Remote Sensing of Environment 112 (2008) 3773–3783

Contents lists available at ScienceDirect

Remote Sensing of Environment

journal homepage: www.elsevier.com/locate/rse

Using multiple endmember spectral mixture analysis to retrieve subpixel fire properties from MODIS

Ted C. Eckmann *, Dar A. Roberts, Christopher J. Still

Geography Department and Institute for Computational Earth System Science, University of California at Santa Barbara, Santa Barbara, CA 93106-4060, United States of America

ARTICLE INFO

Article history:
Received 28 February 2008
Received in revised form 20 May 2008
Accepted 24 May 2008

Keywords:
Fire
Subpixel
Size
MESMA
FRP
MODIS
ASTER

ABSTRACT

The Moderate-Resolution Imaging Spectroradiometer (MODIS) sensors on NASA's Terra and Aqua satellites image most of the Earth multiple times each day, providing useful data on fires that cannot be practically acquired using other means. Unfortunately, current fire products from MODIS and other sensors leave large uncertainties in measurements of fire sizes and temperatures, which strongly influence how fires spread, the amount and chemistry of their gas and aerosol emissions, and their impacts on ecosystems. In this study, we use multiple endmember spectral mixture analysis (MESMA) to retrieve subpixel fire sizes and temperatures from MODIS, possibly overcoming some limitations of existing methods for characterizing fire intensities such as estimating the fire radiative power (FRP). MESMA is evaluated using data from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) to assess the performance of FRP and MESMA retrievals of fire properties from a simultaneously acquired MODIS image, for a complex of fires in Ukraine from August 21, 2002. The MESMA retrievals of fire size described in this paper show a slightly stronger correlation than FRP does to fire pixel counts from the coincident ASTER image. Prior to this work, few studies, if any, had used MESMA for retrieving fire properties from a broad-band sensor like MODIS, or compared MESMA to higher-resolution fire data or other measures of fire properties like FRP. In the future, MESMA retrievals could be useful for fire spread modeling and forecasting, reducing hazards that fires pose to property and health, and enhancing scientific understanding of fires and their effects on ecosystems and atmospheric composition.
© 2008 Elsevier Inc. All rights reserved.

1. Introduction

Fires are major sources of trace gas and aerosol emissions (e.g. Andreae & Merlet 2001), ecosystem disturbance (e.g. Pyne et al., 1996), and land-cover change (e.g. Cochrane et al., 1999) at local, regional, and global scales. Fires can also pose hazards to property and health, and forecasts of fire spreading are often very poor (Bianchini et al., 2005). Furthermore, the roles that fires play in global climate have not been fully quantified (e.g. Hoelzemann et al., 2004), and climate change is likely altering these roles. This study therefore seeks to improve monitoring and understanding of fires and their impacts.

The Moderate-Resolution Imaging Spectroradiometer (MODIS) sensors on NASA's Terra and Aqua satellites can provide data to help address these issues by imaging much of the Earth's surface multiple times each day, providing fire data that cannot be practically acquired using *in situ* measurements or other sensors. MODIS data currently enable the creation of active fire products that support wildfire management, and frequently offer multiple snapshots of a fire's progression over time, which can provide more detailed measurements of fire behavior than are available from post-fire burned area maps. For example, Peterson et al. (2005) used pixel-level fire products from 11 separate MODIS overpasses, collected over 58 h of a fire's lifespan, to initialize and validate the widely-used Fire Area Simulator (FARSITE) model, which is described in Finney (1998). MODIS fire products have a nominal spatial resolution of 1 km, which is very coarse relative to the sizes of typical wildfire features (e.g. Morisette et al., 2005), but these MODIS products are often the best data available for monitoring and modeling many fires. This is because in many areas of the world, fires that are detected by MODIS are reported inconsistently or not reported at all by suborbital or on-the-ground surveys, and other satellite sensors currently or previously used for monitoring fires are in some ways more limited than MODIS in spatial or temporal coverage, revisit frequency, geolocational accuracy, false-alarm rates, or sensitivity to small fires (e.g. Csiszar et al., 2005, Giglio et al., 2006).

MODIS fire detection algorithms have been validated at the pixel level (e.g. Morisette et al., 2005) but MODIS fire pixels are actually mixed pixels that usually contain unburned areas, along with smaller flaming, smoldering, and burned components. Pixel-level MODIS fire products thus leave substantial uncertainties about any given fire's overall size, and the sizes and temperatures of its flaming, smoldering, and burned components. Kaufman et al. (1998), Wooster et al. (2003), and Roberts et al. (2005) described methods for estimating the total radiant power of a fire within a MODIS pixel, but this quantity cannot separate a fire's size and temperature: a small hot fire can have the same radiant power as a larger, cooler fire. Because a fire's size and its temperature have different

* Corresponding author.
E-mail addresses: ted@geog.ucsb.edu, ted.eckmann@gmail.com (T.C. Eckmann).

0034-4257/$ – see front matter © 2008 Elsevier Inc. All rights reserved.
doi:10.1016/j.rse.2008.05.008

influences on the amount and chemistry of its trace gas and aerosol emissions (Andreae & Merlet, 2001), ecosystem impact (e.g. Hanley & Fenner, 1998), and fire spreading behavior (Pyne et al., 1996), estimates of a fire's radiant power (FRP) may not provide enough information for precisely quantifying some aspects of fires and their effects.

While not designed specifically for fires, a technique for subpixel unmixing developed by Roberts et al. (1998), called multiple endmember spectral mixture analysis (MESMA), may be able to overcome these and other limitations of existing fire products. MESMA uses spectral shape to unmix each pixel as a combination of subpixel features, called endmembers. In this paper, we apply MESMA to a MODIS image of fires in Ukraine by unmixing each fire pixel using a library of pre-generated fire endmembers of various temperatures, and background endmembers (spectra selected from non-burning pixels in the same image), thus estimating the subpixel sizes and temperatures of fires in each pixel. We also calculate FRP and compare MESMA fire area and FRP to measures of fire size from a coincident higher-resolution image from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) to assess the relative performance of FRP and MESMA for this Ukraine image. The Ukraine image was chosen because it contains several fires of varying sizes, and because it represents a geographical area that has not been investigated previously in similar studies. Despite the finer spatial resolution of ASTER, measures of subpixel fire properties from MODIS are still useful because ASTER has a narrower swath and a much longer return interval than MODIS, so MODIS can image a larger number of fires and provide more frequent images of an area's fires. MODIS is thus generally much more useful than ASTER for monitoring fires in near real-time and for comprehensive global fire climatologies.

2. Background

Planck's equation describes the spectral emitted radiance from a blackbody where T is the object's kinetic temperature in Kelvin, h is Planck's constant (6.63×10^{-34} J s), c is the speed of light (3.00×10^{8} m s^{-1}), λ is wavelength in meters, L_λ is emitted radiance at wavelength λ, and k is Boltzmann's constant (1.38×10^{-23} J K^{-1}):

$$L_\lambda = \frac{2hc^2}{\lambda^5\left(e^{\frac{hc}{k\lambda T}}-1\right)} \tag{1}$$

In the case of remote sensing, measured radiance L_λ for a pixel usually comprises the radiance emitted by several different objects (a "mixed" pixel) that may all have different temperatures and spectral emissivities, instead of a single pure pixel containing only one object at a single temperature. Methods that can address this and other issues related to retrieving subpixel fire properties include the Dozier (1981) approach, FRP (Kaufman et al., 1998), and MESMA (Roberts et al., 1998). Each approach is described in the following sections.

2.1. The dozier approach

Dozier (1981) developed a method for retrieving the sizes and temperatures of subpixel objects, which has been modified and applied widely to a variety of sensors by many other investigators. Dozier (1981) showed that as the equation below exists for each band, and given at least two bands (usually near 3.8 μm and 10.8 μm), the resulting system of equations can be solved to retrieve temperatures and subpixel areas of "hot" and "background" surfaces within a single pixel:

$$L_\lambda = f_{\text{hot}}\beta(\lambda, T_{\text{hot}}) + f_{\text{background}}\beta(\lambda, T_{\text{background}}) \tag{2}$$

where L_λ is measured radiance at wavelength λ, f_{hot} is the fraction of the pixel covered by the hot surface of temperature T_{hot}, $f_{\text{background}}$ is the fraction of the pixel covered by the background surface of temperature $T_{\text{background}}$, $\beta(\lambda,T)$ is the Planck equation (see Eq. (1)), and f_{hot} and $f_{\text{background}}$ sum to 1. Although others have modified this approach, the version described in Eq. (2) assumes that the objects emit as blackbodies, and does not account for atmospheric influences on at-sensor radiance. This approach generally also requires assumptions that the pixel comprises only two objects with different temperatures, and that some of the unknowns can be constrained, such as estimating the background object's temperature from adjacent pixels, or assuming that two adjacent pixels have the same temperatures for the hot and background objects.

Many have applied modifications of the Dozier approach for estimating the subpixel sizes and temperatures of fires, volcanoes, and other hot objects, using a variety of sensors. Examples of applications to fires include Flannigan and Vonder Haar (1986) using NOAA's Advanced Very High Resolution Radiometer (AVHRR), Prins and Menzel (1992) using NOAA's Geostationary Operational Environmental Satellite (GOES) Visible Infrared Spin Scan Radiometer Atmospheric Sounder (VAS), and Wooster et al. (2003) and Oertel et al. (2004) with the Bi-spectral InfraRed Detection (BIRD) satellite. Matson and Dozier (1981) also applied the technique to estimate the sizes and temperatures of gas flares from oil fields and steel mills using the NOAA-6 AVHRR. Lombardo et al. (2006) applied a similar method to study subpixel features of a volcano using the Digital Airborne Imaging Spectrometer (DAIS) 7915 spectrometer and Landsat TM.

Applications of the Dozier approach generally require the following assumptions: 1) the hot object has a single, uniform temperature; 2) the background object radiates as a blackbody; 3) atmospheric effects are minimal. According to Giglio and Kendall (2001), these assumptions are usually unrealistic and generally produce large errors in retrievals of fire sizes and temperatures. The choice of wavelengths used in Eq. (2) can also produce substantial errors in retrieved fire size and temperature, as Giglio and Justice (2003) demonstrated.

2.2. The fire radiative power (FRP) approach

Kaufman et al. (1998) and Justice et al. (2002) described methods for estimating a fire's radiative power (FRP) from MODIS, and FRP values calculated with these methods are included in the MOD14 "Fire and Thermal Anomalies" product, which also provides binary fire/no-fire detection data for virtually all MODIS images (Giglio et al., 2003). Wooster et al. (2003) described a similar algorithm, referring to it as an estimate of the fire's radiative energy (FRE), and compared FRE from MODIS to FRE from BIRD for a fire imaged simultaneously by both sensors. Likewise, Roberts et al. (2005) compared FRP from MODIS with near-simultaneous FRP from the Spinning Enhanced Visible and Infrared Imager (SEVIRI) aboard Meteosat-8. All of these approaches aim to estimate a fire's true radiative power (FRP_{true}) in J s^{-1} (or W), which, according to Roberts et al. (2005), is:

$$FRP_{\text{true}} = \varepsilon\sigma\sum_{i=1}^{n} A_n T_n^4 \tag{3}$$

where σ is the Stefan–Boltzmann constant (5.67×10^{-8} J s^{-1} m^{-2} K^{-4}), A_n is the area of the nth thermal component of the fire (in m^2), T_n is the temperature of the nth thermal component (in K), and ε is the effective mean emissivity over all emitting wavelengths (unitless). Most sensors do not measure radiation over all the wavelengths at which fires emit, and because most pixels that contain fires also contain non-burning components, this becomes a mixed-pixel problem, so for most sensors and situations, direct measurement of FRP_{true} is not practical. However, Wooster et al. (2003) showed that over a realistic range of fire and background sizes, temperatures, and sensor types, there is an approximately linear relationship between FRP_{true} and the sensor's measured radiance above the adjacent non-burning background pixels in the mid-infrared (around 4 μm). Algorithms that exploit this relationship to estimate FRP_{true} are generally derived using a semi-empirical

Download English Version:

https://daneshyari.com/en/article/4460339

Download Persian Version:

https://daneshyari.com/article/4460339

Daneshyari.com