USE OF MULTI-SENSOR ACTIVE FIRE DETECTIONS TO MAP FIRES IN THE UNITED STATES: THE FUTURE OF MONITORING TRENDS IN BURN SEVERITY

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Abstract—The effort to utilize satellite-based MODIS, AVHRR, and GOES fire detections from the Hazard Monitoring System (HMS) to identify undocumented fires in Florida and improve the Monitoring Trends in Burn Severity (MTBS) mapping process has yielded promising results. This method was augmented using regression tree models to identify burned/not-burned pixels (BnB) in every Landsat scene (1984–2012) in Worldwide Referencing System 2 Path/Rows 16/40, 17/39, and 1839. The burned area delineations were combined with the HMS detections to create burned area polygons attributed with their date of fire detection. Within our study area, we processed 88,000 HMS points (2003–2012) and 1,800 Landsat scenes to identify approximately 300,000 burned area polygons. Six percent of these burned area polygons were larger than the 500-acre MTBS minimum size threshold. From this study, we conclude that the process can significantly improve understanding of fire occurrence and improve the efficiency and timeliness of assessing its impacts upon the landscape.

INTRODUCTION

Beginning in 2006, the Monitoring Trends in Burn Severity (MTBS) project was tasked to map and assess burn severity for all “large” fires across the United States from 1984 to the present using 30-meter Landsat imagery (Eidenshink and others 2007). Federal fire occurrence data (FOD) from 2004 were used to estimate the magnitude of the nationwide fire occurrence as well as the staffing and data resources required to meet MTBS project objectives. Based upon this analysis, minimum size constraints were imposed: 1000 acres in the West and 500 acres in the East. At the outset of the MTBS project, Landsat imagery was not free, so there were constraints the on the number of Landsat scenes that could be purchased in a given year. Consequently, many fires identified in the FOD could not be reliably mapped because optimal imagery could not be obtained.

Since 2004, the annual number of fire occurrences in the FOD has grown because of better fire event reporting, which has led to more fires being mapped and the subsequent need for more resources to map fires (table 1). Some of these wildfire and prescribed fire records were duplicates as multiple agencies reported the same fire. As awareness of the MTBS program grew, State fire management agencies, primarily in the Southeastern United States began to provide records of fire occurrence. However, due to the magnitude of the additional fire events, the project decided to postpone assessment of the State reported prescribed fires until all historical Federal fires had been completed. By 2010, the yearly FOD contained many more fire records in comparison with the 2004 (table 1). Of the 1,249 mapped fires for 2010, 1,134 were mapped as “initial” assessments (i.e., using imagery collected shortly after the fire was out because the fire scar quickly fades from the landscape), and 115 were mapped as “extended” assessments (i.e., using postfire imagery acquired usually in the year following the fire in order to assess recovery and delayed mortality).

In 2008, the Landsat archive was opened for free distribution. This provided an opportunity to investigate thousands of historical fire records that were originally declared “unmappable” due to imagery constraints. It became apparent that MTBS processing methods need to be improved to efficiently process large numbers of fires for both current and future fire assessments and for a better assessment of historical fire occurrence. More specifically:

1. There needed to be an automated method for identifying fire events. Each year, MTBS uses the FOD information from the previous year to guide the

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mapping program. This time lag is due to the need for individual agencies to finalize the current year's fire records and for MTBS to compile the finalized records. Mapping, review, and preparation for distribution take more time. Therefore, it can be almost two years before the annual burn severity products are available. This delay is problematic for users who depend on MTBS fire records to evaluate important fire-related disturbance and ecological change.

2. A complete record of fire events is needed. When mapping known fires, MTBS is required to map any "discovered" fires, i.e., those meeting MTBS size requirements but not reported in the FOD. Since 2006, over 17,000 fires have been mapped by MTBS and more than 2,200 were discovered during the process of mapping known fires. These discovered fires may actually be undocumented or exist in the FOD but have an error of location and/or date. Because we only look at scenes for fires identified within the FOD, we suspect there are many fires yet to be discovered, especially in the historical era. Early historical fire record keeping was inconsistent, error prone, and not comprehensive. The latter is an issue especially in the southeastern States, which have a long tradition of widespread prescribed burning. Therefore, a method that does not rely upon human-recorded tabular data is needed.

3. A more efficient method is needed for the selection of imagery to complete the burn severity assessment. The MTBS mapping protocol involves an analysis of a prefire image in conjunction with a postfire image acquired up to one year postfire in order to assess the impacts of the fire, allowing for postfire recovery or mortality to be expressed. The current scene selection process is very labor intensive and compromised by online browse imagery with low resolution: fires near the MTBS size threshold are difficult to see, so it is hard for an analyst to confirm that the FOD point actually falls on a fire in the image.

4. The MTBS protocol must be applicable for all fires. Local land managers and fire ecologists are interested in fires that are below MTBS size thresholds. They will need a way to find and assess these fires.

METHODS

Study Area

We obtained the historical fire records for three national forests in Florida: the Apalachicola, Osceola, and Ocala (fig. 1). These forests were chosen because of their complete burn histories (1984–2012) and because of the large number of prescribed burns conducted during this time frame. They are located within three Landsat Path/Rows in the Southern Coastal Plain, a region with a long history of prescribed burning for clearing undergrowth, reducing hardwood encroachment into pinelands, and promoting various wildlife species (fig. 1). Hundreds of prescribed fires occur each year within this area.

Inputs

Hazard Mapping System Fire Detections— The National Oceanic and Atmospheric Administration (NOAA) Hazard Mapping System (HMS) utilizes satellite-based fire and smoke detections that are collected daily by GOES, AVHRR, and MODIS sensors. The detections are logged as point locations and utilized by NOAA's Air Resources Laboratory to model the next 48 hour's potential smoke emissions and dispersion across North America (Ruminski and others 2006). Frequent observations, as often as every 15 minutes (Zhang and others 2011), allow for a more timely and spatially complete record of fire occurrence than is available from Federal and State fire records. Daily HMS observations have been archived since 2003, which will support retrospective assessments. Operationally, the daily observations are quality checked by NOAA HMS analysts to remove commission errors and add fires visible within the imagery that were not detected by the sensors (Ruminski and others 2006). These data are posted weekly and available online for six months. All post-2011 HMS data were downloaded from the HMS website (http://satepsanone.nesdis.noaa.gov/FIRE/fire.html). HMS data prior to 2011 were obtained from NOAA.

Landsat-Derived Burned Area Polygons—During the development phase of this project, the burned/not-burned (BnB) methodology was developed to automatically generate burned area perimeters from Landsat imagery. A number of previously mapped MTBS fires in the three Paths/Rows of interest were selected. The fires events chosen represented a variety of vegetation types, phenological seasonality, burn severity ranges, and geographic distribution over these Path/Rows. Landsat imagery was chosen that best represented the freshly burned extent of each fire. MTBS burn severity images, produced by the methodology described in Eidenshink and others (2007), were used to identify areas of low, moderate, and high severity within each fire event. Each fire was sampled throughout its range of burn severity as well as was surrounding unburned vegetation. All samples were combined into a training dataset to create a regression tree model, which is a collection of multivariate linear models (Cubist; Rulequest Research 2004). The regression tree model was then run using selected Landsat imagery to create a "likelihood estimate" that each pixel was recently burned. The continuous estimate (1-100) was thresholded at a selected value (i.e., 95 and above) to standardize all the image estimates and create a binary thematic product identifying burned pixels in each Landsat image (1984–2012). Because clouds and shadows in Landsat imagery can obscure portions of fire perimeter, our approach combines all available Landsat imagery to fully delineate a fire perimeter.

The accurate fire perimeters are delineated using Landsat, validated by the presence of an HMS point, and labeled with the correct fire date determined by the HMS record. The burned area polygons provide spatially accurate data, but the temporal resolution is limited to 16 or 8 days depending on satellite availability. Using the capabilities of spatially enabled open source PostgreSQL/PostGIS software, we combine the temporal strengths of the HMS data and the spatial strengths of Landsat imagery to determine the start date and spatial extent of a fire.

Open Source Software—One goal of this effort is to freely distribute data processing scripts developed for this project. We utilized open source (http://www.osgeo.org) PostgreSQL/PostGIS (http://www.postgresql, http://postgis.net) to process all data and Quantum GIS (QGIS; http://www.qgis.org) to view the data. PostgreSQL is a relational database that can be spatially enabled by coupling it with the PostGIS extension. Complex queries can be performed in PostgreSQL to determine the spatial relationships of objects.

Data Processing

Landsat image processing methods currently used by MTBS involves several steps. Each terrain-corrected (L1t) scene is downloaded from the U.S Geological Survey (USGS) Earth Resources Observation and Science (EROS) Center's image archive by the analyst. The imagery is then corrected to top of atmosphere reflectance, reprojected from UTM to Albers Equal Area, and processed to create a Normalized Burn Ratio (NBR) image. To increase our image processing throughput, the USGS Land Satellites Data System Science Research and Development Project and the EROS Science Processing Architecture (ESPA) system used processing scripts to process 1,800 Landsat scenes covering our study area. All Landsat 5 TM and Landsat 7 ETM+ reflectance images, water, cloud, and cloud shadow masks were created by ESPA. This Landsat imagery was used to determine possible burned areas using the Landsat burned area delineation described above.

To accurately date each burned area, we utilized PostgreSQL/PostGIS queries to determine whether HMS points were within 1,500 m of the Landsat-derived fire perimeters and if they were correctly associated with the proper Landsat acquisition (i.e., dated no more than 8 days prior to the Landsat acquisition first showing the burned area polygon). It is likely that a fire could be obscured by clouds in several Landsat overpasses before it is visible. More sophisticated queries can be created to determine precise HMS dates; however, the burned area polygons are sufficient to identify a "probable" fire.

PRELIMINARY RESULTS AND DISCUSSION

Approximately 1,800 Landsat images (1984–2012) and 88,000 HMS points (2003–2012) were assessed for Paths/Rows 16/40, 17/39, and 18/39. Within these Paths/Rows, we identified approximately 300,000 burned area polygons. The average size of these fires was 257 acres, and almost 18,000 fire polygons exceeded the MTBS 500-acre minimum threshold. By comparison, MTBS mapped 1,400 fires covering the 1984–2011 time period. This suggests there are many unreported prescribed fires above the MTBS size thresholds. However, the southeast region is probably a "worst case scenario" as prescribed fires are not nearly as common in the Western United States. Additionally, it is clear this approach identifies many smaller fires; however, we have not yet determined the minimum fire size threshold that can be reliably delineated and mapped.

To determine the reliability of the results, we visually compared the data to the U.S. Forest Service National Forests of Florida (Apalachicola, Ocala, and Osceola) fire records. We found the fires identified by the burned area delineation process closely matched National Forest records. We identified potentially more MTBS-sized fires than were assessed by MTBS (fig. 2), and for the post-2003 fires, the dates of occurrence were effectively determined by HMS (fig. 3). Further, the burned area perimeters better represented the overall fire patterns and should provide more accurate estimates of burned acreage because MTBS does not delineate unburned islands within the overall perimeter (fig. 2).

After reviewing the burned area products, we determined that some of the burned pixels were detected within urban areas, harvested cropland, and seasonally flooded areas. MTBS is not concerned with cropland, but these areas can be set aside for anyone who has interest in burnable agriculture. Some actual commission errors occurred, apparently due to confusion with freshly plowed agricultural ground, clear cuts, and special types of wetland vegetation in senescence. No effort was made at this time to separate these from the truly burned areas. A refinement of burned croplands vs. plowed ground, and burned emergent wetlands vs. senescent vegetation, are potential problems. A majority of the urban area confusion appears to have a seasonal (solar angle) component that might be addressed by application of a seasonally tuned regression tree model.

For MTBS, it is necessary to identify the best prefire and postfire Landsat images in order to create the burn severity assessments. In the past, MTBS analysts reviewed low resolution browse imagery. This has been improved utilizing ESPA processing system, which searched the Landsat archive and retrieved candidate scenes and clipped them based upon a bounding box derived from the automatically generated burned area perimeter. The full resolution image subsets provide analysts with a more detailed view of the data than was previously possible with the low resolution browse images.

MTBS Viewer Tool and Automation

All the candidate full resolution Landsat image clips are loaded into a Google Earth® KML and viewed with the MTBS QuickLook tool (fig. 4). The QuickLook tool allows analysts to rapidly review the Landsat clips to determine if the detection is in fact a fire and then to record the optimal scenes for the severity assessment, whether the assessment type will be initial (within several months) or extended (at peak of green the following season), and the vegetation type in which the fire occurred. All information entered into the QuickLook tool is stored in a PostgreSQL database.

ESPA processing eliminates many of the image preprocessing steps outlined in the “Processing” section above. Currently, MTBS burn severity processing scripts are run manually after analysts select and order the optimal scenes and make other critical processing decisions (e.g., initial vs. extended). These critical analyst processing decisions are collected by the MTBS QuickLook tool and will be used to automatically drive the MTBS process using the existing scripts: creation of the differenced NBR (dNBR) and Relativized dNBR (RdNBR) images which form the basis of the thematic burn severity map.

Furthermore, we have completed regionally based analyses of all 1984–2010 historical MTBS analyst-determined burn severity breakpoints for each vegetation type (Fry and others 2011) throughout the Unites States to determine the regional average burn severity breakpoints for each vegetation type. These breakpoints will be used to automatically create preliminary MTBS burn severity products. MTBS analysts will then review preliminary/default burn severity products with the next iteration of the automation process.

Potential Improvements to Current MTBS Process

This project has the potential to improve the MTBS fire perimeter and burn severity mapping process. The overall effect of these improvements is to enable the processing of many more fires that would have been previously too time-consuming and expensive to undertake. Further testing of the automated procedures and subsequent product outputs still needs to be completed; however, the basic automated processing framework has been developed. This current project worked on a small subset of the total footprint of the United States that will need to be processed if burn perimeters and severity are to be mapped on a nationwide scale. The methods will be tested in other regions as resources are available.

We anticipate that the previously described automated fire perimeter mapping, creation of thresholded burn severity images, and subsequent review of all products should increase the MTBS mapping capabilities. MTBS will be able to map and review fires more quickly, thereby reducing production time and cost. MTBS may subsequently be able to decrease the current fire mapping thresholds 1,000 acres in the Western United Staes to increase its mapping capabilities. Overall, this would result in the production of a more complete fire history within the United States.

Generally, MTBS fire products become available within two years after fire occurrence. This production timing is purposely structured in this manner to allow for the mapping of extended fire assessments and a rigorous quality control process to ensure that all mapped fires meet MTBS’s stringent mapping requirements. If the MTBS project is able to complete the current mapping output in less time, it may be possible to map initial assessments of fires in near real-time. Under this paradigm, MTBS would use HMS fire detections in conjunction with recent postfire Landsat BnB fire perimeters to automatically map fire perimeters. Automated processes would generate thresholded burn severity products. All products would be reviewed for accuracy and revised as needed by MTBS analysts using the QuickLook viewer. This process would be different from the current MTBS mapping process because it would create initial assessments of burn severity for the entire United States. Subsequent extended assessments of burn severity for the United States would be mapped using the original MTBS protocols.

In addition to improving the MTBS process, we expect that the HMS and BnB combined fire perimeter mapping protocols will generate products useful to managers of public and private lands. Many more mapped fires will subsequently become available. Better geospatial records should inform land managers’ decisions when attempting to reduce wildfire risk and managing fire-adapted ecosystems with prescribed fire.

CONCLUSION

Our protocols provide a useful methodology for determining previously unknown burned areas within the Southeastern United States. These products will provide MTBS with potential fire perimeters that can then be used to drive the semi-automated procedures that result in the more efficient identification of suitable Landsat imagery and production of burn severity products. Although MTBS will not assess fires that are less than 500 acres, these fire perimeters can provide land managers with a more complete resource then is currently available to monitor the actual extent and acreage of wildfires and prescribed fires on their lands. In the future, there is the potential that these project methodologies could be used to identify potential fire perimeters at near real-time as new Landsat images become available for the continental United States. This would work towards the creation of a national fire atlas.

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LITERATURE CITED

Eidenshink, J.; Schwind, B.; Brewer, K. [and others]. 2007. A project for monitoring trends in burn severity. Fire Ecology. 3(1): 3-21.

Fry, J.A.; Xian, G.; Jin, S. [and others]. 2011. Completion of the 2006 national land cover database for the conterminous United States. Photogrammetric Engineering and Remote Sensing 77: 858-864.

Rulequest Research. 2004. Data mining tools. http://www.rulequest.com/ [Online] (verified 23 September, 2014).

Ruminski, M.; Kondragunta, S.; Draxler, R. [and others]. 2006. Recent changes to the hazard mapping system. In: Reinventing Inventories: New Ideas in New Orleans: Proceedings of the 15th International Emission Inventory Conference [Online]. [Place of publication unknown]. http://www.epa.gov/ttn/chief/conferences.html. [Date accessed: January 17, 2014].

Zhang, X.; Kondragunta, S.; Quayle, B. 2011. Estimation of biomass burned areas using multiple-satellite-observed active fires. IEEE Transactions on Geoscience and Remote Sensing. 49(11): 4469-4482.

Table 1—FOD tallies and total number of MTBS fires that were assessed in 2004 and 2010

FOD year	Federal fire records	Total fires mapped	Wildfires mapped	Prescribed fires mapped
2004	1,257	427	326	101
2010	3,164	1,249	309	940

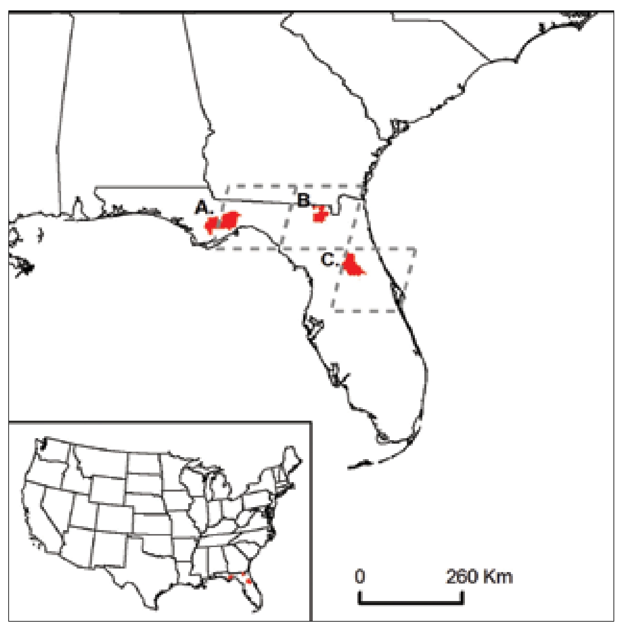

Figure 1—Location of the Apalachicola (A.), Osceola (B.), and Ocala (C.) National Forests (red). Dashed gray lines indicate the approximate Landsat WRS2 Path/Row locations for 18/39 (nearest A.), 17/39 (nearest B.) and 16/40 (nearest C.).

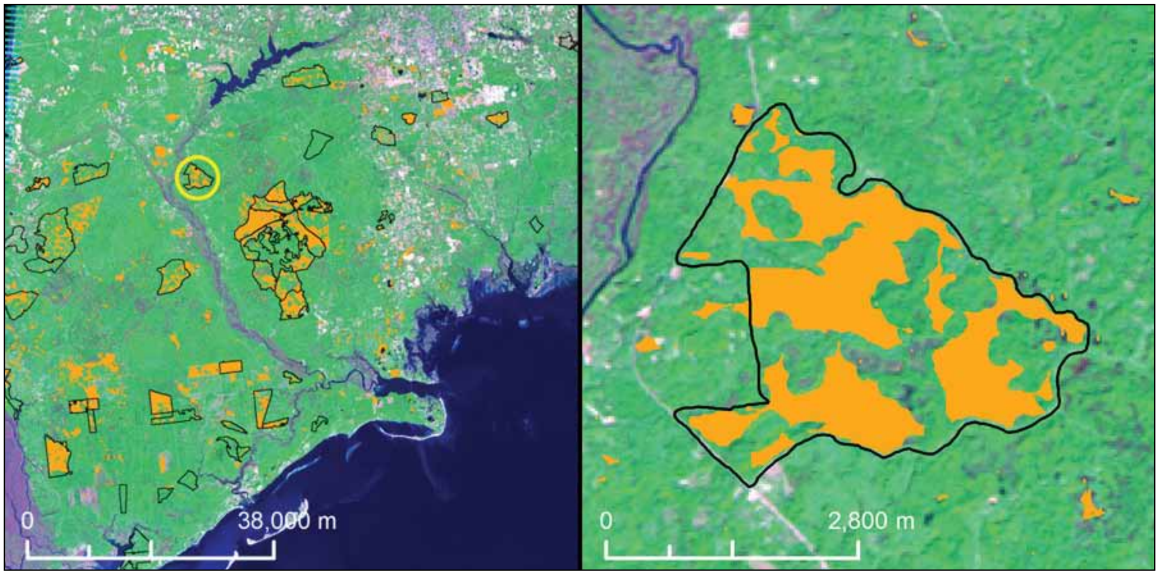

Figure 2—Example of 2011 compiled burned area fire polygons (orange) and their proximity to the MTBS Fire Occurrence Database (FOD) fire perimeters (black). MTBS fire perimeters without any associated orange polygons result from the FOD fire perimeters being derived from 2012 Landsat imagery. The yellow circle in the left image denotes the location of the enlarged fire perimeter shown in the right image and a more precise delineation of the burned area when compared to the MTBS perimeter.

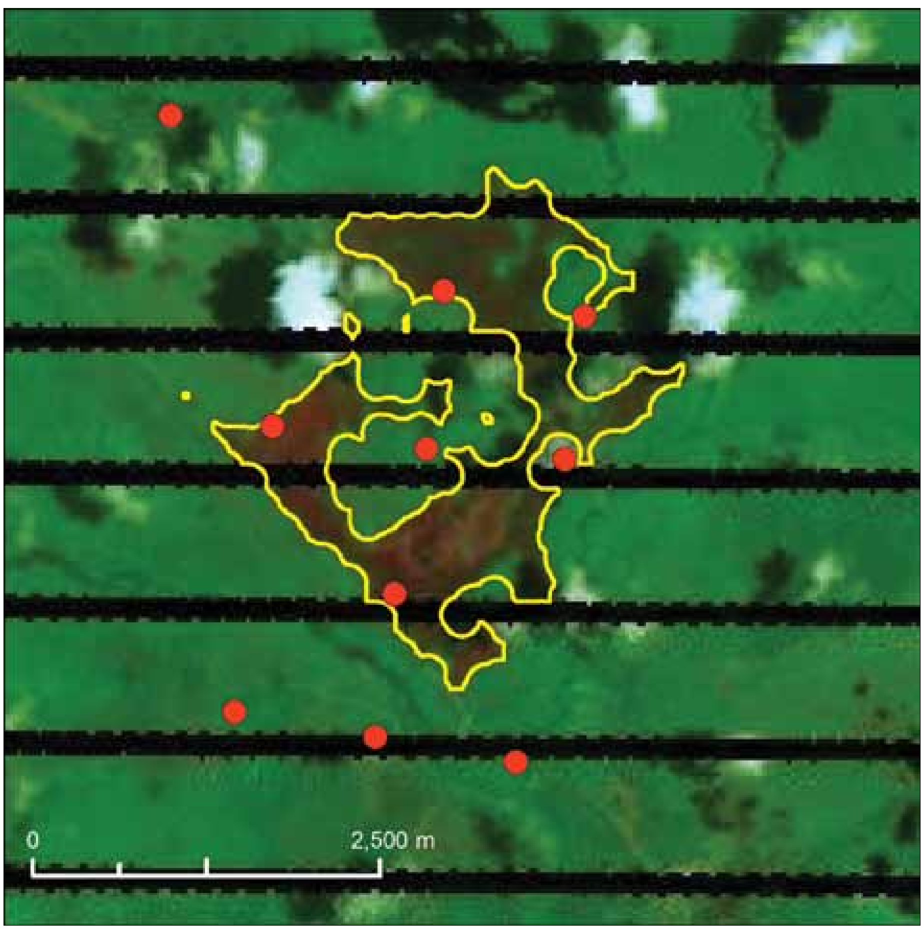

Figure 3—Example of 924-acre burned area polygon (yellow) derived from Landsat scene dated 7/6/2012 and corresponding HMS fire detections (red dots) from 6/29/2012.

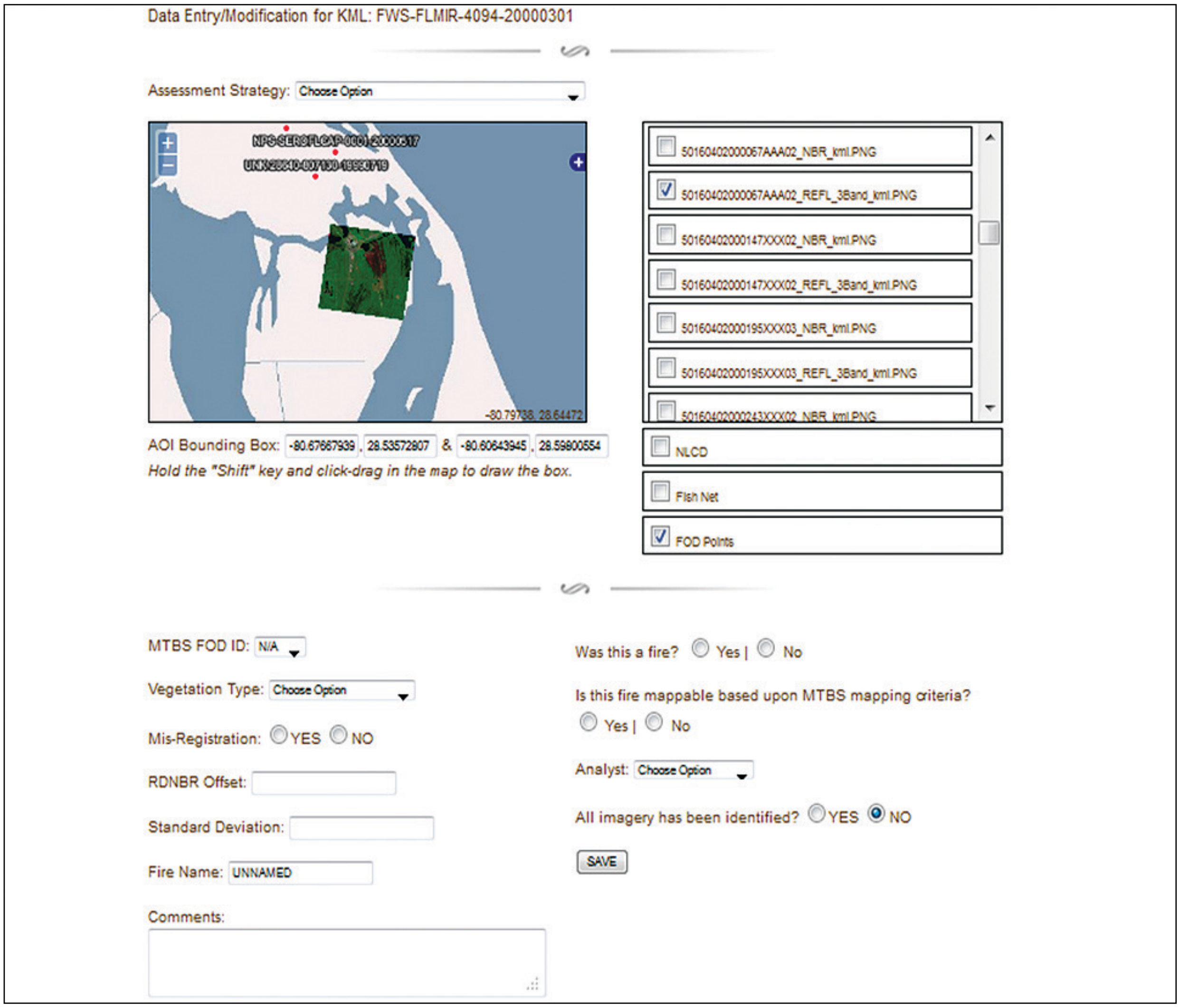

Figure 4—Screen shot of the MTBS QuickLook Web-enabled viewing and analyst data entry tool used to store information about each fire assessment.