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SMARTFIRE Algorithm Description

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INTRODUCTION

For large wildfires and wildland fire use (WFU) fires for which there is a federal response, Incident Command Summary reports (known as ICS-209 reports) are created on a near-daily basis. ICS-209 reports contain useful information about particular fires or fire complexes from the incident command team on the ground, such as descriptions of the fuel loading, growth potential, and type of fire. However, ICS-209 reports also have several limitations. Daily estimates of actively burning areas are required, but ICS-209 reports provide only the ignition point of the fire and an estimate of the total area burned over the lifetime of the fire. For large fires, active flame fronts can move dozens of kilometers from the original ignition point of the burn. More importantly, ICS-209 reports are only created for a small subset of fires. Fires that are not tracked with ICS-209 reports include prescribed burns, agricultural burns, and wildfires for which there is no federal response. Taken together, these missing fires represent a large fraction of the total area burned and resulting smoke emissions. The National Interagency Fire Center (NIFC) reports that at least 9000 km^2 of prescribed burning has been accomplished each year since 2001 in the US, representing up to 40% of the total area burned (http://www.nifc.gov/fire_info/fire_stats.htm).

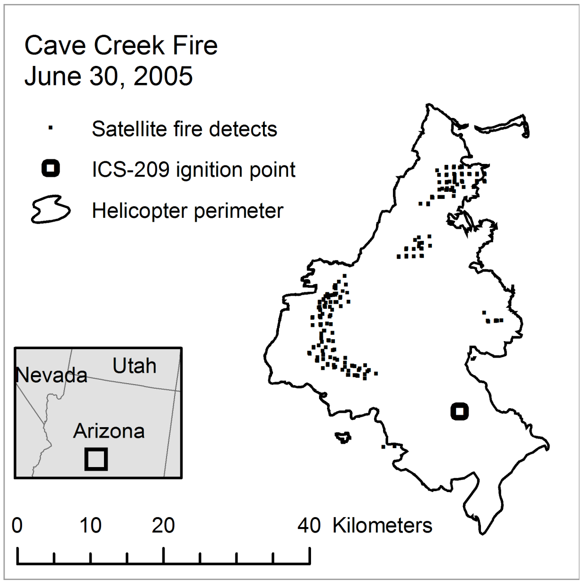
Numerous jurisdictions have burn authorization and reporting systems that provide information on prescribed fires. These data systems are the primary source of information for prescribed fires. Unfortunately, these individual systems were not developed to be interoperable which introduces difficulty in synthesizing their information in a regional- or national-scale system. For example, formats are inconsistent, contain different burn information, are difficult to acquire, and include information on potential prescribed burns that may never occur. Some of these issues are currently being addressed with the Fire Emissions Tracking System (FETS), which will provide a unified burn reporting system for the western United States (http://www.wrapfets.org/).

Near real-time fire information is also available from satellite-derived measurements (e.g., Dozier, 1981; Justice et al., 2002; Prins and Menzel, 1994; Li et al., 2000). Fire information from current space-borne instruments provides many advantages over ground-based reporting systems, including daily or better temporal resolution, the ability to detect relatively small fires, and consistency across jurisdictions. However, satellite-derived fire observations are limited by false positive detections, interference from clouds, and limited information about the total area burned. Total area burned can be derived from analysis of burn scars from satellite data (Li et al., 2004), but satellite burn scar data are not currently available in near real-time (i.e., data available on the day of detection). In the absence of burn scar data, other studies have used the sensor's nominal resolution (e.g., 1 km^2 for MODIS) as an upper limit of the total area burned by the fire (Wiedinmyer et al., 2006), sensor-based calculations of Fire Radiative Power to estimate the instantaneous burning area (Wooster et al., 2005), or used regression tree analysis to develop area-per-pixel relationships dependant on forest cover, region, and pixel cluster size (Giglio et al., 2006).

The Satellite Services Division (SSD) of NOAA's National Satellite and Data Information Service (NESDIS) produces a daily quality controlled fire and smoke analysis for the United States using the Hazard Mapping System (HMS) (Ruminski et al., 2006). The HMS integrates satellite data from three instrument types (Geostationary Operation Environmental Satellite (GOES), Moderate Resolution Imaging Spectroradiometer (MODIS), Advanced High Resolution Radiometer (AVHRR)) onboard seven different satellite platforms. Trained NOAA satellite analysts use the output from automated fire detection algorithms as well as various ancillary data layers. The automated fire detection algorithms produce false detections, especially in areas of high surface reflectance, sun glint, or high surface temperature (Hoelzemann et al., 2004; Giglio, 2005). The analysts review fire detects from the algorithms to reduce false detects and scan the satellite imagery and add fires that the algorithms have not detected (i.e., if a smoke plume detected in visible imagery has no associated fire detect, it will be added). The analysis is updated at http://www.ssd.noaa.gov/PS/FIRE/hms.html several times a day. The HMS is described by Ruminski et al. (2006),

Ideally, a daily, operational fire reporting system would take advantage of all available data sets to produce the most complete picture of daily area burned; however, simple summation of all data sets will result in double counting of some fires due to information overlaps. Multiple data sets can be combined if the data overlaps can be identified and rectified. Identifying data overlaps is difficult due to both the differences in the data sources and the fact that a fire can move many kilometers from its original ignition point over the course of its lifetime. For example, Figure 1 shows a June 30, 2005 snapshot of information for the Cave Creek wildfire, which burned over 800 km^2 of Arizona wildland in 2005. This fire ignited on June 22, 2005. The reported burn perimeter derived from a helicopter overflight shows the approximate final shape of the Cave Creek fire. Hot-spot points detected by satellite show the actively burning flame fronts for the June 30, 2005. From the helicopter perimeter, (which we do not have reliable access to in an operational time frame), it is obvious that all of the clusters of satellite fire points are actively burning sections of the same wildfire event. The ground-reported (ICS-209) fire ignition point is 50 km from some of the satellite points. To use multiple overlapping data sets, an algorithm for reconciliation must be developed. In this manuscript, we describe the SMARTFIRE algorithm and database system that combines disparate data on fires into a unified datasets. SMARTFIRE was developed specifically for use in the BlueSky smoke modeling framework (Larkin et al., 2009)) although, in principle, it should be portable to other modeling and emission inventory applications.

Figure 1. An illustration of the single-day satellite fire detection pixels for the day of June 30, 2005, the ICS-209 helicopter-flown final burn area perimeter, and ICS-209 ignition point for the Cave Creek Fire in Arizona.



METHODS

Data Sources

SMARTFIRE is an algorithm and database system developed and built within a geographic information system (GIS) framework that combines multiple sources of fire information and reconciles them into a unified data set. It was developed to take advantage of multiple data sources while avoiding double counting. The BlueSky system, developed by the US Forest Service, is a framework that attempts to serve these needs by connecting several submodels to produce predictions of emissions and resulting concentrations of smoke pollution from fires, both in near-real-time and retrospectively (Larkin et al., 2009).

SMARTFIRE was built with the capability to ingest multiple disparate fire reporting data sets to produce a single unified data set. Currently, two input data sources have been implemented within SMARTFIRE: (1) ICS-209 reports and (2) satellite data from the NOAA Hazard Mapping System (HMS).

Development of the SMARTFIRE Algorithm

The SMARTFIRE algorithm consists of four general steps, outlined for a small area in Figure 2 a-d:

a. Daily input data are loaded into the geodatabase.
b. Individual data points are associated together by proximity into Fire Perimeters representing contiguous burning regions.

c. Fire Perimeters are associated to Fire Events by proximity in time and space. Fire Events grow over time as long as the fire continues to be detected and represent the history and progression of the fire.

d. Fire Perimeter polygons are converted to point data for modeling by calculating centroids. For each model point, an area burned is estimated.

(a) Input Data

Daily input data are loaded into a geographic information system database (geodatabase). The currently implemented data sets, ICS-209 ignition points and HMS fire pixels, are both point data sets (i.e., they have a coordinate location but no associated shape); however, the algorithm could also incorporate line or polygon sources. The data for a small area on a single day are shown in panel (a). The region shown contains a single ICS-209 reported fire and many HMS fire pixels.

(b) Create Fire Perimeters

Data are converted from points to polygons by drawing circles of a specific radius centered on each point and then dissolving all intersecting circles into a set of disjoint polygons called Fire Perimeters (b). This is done to associate nearby data into contiguous burning areas (clusters) and to minimize double counting from multiple data sources detecting the same burning area. The radius varies by data source. For HMS, the value is an adjustable parameter set at 750 m, which assures that adjacent pixels are associated (HMS data are on a 1-km resolution grid). ICS-209 reports provide cumulative instead of daily area burned. To create a Fire Perimeter for an ICS-209 report, an estimate of the daily area burned is made by subtracting the cumulative area of the current report from the cumulative area of the previous report of the same name.

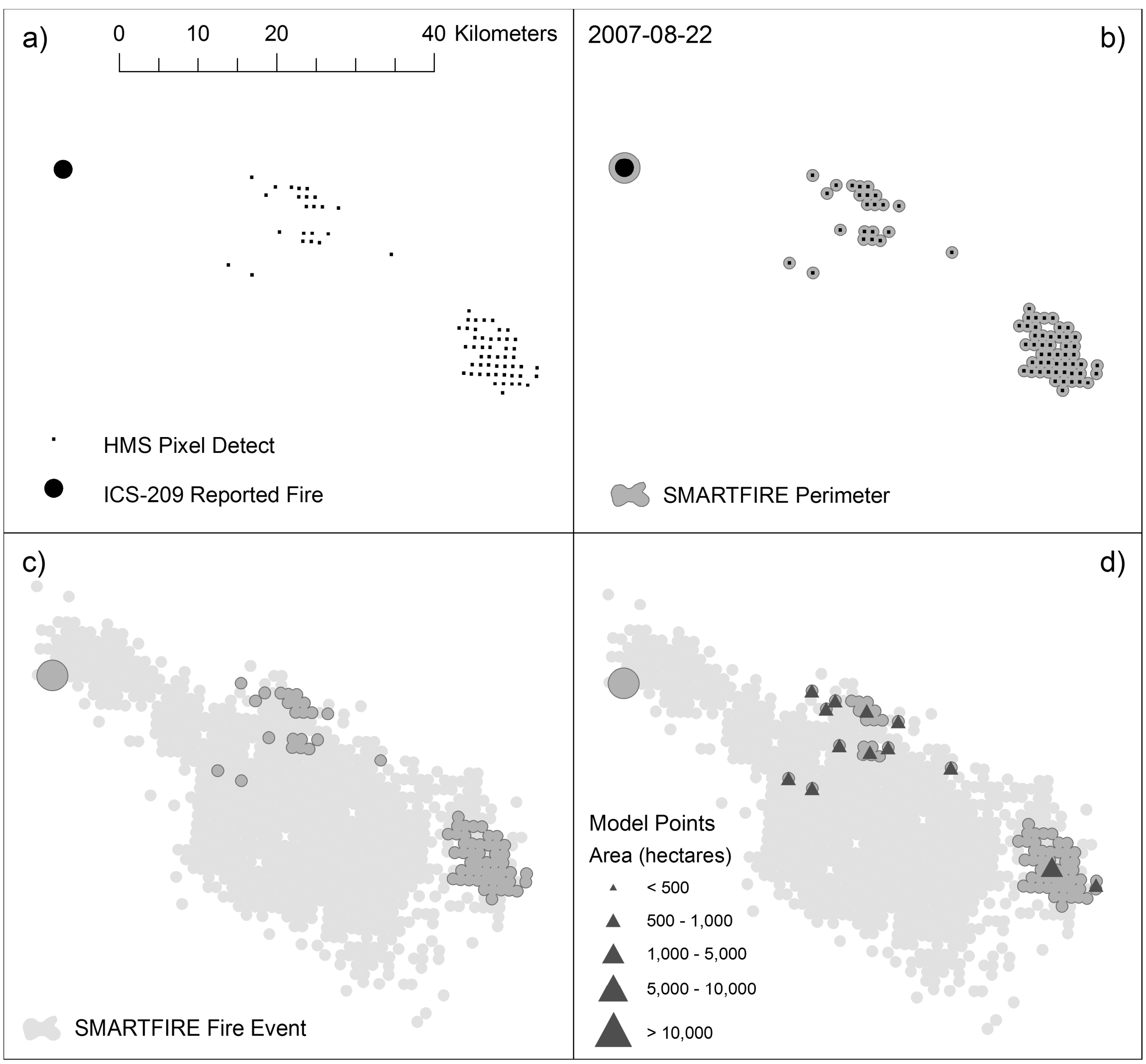
(c) Associate Fire Perimeters to Fire Events

The next step in the algorithm is to associate Fire Perimeters to active Fire Events in the SMARTFIRE geodatabase by proximity. A Fire Event is a collection of fire information that has been associated together. The Fire Event groups information into collections that resemble the way fires are understood in the fire management community. For example, all detection information from a single named fire should be associated into a single Fire Event. Fire Events can span multiple days. Fire Perimeters are associated with Fire Events by drawing a buffer around the Perimeters and intersecting them with active Fire Events. Buffer distance is a function of the Perimeter area (500 m for Perimeters less than 1.77 km^2; 1500 m for larger Perimeters). Buffer distances were selected by examining several wildfires and wildfire complexes and determining the distances which minimized false associations while maximizing positive associations. If no active Fire Event is found within the buffer distance, one is created. After four days without new data, Fire Events become inactive and are no longer considered in the algorithm (i.e., additional Fire Perimeters will be assigned to new Fire Events). Four days was chosen to account for gaps in the data stream, such as when clouds obscure satellite detections or no ICS-209 reports are produced.

(d) Create Model Points

The SMARTFIRE geodatabase provides activity data for predictive and historical modeling of air quality impacts from fires, such as the BlueSky smoke modeling framework. BlueSky requires burning point locations identified as latitude/longitude pairs and an associated estimate of area burned. Fire Perimeter polygons cannot be used as inputs for BlueSky and must be converted into point locations with area estimates. Points are created by calculating centroids from HMS Fire Perimeters (d). ICS-209 based perimeters are used if no HMS perimeters are available for the Fire Event on the specific date. Area burned estimates for each model point are not equal to their parent Fire Perimeter areas, but are scaled to them. The development of area estimates for model points is detailed below.

Figure 2. SMARTFIRE reconciliation algorithm illustration. (a) One day of input data (ICS-209 report and HMS pixels for the Zaca Fire on 2007-08-22, (b) SMARTFIRE Perimeters added to each data source, (c) the Perimeters overlaid on the active SMARTFIRE FireEvent from the previous day, (d) The SMARTFIRE Model Points at the centroid of each HMS-based Perimeter.



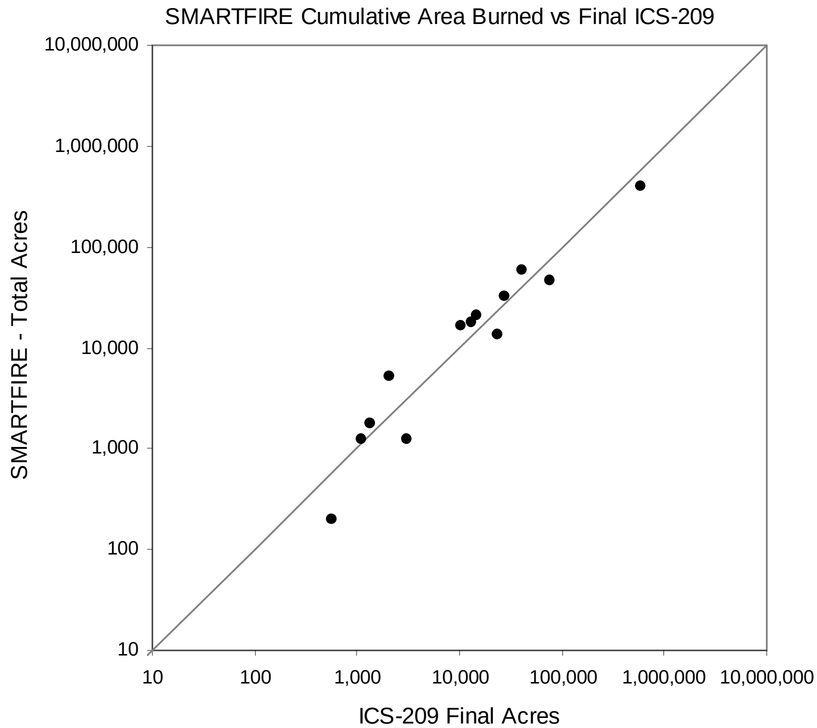
(e) Area Estimation

Satellite-derived hot-spots from HMS do not provide information about the area burned. SMARTFIRE area burned estimates for HMS data are estimated using one technique for large, multi-pixel fires and a second technique for small, single-pixel fires.

Large wildfire burn area estimates were derived by comparing HMS pixel perimeters to ICS-209 burned area polygons. For large wildfires, the responsible incident command team produces burned area polygons produced by helicopters equipped with GPS data loggers flying around the perimeter of the fire. The area within the last flown perimeter represents an estimate of the total area burned. The area per pixel in SMARTFIRE was determined by correlating final helicopter perimeter areas to total cumulative HMS pixel perimeters for 14 large fires (Figure 3). The fires ranged from about 2 to 2500 km^2 in size over various parts of the United States. The resulting area per pixel is 0.6 km^2. However, not all of the area encompassed by a helicopter-flown perimeter will have burned in a typical wildfire. Thus the actual burned area (sometimes called the blackened area) will be some fraction of the perimeter area. Based on past research, we estimated this fraction as 0.8 (Tom Pace, EPA, personal communication). Accounting for the estimate of only 80% of the helicopter perimeter area burned results in a per pixel area of 0.49 km^2.

Small single-pixel fire burn area estimates were derived by a comparison of a silvicultural prescribed burns database with HMS fire detects. The multi-pixel burn area estimate does not apply to small fires, which may be detected by only a single satellite pixel. To estimate the per pixel area burned by these fires, we used a silviculture database provided by the state of Georgia. The database provides information on the number and total acreage of fires by month and county for the year 2002. According to the database, about 20,000 prescribed fires burned a total of over 3100 km^2 in 2002. Unfortunately, HMS data do not exist for the full year in 2002. The prescribed fire count and total area were compared to HMS pixel counts for Georgia for 2004, 2005, and 2006. Pixel counts for these years ranged from 6,700 to 8,700 and averaged 7,723. The fires in the Georgia database were mostly small in size (< 0.4 km^2) so the vast majority of fires were detected by a single HMS pixel. Thus, HMS detects approximately 40% of the small fires in Georgia. Many fires are either too small to be detected or obscured by cloud cover or canopy. To account for the total reported acreage, we divide the annual average HMS pixel count by the total reported acreage in the database. The resulting area per pixel for single pixel fires is 0.4 km^2. Note that this value is much smaller than the nominal pixel resolutions for any of the instruments that HMS uses.

Figure 3. Scatter plot of SMARTFIRE total burn area estimates with ICS-209 helicopter burn perimeter areas.



Limitations

Four years (2003-2006) of daily area estimates across the continental US have been processed. Robust validation of the SMARTFIRE algorithm and its parameters is currently underway. The data used to tune the algorithm parameters were limited, especially for small fires. For example, area estimates for fires detected by a single HMS pixel are based on a prescribed fire database from the state of Georgia. This estimate needs to be corroborated with other data sources in other regions. The buffer distance parameters that dictate which ICS-209 reports and satellite pixels get reconciled have not been rigorously tested. False associations and non-associations sometimes occur.

Because SMARTFIRE was originally designed primarily to support predictions on a near-real-time basis, the possible input sources are limited. ICS-209 data are created by hand input and sometimes contain typographical errors. The most common errors are incorrect cumulative area burned from adding an extra zero to the value and transposed latitude and longitude. HMS data are currently produced on a 1-km grid that is lower resolution than some of the satellite input sources. Also, HMS does not report potentially useful values such as the fire radiative power, which could be used to calculate total emissions (Jordan et al., 2008). More refined and potentially more accurate data sources, such as satellite-derived burn scars, are available for retrospective studies. Future work will explore the incorporation of these high quality but time lagged data sets for retrospective analyses such as emission inventories.

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