1238

REMOTE SENSING OF FORESTED EARTHFLOWS

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ABSTRACT

The potential use of remote sensing techniques to detect and map existing earthflow landslide hazards on forested hillslopes is examined. Mean band radiances are found to respond to changes in canopy closure, understory vegetation, and background reflectance for various levels of forest canopy disturbance associated with slide movement. At low slide movement rates the canopy is thinned and increased understory exposure causes infrared reflectance to increase. At moderate movement rates decreases in the band 4 and 5 radiances (.76-.91 and 1.13-1.35um), attributed to exposed dead wood, are found while the band 6 and 7 radiances (1.57-1.71 and 2.1-2.38um) increase. At high movement rates the canopy is completely destroyed and reflectance increases across the spectrum. Scene temperatures increase systematically with canopy disturbance. Canopy alterations due to earthflow movement increase the spatial contrast of the forested scene. Both edge density and inertia texture measures are able to characterize these contrast changes and separate slide versus non-slide forest in the example tested. Degrees of canopy disturbance are separable using spectral/textural measures with success of separability being commensurate with the amount of disturbance that has occurred.

INTRODUCTION

Earthflows are a slow moving variety of landslide that creep downslope at typical rates of centimeters to meters per year. They occur most frequently in weak soil and rock materials such as clay and shale, that behave plastically in response to stress. Earthflows are common in the coastal mountains of California, Oregon, and Washington and can range in size from tens of meters across their width to large complex nested masses of slides that involve several square kilometers of area. In appearance and style of movement, they resemble glaciers. Earth flows are a geologic hazard imposing significant limitations on hillslope land use practices.

Earthflows on forested hillslopes often do not move rapidly enough to completely destroy the overlying timber canopy. Rather the canopy will be disturbed to some degree

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proportional to the rate of movement. Characteristics of this disturbance include trees tilted off vertical, trees felled, and changes in the understory vegetation of the resultant canopy openings. Disruption of the local groundwater system may also occur causing accentuated wet/dry gradients within the flow. Forested earthflows may be subtle and difficult to detect over large areas on airphotos when a significant degree of canopy remains. Agencies such as the USDA Forest Service who manage large tracts of forested mountainous areas thus have a need for an improved methodology of detecting and mapping forested earthflows.

This paper reports preliminary results of an ongoing research project evaluating the use of spectral and spatial analysis of multispectral imagery for automated detection and mapping of forested earthflows. This earthflow research is a portion of a three year joint project by the USDA Forest Service, the US Geological Survey and NASA dealing with the potential use of remote sensing techniques to investigate landslides.

While earthflows with lower movement rates may not completely destroy the forest cover, the earth movement will disrupt and stress the canopy. Such disturbance of a canopy by an earthflow can cause a variety of scene changes that are known to affect the spectral character of remotely sensed data. Tilting of trees and thinning of the forest by downed trees will lower the percent crown closure of the site, expose the sides of the crowns of the tilted trees, and expose the bark on the trunks of the the tilted and downed trees to an overhead sensor. Understory vegetation, with reflectance qualities significantly different from those of the coniferous overstory is exposed as the percent cover of the overstory decreases. Surface ponding of water occurs frequently within large earthflows and may be visible through a thinned canopy. Conversely, tensional zones within an earthflow may improve groundwater drainage and result in very dry areas which, in combination with tree root disruption, may impose moisture stress on the canopy. These factors should result in radiometric qualities different from undisturbed forest, creating patterns both texturally and spectrally higher in contrast.

STUDY SITE

To test this hypothesis, an earthflow study site, Jude Creek, was selected within the Willamette National Forest in central Oregon (Fig. 1). This site was chosen for the initial test site because it represents a broad range of earthflow movement and forest conditions found in the coastal mountains of California and Oregon. In addition, previous field work has established quantitatively the boundaries and rates of movements of the slide. This earthflow is composed of three segments moving at distinctly different rates allowing an assessment of remote sensing techniques for distinquishing between zones of different movement rates within a slide, as well as between slide and non-slide. The segments occur in ascending order of movement rate with the low rate (0-1m/yr.) at the head or upslope end of the slide and the high movement rate (5-10 m/yr.) at the toe or downslope portion of the slide. The dominant species of the forest at the site are Douglas-Fir (Pseudotsuga menziesii) and Western Hemlock (Tsuga heterophylla).

EXPERIMENTAL DESIGN

Using a systematic procedure with a random starting point, fixed area plots were established within the three zones of the earthflow and in the surrounding undisturbed forest. The canopy and understory structural and species characteristics were measured in these plots and samples of the canopy were taken for further analysis of needle cell structure and chemistry. The sampling coincided with the acquisition of multispectral scanner data on three dates during the summer of 1989. Data were acquired on one date (9/5/89) using the NS001 scanner onboard the NASA C130 aircraft, two dates (early June and mid July) using the Daedalus TMS onboard the NASA ER-2, and two dates (early June and mid July) via LANDSAT TM data.

Both spectral and textural analyses of the remotely sensed data are being used to evaluate changes in the forest related to earthflow movement. Reported here are the results from the highest resolution data, the September 5, 1989 NS001 scanner data set. This data set has a spatial resolution of approximately 6 meters. The spectral range of the NS001 is presented in Figure 2.

PRELIMINARY RESULTS

Spectral Analysis- The digital data from the NS001 were converted to radiance using calibration data from the image header file. The data were corrected for scan angle variance across the flight path. Both radiance data and a series of vegetation indices were extracted for the three slide rate movement zones, two areas of undisturbed forest, and three stages of forest clear cut regrowth. The non-slide test areas were chosen holding aspect constant to minimize the effect of sun angle on spectral differences. Means and covariance matrices were calculated for the band radiance of each class. Band mean values show logical trends that reflect the percent of canopy closure and the effects of exposure of the understory vegetation. Figure 3 illustrates these trends displayed as the percentage of change in mean band radiance for bands 2 through 8 from an undisturbed old growth forest through the highest rate of earthflow movement at the Jude Creek slide.

Radiance in all eight bands increases from the undisturbed forest to the slowest rate of slide movement. Radiance increases in the visible wavelengths for some forested areas have been reported in the literature and attributed to increased exposure of a more reflective background and reduced absorption by the overstory canopy as the percent of canopy cover decreased (Spanner et al., 1990). Similarly, earthflow movement thins the forest slightly and exposes the brighter deciduous understory. This increases the radiance of both bands 2 and 3. The understory effect is seen even more dramatically in the large increases in the near infrared bands 4 and 5. Bands 6 and 7 also show large increases in radiance that may be attributed to background and understory effects. Increases in band 6 radiance relative to those of bands 4 and 5 from stressed coniferous forests have been detected by Vogelmann and Rock (1986) using the NS001 sensor. The slight forest disturbance at low slide movement rates also increased the thermal digital count several percent.

In the transition from low to moderate rate of slide movement, the canopy disruption increases and more of the overstory trees are downed. This results in a lower percent canopy closure with a slightly greater amount of deciduous understory present and substantially more dead wood laying on the ground. As a consequence of this further reduction in absorption and shadowing by the canopy, there is some brightening of the area evidenced in bands 2 and 3. In contrast, however, the near infrared bands (4 and 5) change very little and in fact may decrease slightly. Bands 6 and 7, on the other hand, increase in radiance by about 10 percent. Similar trends were observed by Vogelmann and Rock (1986) and attributed to the reflectance properties of dead wood in the spruce forest of their study. Laboratory reflectance values of the dead spruce limbs showed higher band 6/5 and 6/4 ratios and lower band 4/3 ratios. This suggests that the mass of downed tree trunks in the moderate movement rate zone has increased enough to impact the scene reflectance. The further reduction in overstory canopy is accompanied by an increase in the thermal count by another 5 percent.

At the high movement rate, the earthflow is moving quickly enough to almost completely destroy the overstory canopy except for a few isolated surviving trees. Bare soil (gray, clay-rich or reddish brown coarse-grained) is exposed in parts of this area of the slide. Other parts of this area are densely overgrown with deciduous vegetation. The bare soil exposure greatly increases the brightness of the scene in both the visible bands (2 and 3) and the mid-infrared bands (6 and 7). The near infrared band (4 and 5) radiances are greatly increased by the deciduous growth and the reduction in exposed dead wood which at this point has been largely buried in the slide mass in contrast to the zone of moderate movement. The thermal digital count increases an additional 10 percent, as might be expected due to areas of bare soil and lack of any significant shading.

As an initial step in the development of a classification procedure to identify forested earthflows, the eight bands of the NS001 scanner have been examined individually, as ratios, and in groups to assess their ability to separate the undisturbed forest and the three zones of different movement rates. This assessment was done using the statistical divergence of the band means from one movement rate zone to another. By this procedure it was determined that 4 band combinations with one band being 8 and another being the 6/4 ratio gave superior separabilities. Some of the results of this evaluation of band combinations are shown in Figure 4. In this figure the two control areas of undisturbed forest are noted as F1 and F2. The other terms refer to the earthflow movement rates described previously. From the divergences in Figure 4 it is apparent that the high movement rate can be successfully distinguished from all others. The least separable rate zones within the slide are clearly the low and moderate. The undisturbed forest can be separated with some success from the low and moderate slide movement rates. If band ratio 6/4 is used in place of band 6 in the band 2,5,6,8 combination, then the divergence of undisturbed from low or moderate movement rate rises approximately 20%.

Textural Analysis- The same factors that suggest spectral differences in forest canopies overlying earth flows lead to expectation of textural differences. Texture may be defined as "patterns of spatial relationships...among grey levels of neighboring pixels" (Shih and Schowengerdt, 1982). Because of wider tree spacing and exposure of understory, it is more likely that pixels will contain pure, contrasting targets leading to a higher contrast pattern within the slide zone. To define this textural character and its usefulness in delineating earthflows the Jude Creek slide is examined in detail.

Overviews of texture analysis methods in image processing may be found in Haralick (1979) and Davis (1982). In the interest of computational efficiency and due to the lack of any unique structural form to slide disruption patterns two methods of statistical textural analysis were tested 1) standard deviation based edge density (Hlavka, 1989; Shih and Schowengerdt, 1982) and 2) inertia, a co-occurrence measure of local contrast:

$$I_d=\Sigma((i-j)^2 * P(ij))$$

i=grey level
j=adjacent grey level
d=angle of adjacency
P=probability of i occurring next to j

The former has been used successfully for urban/nonurban land classification, and differentiation of geological terrains. Inertia contains potentially more information such as directional texture but is more computationally expensive.

Statistical texture is usually calculated over rectangular subsections (windows) of the image. This measure represents the basic unit of texture. This basic unit may be used as the texture measure itself or become the basis of a larger texture pattern. The scale at which the texture is defined can significantly affect the results, i.e. a coarse texture with variation on the order of the window size will appear as a low contrast area. Given the flight resolution and the Jude Creek slide dimensions, two window sizes were considered, 3x3 pixels (18x18 m) in which case the slide is characterized by many texture units, and 11x11 pixels in which the slide texture is considered in a more general form approaching the size of the slide itself. Three measures were calculated for each of the eight sensor bands:

1. Edge density - standard deviation using a 3x3 window to define "edgeness" followed by edge density calculation on over an 11x11 window (see Hlavka, 1987 for a detailed description of method).
2. Inertia - 3X3 window
3. Inertia - 11x11 window

Inertia was calculated for four directions, horizontal, vertical, right diagonal, and left diagonal. No consistent relationship with direction was found for the slides, therefore, the values for the four directions were averaged.

The resulting gradient of textures supports the trend of increasing contrast expected (Fig. 5). The slide contains higher contrast and/or a greater degree of "edge" than the non-slide zones. The contrast forms a decreasing, albiet overlapping gradient through the zones to undisturbed forest, with a concurrent decrease in separability.

The separability of the slide zones, and the slide versus forest and clear cut were evaluated based on the statistical divergence of the texture measures for the defined Inertia calculated over an 11x11 window. Edge density in band 2 performed best for separating clear cut vs. slide (Fig. 6). Clear cuts have lower contrast in this instance compared to either forest or slide and are easily separable over the regrowth ages considered.

Highest separation of the three zones within the landslide was obtained using band 3 and Inertia with an 11x11 window, with the exception of high rate versus low rate which performed better using the smaller 3x3 cycle. This may indicate that texture cycles at a smaller scale are necessary for the latter differentiation. Although the high rate zone was separable from either moderate or low movement, the divergence between moderate and low rates was considerably less.

In summary, the spatial variation of the forest canopy over the earth flow is different from that of undisturbed forest. The degree of difference is related to the rate of movement. The texture measures considered were successful in separating high rate slide movement from both clear cuts and undisturbed forest. Success in other rate movement zones varied. All three measures performed well, with Inertia over an 11x11 window the most successful. No consistent directional component was found. The thermal channnel of the NS001 proved to be the most useful for slide/forest differentiation, although high divergences were obtained for the mid-infrared channels also. Textures using band 3 were consistently best for within slide zone differentiation. Band 2 was uniquely useful for separation of clear cut from other. Potential exists for the separation of earth flows with rate zones moving more than 5 m/yr. using textural analysis alone. Multiple bands and window sizes may be necessary. The pattern of class separability does not differ from the spectral analysis results, however, the method may be less subject to atmospheric affects and imagery calibration for large area classification.

CONCLUSIONS

There are spectral/textural differences between undisturbed forest and the forest canopy over the Jude Creek earthflow. These differences are present to a lesser extent between movement rate zones within the slide. The trend of these differences agrees with the hypothesis that contrast increases with the degree of ground movement. Changes in the spectral character of the forests during disruption by the earthflow seem to be controlled by the percent canopy closure, the amount of understory present and exposed through the canopy, and the amount and type of other background material exposed such as fallen tree trunks and bare soil. Band 8 and band ratio 6/4 were most significant in improving the spectral separability. Of the three textural measures tested, Inertia over an 11x11 pixel area (66x66m) performed somewhat better than the edge density method used or Inertia over a 3x3 pixel area.

Using either spectral or textural methods alone, movement rates greater than 5 m/yr. appear to be detectable and separable from undisturbed forest, clearcuts, and low and moderate movement rates. Some success was achieved separating the undisturbed forest from all levels of slide movement including the low rate. The minimum separability was found between the low and moderate movement rates.

Given this single slide, it is possible to distinguish earthflow from non-earthflow. Extension of these methods to a broader area and testing on a variety of slides with differing rate movements and aspects will be addressed in the next phase of this project.

ACKNOWLEDGEMENTS

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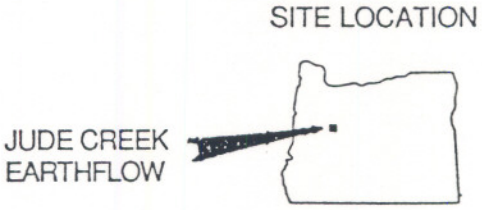

FIGURE 1

NS001 TM - Spectral Characteristics

BAND	WAVELENGTH (um)
1	0.458-0.519
2	0.529-0.603
3	0.633-0.697
4	0.767-0.910
5	1.130-1.350
6	1.570-1.710
7	2.100-2.380
8	10.90-12.30

FIGURE 2

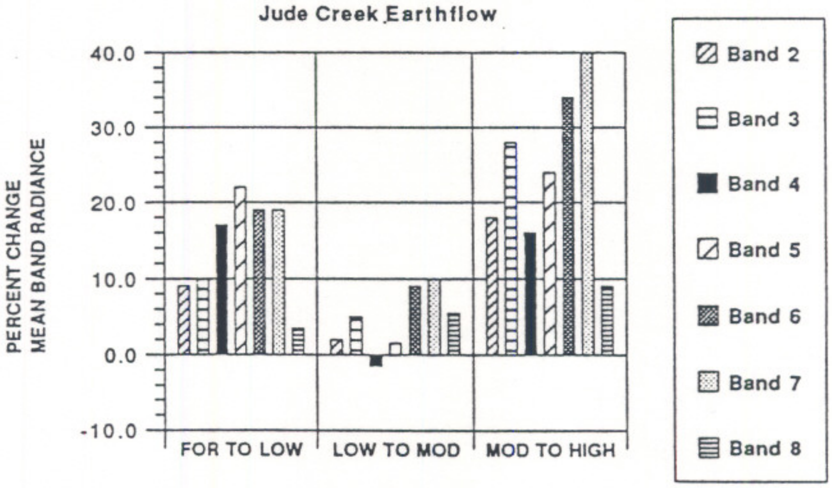

FIGURE 3

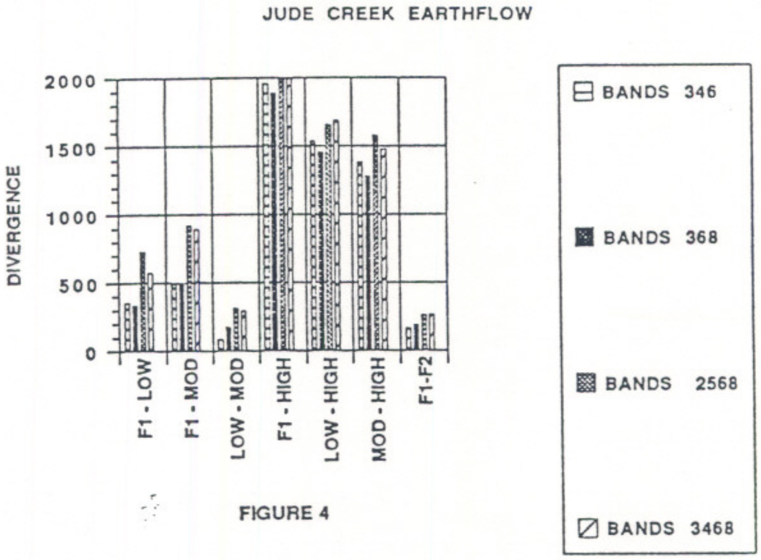

FIGURE 4

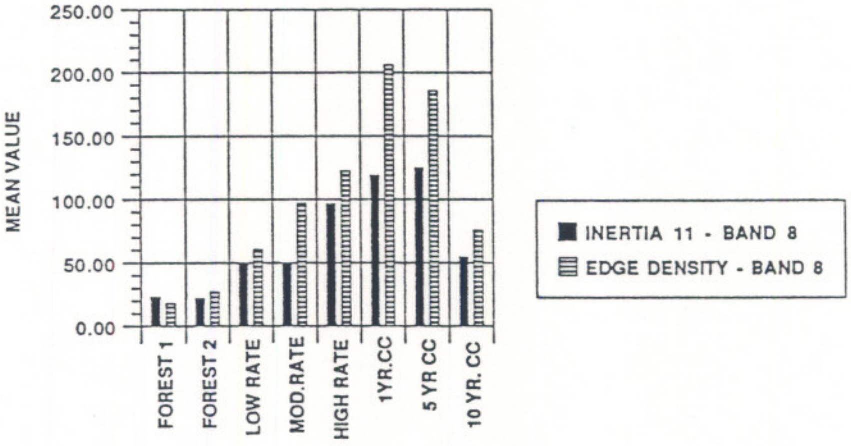

FIGURE 5

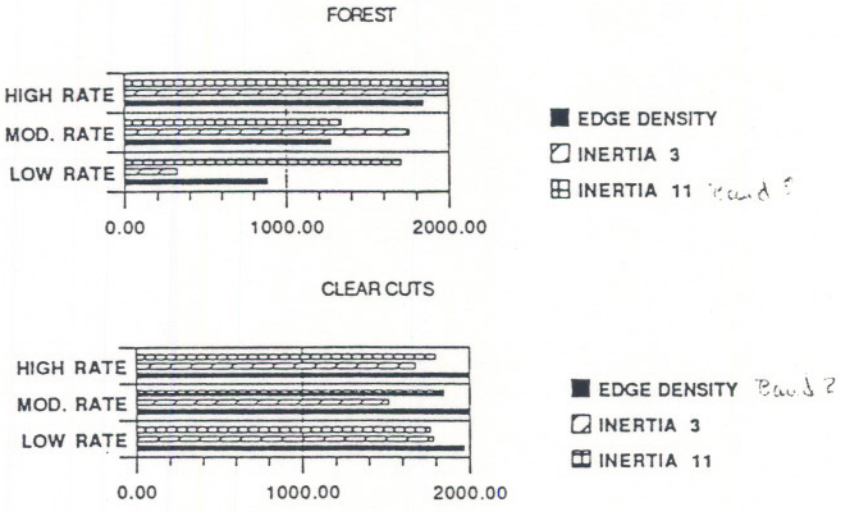

FIGURE 6 - SLIDE VERSUS FOREST AND CLEAR CUT DIVERGENCES