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Mapping plant functional types from MODIS data using multisource evidential reasoning

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Abstract

Reliable information about the geographic distribution and abundance of major plant functional types (PFTs) around the world is increasingly needed for global change research. Using remote sensing techniques to map PFTs is a relatively recent field of research. This paper presents a method to map PFTs from the Moderate Resolution Imaging Spectroradiometer (MODIS) data using a multisource evidential reasoning (ER) algorithm. The method first utilizes a suite of improved and standard MODIS products to generate evidence measures for each PFT class. The multiple lines of evidence computed from input data are then combined using Dempster's Rule of combination. Finally, a decision rule based on maximum support is used to make classification decisions. The proposed method was tested over the states of Illinois, Indiana, Iowa, and North Dakota, USA where crops dominate. The Cropland Data Layer (CDL) data provided by the United States Department of Agriculture were employed to validate our new PFT maps and the current MODIS PFT product. Our preliminary results suggest that multisource data fusion is a promising approach to improve the mapping of PFTs. For several major PFT classes such as crop, trees, and grass and shrub, the PFT maps generated with the ER method provide greater spatial details compared to the MODIS PFT. The overall accuracies increased for all the four states, with the biggest improvement occurring in Iowa from 51% (MODIS) to 64% (ER). The overall kappa statistic also increased for all the four states, with the biggest improvement occurring in Iowa from 0.03 (MODIS) to 0.38 (ER). The paper concludes with a discussion of several methodological issues pertaining to the further improvement of the ER approach.

Keywords: Plant functional type (PFT); Data fusion; Evidential reasoning; Dempster–Shafer theory of evidence; Evidence measures; MODIS data

1. Introduction

Plant functional types (PFT) are groups of plant species that share similar functioning at the organismic level, similar responses to environmental factors, and/or similar effects on ecosystems (Smith et al., 1997). Reliable information about the geographic distribution and abundance of major PFTs around the globe is increasingly needed for global change research. For example, the National Center for Atmospheric Research land surface model (NCAR LSM) has shifted from using biome-based land cover information to using satellite-derived PFT maps (Bonan et al., 2002; Tian et al., 2004). The carbon models used to scale carbon fluxes also typically require specification of PFTs (Denning et al., 1996; Sellers et al., 1997). Using remote sensing techniques to extract reliable PFT information can therefore contribute to improved predictive capabilities of global and regional carbon cycle, climate and ecosystem models.

The increased utilization of PFT information stems from the realization that traditional biome-based land cover characterization can no longer meet the needs of recent advances in global change research. For example, most land models are expanding beyond their traditional biogeophysical roots to include biogeochemistry, especially photosynthesis and the carbon cycle (Bonan, 1996; Dickinson et al., 1998; Foley et al., 1996; Kucharik et al., 2000). Inclusion of photosynthesis and the carbon cycle in land models requires specification of many leaf-level and whole-plant physiological parameters. The

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functions are very difficult to be parameterized in the case of mixed life-form biomes such as savannas and mixed forests, because a mixed life-form biome consists of physiologically distinct plant species.

Representing vegetation as patches of PFTs offers several important advantages over the biome-based land classification approach (Bonan et al., 2002). First, PFT provides a direct link to leaf-level physiological measurements, making it possible to more accurately set vegetation parameters in land models. Second, PFT allows modelers to more accurately represent the land surface by separately specifying the composition and structure of PFTs within a grid cell. Third, representing vegetation in terms of PFTs also allows land models to better interface with ecosystem dynamics models, because the latter typically simulate vegetation change in terms of the abundance of PFTs (Gamon et al., 2004; Running & Coughlan, 1988; Sitch et al., 2003; Smith et al., 2001).

The Moderate Resolution Imaging Spectroradiometer (MODIS) Land Team is producing a global PFT map (i.e., MODIS Land Cover Type 5) for use in the Community Land Model (CLM) (http://edcdaac.usgs.gov/modis/mod12q1v4.asp). This PFT product is generated by re-labeling the International Geosphere–Biosphere Programme (IGBP) classes of MODIS Land Cover Type 1 product (Friedl et al., 2002; Strahler et al., 1999). The MODIS PFT is the only global PFT data set currently available. However, the error magnitudes of the MODIS PFT product and their spatial and temporal distributions have not been fully characterized. Errors and uncertainties in PFT data can multiply and compromise the credibility of global change research. Several studies have demonstrated that the use of different PFT data sets has a significant effect on climate modeling results (e.g., Bonan et al., 2002; Oleson & Bonan, 2000; Tian et al., 2004).

The increased availability and information content of remotely sensed data being generated by Earth Observing System (EOS) sensors and other sensors has provided considerable potential for the extraction of PFT information. However, due to the enormous diversity of terrestrial plant species and the spatial and temporal variability in the morphological and spectral characteristics of PFTs, accurate mapping of PFTs over large areas is a difficult task (Box, 1996; Prentice et al., 1992; Semenova & van der Maarel, 2000; Smith et al., 1997). Sun and Liang (2007) recently discussed several methodological issues pertaining to the mapping of PFTs over large areas. Their study shows that at the present time no satisfactory methodology exists for the extraction of PFTs from satellite observations. A main conclusion from their study is that incorporation of a wide array of information including both satellite observations and ancillary data into PFT classification procedures is indispensable to improved mapping of PFTs at continental to global scales.

In this paper we report some preliminary results from an ongoing research that aims to map PFTs from MODIS data using a data fusion approach. The main idea behind our methodology is that since a PFT has its manifestations in multiple domains such as plant physiognomy, vegetation structure, phenology, and environmental conditions (Running et al., 1995), the use of multiple lines of evidence reflecting the characteristics of a PFT in the above domains should help enhance the ability to extract PFTs. In this research, the evidence used to discern PFTs is generated from a suite of improved and standard MODIS products including LAI, EVI and albedos. The multiple lines of evidence computed from the input data are then fused using an evidential reasoning algorithm.

Evidential reasoning is a method of inexact reasoning (Giarratano & Riley, 1998; Peddle, 1995a,b). The method is based on the recognition that the knowledge and information we use in making decisions such as image classification is often uncertain, incomplete, and occasionally imprecise. As such, the method is designed to capture the natural behavior of reasoning by narrowing the hypothesis set down to a smaller number of possibilities as evidence increases (Lein, 2003). Evidential reasoning has been used in a variety of earth resources and geoscience applications, such as geological mapping (Moon, 1990, 1993), water resources (Caselton & Luo, 1992; Peddle & Franklin, 1993), forestry mapping (Goldberg et al., 1985), sea ice identification (Soh et al., 2004), and land cover classification (Cohen & Shoshany, 2005; Lee et al., 1987; Lein, 2003; Peddle, 1995a,b; Srinivasan & Richards, 1990). Past research has shown that evidential reasoning can produce more accurate results compared to traditional classifiers (Le Hégarat-Mascle et al., 2003; Lein, 2003; Peddle, 1995a,b; Soh et al., 2004).

The proposed method is tested over the states of Illinois, Indiana, Iowa, and North Dakota, USA. These four states represent an important type of landscape of the United States where crops dominate. The Cropland Data Layer (CDL) data provided by the National Agricultural Statistic Service of the U.S. Department of Agriculture are used to validate our results.

2. PFT classification scheme, input data, and reference data

The PFT classification scheme used in this study is the same as the one used in the MODIS PFT product. The MODIS PFT scheme consists of 12 classes including water, evergreen needleleaf trees, evergreen broadleaf trees, deciduous needleleaf trees, deciduous broadleaf trees, shrub, grass, cereal crop, broadleaf crop, urban and built-up, snow and ice, and barren or sparse vegetation.

Nine MODIS data sets are used in this study as the sources of evidence. These include improved MODIS LAI, MODIS EVI (MOD13A2), and seven spectral bands of MODIS "black-sky" albedo (MOD43B3) for the year 2001. The choice of these input data sets is based primarily on their utility for the recognition and discrimination of different PFTs. MODIS Leaf Area Index (LAI) and MODIS Enhanced Vegetation Index (EVI) are chosen because they contain information about the properties of different PFTs in terms of their plant physiognomy (e.g., canopy structure and leaf longevity), vegetation structure (e.g., fractional vegetation cover), and phenology (e.g., onset and duration of greenness). MODIS albedo products can also aid the discrimination of PFTs because they contain spectral information about land surface properties under perfect scattering conditions. A more detailed discussion of the utility of MODIS products as sources of evidence for mapping PFTs can be found in Sun and Liang (2007).