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Global estimation of burned area using MODIS active fire observations

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Abstract. We present a method for estimating monthly burned area globally at 1° spatial resolution using Terra MODIS data and ancillary vegetation cover information. Using regression trees constructed for 14 different global regions, MODIS active fire observations were calibrated to burned area estimates derived from 500-m MODIS imagery based on the assumption that burned area is proportional to counts of fire pixels. Unlike earlier methods, we allow the constant of proportionality to vary as a function of tree and herbaceous vegetation cover, and the mean size of monthly cumulative fire-pixel clusters. In areas undergoing active deforestation, we implemented a subsequent correction based on tree cover information and a simple measure of fire persistence. Regions showing good agreement between predicted and observed burned area included Boreal Asia, Central Asia, Europe, and Temperate North America, where the estimates produced by the regression trees were relatively accurate and precise. Poorest agreement was found for southern-hemisphere South America, where predicted values of burned area are both inaccurate and imprecise; this is most likely a consequence of multiple factors that include extremely persistent cloud cover, and lower quality of the 500-m burned area maps used for calibration. Application of our approach to the nine remaining regions yielded comparatively accurate, but less precise, estimates of monthly burned area. We applied the regional regression trees to the entire archive of Terra MODIS fire data to produce a monthly global burned area data set spanning late 2000 through mid-2005. Annual totals derived from this approach showed good agreement with independent annual estimates available for nine Canadian provinces, the United States, and Russia. With our data set we estimate the global annual burned area for the years 2001–2004 to vary between 2.97 million and 3.74 million km^2, with the maximum occurring in 2001. These coarse-resolution burned area estimates may serve as a useful interim product until long-term burned area data sets from multiple sensors and retrieval approaches become available.

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1 Introduction

Research over the past 25 years has led to increased recognition of the important role biomass burning plays in the global carbon cycle and the production of trace gas and aerosol emissions. Consequently, Earth-system modeling efforts now often include fire-related information. In particular, there is a strong need for spatially and temporally explicit estimates of the quantity of biomass consumed through combustion (Scholes et al., 1996). Typically such estimates are based on a simple relationship of the form (e.g., Seiler and Crutzen, 1980; Hao et al., 1990; Pereira et al., 1999)

$$M = ABc, \tag{1}$$

where M is the mass of vegetation combusted within a given time interval, A is the area burned during the same time interval, B is the biomass density, and c is a factor describing the completeness of combustion. Although all of the terms appearing on the right hand side of Eq. (1) are highly variable, burned area is particularly difficult to estimate because of the potentially high spatial and interannual variability in this quantity at continental to global scales. It is therefore especially important that accurate, spatially explicit, multi-year estimates of burned area are available when relying on a relationship having the form of Eq. (1). At present, however, there is a dearth of such data. While a number of satellite-based global burned area products are currently under development, specifically GLOBSCAR (Simon et al., 2004), GBA2000 (Tansey et al., 2004), and the MODIS burned area product (Justice et al., 2002; Roy et al., 2002), none are yet available on a multi-year basis.

Unlike burned area data, long-term observations of active fires made with spaceborne sensors are readily available. Representative multi-year examples include the Along-Track Scanning Radiometer (ATSR) nighttime fire product (Arino and Rosaz, 1999), the Visible and Infrared Scanner (VIRS) monthly fire product (Giglio et al., 2003a), the Moderate Resolution Imaging Spectroradiometer (MODIS) global fire product (Justice et al., 2002), and the Geostationary Operational Environmental Satellite (GOES) Wildfire Automated Biomass Burning Algorithm (WF_ABBA) fire product (Prins et al., 1998). At their most basic level, active fire products contain information about the location and timing of fires that are burning at the time of the satellite overpass, usually in the form of swath-based fire masks or as lists of fire pixel locations and dates. These observations are in turn often summarized at coarse spatial resolutions (e.g., $0.5^\circ \times 0.5^\circ$) over daily or monthly time periods, yielding data products containing gridded counts of active fire pixels. Although these "fire count" products capture many aspects of the spatial distribution and seasonality of burning, it is difficult to relate them to actual area burned due to inadequate temporal sampling, variability in fuel conditions and cloud cover, differences in fire behavior, and issues related to spatial resolution (Scholes et al., 1996; Eva and Lambin, 1998; Kasischke et al., 2003).

Despite these difficulties, the lack of long-term, spatially-explicit global burned area data has meant that active fire observations must often be used as a proxy for area burned (e.g., Setzer and Pereira, 1991; Scholes et al., 1996; Stroppiana et al., 2000; Potter et al., 2001; van der Werf et al., 2003, 2004; Langmann and Heil, 2004). Perhaps the most common approach has been to assume that the area burned is proportional to simple counts of fire pixels, i.e.

$$A(i, t) = \alpha N_{\mathrm{f}}(i, t), \tag{2}$$

where A is the area burned within a particular spatial region labeled by the index i – typically a grid cell – during a fixed time period labeled by the index t, N_{f} is the number of fire pixels observed within the same region during the same time period, and α is a constant representing the effective burned area per fire pixel.

8 Conclusions

We have presented a method for estimating monthly burned area globally at 1° spatial resolution using Terra MODIS active fire observations and ancillary vegetation cover information. Using regional regression trees, these data were calibrated to burned area estimates derived from 500-m MODIS imagery based on the conventional assumption that burned area is proportional to counts of fire pixels under specific conditions. Traditionally, the constant of proportionality (α) has either been held fixed, or adjusted based on a single vegetation-related parameter. Neither practice is satisfactory at a global scale. We propose a more flexible approach in which α is permitted to vary as a function of both tree and herbaceous vegetation cover (or alternatively bare ground fraction), and the mean size of monthly cumulative fire-pixel clusters within each 1° grid cell. Though we found this to be usually unnecessary, we also allowed α to vary with fire pixel counts to accommodate slight deviations from the assumption of linearity. The exact form of the functional dependence of α on these predictive variables was not specified a priori, but was constructed through recursive partitioning and expressed in terms of the splits and leaves of a regression tree. In addition to their considerable flexibility, regression trees offer the advantage of readily accommodating additional explanatory variables on a trial basis.

Recognizing limits in our ability to measure burned area in closed canopy tropical forests, we used information about monthly fire persistence and tree cover to identify locations and time periods within the tropics requiring the application of a fixed correction factor to the burned area predictions obtained from the regression trees.

Regions showing good agreement between predicted and observed burned area included Boreal Asia, Central Asia, Europe, and Temperate North America, where the estimates produced by the regression trees were relatively accurate and precise. Poorest agreement was found for SH South America, where predicted values of burned area are both inaccurate and imprecise. The poor result obtained in this region is most likely a consequence of multiple factors that include extremely persistent cloud cover and a degradation in the quality of the 500-m burned area maps used for calibration. Agreement in the nine remaining regions fall between these two extremes, yielding comparatively accurate, but less precise, estimates of monthly burned area.

We used the regional regression trees to produce multi-year, global burned area estimates on a monthly basis from the current archive of Terra MODIS active fire data. Annual totals derived from these data showed good agreement with independent annual estimates available for nine Canadian provinces, the continental United States, and Russia. Using these data, we estimated the global annual burned area for the years 2001–2004 to vary between 2.97×10^6 and 3.74×10^6 km^2, with the maximum occurring in 2001. The most extensive burning consistently occurred in NH Africa, with well over 10^6 km^2 burned in this region each year. Over this four-year period significant interannual variability occured in Boreal North America, Boreal Asia, Equatorial Asia, and Australia. Taken together, the total area burned in northern- and southern-hemisphere Africa and Australia from 2001–2004 comprised 80% of the total area burned globally.

We reiterate that we are not promoting our regression-tree approach (or, indeed, any active-fire calibration approach) as a substitute for burned area maps generated from direct observations of burn scars. Rather, for some applications, statistical coarse-resolution burned area estimates derived from MODIS active fire observations can serve as a useful interim product until long-term burned area data sets become available.