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Modeling effects of land use on carbon storage in the forests of the Pacific Northwest, USA: the challenge for remote sensing

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ABSTRACT

Within the context of a study to model the effects of land use on carbon storage in the Pacific Northwest region of the United States we are processing about 100 Landsat images. The image processing challenges within the study are numerous. To determine the utility of our proposed methods many of our them are being tested on a 1.2 Mha area within the region. The major challenges include mapping of forest cover type and seral stage, radiometric and geometric rectification, and change detection. In this paper we present preliminary results.

1. Introduction

Satellite imagery has been available for over twenty years, and through it the Earth's human populations have caught glimpses of its splendor and beauty. A new sensitivity to the severity of human impacts has ensued, and a discipline called Earth System Science was born. With this has come an increasing emphasis in research on the role of remote sensing in helping to understand our planet. As a result, remote sensing scientists now face the challenge of providing more accurate information derived from satellite and other relevant forms of data over greater spatial scales than might be contained in a single satellite image. Likewise, an intensified temporal focus requires coordinated use of multiple image data sets.

Although methodology for use of multiple images has developed to where we now have algorithms for amelioration of differential atmospheric, sun angle, and topographic effects, and though we now have more precise geometric rectification procedures, there are still numerous improvements to be made. Atmospheric models are imprecise, and often, ancillary data needed for these models are lacking. Corrections for sun angle and topographic effects are used, but often, these are not particularly relevant in light of the interaction of these phenomena with the vertical structure of the Earth's surface features (e.g., vegetation). Geometric models have greatly improved, but even the best of these leaves coregistered images somewhat askew of each other. Then, there are vegetation phenological responses that must be either enhanced or suppressed, depending on needs. Temporal analyses are not new, but while a number of so called "change detection" algorithms exist, this is one aspect of remote sensing that has not developed in any significant way.

The problems of using multiple data sets aside, there is still the problem of accurately deriving the desired biophysical, geophysical, or climatological information from the satellite data. For example, we still are uncertain as to the mechanisms driving remote sensing vegetation indices. Although there is abundant theory on this topic, the theory is incomplete, and some important indices have hardly been considered. Thus, the majority of information extraction algorithms put to use are correlative in nature. Though these are certainly useful, a more mechanistic understanding of the interaction of radiation with surface features, and how this interaction manifests itself in remotely sensed images, should lead to more accurate derived information.

Within the context of a current research project we are having to address these important concerns. That research involves the use of almost 100 Landsat MSS and TM images, in conjunction with ecosystem and climate simulation models, to evaluate the effects of land use on carbon storage in the Pacific Northwest region of the United States between the period of 1972 and 1992 (Cohen et al., 1992). This paper summarizes our experiences on that project to date in four general categories: 1) mapping of forest seral stage, 2) radiometric rectification in space and time, 3) geometric rectification in space and time, and 4) change detection.

2. Mapping of Forest Seral Stage

We have thus far mapped land cover, and forest seral stage, on a 1.2 Mha area in the Central Oregon Cascade Range. An area dominated by western hemlock/Douglas fir forests. This area is serving as a pilot for further development and testing of our methods to be used for the full project area.

Our approach involves a combination of unsupervised classification and regression analysis. The classification provides a 95% accuracy (derived from a combination of ground and airphoto sampling) on the following classes: 1) water, 2) high alpine snow and ice, 3) open, nonvegetated land (<30% vegetation cover), 4) partially vegetated land (30-85% cover), 5) fully vegetated mixed deciduous/coniferous forest (>85% cover), and 6) coniferous forest (>85% cover). Within the conifer forest class, the stand age regression model developed by Cohen and Spies (1992) was applied. The regression model was derived from the relationships between the TM Tasselled Cap wetness index and ground survey data from a variety of forest stands. The model has a coefficient of determination of 0.81. Ground field checking revealed that accuracy for the map of age classes derived from this model is 75% for three classes: <80 years old, 80-200 years old, and >200 years old. For the combined land cover and age class map the overall accuracy is 83%.

Some of the error in the age model results from the fact that we selected only typical examples of forest conditions for model development. Thus, some atypical stands visited for accuracy assessment were outliers. These outliers were generally younger forest stands that appear older in the imagery because of an increased rate of structural development due to site conditions. We are currently evaluating means by which to obtain better estimates for age of these atypical stands.

3. Radiometric Rectification in Space and Time

Radiometric rectification is used here to refer to some sort of normalization applied to image data to make multiple data sets more radiometrically compatible. Several options are available, but we are first testing a method developed by Hall et al. (1991). This method "matches" digital numbers of each band of a subject image to those of a reference image. First, dark and bright radiometric control sets are selected from the reference and subject images in Kauth-Thomas two-dimensional brightness-greenness space. The control sets are selected interactively by viewing images and highlighting potential control set pixels in the images. Then, raw band-to-band linear transformations are developed from relationships between control sets of the subject and reference images, and the resultant linear transformations are applied to rectify each band of the subject image.

When we attempted to apply the Hall et al. (1991) methodology, we were immediately confronted with an unexpected challenge. Our brightness-greenness histograms had a considerably different shape than those illustrated in Hall et al. (1991). Whereas their histograms had a distinctly triangular shape, our histograms has several "tails" making up the brightness axis, or "leg" of an otherwise triangular shape. The dark end of the brightness axis was close to what we expected, but the bright end of this axis contained several bifurcations. This raised the issue of where to select control sets.

After experimenting with control set selection we found that the bifurcation which most closely resembled the Hall et al. (1991) brightness axis did not provide good results for our images. Rather we found that one or more bifurcations below the brightness axis (i.e., into negative greenness) gave better results. Because the bifurcation which worked best was variable, we could not consistently get the desired result simply by picking what appeared to be the best brightness control set. Thus, we found it necessary to select three to five candidate bright control sets and evaluate which worked best. Furthermore, we found that which control set worked best was band dependent. In the final analysis, we decided to use the control set which worked best for a given band to rectify that band. This was determined from a combination of visual assessment and comparison of digital numbers from test sites of ground areas which overlapped in the subject and reference image.

The correction is imperfect, but does provide significantly improved radiometric matching among images. This now permits us to spatially mosaic images together, and to do temporal analyses on spatially coincident images, without having to overly concern ourselves about differing radiometric properties.

4. Geometric Rectification in Space and Time

Methods for accomplishing geometric rectification are fairly straight-forward, and are included in most image processing software programs. In question however, are (1) how many ground control points (GCPs) are required per unit ground area in complex terrain to provide an acceptable root mean square (rms) error?, and (2) what effect does the reduction in number of GCPs have on image to image registration, even if the rms error is unaffected by this reduction? We conducted a simple test to evaluate these problems.

Using a 1988 TM image of our 1.2 Mha study area as the reference image, we selected 36 GCPs well distributed in space. We then located the same GCPs in 1991 TM, 1976 MSS, and 1984 MSS subject images of the same area. Using a nearest neighbor resampling algorithm to rectify the subject images, the rms for each subject image was obtained for both first and second order polynomial transformations. We then reduced the number of well-distributed GCPs to 21, 11, and 5 for first order transformations, and to 21, 11, and 6 for second order transformations.

To aid in our analysis, we digitized 10 spatially well-distributed polygons around features readily identifiable in the reference image. These polygons were then displayed as an overlay on the rectified subject images to determine the euclidean distance shift between the visual location of the digitized features and the actual polygon locations.

Results indicate that the lowest rms is obtained with the fewest number of GCPs. This is understandable for the second order polynomials, where the rms was equal to zero, given that six GCPs is the minimum number permitted and the minimum number will mathematically yield a zero rms. The largest rms was in almost all cases associated with the largest number of GCPs. In general however, there was little difference between rms values for the transformations using 21 and 36 GCPs. In almost all cases the rms was lower for the second order than the first order transformations.

Polygons were almost always more accurately located for both first and second order transformations when larger numbers of control points were used. For the TM subject image the shift was less for the first order transformation, regardless of the number of GCPs. The opposite was true for the MSS data.

In summary, the rms was less than one TM pixel regardless of the number of GCPs or order of transformation. Taken on this basis alone, any number of GCPs would appear to give excellent results, and may cause one to ignore the fact that there may still be a significant misregistration among images. Perhaps the most meaningful use of rms values is to eliminate "bad" GCPs from a set, not to indicate in any real way how much actual error in image matching has occurred as a result of georeferencing. The actual shift in polygon locations varied between zero and over five pixels. The mean shift for the ten polygons using any given combination of number of GCPs and order of transformation was between zero and 2.29. Thus, any given ground scene area in this scenario was shifted up to at least five pixels in the subject image relative to its location in the reference image. This can cause serious errors in detection of change for temporal image sets, and can cause false boundaries along seams in a spatially mosaicked image.

5. Change Detection

Change detection, when done in a spatially explicit manner involves spatial overlay of two or more images from different dates. Three types of change detection algorithms are commonly used: 1) difference, 2) ratio, and 3) principal component analysis (PCA). The difference and ratio algorithms require simply subtracting one image from another, or dividing one image by the other, respectively. These two algorithms are generally limited to comparison of two images, and should give similar results except for how the resultant image is scaled. The PCA algorithm can be applied to any number of images, with each PC axis generally representing change between two distinct time periods. Other algorithms have been applied, but to date, only in isolated situations.

We have not yet begun to experiment with change detection, so we have nothing to report here. We are aware however, that spatial misregistration will cause erroneous results around "sharp" edges such as clearcut and forest boundaries. To some extent we think we will be able to filter these narrow boundaries out of the change image.

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