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An improved algorithm for small and cool fire detection using MODIS data: A preliminary study in the southeastern United States

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Abstract

Traditional fire detection algorithms mainly rely on hot spot detection using thermal infrared (TIR) channels with fixed or contextual thresholds. Three solar reflectance channels (0.65 μm, 0.86 μm, and 2.1 μm) were recently adopted into the MODIS version 4 contextual algorithm to improve the active fire detection. In the southeastern United States, where most fires are small and relatively cool, the MODIS version 4 contextual algorithm can be adjusted and improved for more accurate regional fire detection. Based on the MODIS version 4 contextual algorithm and a smoke detection algorithm, an improved algorithm using four TIR channels and seven solar reflectance channels is described. This approach is presented with fire events in the southeastern United States. The study reveals that the T_{22} of most small, cool fires undetected by the MODIS version 4 contextual algorithm is lower than 310 K. The improved algorithm is more sensitive to small, cool fires in the southeast especially for fires detected at large scan angles.

Keywords: Algorithm; Remote Sensing; MODIS; Regional fire detection; Small, cool fires

1. Introduction

The southeastern United States is one of the areas in the country where wildland fires and prescribed fires are common (USDA Forest Service, 1998). An estimated 3.2 million hectares of wildland are burned per year in the southeastern United States (Wade et al., 2000). Most of the prescribed fires, and some of the wild fires, can be classified as understory surface fires, characterized by their small burn area and relatively low temperatures (Stanturf et al., 2002).

It is difficult to detect small and cool fires using current remote sensing algorithms because these fires do not emit sufficient radiation to penetrate dense canopies and cannot be easily distinguished from non-fire background radiation. To date, most algorithms are designed for global fire detection, and rely on identifying hot spots using thermal infrared (TIR) channels. The limitation of that technology is that false alarms are occasionally generated over certain surface types during the day time, and small, cool fires are oftentimes missed using relatively high thresholds optimized for global fire detection.

In this paper, we review problems with state of the art remote sensing of small, cool fires. We present an improved algorithm designed to detect small, cool fires in the southeastern United States with MODIS daytime observations. Two cases are presented to illustrate the performance of this algorithm.

2. Data and methods

2.1. Data and software

Reflectance from MODIS solar reflective channels in 1 km resolution, is employed to derive smoke pixels. The 0.41 μm

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and 0.94 μm channels, denoted by R_8 and R_{19}, respectively, are used to reject vegetation pixels. The 2.13 μm and 0.44 μm channels, denoted by R_7 and R_9, respectively, are applied to reject bare soil pixels. The reflectance from the blue channel is denoted by R_3, along with R_8 to reject water pixels.

Three thermal infrared channels and one solar reflective channel are applied to detect fire pixels. The brightness temperatures derived from 3.96 μm channels and the 11.03 μm channel are denoted by T_{22}, and T_{31}, respectively. The reflectance from the 0.86 μm channel in 1 km resolution is denoted by R_2. The reflectance from R_2, and the 0.65 μm channel, denoted by R_1 along with the brightness temperature derived for the 12.02 μm channel (T_{32}) and the 7.3 μm channel (T_{28}) are used to flag cloud pixels and reject cloud edge false alarms.

All data are downloaded from the Earth Observing System Data Gateway, Land Processes Distributed Active Archive Center (DAAC) (Justice et al., 2002b), including MODIS Level 1B Radiance product (MOD02/MYD02), geolocation data set (MOD03/MYD03), and thermal anomalies, fires, and biomass burning product (MOD14/MYD14).

To generate true color images, the MODIS Direct Readout (DR) software package MODISNDVI_DB_V2.1 is employed to calculate solar reflectance with atmospheric correction at three visible channels. The MODIS fire product at 18:50 GMT, December 20, 2004, not available at the DAAC, is generated by the DR software package MOD14-4. DR software, provided by the Direct Readout Laboratory at http://directreadout.gsfc.nasa.gov/. MATLAB is used to implement the improved algorithm.

2.2. Existing algorithms

A small number of authors (Dozier, 1981; Giglio et al., 1999; Langaas, 1993; Lasaponara et al., 2003) have focused on small fire detection based on theoretical analysis, fixed threshold method, or contextual algorithms using NOAA Advanced Very High Resolution Radiometer (AVHRR) multi-channel data. Since the Moderate Resolution Imaging Spectroradiometer (MODIS) instruments onboard Terra and Aqua began collecting data in February 2000 (Terra) and June 2002 (Aqua), satellite fire detection capability has been improved using two 3.96 μm channels.

In the MODIS version 3 active fire detection algorithm (Kaufman et al., 1998), sensitivity to relatively small fires were sacrificed in order to reduce persistent false alarms over certain surface types during the day time (Justice et al., 2002a). An enhanced contextual fire detection algorithm (Giglio et al., 2003) was recently used for MODIS version 4 fire products, in which the sensitivity to small, cool fires increased. This algorithm achieved significantly lower false alarm rates by using several solar reflectance channels to reject false alarms, and by adjusting the potential fire threshold and contextual thresholds in the earlier version of the MODIS contextual algorithm.

Contextual algorithms (e.g. Flasse & Ceccato, 1996; Giglio et al., 2003; Justice et al., 1996; Kaufman & Justice, 1998; Kaufman et al., 1998; Lee & Tag, 1990) use dynamic thresholds, relying on the contrast between a potential fire pixel and its background pixels (Boles & Verbyla, 2000) to detect fires. These algorithms are more flexible and effective in variable surface conditions than fixed threshold approaches (Flasse & Ceccato, 1996; Li et al., 2001). The MODIS contextual fire detection algorithm, designed for operational global fire monitoring, has the weakness for regional fire detection, including: fixed thresholds for identifying potential fire pixels; the assumption of a similar non-fire background nearby fire pixels; the effects of reflected solar radiation; the impact of undetected fires in the valid background pixels; problems caused by solar zenith angle and scan geometry; and the influence of atmospheric optical thickness. When applied to regional active fire detection in the southeast, small, cool fires are oftentimes missed due to special regional wildland fire patterns and environmental factors (Martin & Boyce, 1993; Stanturf et al., 2002). In addition, small, cool fires exhibit different characteristics depending on biome, amount of fuel burning, time of day, fire-line, season, geographic region, and view geometry (Giglio et al., 1999).

The MODIS contextual algorithm is composed of three basic parts, including preliminary thresholds to identify potential fire pixels, contextual tests to confirm fires among the potential fire pixels (Martin et al., 1999), and thresholds to reject false alarms. In the first part, the selection of fixed thresholds is subtle as an over-high setting runs a risk of omitting fire pixels. Meanwhile, an over-low setting causes more noise in deriving the parameters of the background pixels (Li et al., 2001) and generates more false alarms. The MODIS version 4 contextual algorithm employs fixed thresholds globally to identify potential fire pixels. For global applications, the preliminary thresholds cannot be set low enough to detect most small fires that can be physically detected for regional concern. Therefore, it needs improvement for fire monitoring and management at the regional scale.

Since fire severity varies with fuel type, fuel loading and weather conditions, potential fire thresholds should be contingent on these variables for regional applications (Li et al., 2001). Boles and Verbyla (2000) and Chuvieco and Martin (1994) demonstrated that fire detection accuracy was improved by using a fuel mask model. Csiszar et al. (2003) also suggest that adjusting thresholds to local conditions is necessary to reach a reasonable compromise between omission and commission errors for regional fire detection. These studies indicate that potential fire thresholds should be based on regional variations or they should be set as a function of a vegetation index for regional fire detection (Chuvieco & Martin, 1994; Martin et al., 1999).

In the second part of the MODIS algorithm, it is critical to determine valid neighboring pixels for every potential fire pixel, which will be used to derive the background parameters designed to set the remaining dynamic thresholds. The separation of fire pixels and non-fire background pixels becomes ambiguous with increasing background temperature caused by the presence of undetected background fires, seasonal change and certain surface types. This can directly affect the performance of the contextual algorithms. Giglio et al. (1999) excluded the eight pixels surrounding the potential fire pixel from the processing window in order to take out the fire contaminated background pixels. This algorithm showed a higher sensitivity to small, cool fires compared with the algorithms of Justice et al. (1996) and Flasse and Ceccato (1996).