Applications of Multi-temporal Land Cover Information in the Mid-Atlantic Region: a RESAC Initiative

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ABSTRACT

The mid-Atlantic Regional Earth Science Applications Center (RESAC) was established in the Geography Department at the University of Maryland (UMD) by NASA's Earth Science Applications Program. The mid-Atlantic RESAC is to provide improved land cover mapping and ecological modeling capabilities for a diverse consortium of partners in Government, Academia, Industry and NGOs within the 178,000 km^2 Chesapeake Bay watershed. It is one of 7 regional centers established nationwide and leverages expertise in satellite remote sensing to address applications of regional significance including land cover change, land use planning, carbon exchange modeling, and integrated environmental monitoring. Examples of issues that are being addressed include nutrient runoff to the Chesapeake Bay, urban sprawl, farm and forest productivity, landscape fragmentation effects on biodiversity, a land manager decision support system, and educational outreach. The mid-Atlantic RESAC provides an example of how scientific advances can be focused on practical applications that challenge our ability to manage resources sustainably.

A brief overview of the RESAC is provided and specific applications are reviewed using examples that emphasize the utility of remote sensing and GIS capabilities. Results of field activities undertaken during the 1999 growing season, for example, are used with a fusion of multi-temporal Landsat-7 Enhanced Thematic Mapper and SPOT panchromatic imagery to classify vegetation types, and to characterize development of the severe drought that took place in the region.

THE MID-ATLANTIC RESAC

The mid-Atlantic RESAC at the University of Maryland, College Park, is one of 7 regional centers established to apply NASA products to a wide range of earth science and resource management issues. Foremost among these are land cover properties derived from digital remote sensing and spatial information technologies made possible by NASA research, including data from a variety of revolutionary new aircraft and satellite sensors. To accomplish this in the mid-Atlantic region, which encompasses the entire Chesapeake Bay watershed, the RESAC has partnered with nearly 40 educational, research, non-profit and governmental organizations at local, state and federal levels whose needs for this information are guiding application development. The ultimate goal of the RESAC is and to aid decision making on a wide range of issues including land use planning, agricultural practices, and forest and water managment, and to provide improved information and technologies to assess regional impacts of environmental change.

We provide a brief overview of the mid-Atlantic RESAC, focused on land cover change, ecosystem modeling, land use planning, and technology applications. We then focus on a key objective - mapping land cover using multi-temporal Landsat-7 imagery, SPOT panchromatic imagery, and field sampling, all conducted in a geographical information system framework.

Land Cover Change

Among the main components of land use decisions is the condition of the land itself and changes in land use, in part revealed by land cover data obtainable through satellite remote sensing. In consultation with project partners, which include the Chesapeake Bay Program, the mid-Atlantic RESAC has identified problem areas that existing land cover data is inadequate to address and that have high priority for decision-making purposes. For example, existing land cover data, derived from 30 meter resolution Landsat images, has not been adequate for monitoring of riparian buffer strips, which are important in controlling chemical runoff to the Chesapeake Bay. Other key challenges are to distinguish and map crop lands from grass and pasture lands, different densities of residential development, monitoring of forest growth and carbon dioxide exchange with the atmosphere, wetland loss, and conversion of farmland and forest areas to residential and commercial development.

Ecosystem Modeling

One purpose of developing these applications is to be able to provide better estimates of forest and crop production, as well as nutrient inputs to the Chesapeake Bay, including their sources and pathways. This information is needed for ecosystem modeling that is used to monitor the health of the Bay, and to enforce regulations for long-term restoration. This is a policy priority for the Chesapeake Bay Program, and is expected to become even more important this year, as caps on nutrient levels go into effect, because it will require new sources to be offset by reductions in other areas. Present modeling efforts tell us about overall trends but have been not been able to link specific management actions to their consequences for water quality and the living resources of the Bay.

Land Use Planning

Another application, not unrelated to restoration of the Bay, is to provide better information for planning and management of growth, consistent with the capacities of local and state governments as well as the environment. This is particularly important to provide the services needed to support a growing population. Monitoring urban growth in the Washington DC metropolitan area, based on changes observed in satellite imagery, shows a loss of 22 km^2 a year between 1973 and 1996, or approximately 600 square meters of land conversion per person. More detailed analysis of this kind of data, at higher resolutions, is expected to provide the basis for modeling that identifies specific areas where land conversion is expected, and provides the basis for analyzing trade-offs and establishing land use priorities.

Technology Applications

Initial RESAC activities have been directed at land cover mapping, in some cases to find out more precisely what can be accomplished with emerging new technologies. Among the advantages of Landsat 7, launched in April 1999 with the Enhanced Thematic Mapper (ETM+), is that the data are being made available very soon after acquisition, and at a more affordable cost to users. This has made it more feasible to use multi-temporal imagery which provides more information than can be obtained from one image at a single point in time and has important implications for land cover mapping and land use classification. This capability is particularly useful for distinguishing different types of crops and vegetation. It also makes it possible to work with more recent images when conducting fieldwork.

In the summer of 1999 RESAC members conducted fieldwork throughout the mid-Atlantic region to use in supervising a land cover classification and to provide independent validation of the utility of satellite data for mapping these important land cover distinctions. Although most Landsat data is 30 meters in resolution, a feature new to Landsat 7 is a 15 meter channel, which permits detection of finer scale features such as field boundaries and riparian buffers. The new IKONOS satellite provided 1 meter data over a portion of the study area, but is prohibitively expensive to use regionally in a monitoring framework. Use of higher resolution images in test areas, however, provides another data source with which to validate features observed in lower resolution imagery. We demonstrate the utility of some of these high-resolution data sources using aircraft imagery recently acquired in the region.

IMPROVED LAND COVER MAPPING: A PRIMARY RESAC OBJECTIVE

A common thread in many of the RESAC partner activities is the need for improved land cover characterization. Given the breadth of activities within the Chesapeake Bay research community it is unreasonable to expect any single classification to adequately address many diverse land cover needs. In lieu of producing a generalized land cover map to be incorporated into various applications, the RESAC is developing methodologies where customized land cover products can be derived from a data base of remotely sensed and GIS data. This requires algorithms that are flexible in design and easily automated to remove the overhead involved in a manual process. The goal is to provide a database of land cover information and a mapping algorithm that is repeatable and modifiable to tailor to specific data requirements, ideally improving accuracy for the end user. A rich archive of supporting data are being accumulated in a GIS, including high spatial and temporal resolution remotely sensed data, hyperspectral data, census data, elevation data, digital line graphs, digital orthophoto quarter quadrangles, aerial photography, detailed county level planametric maps, field measurements, and NASS crop statistics. This archive serves as the basis for all land use / cover mapping exercises.

We tested an initial goal of producing a Landsat 7 ETM+ land cover classification of the Chesapeake Bay watershed. Approximately 18 Landsat WRS-2 scenes were required to produce a complete image of the 178,000 km^2 watershed. The methodology was first applied to a single Landsat path/row, WRS-2 path 15, row 33, centered around the Washington, DC area. The resulting land cover map of the DC area, an accuracy assessment, and a multi-temporal analysis are briefly summarized below.

Classification Methodology

A decision tree approach was used to incorporate both categorical and remotely sensed data. Trees can be pruned, grafted, or forced to split based on user defined criterion. In the hierarchical tree structure, each split in the tree results in two branches. The algorithm searches for the dependent variable, that if split into two groups, would explain the largest proportion of deviation of the independent variable. At each new split in the tree, the same exercise is conducted and the tree is grown until it reaches terminal nodes, or leaves, each node representing a unique training pixel. Every leaf has a land cover class assignment. The machine learning software package c5.0 was used to generate the classification trees.

The dependent variables used to grow the tree include a multi-temporal time sequence of Landsat 5 data. Six dates were available: 27 March, 12 and 28 April, 2 July, 8 August and 22 November 1998. As more recent Landsat 7 data become available they will be included in the analysis. All bands except the thermal (channel 6) were included in the analysis. Other dependent data layers included a 30 meter DEM, corresponding slope and aspect, and a physiographic provinces map.

Training data at the Anderson II Level were derived from Landsat imagery enhanced by spectral merging with higher resolution panchromatic data from SPOT and ETM+. Spectral merging improves visual interpretation by compressing more spectral information into a visible range, which in turn improved the ability to identify sites for training. Agricultural and forest training data were collected during a month-long field sampling campaign conducted during the summer of 1999. Ancillary GIS vector coverages, digital orthographic quarter quadrangles (DOQs), National Wetlands Inventory data, and other classification products were used to assist in site identification.

We investigated the use of multi-temporal imagery made possible by the availability with two Landsat satellites in orbit to investigate the merits of multiple versus fewer image acquisitions. The same training data were used to produce a classification of a single date (August 8th) and also a leaf-on/leaf-off classification (March 27th and August 8th). In order to evaluate the overall accuracy of the results two comparisons were conducted. The first was with the Multi-Resolution Landcover Characterization (MRLC) product for Federal region 3. The second comparison was with a vector based land cover map of the state of Maryland produced by the Office of Planning (MOP), derived using a combination of Landsat imagery, property data, and aerial photography.

Results

A land cover classification of the region was produced, together with comparisons between the RESAC classification and that of MRLC and MOP (see *www.geog.umd.edu/resac*). The first split in the classification tree was based on April 12th band 5. The next two binary splits occur with March 27th band 2 and November 11th band 1. These high-order splits emphasize the importance of image acquisitions that would likely be omitted from a leaf-on (peak summer) versus leaf-off classification. Spring and fall dates were particularly useful for discriminating crops, pasture and grasslands.

Kappa statistics, a measure of agreement between two matrices, was calculated for each of the three temporal analyses in terms of the two reference data sets. All Kappa values were large and negative, suggesting negative relationships between the reference data, both MRLC and MOP data, and current results. The comparison between MRLC and MOP was also negative. Whereas a near zero kappa value suggests no relationship between two sources of data, a negative value may be indicative of systematic misclassification. This occurs primarily between spectrally related land cover classes (e.g., high density residential & high density industrial/commercial). The results suggest that although no accuracy was gained in the urban classes, higher frequency image acquisitions improve the accuracies of land cover classes dominated by vegetation. The flexibility of the decision tree design allows incorporation of this type of information.

SUMMARY

While useful for understanding environmental patterns and conditions over a broad area such the Chesapeake Bay watershed, we recognize that land cover information by itself is not sufficient for making land use decisions. Such decisions are inherently controversial because of multiple and often conflicting social objectives. They require information that links land conditions to causal factors and that helps to identify uncertainties, decision options, their implications for different parties, and also anticipates conflicts. Thus, the mid-Atlantic RESAC is developing an integrated approach that prioritizes information needs for informed decision making by incorporating scientists and policy makers in the definition of objectives through a variety of demonstration projects. The mid-Atlantic RESAC expects to continue to expand partnerships with regional interests as information is distributed through the NASA/UMD Earth Science Information Partership.

For more information visit the RESAC web pages at *www.geog.umd.edu/resac.*