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Detection rates of the MODIS active fire product in the United States

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Abstract

MODIS active fire data offer new information about global fire patterns. However, uncertainties in detection rates can render satellite-derived fire statistics difficult to interpret. We evaluated the MODIS 1 km daily active fire product to quantify detection rates for both Terra and Aqua MODIS sensors, examined how cloud cover and fire size affected detection rates, and estimated how detection rates varied across the United States. MODIS active fire detections were compared to 361 reference fires (≥18 ha) that had been delineated using pre- and post-fire Landsat imagery. Reference fires were considered detected if at least one MODIS active fire pixel occurred within 1 km of the edge of the fire. When active fire data from both Aqua and Terra were combined, 82% of all reference fires were found, but detection rates were less for Aqua and Terra individually (73% and 66% respectively). Fires not detected generally had more cloudy days, but not when the Aqua data were considered exclusively. MODIS detection rates decreased with fire size, and the size at which 50% of all fires were detected was 105 ha when combining Aqua and Terra (195 ha for Aqua and 334 ha for Terra alone). Across the United States, detection rates were greatest in the West, lower in the Great Plains, and lowest in the East. The MODIS active fire product captures large fires in the U.S. well, but may under-represent fires in areas with frequent cloud cover or rapidly burning, small, and low-intensity fires. We recommend that users of the MODIS active fire data perform individual validations to ensure that all relevant fires are included.

Keywords: MODIS active fire detection; MOD14; MYD14; Clouds; United States

1. Introduction

Satellite sensors can monitor global fire patterns (Csiszar et al., 2005; Dwyer et al., 1998; Dwyer et al., 2000) and have increased our understanding of fire emissions (Kaufman et al., 1992; Seiler & Crutzen, 1980), land-use/land-cover change (Eva & Lambin, 2000), and fire risk (Chuvieco & Congalton, 1989). Satellite fire data offer clear advantages over other fire data sources. In the U.S., many public agencies keep fire occurrence records, but may not include fires occurring on private lands (Brown et al., 2002). Collecting fire data in the field is time consuming, expensive and difficult, especially in remote areas. Satellite fire observations thus offer a reliable source of fire occurrence data that may overcome some of the limitations of traditional fire monitoring (Csiszar et al., 2005; Eva & Lambin, 1998a; Flannigan & Vonder Haar, 1986; Korontzi et al., 2006). However, although satellite fire data offer valuable information, uncertainty in their detection rates can make interpretation difficult (Congalton & Green, 1999).

A variety of sensors have been used to detect and map fires. Global to continental coverage has been derived from the Advanced Very High Resolution Radiometer (Flannigan & Vonder Haar, 1986; Li et al., 1997), and Moderate Resolution Imaging Spectroradiometer (MODIS) onboard the EOS Terra and Aqua satellites (Justice et al., 2002a). Other moderate to coarse resolution sensors used for fire monitoring include Geostationary Operational Environmental Satellite (Prins & Menzel, 1992), Along Track Scanning Radiometer (Eva & Lambin, 1998a), Defense Meteorological Satellite Program-Operational Linescan System (Elvidge et al., 1996; Fuller & Fulk, 2000), Visible and Infrared Scanner (Giglio et al., 2000), and SPOT VEGETATION (Fraser et al., 2000). For regional fire mapping, finer-resolution sensors, such as Landsat (Chuvieco & Congalton, 1989; Minnich, 1983; Pereira & Setzer, 1993), Advanced Wide Field Sensor

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(Chand et al., 2006) and Advanced Spaceborne Thermal Emission and Reflection Radiometer (Csiszar et al., 2006; Morisette et al., 2005a; Morisette et al., 2005b) have been used.

Regardless of the sensor, two general approaches to fire mapping have been taken; burn scar mapping and active fire detection. Burn scar mapping involves identifying the area affected by fire after the event has occurred (Chuvieco & Congalton, 1988; Kasischke et al., 1993; Pereira & Setzer, 1993). In contrast to burn scar delineation, active fire detection maps the flaming front of fires at the time of satellite overpass (Flannigan & Vonder Haar, 1986; Flasse & Ceccato, 1996; Matson & Dozier, 1981). In this paper, we focused on MODIS active fire detections because they represent the state-of-the-art in global fire mapping and can be used as a basis for other fire products, for instance to distinguish burned areas from other disturbances (Giglio et al., 2006; Loboda et al., 2007).

Active fire detection is possible because radiant energy increases with temperature, producing a high contrast fire pixel relative to cool surrounding non-fire pixels. Small increases in an object's temperature result in large increases in radiance in the mid-IR range (3–5 μm) and slight increases in the thermal-IR range (5–12 μm) and because of this, even sub-pixel size fires can be detected (Dozier, 1981; Matson & Dozier, 1981). In practice, active fire detection algorithms either evaluate individual pixel values relative to a threshold (Flannigan & Vonder Haar, 1986; Matson & Dozier, 1981); compare a pixel's temperature contextually to its neighboring pixels (Flasse & Ceccato, 1996; Giglio et al., 2003); or track temporal changes in temperature (Cuomo et al., 2001; Lasaponara et al., 2003).

Errors of commission in active fire mapping can be caused by non-fire surfaces that are highly reflective such as urban areas, senescent vegetation, bare soil, water, or clouds (Flannigan & Vonder Haar, 1986; Giglio et al., 2003; Setzer & Verstraete, 1994). Contextual algorithms sometimes exhibit commission errors where there is sharp radiometric contrast, for example, between desert and vegetation (Giglio et al., 2003). Errors of omission may occur, if there is a difference between the time of fire occurrence and satellite overpass, and these errors are particularly common when satellite overpass does not coincide with peak daily fire activity (Cardoso et al., 2005; Giglio, 2007; Prins et al., 1998). Clouds and thick smoke can also obscure fire activity (Flannigan & Vonder Haar, 1986). Theoretically, small fires should be identifiable by even moderate resolution sensors such as AVHRR or MODIS (Dozier, 1981; Giglio et al., 1999; Matson & Dozier, 1981), but in practice, they may lack the intensity needed to trigger detection thresholds and will remain undetected especially at large scan angles where the amount of energy reaching the satellite is limited (Giglio et al., 2003; Giglio et al., 1999; Schroeder et al., 2005). Contextual algorithms are more likely to miss fires in heterogeneous land-cover, which complicates the selection of an appropriate background temperature (Lasaponara et al., 2003; Schroeder et al., 2005; Wang et al., 2007).

The MODIS active fire products are produced using a contextual algorithm for the MODIS sensors on NASA's two Earth Observing System (EOS) satellites: Terra and Aqua. Interested readers should refer to Giglio et al. (2003) for details about the algorithm. The two satellites are in sun-synchronous orbits with different local overpass times; 1:30 and 13:30 for Aqua, and 10:30 and 22:30 for Terra (Lillesand & Kiefer, 1999). Aqua generally detects more fires than Terra because its afternoon overpass time is closer to daily peak fire activity in many regions (Justice et al., 2002a).

Several approaches have been taken to quantify errors in fire data, including simulation models, comparison with independent but simultaneously collected satellite data, and comparison with field data. Simulation models predict that commission errors of MODIS and other satellites' fire detections are very low (Giglio et al., 2003; Giglio et al., 1999). However, errors of omission are likely and simulations show that MODIS has a 50% probability of detecting a 100 m^2 flaming fire (~1000 K) or a 1000–2000 m^2 smoldering fire (~600 K; Giglio et al., 2003; Kaufman et al., 1998). Detection limits are generally similar among biomes, but somewhat lower for dry tropical savannas (Giglio et al., 2003; Giglio et al., 1999). These simulation results suggest that small fires can be detected under ideal conditions, but validations with real fire data are needed to fully understand the detection capabilities of MODIS.

Quantifying fire activity on the ground at satellite overpass times is logistically difficult (Roy et al., 2005). One approach is to use data collected by the ASTER sensor, also onboard the Terra satellite with MODIS. ASTER senses energy in the 0.5 to 10 μm wavelengths, has finer spatial resolution (15–90 m) than MODIS, and its simultaneous but independent observations of fire events can validate MODIS active fire products (Csiszar et al., 2006; Justice et al., 2002b; Morisette et al., 2005a; Morisette et al., 2005b). Comparisons with ASTER suggest commission errors in the MODIS active fire data are rare (0.01% in Brazil (Morisette et al., 2005b) and 0.002% in northern Eurasia (Csiszar et al., 2006). Errors of omission are more common, especially for small fires. For instance, MODIS has a 50% detection rate when fire activity spanned clusters of 47 or more ASTER pixels (30-m resolution each) in Brazil (Morisette et al., 2005b), 25–34 ASTER pixels in southern Africa (Morisette et al., 2005a) and ~60 ASTER pixels in northern Eurasia (Csiszar et al., 2006). When aggregated to MODIS resolutions, the actual fires mapped by ASTER can be composed of many individual fire components and each fire component potentially has a different temperature. In contrast, the theoretical simulations of MODIS fire detection capabilities ignore the heterogeneity of individual fire components and are based on one temperature describing the entire active fire area. It is impossible to know what portion of each ASTER pixel was actively burning at the time of image capture, but results from ASTER validation studies suggest the actual MODIS 50% detection threshold could be considerable larger than theoretical predictions (Giglio et al., 2003).

The true fire size detection threshold of MODIS may be even lower because the ASTER imagery is restricted to a portion of the MODIS viewing area. The MODIS sensors collect data over a 2330 km wide swath. In comparison, ASTER collects SWIR and TIR data in 60 × 60 km segments within ±116 km of the center of MODIS Terra's path (Yamaguchi et al., 1998). Results from validation studies based on ASTER data are limited to that range and may overestimate MODIS detection rates because detection capabilities are reduced at the periphery of MODIS' swath (Schroeder et al., 2005). Furthermore, ASTER provides no information about fire activity occurring at times different from MODIS Terra overpass (10:30/22:30; Csiszar et al., 2006; Morisette et al., 2005a; Morisette et al., 2005b).