Remote sensing: Land cover

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Remote sensing: land cover

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I Introduction

Land cover is an intrinsic element of most remote sensing analysis. An obvious example is the use of remotely sensed imagery for straightforward land cover classification (Franklin and Wulder, 2002; Alvarez *et al.*, 2003). Less obvious, perhaps, is the role of land cover in disease mapping (Tran *et al.*, 2002) or climate change studies (Kalluri, 2002). The reason land cover has such a key position in the field of remote sensing relates to the way remotely sensed data are acquired. Remote sensing involves measuring electromagnetic radiation (commonly, reflected sunlight) from features on the Earth's surface (Aplin, 2003). Land-based features may be categorized according to land cover classes (e.g., grass, concrete, water, etc.) (Smith *et al.*, 2003), and since different land cover features reflect radiation in different ways, remotely sensed images provide a basic representation of land cover variation on the Earth's surface. Even where land cover information is not the ultimate goal of remote sensing studies, it is often a useful aid for further analysis. Given this importance of land cover to the field of remote sensing and, in particular, the many physical geographical applications of remote sensing, this Progress Report will focus on recent developments in land cover research.

In general, there are two main areas of remote sensing-based land cover research, (1) environmental management and (2) environmental understanding. Environmental management refers to the control and use of land cover distributions to exploit land resources while safeguarding environmental concerns. Environmental understanding refers to the scientific analysis of processes (both natural and those caused by humankind) involved in determining land cover. Each of these general research areas is discussed in turn but, given that there is considerable overlap between environmental management and environmental understanding, some general points are made that refer to both topics. Initially, reviews of recent developments in land cover classification and land cover change lead into discussions on environmental management and environmental understanding. Finally, a brief summary of general developments in the field of remote sensing is provided.

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II Land cover classification

Perhaps the most basic form of land cover analysis within the field of remote sensing is land cover classification. This involves the association of features within remotely sensed imagery (often, pixels) with specific land cover classes and results in the production of land cover maps (Smith *et al.*, 2003). Land cover classification has been used widely for over two decades (King, 2002; Briem *et al.*, 2002), yet there continues to be much interest in developing new classification techniques or adapting old ones (Liu, X.H., *et al.*, 2002; Ju *et al.*, 2003; Peng *et al.*, 2003). In particular, research efforts are being made to refine subpixel classification techniques, the means by which individual pixels are assigned proportional membership to multiple land cover classes rather than full membership to a single class (Hagen *et al.*, 2002; Huang and Townshend, 2003). For instance, Ju *et al.* (2003) present an adapted subpixel classifier that combines the structural simplicity of a linear mixture model and the discriminatory power of a neural network.

Another area of considerable recent interest is in the development of multiple classifiers, the process of combining independent classification algorithms to increase the accuracy with which land cover maps are produced (Briem *et al.*, 2002; Debeir *et al.*, 2002; Liu, X.H., *et al.*, 2002). Bruzzone and Cossu (2002) combined both multiple classification algorithms and multitemporal imagery in a novel cascading classification structure to enable the regular updating of land cover maps.

In addition to work on developing classification techniques, there has been much recent interest in testing different data sources for land cover classification (Briem *et al.*, 2002; Liu *et al.*, 2003). This is useful since certain sources of data are particularly suitable for discriminating specific land cover features. For instance, Gamba and Houshmand (2002) demonstrate the integration of photographic, synthetic aperture radar (SAR) and light detection and ranging (Lidar) imagery for classifying urban land cover features, while Goel *et al.* (2003) used hyperspectral imagery to distinguish subtle differences in vegetation growth. In contrast, Zhang *et al.* (2002) employed multiangle imagery from the Terra satellite's Multiangle Imaging Spectro-Radiometer (MISR) instrument to map land cover. Other studies have merged contextual or other ancillary data with remotely sensed imagery to increase the accuracy of land cover classification. Liu *et al.* (2003), for instance, introduced geophysical information such as elevation and temperature into the classification procedure, and Debeir *et al.* (2002) included topographic features such as roads and rivers.

In stark contrast to further development of automated land cover classification techniques, King (2002) calls for a return to land cover mapping principles, whereby expert knowledge on the part of the observer should contribute to the classification process. King (2002) asserts that the reliance of most current classification techniques on a single property, reflectance, to map land cover is a weakness, and that additional interpretation elements such as size, shape and position should be included in the procedure.

III Monitoring land cover change

Generally, land cover classification provides a snapshot of the distribution of land cover at a given time. However, given that land cover distributions are dynamic, it is often useful to monitor them. In fact, 'Landscape dynamics' is the subject of a recent special issue of the *Photogrammetric Engineering and Remote Sensing* journal, published in October 2002 (Bian and Walsh, 2002). A fairly straightforward means of monitoring land cover change is to compare images of a given area acquired at different times but classified using common land cover classes (Chen, P., *et al.*, 2002; Staus *et al.*, 2002; Rees *et al.*, 2003).

Prior to conducting land cover change analysis, certain preprocessing steps are necessary to standardize multitemporal images. In particular, it is important to perform atmospheric correction to remove any differences between the images arising from effects such as cloud, haze and atmospheric scattering (Lu *et al.*, 2002). It is also important to geometrically register the images to a common coordinate system to ensure an accurate spatial comparison between images (Salas *et al.*, 2003).

Perhaps the most straightforward way of monitoring land cover change is to use a single source of imagery, such as that from the Advanced Very High Resolution Radiometer (AVHRR) (Jakubauskas *et al.*, 2002) or from sensors on board the Landsat (Rees *et al.*, 2003) or Système Pour l'Observation de la Terre (SPOT) (Herold *et al.*, 2002) satellites. Use of a single image source enables a simple comparison of classified images without the need to take account of differences such as pixel size. It is possible to use multiple image sources, but this may involve additional procedures such as data conversion. For instance, Bewket (2002) digitized aerial photographs to enable their integration with digital imagery within a geographical information system (GIS). In other studies, remotely sensed images have been combined with alternative data sources to monitor land cover change (Lo and Yang, 2002; Hayes *et al.*, 2002). For instance, Petit and Lambin (2002) combined historical map data with recent remotely sensed imagery to measure land cover changes in a Belgian study area over the last 225 years. Williams' (2003) investigation extended further back in time as pollen data and AVHRR imagery were combined to assess forest cover change since the last glacial maximum.

While much land cover change analysis is performed using the fairly simple technique of post-classification comparison, alternative procedures can be used (Brown *et al.*, 2002; Chen *et al.*, 2003). For instance, rather than using land cover classes as the basis for change detection, Normalized Difference Vegetation Index (NDVI) values can be used (Bergen *et al.*, 2002; Jakubauskas *et al.*, 2002). In contrast, Herold *et al.* (2002) used remotely sensed imagery to derive landscape metrics (generated through texture and context analysis) as a means for identifying land cover change, and Soares *et al.* (2002) developed a cellular automata model to simulate land cover changes according to certain rules and assumptions, and compared the results with classified images.

IV Environmental management

Procedures for both classifying land cover and monitoring land cover change are used extensively in environmental management. Land cover classification is useful in this context since it provides a means of compiling inventories of land resources, providing knowledge that is valuable for determining land management practices (Cihlar *et al.*, 2003; Tapiador and Casanova, 2003). Such land cover inventories are used for environmental management at a variety of spatial scales, from local studies

(Shanmugam *et al.*, 2003; Volstad *et al.*, 2003) to global initiatives (Friedl *et al.*, 2002; Zhu and Waller, 2003). For instance, at the local scale, urban planners make extensive use of land cover information to assist management decisions (Civco *et al.*, 2002; Epstein *et al.*, 2002; Herold *et al.*, 2002).

There has been considerable recent interest in large area land cover classifications (Franklin and Wulder, 2002), a result of both the growing need for land cover information and advances in technology. In particular, increases in computer power and the availability of enhanced, low-cost remotely sensed imagery (e.g., data from the Terra satellite's Moderate Resolution Imaging Spectroradiometer (MODIS; Friedl *et al.*, 2002) or the VEGETATION instrument on board SPOT-4 (Bartalev *et al.*, 2003)) have encouraged implementation of large area studies (Cihlar *et al.*, 2003). Examples include national land cover classifications of Canada (Cihlar *et al.*, 2003), China (Liu *et al.*, 2003) and Mexico (Alvarez *et al.*, 2003), and a multicontinent classification of Northern Eurasia (Bartalev *et al.*, 2003). Certain large area classifications have been conducted to meet specific environmental goals, such as mapping bird habitats throughout North America (Taulman and Smith, 2002) and investigating the potential re-emergence of malaria in Europe (Kuhn *et al.*, 2002).

Monitoring land cover change has obvious application in environmental management since knowledge of land cover dynamics can help indicate where natural resources require protection (Feoli *et al.*, 2002; Vasconcelos *et al.*, 2002; Ayyad, 2003; Zhao *et al.*, 2003) and where human resources require development (Civco *et al.*, 2002). For instance, several studies report the use of remote sensing in monitoring tropical deforestation in South America (Jokisch and Lair, 2002; Hayes *et al.*, 2002; Sanchez-Azofeifa *et al.*, 2002). Alternatively, Sajeev and Subramanian (2003) used land cover change analysis to investigate the effect of human development on a wetland ecosystem in Kerala, India, while Egbert *et al.* (2002) used remote sensing to guide a major initiative to convert agriculture land to native land cover (woodland, grassland, etc.) in Kansas, USA.

While remote sensing has a key role in much environmental management, GIS are also commonly used to provide a framework for storing and analysing spatial land cover data (Omotayo, 2002; Smith, 2003; Geneletti and Gorte, 2003; Lunetta *et al.*, 2003). Aspinall (2002) describes the development of a powerful land cover data infrastructure whereby remotely sensed imagery is used to generate land cover information and a GIS is used for measuring, modelling and analysing land cover change. Similarly, Tapiador and Casanova (2003) developed a GIS to deliver land cover information on request, as an aid to regional planning in Segovia, Spain.

V Environmental understanding

Land cover information derived from remotely sensed imagery can aid our understanding of how the Earth functions as a system. In particular, remote sensing can be used to investigate the function of land cover in environmental processes (Huete *et al.*, 2002; Lotsch *et al.*, 2003). However, the situation is far from straightforward since a complex interplay exists between land cover and environmental factors such as surface energy fluxes and climate. For instance, not only does the climate influence land cover (Sun and Zhu, 2001; Galvin *et al.*, 2001; Silapaswan *et al.*, 2001; Jakubauskas *et al.*, 2002), but the distribution of land cover affects the climate (Kalluri, 2002; Boschetti *et al.*, 2003). Piwowar and Ledrew (2002) claim that a sufficiently long time-series of remotely sensed imagery is now available to enable routine climate change studies.

Much recent interest has focused on the quantification of biophysical properties of vegetated land cover (Dymond and Johnson, 2002; Combal *et al.*, 2002; Weiss *et al.*, 2002; Meza Díaz and Blackburn, 2003). Biophysical properties such as leaf area index (LAI) and fraction of photosynthetically active radiation (fPAR) are useful for explaining biogeochemical processes and can be used as inputs in climate and other environmental models (Jin and Zhang, 2002; Lacaze and Roujean, 2002; Myneni *et al.*, 2002). Many such studies have focused on forests (Hoekman and Quiñones, 2002; Peddle *et al.*, 2002; Cohen *et al.*, 2003), but biophysical analysis has been performed in various other environments, including arid (Qi and Wallace, 2002) and arctic (Laidler and Treitz, 2003) conditions. Land cover information has also been used to quantify soil moisture (Oldak *et al.*, 2002; Uitdewilligen *et al.*, 2003; Wigneron *et al.*, 2003) and evapotranspiration (Chen, J.H., *et al.*, 2002; Kustas *et al.*, 2003).

The role of vegetated land cover in the Earth's carbon cycle has received considerable attention from the remote sensing community (Veroustraete *et al.*, 2002; Wicks and Curran, 2003; Bergen *et al.*, 2003). Concern about the effect of rising levels of atmospheric carbon dioxide on the global climate has led to the formulation of international environmental policies, requiring countries to monitor carbon sources and sinks (Keenan, 2002). Land cover maps provide useful information towards the quantification of carbon stocks in vegetation (Wang *et al.*, 2001; Coombes *et al.*, 2002), although further work is required in this area to increase the accuracy of carbon estimates (Keenan, 2002). To date, a great deal of interest has focused on forested areas (Leckie *et al.*, 2002; Williams, 2003), given the importance of large forests as major carbon sinks. Emissions of other greenhouse gases such as methane have also been investigated through remote sensing (Takeuchi *et al.*, 2003).

VI General developments in remote sensing

Thus far, this Progress report has focused on land-based applications of remote sensing. However, there have also been notable recent developments in oceanic and atmospheric remote sensing. For instance, Froidefond *et al.* (2002) describes the exploitation of data from the sea-viewing wide field of view sensor (SeaWiFS) for coastal environment research. In fact, the *International Journal of Remote Sensing* published a special issue on 'Remote sensing of the coastal marine environment' in July 2003 (Malthus and Mumby, 2003). In other oceanic investigations, Sumner *et al.* (2003) demonstrate marine biophysical models, and Mumby and Edwards (2002) test the value of IKONOS imagery for mapping marine environments.

Given current interest in climate change, much atmospheric remote sensing has focused on the measurement of aerosol properties (Liu, G.R., *et al.*, 2002; King *et al.*, 2003) and, more generally, ozone (Eriksson and Chen, 2002; Del Frate *et al.*, 2002). There have also been various studies on cloud detection (Gao *et al.*, 2003) and analysis (Skofronick-Jackson *et al.*, 2002).

The market for commercial fine spatial resolution satellite sensor imagery has become more competitive than ever, with the launch of another mission, OrbView-3, in June 2003. OrbView-3 has similar technical specifications to IKONOS and is capable of acquiring 1-m spatial resolution panchromatic imagery and 4-m spatial resolution multispectral imagery. Interest in using fine spatial resolution imagery remains high, and a January 2003 'focus issue' of the *Photogrammetric Engineering and Remote Sensing* journal was dedicated to 'Rational functions for IKONOS imagery' (e.g., Fraser and Hanley, 2003; Di *et al.*, 2003). In contrast, there is some uncertainty regarding future provision of medium spatial resolution satellite sensor imagery to the research community. In early 2003, the USA announced a new commercial remote sensing policy, one implication of which is that data from any future Landsat missions may only be available at relatively high commercial rates. Given that the SPOT programme will not continue beyond the SPOT-5 mission, it is unclear whether or not relatively low-cost medium resolution satellite sensor imagery will be generally available for research. At a coarser spatial resolution, MODIS data products, available at low prices or free of charge, provide great opportunities for the research community. For further information on MODIS, see the November 2002 special issue of the *Remote Sensing of Environment* journal (Justice and Townshend, 2002).

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