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Evaluation of remotely sensed indices for assessing burn severity in interior Alaska using Landsat TM and ETM+

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Abstract

We evaluated 13 remotely sensed indices across four wildfire burn sites in interior Alaska. The indices included single bands, band ratios, vegetation indices, and multivariate components. Each index was evaluated with post-burn and differenced pre/post-burn index values. The indices were evaluated by examining the correlation between each remotely sensed index and field-based Composite Burn Index (CBI) values. Radiant temperature was strongly correlated with field-based CBI when a post-fire image from autumn was used. Indices that used red and near-infrared bands performed poorly relative to indices that incorporated mid-infrared bands. The Normalized Burn Ratio (NBR), which incorporates near- and mid-infrared bands, was ranked within the top three indices for each of the four burns using post-burn images, and for three of the four burns using pre- and post-burn images. When indices were summed based on ranked correlations, the NBR was highest for both the post-burn and pre/post-burn approaches. The NBR had high correlations with the field-based CBI in closed needleleaf, mixed, and broadleaf forest classes. However, the NBR was useful as an index of burn severity only for forested sites. The correlation between NBR and field-based CBI was low in non-forested classes such as woodland, scrub, and herb land cover classes.

Keywords: Fire; Composite burn index; Normalized burn ratio; Burn severity; Alaska; Landsat TM; Landsat ETM+; Boreal forest

1. Introduction

Interior Alaska is a region covering nearly 140 million hectares between the Alaska Range to the south and the Brooks Range to the north. Fire is the predominant disturbance in the region and it has been an important influence on Alaskan vegetation for thousands of years. The annual area burned in interior Alaska varies greatly. Typically a few large fires contribute to a large portion of the total area burned (Barney, 1971; Kasischke et al., 2002). The fire return time ranges from 50 to 200 years, depending on the site and vegetation type (Barney, 1971; Gabriel & Tande, 1983; Heinselman, 1981; Viereck & Schandelmeier, 1980; Yarie, 1981). In upland white spruce sites, a short fire cycle may maintain the dominance of early seral, fast growing, shade intolerant tree species such as aspen, while areas with a longer fire cycle would tend to be dominated by later seral, slower growing, shade tolerant species such as white spruce (Mann & Plug, 1999). The fire return interval may also be accelerated with climate warming due to a longer fire season, hotter weather, increased lightning, and drier fuel conditions (Rupp et al., 2000; Wotton & Flannigan, 1993).

Variation in burn intensity and fire interval leads to a mosaic of vegetation age and cover classes across the landscape (Arseneault, 2001; Johnson et al., 2001; Lutz, 1956). All tree species in interior Alaska germinate best on exposed mineral surfaces (Zasada et al., 1983), and these species have different establishment and growth rates depending on burn severity effects (Johnstone & Chapin, in press). Therefore, estimates of burn severity are important for understanding the effects of fire on post-fire vegetation succession. Burn severity mapping also has important

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implications for carbon emissions modeling (Cahoon et al., 1994; Kasischke & French, 1995; Michalek et al., 2000; Conrad et al., 2002).

The objective of this study is to evaluate 13 remotely sensed indices for mapping burn severity in interior Alaska. Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) data were utilized due to the favorable spectral regions and spatial resolution of these sensors, and because of the historical coverage and large spatial extent of available imagery.

1.1. Field and remotely sensed estimates of burn severity

Burn severity is the degree of environmental change caused by fire. How investigators estimate burn severity in the field varies depending upon the environmental change of interest. Single metrics have been applied such as estimates such as of canopy consumption and tree mortality (Choung et al., 2004; Greene et al., 2004; Isaev et al., 2002) or consumption and charring of organic soil profiles (Charron & Greene, 2002; Johnstone & Chapin, in press; Miyanishi & Johnson, 2002). Other burn severity indices have been based on a combination of factors such as consumption of organic horizon, degree of standing trees, and degree of canopy consumption and mortality (Key & Benson, 2002; Michalek et al., 2000; Ryan & Noste, 1985; van Wagtendonk et al., 2004).

Fire causes substantial spectral changes by consuming vegetation, destroying leaf chlorophyll, exposing soil, charring stems, and altering both aboveground and belowground moisture. Reduction of chlorophyll absorption leads to increased reflectance in the visible electromagnetic region, along with leaf tissue damage leading to a decreased reflectance in the near-infrared (NIR) region (Jensen, 2000). In contrast, with a decrease in crown shadow and a decrease in canopy moisture, mid-infrared (MIR) reflectance typically increases following a fire (van Wagtendonk et al., 2004; White et al., 1996), and the change in the NIR and MIR regions has been effectively exploited for mapping burned regions (Jakubauskas et al., 1990).

Indices applied to burn mapping have included single date, post-burn and bi-temporal, pre- and post-burn approaches. Single date models have several advantages over bi-temporal models. They are less expensive, less time-consuming, and they also reduce inherent error found in bi-temporal models (Koutsias et al., 1999). Between-date errors can be caused by differences in phenology (van Wagtendonk et al., 2004), misregistration of image pixels (Verbyla & Boles, 2000), and differences in sensor calibration, sun–sensor geometry, and atmospheric effects. Sensor differences and some atmospheric effects may be corrected through radiometric normalization techniques, but differences in vegetation phenology may be unavoidable, especially in cloudy regions, such as interior Alaska, where there may be few cloud free optical images available. Use of a single post-burn image avoids these problems, but lack of a pre-burn reference image lead to difficulties in mapping spectrally similar areas such as water and recent burns, or senescent vegetation and older burns (Pereira, 1999; Pereira & Setzer, 1993).

2. Study areas

Four burned regions were evaluated in this study. The Survey Line fire (SL246) was accidentally ignited by a survey crew in June 2001 and burned 45,000 ha by the end of the fire season in autumn 2001 (Fig. 1). The three additional fires burned during the summer of 1999 in the Yukon–Charley Rivers National Preserve and were designated as burns YC242, YC248 and YC260 (Fig. 1). The three Yukon–Charley fires were ignited by lightning and burned a total of 47,000 ha. Fire suppression on all four fires was limited, and the burned areas were not substantially disturbed by firefighting efforts.

The climate in the Survey Line burn area is continental with cold winters and warm summers. Mean annual precipitation is 26 cm, mostly as summer rain. Mean annual temperatures in this area is 3.0 °C (Alaska Climate Research Center,http://climate.gi.alaska.edu/Climate/index.htm). The Survey Line burn site is on the Tanana River floodplain with an abundance of fens and saturated soils, and relatively few densely forested stands. The vegetation ranges from white spruce (*Picea glauca*) forest on higher alluvial terraces, to wet sedge communities and black spruce (*Picea mariana*) woodland on wet sites. Black spruce or mixed black/white spruce forest are found in more upland areas, along with small patches aspen (*Populus tremuloides*) and paper birch (*Betula papyrifera*) broadleaf forest.

The climate of the higher elevation Yukon–Charley region is colder and wetter than the Survey Line burn region with a mean annual temperature of −4 °C and 30 cm of mean annual precipitation (Alaska Climate Research Center,http://climate.gi.alaska.edu/Climate/index.html). The topography is more variable, with elevation rising from the Yukon River floodplain to peaks above treeline at over 1000m. The vegetation varies from saturated sedge and tussock areas near the river, to warmer and dryer south-facing slopes dominated by aspen and birch. Open and closed forests of both needleleaf and broadleaf trees are common, as is alpine tundra above treeline.

3. Methods

Thirteen remotely sensed indices were chosen based on a literature search of burn severity studies. Each index was evaluated as both a single date (post-burn) and a bi-temporal (pre- and post-burn) analysis.

Our strategy was to compare the correlation between remotely-sensed indices and field estimates of burn severity from the four burns. From this analysis, the best performing