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ABSTRACT

The U.S. Geological Survey (USGS) and Colorado State University (CSU) have used historical land cover datasets in atmospheric mesoscale modeling experiments to investigate the hypothesis that land use changes over the past 100-200 years have affected land surface processes and regional climate variability. The CSU regional atmospheric modeling system (RAMS) represents an important tool to help understand complex interrelationships and quantify the environmental effects of land use changes on land surface processes, interactions with the atmospheric boundary layer, and the potential for convective precipitation. A South Florida case study with RAMS, based on a pre-1900 natural vegetation scenario and early 1990s land use derived from Landsat Thematic Mapper (TM) data, suggested that land use change over the past 100 years is generally associated with decreased July-August rainfall within the interior of South Florida. This case study and similar research within the Eastern United States suggest that Landsat-derived land cover products, such as the USGS National Land Cover Dataset, represent a robust source of spatially accurate and thematically useful data for mesoscale modeling experiments as part of environmental and global change research. Such data can contribute to mesoscale modeling research on land use change, coupled land-hydrologic-ecosystem-atmosphere models, subgrid heterogeneities, and defining synergies between Landsat and MODIS.

INTRODUCTION

The U.S. Geological Survey (USGS) and Colorado State University (CSU) have used historical land cover datasets in regional atmospheric modeling experiments to investigate the potential effects of human-induced land cover change on land surface processes and regional climate variability within the Eastern United States and South Florida. Over the past 100-200 years, these areas have experienced significant land cover changes, including the clearing of native forests, agricultural expansion, farm abandonment, reforestation, landscape fragmentation, growing urbanization, and altered wetlands. In a broader context, understanding the environmental effects of historical land cover changes and predicting the potential consequences of future land use change scenarios are of widespread interest to the environmental modeling, land resource management, and global change science communities. Environmental simulation models, such as CSU's regional atmospheric modeling system (RAMS), represent valuable tools to help understand and quantify the effects of historical land use change on the environment.

Since the late 1980s, the environmental modeling and global change science communities have placed increasing emphasis on land cover and land use studies (for example, NRC, 1990; IGBP, 1993; Goodchild et al., 1993; Meyer and Turner, 1994; NASA, 1996; NRC, 2001a, NRC, 2001b, and Pielke, 2001).[1-8] The U.S. Global Climate Change Research Program (USGCRP) developed plans to map and study global land use histories as an essential requirement for land-atmosphere interactions modeling research.[1] The International Geosphere-Biosphere Programme (IGBP) developed a core project on land use history.[2] Case study examples of regional land-atmosphere interactions models presented in Goodchild et al. (1993) illustrated the importance of land cover characteristics datasets and demonstrated how coupled modeling in the USGCRP was contributing to enhanced environmental simulation models for land, water, and air resource management applications.[3] Correspondingly, Meyer and Turner (1994) described the role of human activities as forcing factors that shape the biosphere and presented case studies on the role of land cover data for environmental modeling involving air, water, and soils resources.[4]

By the mid-1990s, land cover and land use change studies had attained added prominence by becoming one of the five key science priorities in NASA's earth science research plan (NASA, 1996).[5] Recently, the interdisciplinary connections of land cover and land use change studies to other key environmental issues were illustrated by the National Research Council (NRC) Committee on Grand Challenges in the Environmental Sciences (NRC, 2001a).[6] This NRC

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study called for the development of a spatially explicit understanding of land use changes and their consequences. Furthermore, the NRC study suggested that understanding the trends and patterns of land use change would benefit from coordinated research concerning climate variability and its effects on ecosystems and humans. Late 1990s plans of the USGCRP for research on changing ecosystems called for a focus on the understanding of the "relationships among land cover, land use, climate, and weather, particularly how changing land use and land cover affect local and regional climate." Other studies (for example, NRC 2001b; Pielke, 2001) have emphasized the two-way interactions between the land surface and the atmosphere, including the potential for regional climate forcing due to land use changes.[7-8]

The potential consequences of land use change are complex, not easily understood, difficult to quantify, and frequently confounded by environmental variability due to the combined effects of both anthropogenic and natural forcing factors. Land cover and land use changes have been associated with changes in air quality, water quality and availability, microclimate, soil fertility, hazards potential (such as flooding, landslide, frost occurrence, and drought exacerbation), biological diversity, ecosystem processes, regional weather and climate variability, and many other aspects of the biosphere. The complexity of land use dynamics as one of the "grand challenges" for the environmental sciences is illustrated by ongoing studies in South Florida involving land and water resource management research. The seminal book edited by Davis and Ogden (1994), Everglades, The Ecosystem and Its Restoration, included examples of multidisciplinary research activities that focused on the understanding of complex interrelationships involving biologic, hydrologic, geologic, soils, socioeconomic, and other processes.[9] A central goal of research on the South Florida Everglades ecosystem is to understand the predisturbance natural variations of the environment in the context of current environmental conditions, which include variability due to both natural and anthropogenic forcing factors. Questions and issues concerning the consequences of historical land cover and land use change are integral to these studies in South Florida.

The primary focus of this paper is on the role of historical land cover change datasets in atmospheric mesoscale modeling experiments with emphasis on the potential utility of Landsat-derived land cover data. The paper also summarizes how a reconstructed natural vegetation scenario, current land use derived from Landsat data, and the CSU atmospheric mesoscale modeling system were used by the USGS and CSU to investigate the potential effects of historical land use change in South Florida. The hypothesis under investigation is that "historical land cover changes over the past 100 years have contributed to significant variability of land surface, weather, and climatic processes of scientific interest to land resource management issues in South Florida". Section one of this paper describes the historical land cover datasets for South Florida used in the study. These consist of a reconstructed natural vegetation scenario for pre-1900 conditions and contemporary land use patterns derived from early 1990s Landsat Thematic Mapper (TM) scenes. Section two presents the CSU modeling approach and summarizes preliminary modeling results, which build on previous research reported by Pielke et al. (1999).[10] Based on the USGS and CSU research in South Florida and elsewhere in the Eastern United States since 1998, the final section examines the potential role of Landsat-derived 30-m land cover datasets as a spatially accurate and thematically useful resource for atmospheric mesoscale modeling research.

HISTORICAL LAND COVER DATASETS FOR SOUTH FLORIDA

South Florida has experienced extensive land cover changes from the pre-1900s natural vegetation scenario depicted in Figure 1 to the contemporary land use patterns of the early 1990s shown by Figure 2. The native pine forests, dry prairies, and wetlands of Florida have undergone widespread land cover conversion to agricultural farmland and urbanized areas. These land cover conversions also reflect changes to the surface- and ground-water resource systems of South Florida. These water systems have been modified by engineering and water control measures (for example, construction of levees, drainage canals, and water conservation areas) over the past 100 years to control floods and to provide an adequate supply of fresh water for domestic use and agricultural purposes (Light and Dineen, 1994).[11] In addition to providing further insights on land cover changes in South Florida, this section also describes the development of a consistent land cover classification scheme and associated historical datasets for this South Florida modeling study.

Figures 1 and 2 only show the dominant land cover types for the pre-1900 natural vegetation scenario and the early 1990s land use conditions in South Florida, respectively. These selected classes represent a subset of the 40 total land cover classes within the South Florida land cover classification scheme that was developed for use in CSU's Land-Ecosystem-Atmosphere-Feedback-2 (LEAF-2), the land surface parameterization for RAMS (Walko et al., 2000; Lee et al., 1993).[12-13] Many of the 40 classes represent the standard LEAF-2 biome-level land cover classes (for example, evergreen needleleaf tree, deciduous broadleaf tree, mixed agriculture, and residential). These classes were supplemented by wetlands classes, including freshwater marshes (slough, bog, or marsh; saw grass; and wet prairie) as described by Kushlan (1990), woody swamps (Davis, 1943; Pearlstine et al., in press), or complex classes for unique land cover features, such as tree islands and saltwater marshes (Davis, 1943).[14-16] In addition, wetlands complexes, such as evergreen shrub wetlands or deciduous needleleaf trees in Cypress swamps, were based on the standard LEAF-2 classes, which were modified to include hydroperiod information. In fact, hydroperiod information on the normal period of surface-water inundation (beginning and ending month in the calendar year) and the normal inundation depth was developed for each wetlands class in the expanded LEAF-2 classification scheme used in this modeling study.

The atmospheric mesoscale modeling study for South Florida used a nested-grid approach in which a RAMS 10-km inner grid domain over South Florida (Figures 1 and 2) was embedded in a larger RAMS 40-km outer grid domain over the Southeastern United States (approximately 2,600 km by 2,600 km). Each grid was centered over a point just to the southwest of Lake Okeechobee. Separate land cover datasets in the LEAF-2 land cover classification scheme, representing a reconstructed pre-1900 natural vegetation scenario and early 1990s land use, were developed for each model domain. Land cover datasets for the RAMS outer grid domain were developed at a base 1-km pixel size and then spatially aggregated by RAMS to provide the percentage composition of land cover classes in each 40-km grid cell. Land cover data for the inner grid were developed at a base 100-m pixel size and then aggregated to 10-km grid cells. Only the dominant 3-4 LEAF-2 classes plus water within each grid cell were used in the model simulations. The following describes the development of the pre-1900 and early 1990s historical land cover datasets for the RAMS inner and outer grids.

Reconstruction of the pre-1900 natural vegetation scenario in the LEAF-2 classes for South Florida (Figure 1) was based on a GIS analysis of historical maps, USGS paleostudies, historical information, and Kuchler's potential natural vegetation map (Kuchler, 1964). The reconstructed natural vegetation within the Everglades region was based on the South Florida Natural Vegetation Map by Davis (1943), but with key modifications according to research findings of McVoy (1996), McVoy et al. (in press), and Willard et al. (2001).[15,17-19] Based on their findings, the areal extent of sawgrass in the Davis (1943) map to the south of Lake Okeechobee was significantly reduced and replaced by a slough freshwater marsh complex (Figure 1). McVoy analyzed historical records and old photographs to reconstruct the predisturbance sawgrass area, while Willard found evidence to support these findings based on paleostudies of pollen data within sedimentary core samples from the Everglades. The land cover analyses of Costanza (1979), Kuchler (1964), and Kushlan (1990) were also used.[20-21,14] The Kuchler potential natural vegetation dataset was modified in two respects. First, Kuchler's southern mixed forest class in the Southeastern United States, including Florida, was modified to be a predominantly evergreen needleleaf tree class that represents the extensive areas of old-growth longleaf pine and South Florida slash pine in these wildfire-prone areas as suggested by Landers and Boyer (1999).[22] The Kuchler data were also modified to account for the system of St. John's freshwater marshes and swamps in the St. John's River basin and headwaters as described by Kushlan (1990).[14] The modified Kuchler data were used for the RAMS outer grid.

The early 1990s land cover and land use datasets in the LEAF-2 classes for this study were based on 30-m land cover datasets that were previously derived from Landsat TM scenes. These included the USGS 30-m National Land Cover Dataset (NLCD), described by Vogelmann et al. (2001), and the Florida Gap Analysis Project (GAP) land cover dataset, which was cooperatively developed by the USGS and the University of Florida and described by Pearlstine et al. (accepted).[23,16] For the RAMS inner grid over South Florida, the NLCD data were selectively merged with the GAP land cover product that was developed from 1992-94 Landsat TM scenes and extensive field data analysis for more than 60 land cover classes. The resulting 100-m merged dataset permitted a more complete representation of Florida's complex vegetation and wetlands conditions. The NLCD was exclusively used for those parts of the RAMS outer grid external to the domain of the RAMS inner grid. The 30-m NLCD data for the outer grid were aggregated to 1-km grid cells according to the dominant land cover class and then further aggregated by RAMS to provide the percentage composition of land classes within each 40-km grid cell.

Because the South Florida land cover datasets shown in Figures 1 and 2 were developed from relatively high-resolution spatial data sources, the base 100-meter datasets with the 40 LEAF-2 land cover classes preserved small landscape features as part of a consistent land cover classification scheme for both the pre-1900 and early 1990s land cover conditions. This approach permits maximum flexibility in tailoring the land cover data for use in any future model simulations at finer grid cell sizes of 500 m or 1 km. A relatively small tree island may remain a dominant feature in a model grid cell of 500 m. In contrast, spatial aggregation of land cover data to model grid cell sizes of 10 km filters out many of the smaller classes that represent small fractional areas in the grid cell.

MESOSCALE MODELING OF LAND USE CHANGE EFFECTS IN SOUTH FLORIDA

Previous mesoscale modeling experiments and empirical studies have suggested that land use changes can affect land surface processes, the fluxes between the land surface and the lower atmosphere, the properties of the atmospheric boundary layer, and potential regional weather and climate variability (Pielke, 2001). Land use change can modify one or more fundamental land surface characteristics, such as the albedo, roughness length, fractional vegetation, leaf area index, or the fraction of absorbed photosynthetically-active radiation (FPAR), thereby altering the land surface energy, radiation, and moisture budgets. Changes in these land surface processes can affect the exchange of heat, moisture, and momentum between the land surface and the boundary layer of the lower atmosphere and the potential for convective rainfall (Pielke, 2001). Mesoscale modeling experiments, such as with RAMS/LEAF-2, provide a foundation to conduct sensitivity tests as a step toward the quantitative understanding of these complex interrelationships (Chen et al., 2001; Pielke, 2001).[24,8]

The Colorado State University atmospheric modelers conducted a series of mesoscale modeling sensitivity tests to investigate the potential effects of historical land cover change in South Florida on regional weather and climate variability (Marshall et al., 2002; Marshall et al., submitted).[25-26] Analogous to a previous study in South Florida (Pielke et al., 1999), 60-day simulations with RAMS/LEAF-2 were conducted for the July-August summertime convective rainfall season.[10] For each sensitivity test, the pre-1900 natural vegetation scenario and the early 1990s land use data were used in separate mesoscale model simulations, but with a common set of meteorological forcing data for each simulation. Model results from each simulation (e.g., surface latent and sensible heat fluxes, temperatures, total precipitation, and other variables) were analyzed for potential effects due to historical land use changes. The CSU sensitivity tests included meteorological forcing for wet, average, and dry July-August rainfall conditions. Model results were also compared with surface weather observations from available stations.

As described by Marshall et al. (2002) and Marshall et al. (submitted), preliminary results suggested that land use changes can affect land surface processes and seasonal climate variability in South Florida.[25-26] Relative to the pre-1900 natural vegetation scenario, the 1990s land use is generally associated with increased July-August sensible heat fluxes (increased mean temperatures) and decreased latent heat fluxes for the interior regions of South Florida. Relative to the pre-1900 natural vegetation, the CSU simulations also suggested that the 1990s land use is associated with an overall decrease in July-August total rainfall on the order of 10 percent within the interior parts of South Florida. These results are consistent with previous findings reported by Pielke et al. (1999).[10] Time-series analysis of July-August total rainfall at sparsely located surface weather stations also tended to support the modeling results. A more comprehensive discussion of the modeling results is reported by Marshall et al. (submitted).[26]

These atmospheric mesoscale modeling simulation studies reported by Pielke et al. (1999) and Marshall et al. (2002) are believed to be among the first experiments that have used regional 30-m land cover datasets derived from Landsat TM imagery.[10,25] Although mesoscale modeling uses model grid cell sizes that are generally two orders of magnitude larger than the base 30-m pixels of Landsat, this research activity has presented an opportunity to examine the potential role of Landsat-derived products for coupled land-atmosphere modeling experiments.

ROLE OF LANDSAT IN ATMOSPHERIC MESOSCALE MODELING STUDIES

Landsat-derived land cover products have not been widely used in atmospheric mesoscale modeling studies where model geographic domains are generally on the order of 500-1,500 km. However, this research suggests that the USGS NLCD and other large-area 30-m land cover datasets represent important resources for tailored land cover data in mesoscale modeling experiments. For example, the NLCD represents a robust source of spatially accurate and thematically useful data for aggregation to model grid cell sizes from 500 m to several kilometers. The following discussion focuses on the potential role of Landsat-derived land cover products in mesoscale modeling research and describes potential synergies between Landsat and MODIS products within mesoscale modeling experiments.

Atmospheric Mesoscale Modeling Simulations

As discussed in this paper, an important topic of research within the global change research and atmospheric mesoscale modeling communities is the study of the potential effects of land cover change on regional weather and climate variability. For example, mesoscale modeling systems such as RAMS/LEAF-2 are used to determine how the spatial distributions of land cover and soils affect land surface processes, the lower atmospheric boundary layer, and cumulus convective precipitation patterns (Pielke, 2001; Pielke, 2002).[8,27] The horizontal model domains for these types of experiments can range from a 100-km by 100-km geographic area up to much larger regions on the order of 2,000 km by 2,000 km. Frequently, a mesoscale model experiment will utilize a nested-grid approach in which a fine-mesh inner grid on the order of 10-km grid increments is embedded within a coarser mesh outer grid on the order of 40-km grid increments such as that described by Pielke et al. (1997), or a more detailed approach with nested grids of 1-, 3-, 9-, and 27-km grid increments as described by Chen et al. (2001).[28,24] Until recently, the lack of regional land cover data was a major limiting factor in the use of Landsat-derived products by the atmospheric mesoscale modeling community.

However, the USGS NLCD overcomes this impediment and provides the foundation for the greatly expanded application of 30-m land cover datasets in regional mesoscale simulations. Developed from early 1990s Landsat TM satellite data, the NLCD was specifically designed to represent a "reasonably consistent and seamless 30-meter land cover product for the conterminous United States" (Vogelmann et al., 2001).[23] In addition, the NLCD's land cover classification scheme, which consists of 21 hierarchical land cover classes, was designed for use in environmental, land management, and modeling applications to include national-scale analysis (Vogelmann et al., 2001).[23] In the case of mesoscale modeling , the NLCD land cover classes can be remapped into the biome-level land cover classes that are required by the model's land surface parameterization scheme. As a consequence, this seamless 30-m land cover dataset can be geographically subsetted and spatially aggregated according to the requirements of the model's geographic domain and grid cell size. If they wish to, users can still download state-level datasets that can be merged as was done for the eastern third of the United States for this study before the seamless dataset was available.

Given satellite sensor spatial resolution as the sole consideration, a 30-m land cover dataset derived from Landsat should resolve land cover features that would otherwise represent subpixel land cover mixtures within 1-km or coarser resolution land cover products developed from coarser resolution satellite data. (Note: The 30-m pixel can also consist of mixed land cover classes, and there are other issues, such as the effective spatial resolution of a sensor as discussed by Schowengerdt (1997), who estimated the effective resolution of Landsat 5 as 40-45 m, not 30 m.)[29] The ability of Landsat to resolve finer scale landscape features (for example, bare soil, croplands, water, and forests) is important for smaller mesoscale model grid cell sizes of 1-km or less, but it also contributes to improved estimates of aggregated land cover data for model domains with larger model grid cells. To illustrate the model requirements for aggregated data, land surface parameterizations such as LEAF-2 utilize the percentage composition of land cover classes within each model grid cell (Walko et al., 2000) in a mosaic approach described previously by Avissar and Pielke (1989) and Koster and Suarez (1992).[12, 30-31] As described by Walko et al. (2000), LEAF-2 utilizes percentage composition information to subdivide each model grid cell into multiple sub-grid patches that represent the fractional area of the dominant land cover classes within the grid cell. Although current versions of LEAF do not take into account the geolocation of each patch within the grid cell, the LEAF-2 model is separately run for each patch that interacts with the lower atmospheric boundary in a way that is proportional to its fractional area within the grid cell. Therefore, improved estimates of the fractional areas within the model cell could improve the model simulation, especially for small model grid cell increments.

The thematic accuracy of a land cover dataset is an important issue for mesoscale modeling simulations. In the case of the NLCD, an accuracy assessment was conducted for 21 eastern States using a statistical analysis of photointerpreted reference data obtained from a stratified probability sample of pixels (Yang et al., 2001a; Vogelmann et al., 2001).[32,23] They reported accuracy results at the 30-m pixel size of approximately 60 percent for all NLCD classes and approximately 81 percent for more generalized land cover classes, such as open water, urban, barren, forest, agricultural land, and wetland classes. Because mesoscale models use relatively coarse-resolution model grid cells with an emphasis on the predominant land cover classes, spatial aggregation of the NLCD data to even a 500-m grid cell may tend to help minimize the effects of land cover misclassifications (or other potential uncertainties in the accuracy assessment at the 30-m pixel level) by smoothing the data and filtering out those land cover classes that represent the smaller fractional areas of the grid cell.

As a special subset of applications, atmospheric modeling experiments within smaller geographic model domains represent unique opportunities for the expanded use of aggregated 30-m land cover products from the NLCD, GAP, or other datasets. For example, the model grids for small-area simulations could range from 1-km cells for a 50-km by 50-km region to 3-km cells for a 150 km by 150-km region. Applications at these spatial scales could include mesoscale modeling simulations to study the effects of land use change on the urban environment, diffusion and transport of air pollution or toxic substances, or investigation of well-known mesoscale features, such as land-sea breezes, lake effects, mountain-valley circulations, or wind flow over complex terrain (Pielke, 2002).[27] Placed in the context of historical land use change research, mesoscale modeling experiments to investigate such classic mesoscale processes may be of scientific interest, for example, to determine the consequences of land cover change from a reconstructed natural vegetation scenario for predisturbance conditions versus contemporary land use derived from Landsat 30-m data.

Coupled Modeling Research

Advanced land-atmosphere interactions research is also focused on the interactive coupling of hydrologic and ecologic models with a coupled land-mesoscale atmospheric model, such as RAMS/LEAF-2 for regional-scale experiments. The goal is to more realistically account for land surface, hydrologic, and biologic processes as discussed by Pielke et al. (1998), Walko et al. (2000), Eastman et al. (2001), and Chen et al. (2001).[33, 12, 34, 24] Walko et al. (2000) discussed the incorporation of a land surface hydrology model in LEAF-2 to account for the movement of surface and subsurface water horizontally between vegetation patches and downslope. Eastman et al. (2001) linked a plant model with a mesoscale atmospheric model to investigate the effects of CO_2 and land use change in the central grasslands of the United States.[34] Chen et al. (2001) reviewed the progress in coupled modeling research. In addition to regional studies at spatial scales of 1,000-1,500 km, there is also growing interest in finer scale modeling studies over small ecosystems or watersheds.[24] An example is the modeling research on the effects of historical land use change and the Baltimore LTER site, which represents an urban ecosystem and a small watershed. Aggregated Landsat-derived land cover products such as the NLCD are well suited for these higher resolution coupled modeling studies. In fact, the application of the NLCD in these finer scale studies is complemented by the 30-m topographic data available from the USGS National Elevation Dataset (NED). As described by Gesch et al. (2002), NED is a seamless 30-m topographic dataset that is available for the conterminous United States.[35]

Subgrid Landscape Heterogeneities and Mesoscale Modeling Research

Investigations to understand and parameterize subgrid landscape heterogeneities and associated processes represent an important research topic for mesoscale modeling studies (Chen et al., 2001).[24] Subgrid land surface heterogeneities are due to the spatial variability of the vegetation, soils, soil moisture, snow cover, and topographic characteristics within each model grid cell. As described by Pielke (2001), spatial variations of land surface properties directly affect the land surface energy balance and the soil moisture budget that influence the lower atmospheric boundary layer and the potential for convective precipitation.[8] Chen et al. (2001) suggested that subgrid spatial heterogeneity in the vegetation, topographic, and soil moisture characteristics should be studied to determine the contributions of subgrid processes to the surface heat flux and runoff in each grid cell. As summarized by Chen et al. (2001), current research on the approaches for the parameterization of subgrid heterogeneities includes application of the "mosaic" approach defined in the preceding, the use of probability density functions to characterize subgrid variability, and the concept of defining "effective" parameters for estimating area-average fluxes in each model grid cell.[24]

These research issues concerning subgrid landscape heterogeneities and their associated subgrid processes suggest a potential role for 30-m land cover data in land surface parameterization research. Because of its high spatial resolution, Landsat-derived land cover can explicitly capture subgrid landscape fragmentation, including vegetation and bare soil features, on the scale of at least 100- to 200-meter patch sizes within each model grid cell or within the boundaries of a small watershed. As previously noted, aggregated percentage composition information (or fraction areas) for the land cover classes within each model grid cell is readily used in the mosaic approach of LEAF-2 without regard to geolocation of the "patches" within the model grid cell (Walko et al., 2000).[12] As discussed by Vidale et al. (1997), the organization of the subgrid patches within the model grid cell begins to become a consideration for mesoscale circulation processes if the horizontal scales of the subgrid patches are at least twice the depth of the atmospheric boundary layer or approximately 2 km in size or larger.[36] Geolocation information on these 2-km or larger subgrid patches may prove useful for enhanced parameterizations of land surface fluxes. However, geolocation information on subgrid heterogeneities may have broader implications for land surface parameterization research. For example, geolocation information on subgrid land cover patches, including associations with topographic and soil characteristics, appears relevant to the parameterization of surface hydrology and the lateral transport of water as described by Walko et al. (2000).[12] The geolocation information provided by Landsat on subgrid patches may support research on the development of advanced land surface parameterizations that selectively assign the model physics according to the patch size, type, and location within the model grid cell. This is particularly true for smaller study areas and watersheds where both the 30-m land cover and topographic datasets are relevant. An interesting illustration of land surface parameterization research for these smaller study areas involves the use of a large eddy simulation model (LES) as part of a field experiment with flux tower observations to understand subgrid fluxes and to scaleup from the microscale to the mesoscale (for example, see Albertson et al., 2001).[37] High-resolution land cover is used in the LES with grid increments in the 10s of meters where the LES grid is embedded in a mesoscale model grid at coarser grid increments. Landsat-derived land cover has direct application in this type of research.

The spatial variability of the structural properties of a forest canopy represents another example of subgrid heterogeneity of interest to mesoscale modeling research and remote sensing scientists. Forest canopies exhibit variations in the amount of tree crown closure, including gaps in the canopy, which affect the surface radiation budget and other land surface processes. Among the land surface characteristics prescribed for each land cover class, the LEAF-2 land surface parameterization requires information on the maximum fractional vegetation cover, which is a key parameter for many land surface processes, including the partitioning of solar radiation intercepted by the canopy versus the amount reaching the land surface (for example, ground cover or bare soil). Therefore, more detailed land cover mapping information on the structural properties of the forest canopy would definitely benefit current land surface parameterizations such as LEAF-2. However, an additional research issue involves an approach for enhanced parameterization of the solar radiation fluxes through the forest canopy, as proposed by Yang et al. (2001b).[38] Specifically, Yang et al. (2001b) have investigated the parameterization of the solar radiation fluxes within nonuniform vegetation canopies for use in land surface models. Based on sensitivity analysis and comparisons between the most widely used computationally efficient, two-stream canopy radiative transfer (RT) model (Dickinson, 1983; Sellers et al., 1986)[38, 39-40] versus a more detailed but computationally expensive geometric-optical radiative transfer model (Li et al., 1995)[41], Yang et al. (2001b) proposed an efficient modification to the two-stream approach that was designed to more realistically account for the three-dimensional structure of a pine forest canopy. Although still in the early research stages, the implication of the Yang et al. (2001b) study is that land surface models such as LEAF-2 could potentially select the RT physics parameterization on the basis of the type of canopy for a particular forest land cover class.[38]

Plans are underway to use Landsat 7 imagery as the primary basis to develop a second-generation NLCD2000 for the United States (Homer et al., 2002).[42] The NLCD2000 will also include a tree canopy density layer, which will describe the percentage of tree canopy cover in each 30-m pixel (Huang et al., 2001).[43] The preceding discussion indicates that this new NLCD2000 data layer could contribute to mesoscale modeling research on the parameterization of subgrid landscape heterogeneities with existing models, such, as LEAF-2 (Walko et al., 2000), or to the development of new approaches, such as those discussed by Yang et al. (2001b).[12, 38]

Synergies Between Landsat and MODIS

Many potential synergies exist between Landsat and the suite of 250-m, 500-m, and 1-km scientific products now available from the MODIS instrument on the Terra satellite. MODIS Land Products are derived from well-calibrated spectral radiances with small geolocation errors for each pixel. MODIS Atmospheric Products on clouds, water vapor, and aerosols are used in a state-of-the-art, operational radiative transfer algorithm to produce atmospherically-corrected land surface spectral reflectance data. Because the orbits of the Landsat 7 and Terra satellites are very similar (Terra trails Landsat by approximately 30 minutes), a promising research area is the use of MODIS Atmospheric Products to atmospherically-correct Landsat 7 spectral radiances for improved land cover characterization. MODIS land surface reflectance data are the foundation for downstream MODIS Land Products, including vegetation indexes, leaf area index, FPAR, albedos, vegetation continuous fields, and land cover. These types of land surface characteristics datasets from MODIS, including phenological information, promise to help overcome critical data limitations for atmospheric mesoscale modeling and other types of land-atmosphere interactions modeling. For some mesoscale modeling research activities, as outlined previously, detailed spatial information from Landsat is complemented by the temporal and phenological information available from MODIS. The integration of Landsat-derived land cover data and MODIS's validated Land Products, which provide enhanced land cover characteristics and temporal dynamics, including seasonal and interannual variability for mesoscale modeling simulations, is a promising research area.

CONCLUDING REMARKS

Land cover and land use change studies are of growing interest within the environmental modeling and global change research communities. Understanding the effects of past land use changes on environmental processes and predicting the consequences of future land use change scenarios is a central research theme. Frequently, environmental variability includes both the effects of natural variability and the effects due to anthropogenic forcing factors. Land use change can also be associated with feedbacks involving the ecologic, hydrologic, and atmospheric systems. Environmental simulation models, including coupled land-atmosphere interactions models, are increasingly recognized as key tools to understand complex, nonlinear relationships involving the potential effects of land use change.

Empirically based field experiments and modeling sensitivity tests have sought to understand the effects of land use change on land surface processes, the interactions of the land surface with the atmospheric boundary layer, their combined effects on convective rainfall conditions, and the overall potential for changes in regional climate variability (Pielke, 2001).[8] As described by Pielke (2001) and Chen et al. (2001), the atmospheric mesoscale modeling system is a key tool for these types of studies.[8, 24] Research findings such as those reported by Pielke et al. (1999), Marshall et al. (2002), and Marshall et al. (submitted) for South Florida provide insights into the potential effects of land use change on regional climate variability and demonstrate the need for historical land cover and land use datasets.[10, 25-26] Such modeling experiments require reconstructed land use history datasets and contemporary land cover and land use datasets.

This USGS and CSU research suggests that the USGS NLCD and other large-area 30-m land cover datasets derived from Landsat represent important resources for mesoscale modeling experiments. The NLCD represents a robust source of spatially accurate and thematically useful data for aggregation to model grid cell sizes from 500 m to several kilometers. Because mesoscale models typically use biome-level land cover classes, detailed percentage compositions for each model grid cell can be calculated. In addition, Landsat-derived land cover has utility for coupled land-atmosphere modeling in which a mesoscale model is coupled with land surface, hydrologic, and ecosystem dynamics models. Landsat explicitly captures subgrid landscape fragmentation and heterogeneities that are important contributors to land-atmosphere interactions and mesoscale processes. This accurate geolocation of landscape patches within each model grid cell could eventually permit advanced land surface parameterizations to assign the model physics according to the patch size, land cover type, and location within the grid cell. Landscape heterogeneity and patch size are important topics of mesoscale modeling research; for example, as related to the generation of mesoscale circulations. Finally, the NLCD and GAP datasets, plus Landsat scenes, also contributed to the reconstruction of historical vegetation datasets by providing a basis to understand current land cover and land use patterns in terms of terrain, microclimate, ecological regions, soils, and potential natural vegetation, thereby assisting in the interpretation of historical land use information. The integration of Landsat-derived land cover data and MODIS's validated land products to provide enhanced land cover characteristics and temporal dynamics for mesoscale modeling is a promising research area.

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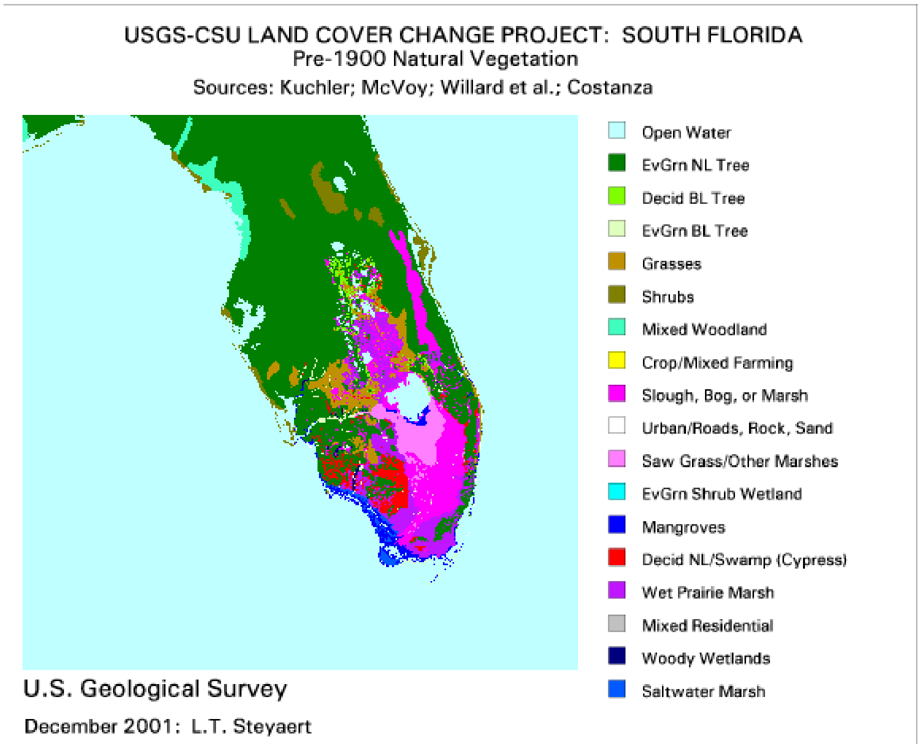

Figure 1. Pre-1900 natural vegetation scenario for South Florida.

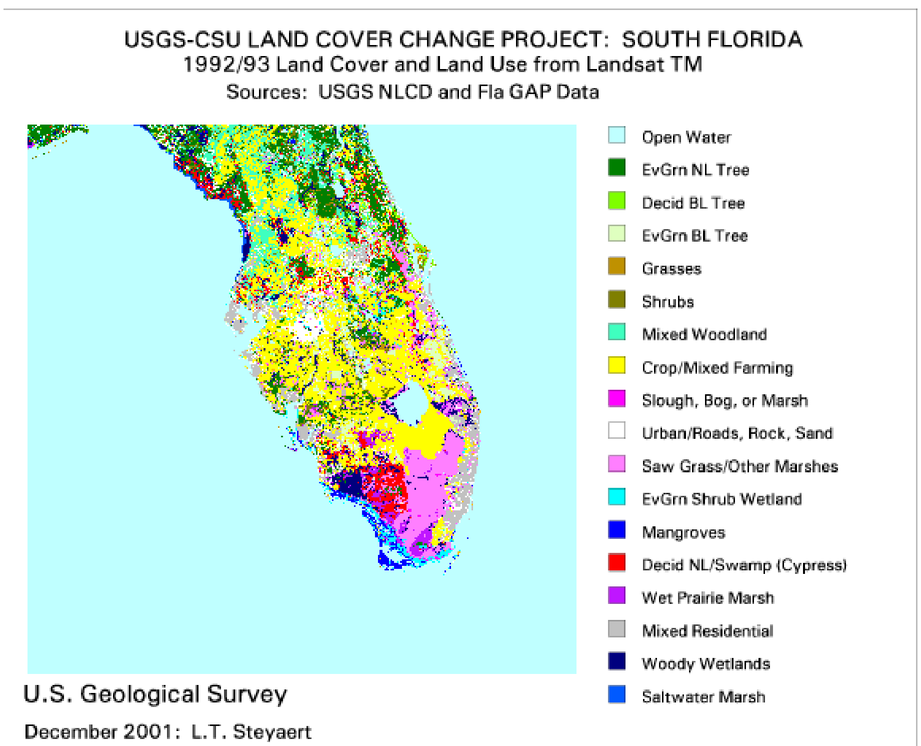

Figure 2. Early 1990s land cover and land use derived from Landsat Thematic Mapper data for South Florida

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