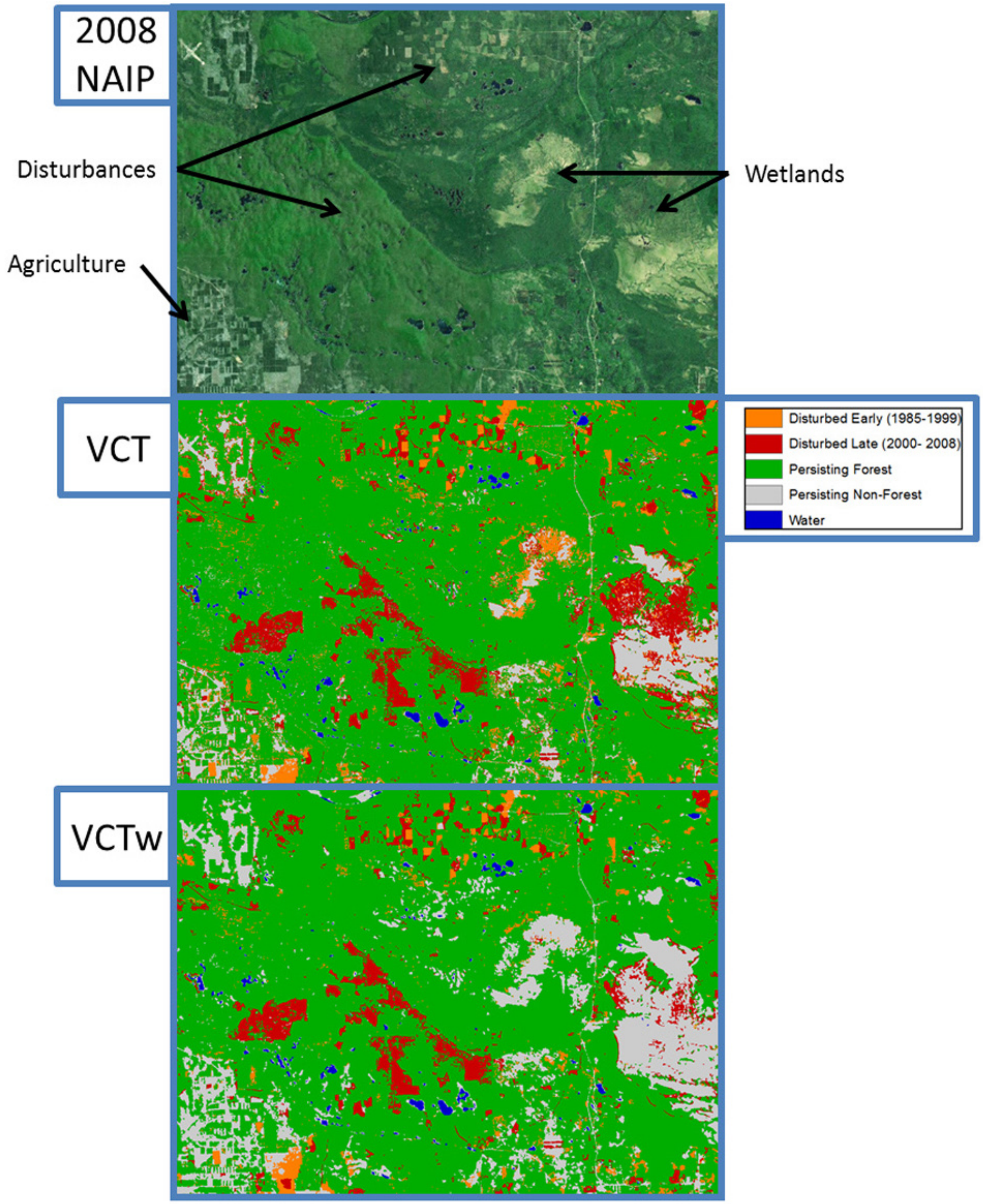

Figure 2.—Example of commission of wetland (right center of panels) and agricultural areas (lower left portion of panels) by VCT. VCT initially classified these areas as persisting forest/forest disturbance. They were then recoded to nonforest.

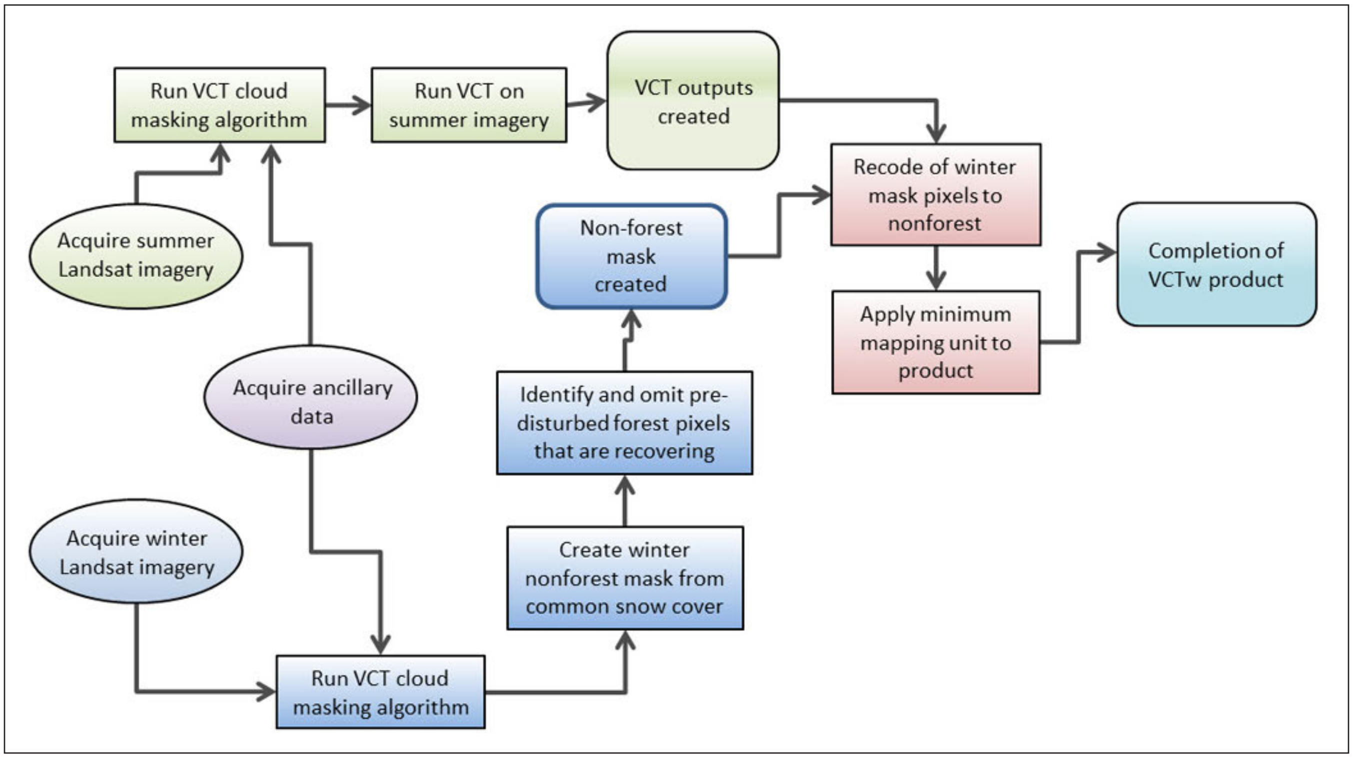

Figure 3.—Flowchart of all major steps of the VCTw workflow. Larger components depicted as different colors are running VCT using the standard protocol (green), creating a nonforest mask using VCT's cloud masking algorithm (blue), and applying nonforest mask and minimum mapping unit (red) to create the final VCTw product.

Because the aerial imagery had to be manually georeferenced, the first stage of the sample design was intended to optimize our reference image preparation time. Therefore, the primary sampling unit (PSU) corresponded with the footprint of a 7.5-arc minute quadrangle. A simple random sample of 7.5-minute quadrangles that fell entirely within the basin was taken based on approximate region area. Thirty-five PSUs were selected in the LLMB and ULMB, and 17 were selected in the LLSB. The secondary sampling unit (SSU) corresponded to individual pixels. A stratified random sample was taken using the five VCTw classes as strata. The number of SSUs varied between strata and region (Table 1). Each SSU was photo-interpreted to determine the proper disturbance or persisting land cover class.

Table 1.—Number of SSUs from each stratum within each region

	PNF	PF	PW	D1	D2
LLSB	9	9	2	10	10
ULMB	5	5	2	6	6
LLMB	7	7	2	8	8

RESULTS

The binned VCT disturbance year product obtained an overall accuracy of 86.3 percent, while the binned VCTw disturbance year product yielded a statistically significant improvement at the 95 percent confidence interval with an overall accuracy of 91.2 percent. The difference between VCT and VCTw varied across the study regions (Fig. 4). The most pronounced improvement occurred in the LLMB, likely because the LLMB contains the largest proportion of the agricultural nonforested areas in which standard VCT erred while VCTw was able to discern. The proportion of agricultural areas in the ULMB and LLSB is lower than in the LLMB.

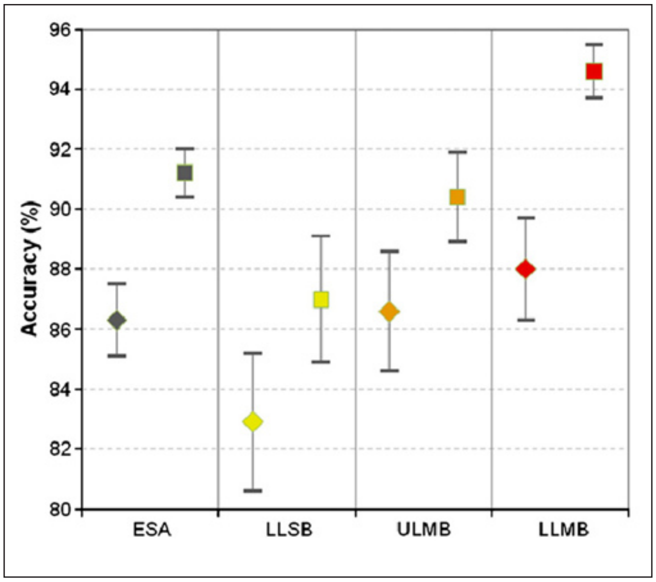

Figure 4.—Overall accuracy of VCT (diamonds) and VCTw (squares) with 95 percent confidence interval bars.

DISCUSSION

In this study, VCTw was used to create a significantly improved landscape-level forest disturbance map using LTSSw. VCTw is a robust, practical approach for mitigating misclassification of wetlands and agricultural areas as forest/forest disturbance in any area with sufficient snowfall. Because this method uses the VCT cloud masking method, it easily fits into the standard VCT workflow. Alternate approaches have proved effective, but generally require substantial model calibration data (Walterman et al. 2008). VCTw requires no calibration data and minimal additional time to implement. An estimated 34 percent of the world's forests receive sufficient snow to implement VCTw. Forested regions that do not receive reliable yearly snowfall would require an alternate approach.

ACKNOWLEDGMENTS

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