Using Satellite-based Products to Enhance Existing Area Burned Data

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Abstract

Although biomass burning is a major contributor of particulate matter and other pollutants to the atmosphere, it is one of the most poorly documented of all sources. Biomass burning can be a significant contributor to a regions inability to achieve the National Ambient Air Quality Standards for PM 2.5 and ozone. Currently, the United States does not have a standard methodology to track fire occurrence or area burned, which are necessary components to estimating fire emissions. One problem is the ownership and management of the land belongs to multiple organizations and private individuals, so there is not one organization that is responsible for thoroughly monitoring fire. Satellite imagery provides the opportunity to remotely sense fire across boundaries. The goal of this investigation is to define the ability of satellite-based fire products to detect active fires in an effort to enhance existing area burned databases and emissions estimates. Two satellite-based fire products are compared temporally and spatially to ground-based data from Florida. The satellite data are coincident with 14% of the reported ground fires, and 25% of the satellite data are coincident with the ground data. When considering the spatial resolution of the instruments, a coincidence of 54% exists between the satellite and ground-based data. Additionally, we identified two regions where fires appear to have burned that are detected by the satellites, but these fire events are not recorded in the ground data. We suggest that satellite data could be used to augment existing fire databases and enhance emissions estimates.

Introduction

In 1990, Congress amended the Clean Air Act (CAA) to require the United States Environmental Protection Agency (EPA) to address regional haze. Regional haze refers to visibility impairment that is caused by the emission of air pollutants from numerous sources located over a wide geographic region that may encompass several states. The EPA Office of Air Quality Planning and Standards (OAQPS) published a rule in 1999 to address regional haze in 156 national parks and wilderness areas such as the Grand Canyon, Yosemite, the Great Smokies and Shenandoah [1]. The rule requires the states, in coordination with the EPA, the National Park Service, U.S. Fish and Wildlife Service, the U.S. Forest Service, and other interested parties, to develop and implement State Implementation Plans (SIPs) to reduce the pollution that causes visibility impairment. Additional information concerning the regional haze program can be found at the EPA's website: http://www.epa.gov/air/visibility/program.html.

As a result of the Regional Haze rule, five Regional Planning Organizations (RPO) were formed across the US in an effort to coordinate affected states and tribes and to initiate and coordinate activities associated with the management of regional haze and other air quality issues. The five RPOs are: the Central Regional Air Planning Association (CENRAP), the Midwest Regional Planning Organization (Midwest RPO), the Mid-Atlantic and Northeast Visibility Union (MANE-VU), the Visibility Improvement State and Tribal Association of the Southeast (VISTAS), and the Western Regional Air Partnership (WRAP). The RPOs are tasked to: (1) develop a plan to define regional source emissions and to establish a plan to identify source emissions by 2007 and (2) to develop SIPs to control regional emission sources, with the goal of returning to natural visibility conditions by 2064.

Haze-causing pollutants (mainly $PM_{2.5}$ - particles 2.5 microns or less in diameter) are directly emitted to the atmosphere by a number of activities (such as electric power generation, various industrial and manufacturing processes, truck and auto emissions, burning related to forestry and agriculture, construction activities, etc.). Biomass burning is a major source of $PM_{2.5}$ and regional haze, particularly on the 25 worst days, which is a significant parameter to monitor for the regional Clean Air Act. The inability to adequately capture biomass emissions is due to the fact that the US does not have a standard database of fire events or area burned for any year. Several organizations [i.e. U.S. Forest Service, Bureau of Land Management] have limited data for their particular geographic regions, but these data are not collected by a standard method, even within an organization. Additionally, these data exclude any biomass burning events that occur outside of these boundaries and often fail to capture agricultural burning (e.g., sugar cane, wheat/rice stubble, and grasses).

Current EPA methodologies for estimating biomass burning emissions (forest fires, wildfires, and prescribed or managed burning) involve the use of fire activity data from a variety of sources and the application of ratio methods or growth factors when current year data are not available or incomplete. For instance, to estimate forest and wildfire emissions for the 1999 emissions year, the EPA used fire activity data for the years 1885-1998 obtained from the U.S. Department of Interior and the U.S. Forest Service for Non-Grand Canyon States. After the emissions estimates were produced, they were often distributed from an aggregated state level to a county level using data from a prior year(s). This can often lead to large errors and inaccuracies when comparing where emissions were shown to occur and where actual biomass burning occurred [2].

The purpose of this research is to work towards improving biomass burning emissions estimates by enhancing the estimates of area burned by fire. One untapped source of data is satellite-derived fire products. Initially, we seek to define the ability of satellite products to detect regions of burning. The focus in this study is on fires that burned in Florida in 2002. The temporal and spatial coincidence in the Florida ground-based fire dataset and satellite-derived fire products is examined. Specifically, the ability of satellite-derived products to actively sense ground fires and the ability of these products to accurately define fire frequency and area burned are explored.

Methods

Satellite–derived fire products are compared to Florida ground fire databases from May 1, 2002 through August 30, 2002. These data are evaluated in time and space to determine the ability of satellite-based data to sense and quantify the total number of fires and the amount of area burned. Implicit throughout most of this investigation is that the Florida ground fire data are truth, however we recognize that this database may not be comprehensive. Two satellite-derived products are considered in this analysis, Geostationary Operational Environmental Satellite (GOES) Automated Biomass Burning Algorithm (ABBA) and the Moderate Resolution Imaging Spectroradiometer (MODIS) thermal anomaly data. The reason for comparing two satellite products is to take advantage of the unique temporal resolution of GOES (15 minute data, 16 km^2 nadir resolution) and the unique spatial resolution of MODIS (twice daily, 1 km^2 nadir resolution).

Both MODIS and GOES ABBA products have demonstrated their ability to detect biomass burning in numerous ecosystems [3-7]. The GOES ABBA algorithm uses GOES visible, shortwave infrared and thermal infrared bands to detect fires. After a fire pixel is located, the algorithm incorporates temperature and ancillary data (i.e. ecosystems, water vapor attenuation, solar reflectivity) to quantify the instantaneous size of a fire. The MODIS instrument exploits the middle infrared and thermal infrared bands to identify thermal anomalies and generate fire locations. Both of the algorithms take advantage of the sensitivity of these wavelengths to fire.

The historic GOES ABBA data are downloaded from the Fire Locating and Modeling of Burning Emissions (FLAMBE) website: http://www.nrlmry.navy.mil/flambe/index.html. One fire dataset is available every half hour from both GOES east and GOES west for North America in 2002. Version 5.9 is exclusively available at the beginning of the study period and version 6.0 is exclusively available at the end of the study period. When both datasets are available, version 6.0 is utilized in this investigation. The text data are integrated into daily data files, and then the data are combined into one spatial file, which includes ancillary data (i.e. date, ecosystem, fire flag) in ArcGIS. Fire flags range from 0 to 5 and correspond to processed (0), saturated (1), cloudy (2), high probability (3), medium probability (4) and low probability (5) fire data. Saturated, cloudy and low probability data are excluded from this analysis. Only processed data contain the estimated instantaneous size of a fire. Consequently, the Florida processed fire size data are averaged, and the fire size average is assigned to the high and medium fire probability categories. The latitudes and longitudes provide locations (point data) and the instantaneous fire size is computed as a circle (polygon) around the point location. First, ABBA estimated location and fire size data are spatially compared to the Florida ground fire data. Then, the fire size is surrounded with an additional 16 km^2 in an effort to realistically estimate the ability of the GOES ABBA product to detect active fire in time and space.

MODIS data are provided by two sources, the MODIS Rapid Response (RR) system and the USDA Forest Service (FS) Remote Sensing Application Center (RSAC). The Rapid Response team generated a fire product using terra 2002 fire data that was collected at the NASA Goddard Space Flight Center (GSFC). RSAC data are available on the USDA FS website: http://activefiremaps.fs.fed.us/. These data are derived as part of a cooperative agreement between the USDA FS RSAC, NASA GSFC and the University of Maryland. Both of these data products use the MODLand Rapid Response algorithm to produce datasets that contain latitude and longitude locations (point data), however no area burned data are provided. These text files are combined and converted to ArcGIS files. First, the overlap between the MODIS point data and the Florida ground data is assessed. Then, in consideration of the MODIS instruments 1 km^2 spatial resolution, the data points are surrounded (buffered) with a 1 km^2 area to evaluate the spatial coincidence between MODIS and ground fire data. Even though there is no precise overlap in the point data, there is overlap in the buffered data. However, both products provide unique detections that are not discernable in the alternative dataset. For example, in some regions, the spatial data overlap is about 50%, however the dates the fires occur are unique. Consequently, when comparing the data spatially, duplicate detections are ignored.

The Florida ground–based fire dataset contains two large databases, one of wildfires and the other, open burns. The wildfire database contains wildfires and prescribed burns that are reported on state and privately held lands. The open burns database contains reported agricultural, land clearing and silvicultural fires, some of which require permits. In both of these databases, many of the reported fires did not include a location (latitude, longitude) or the amount of area burned during the fire event. Because this is a spatial analysis, fire events that lack area or location are excluded from the analysis. These text databases are converted to spatial databases, which include ancillary data (i.e. dates, area, type of fire), within ArcGIS. As with the GOES data, area is used to surround the latitude and longitude point locations to generate polygon data. Finally, the data are combined to construct one ground fire dataset. Every dataset (ground, GOES and MODIS) is projected to UTM zone 18N for continued analysis.

Results and discussion

Limitations of the imagery

In order to understand and accurately assess the satellite-derived data products, one must consider the limitations of the satellite instruments. For one, cloud cover prevents the instruments from detecting active fires, so when thick persistent clouds are overhead, active fires are missed. Also, each instrument is limited in its ability to detect and geolocate fire by its spatial resolution. For instance, when an instrument detects fire, the position of the fire within a pixel is not known. Additionally, the Point Response Function (PRF) of the instrument, which is the actual footprint of the instrument, restricts the ability of an instrument to detect and geolocate a fire (~ 80% of the energy from 1.42 km MODIS and 5.68 km GOES) [8]. In addition, the MODIS instrument is in a sun-synchronous orbit and is limited by two overpasses per day. Consequently, fires that burn between satellite overpasses are excluded. The GOES instrument is in a geostationary orbit and is consistently viewing North America. However, considering the GOES PRF, nadir spatial resolution, and the position of a fire within a pixel, the geolocation of a fire event could be off by maximum of about 10 km (0.05 degrees).

Data coincidence

The Florida fire statistics are provided in Table 1. After excluding incomplete data, the wildfire database contains 1077 records and the open burns database contains 3265 records within the timeframe of this analysis. The MODIS RR file contains 349 records and the RSAC file contains 462 records. The GOES dataset contains 1596 fire records after all exclusions. Consequently, the satellite data contain 55% of the total number of records that the ground fire database holds.

First the coincidence in the ground-based area burned data, the MODIS point data and the GOES instantaneous fire size data is explored. Figure 1 illustrates the spatial coincidence of these data. A total of 9% (74) of the MODIS data points lie on the ground area burned data, and 2% of the ground data is covered with MODIS points. In several instances more than one MODIS point is laying on an area burned. Also, several MODIS points are within 1 km of a reported active fire, which is consistent with the spatial resolution of the instrument (Figure 2). A total of 5% (80) of the GOES fire records intersect the ground data. In several instances, the area reported by GOES is less than 4 km from the actual burning events, which is consistent with the spatial resolution of the product (Figure 3).

The total instantaneous fire size reported by GOES is over 33% of the total area reported burned in Florida. Considering the limitations of the instrument, this is a significant measurement. More importantly, if the spatial resolution of both the MODIS and GOES instruments is not considered, over 90% of the detections do not coincide with the ground data.

For this reason, MODIS data are buffered to 1 km^2 and GOES data are buffered to 16 km^2 to account for the spatial resolution of the instruments (Figure 4). This results in over 14% of the ground data areas being spatially coincident with the satellite data, which means that 86% of the satellite data are not spatially coincident with the ground data. This could be due, in part, to instrument difficulty in locating the center of the fire event. In addition, this comparison assumes the incidence and geolocation (accuracy and precision) of the ground-based data are correct, which is a significant unknown. Next, the actual amount of area burned within the ground-based data is compared to a generated synthetic area burned database for the MODIS and GOES data. Buffered areas represent the area contained within the approximate perimeter of a pixel. Therefore, it is incorrect to assume the entire pixels are filled with fire or the entire area within a pixel is burned. For example, the buffered area of the GOES data is greater than 5 million (M) acres, which is over 7% of the total area within Florida and this is not realistic. The total area reported burned in Florida in 2002 for the entire year is 2 M acres. Nonetheless, after buffering the MODIS data, 4% (8637 acres) of the ground data area is covered with MODIS data or 8% of the buffered MODIS data coincides spatially with the ground data. After buffering the GOES data, 50% (100,960 acres) of the ground data is covered with the buffered GOES data, which is 2% of the total buffered GOES data. Combining the buffered MODIS and GOES data results in a coincidence of 54% (109,597 acres) between the satellite data and ground area burned data. Still much of the satellite data are not coincident with the ground-based data.

Knowing that one of our major goals is to accurately quantify emissions by enhancing estimates of area burned, we focus on regions where large amounts of area are burned. In Canada, the largest 2-3% of the fires account for 97-98% of the area burned [9]. In this study, based on the GOES data, the largest 20% of fire events account for 43% of the area burned, even though the reported instantaneous fire sizes are small. In the open burns database, the largest 1% of the fire events account for 43% of the area burned, and the largest 5% of the fire events account for 77% of the area burned. In the wildfire database, the largest 1% of the fire events account for 75% of the total area burned. Consequently, if the concentration is on the largest fire events, we could define most of the area burned.

The largest area burned (6800 acres) in the wildfire database is by a grass fire on May 3rd, and the fire is detected by 5 MODIS points on May 4th and it is also detected by 5 GOES records on May 3rd and another on May 4th. The total instantaneous fire size provided by GOES on May 3rd is 192 acres, which is 3% of the reported area burned. In the open burn database, the largest area burned is 9000 acres by an agricultural-pasture fire on July 22nd and neither of the satellites identified this fire event, possibly because of cloud cover in the region. The second largest fire event in the open burns database is a silvicultural-hazard removal fire that burned 5000 acres on August 15th. GOES identified this fire with 7 records and a total instantaneous fire size of 193 acres, which is 4% of the reported area burned. The MODIS instrument did not detect this fire event.

Conversely, there are several regions where the GOES and MODIS instruments detect active fires, but the ground fire database does not record a fire event. We understand that the ground fire database may not be complete truth, which makes it difficult to verify the satellite data. Because large fire scars can often be identified using Enhanced Thematic Mapper (resolution 30 m) quick looks, these are downloaded in an effort to verify fire. In several instances, the fires were too small to be recognized with quick looks. However, there is a region in and around the Everglades where MODIS identified numerous fires, however these fires were not reported in the ground data (Figures 5a and

5b). It appears that the fires are evident when inspecting the quick look imagery. Additionally, GOES identified several fire events in and around the Okefenokee Swamp, which are not recorded in the ground data (Figure 6a and 6b). At least one of these fires appears to be a large fire that is evident in the quick look data. Because this is not a spatial analysis and the quick looks are not georeferenced, this evidence is anecdotal, however there is also no evidence available that excludes the satellite-derived fire events.

Conclusions

This paper is the result of an initial investigation that explores the capability of satellite products to detect active fires in Florida between May 1, 2002 and August 30, 2002. The MODIS and GOES satellite products identified 2407 fire events and the ground database holds 4342 fire events, some of which may have been too small for the imagery to detect. We have shown that satellite data are spatially coincident with 14% of the reported ground fires, however this may be an underestimate of the coincidence in these data due to geolocation issues. When buffered to their respective spatial resolutions, the satellite imagery is able to define 54% of the area within the ground fire database, although we would like to caution the reader that these buffered satellite products do not represent area burned. According to the ground fire database, less than 5% of the fires account for over 75% of the area burned. This is significant because it stresses the importance of accurately quantifying large fire events, and large fire events are typically captured by remotely sensed imagery. Additionally, two case studies are presented that highlight numerous satellite detections that do not coincide with ground data. From the satellite perspective, 25% of the data coincides with the ground data, however 75% did not. One of the most significant finding of this initial study is the lack of coincidence in the data sources.

Ground and satellite data provide unique views of patterns of fire in Florida, and this investigation demonstrates that a more rigorous examination of the data is warranted. In the future, we hope to present a thorough temporal analysis of the data and expand the analysis to include additional ecosystems. Remotely sensed data does provide the ability to detect fires outside of national boundaries and also unreported fires. We suggest that satellite data are capable of identifying active fires that are often missed on the ground and these data would enhance incomplete ground datasets, thus improving emissions estimates.

References

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Key Words
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Table 1. Comparison of Florida fire data.

Data source	Number of records	Number of intersecting records (satellite to ground)	Reported acres burned (range)	Ground fire area covered after buffering (acres)	Total area of buffer (acres)
GOES ABBA	1596	80	66,491 (0.23 – 187.2)	100,960	5,044,650
MODIS	811	74	none reported	8,637	107,842
Florida ground fires	4342		201,380 (0.1 – 9000)		

Figure 1. Coincidence in Florida ground fire area, GOES area and MODIS point data.

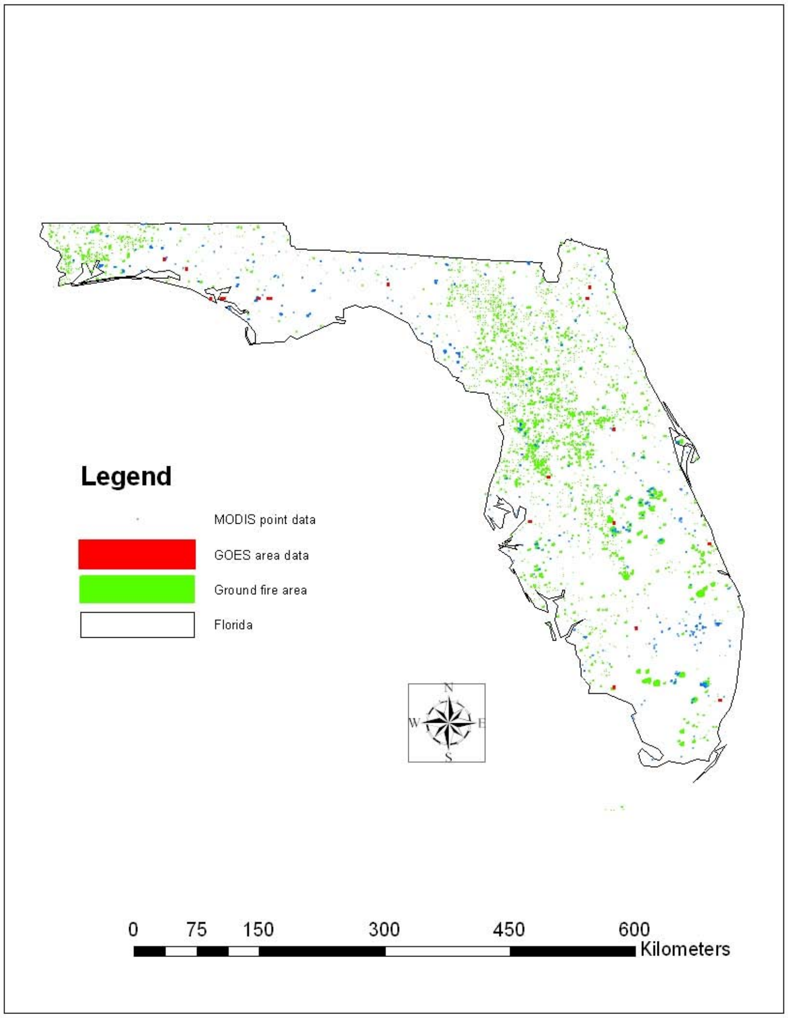


Figure 2. Enlarged view of ground data and MODIS point data demonstrating the proximity of the June 13th and June 14th detections (MODIS spatial resolution 1 km^2). Even though MODIS is most likely detecting these fire events, only 1 data point coincides.

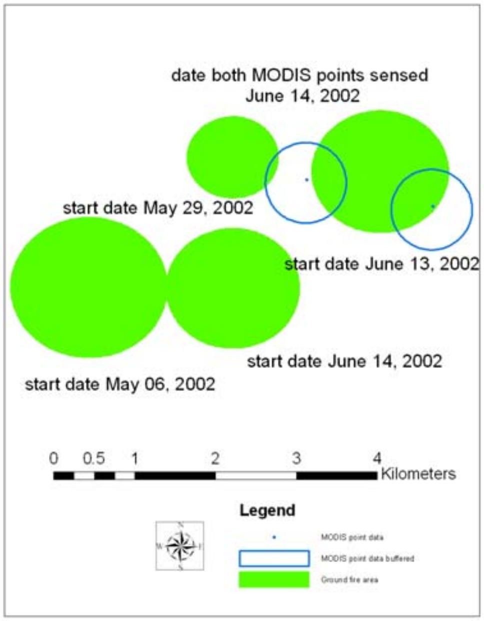


Figure 3. Enlarged view of ground data and GOES instantaneous fire size data demonstrating the proximity of the July 27th and July 28th detections (GOES spatial resolution 16 km^2). Even though GOES is most likely detecting this fire event, the data do not coincide.

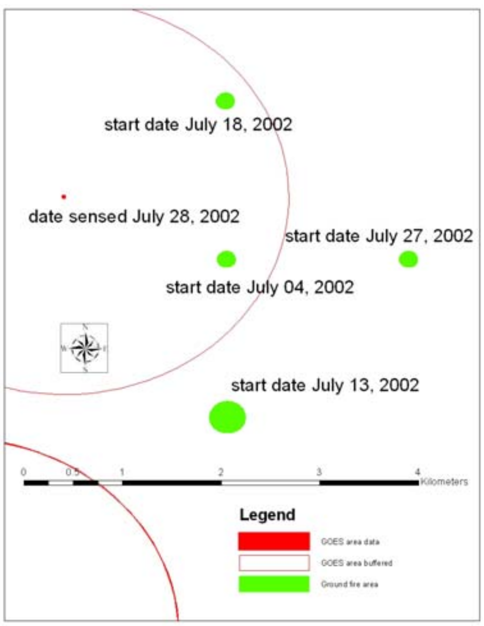


Figure 4. Coincidence in Florida ground fire area and the buffered GOES and MODIS products.

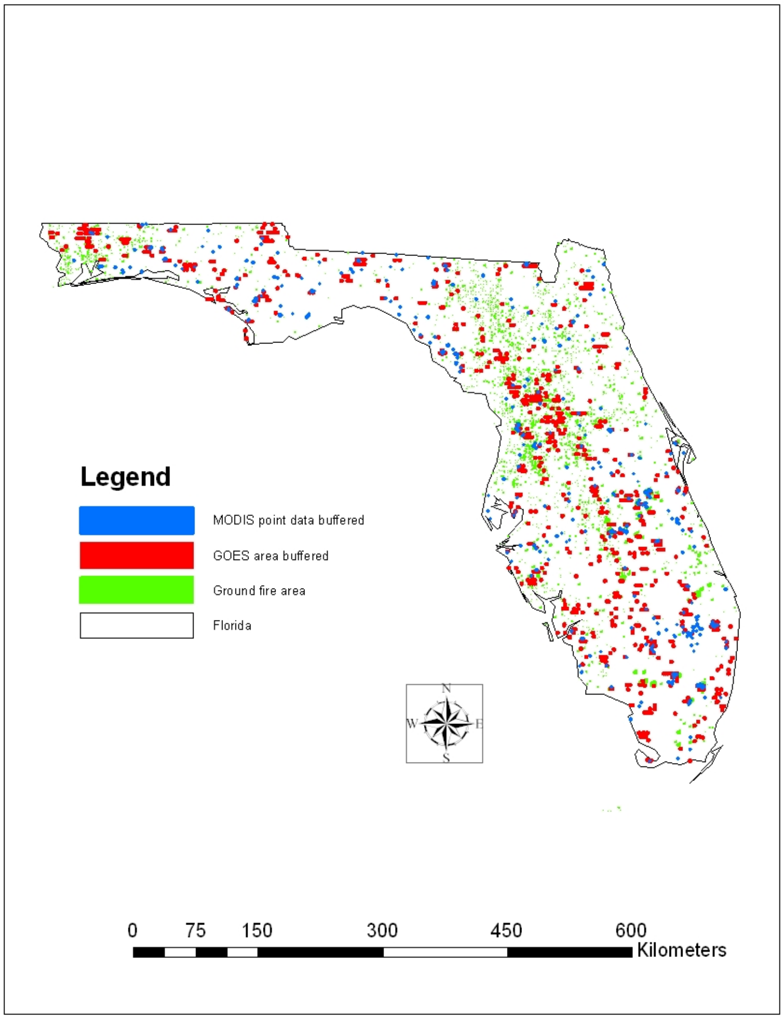
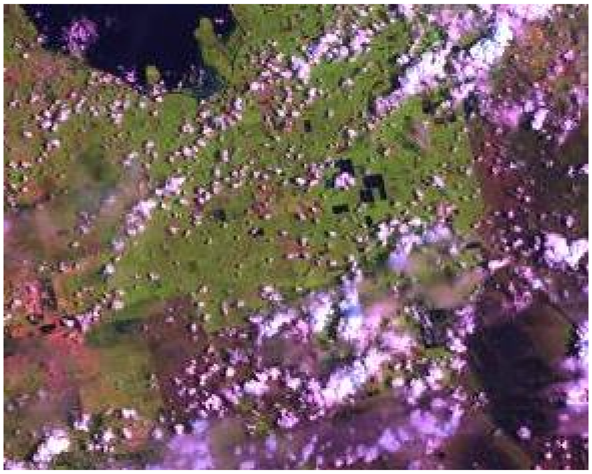
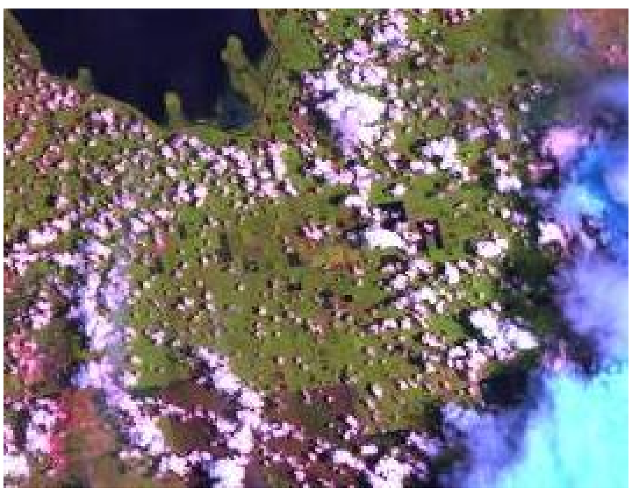


Figure 5. Enhanced Thematic Mapper quick look sensed near the Everglades. The darker brown portions of these images appear to be burned fields. Several more fields appear burned in the August 5^{th} image, which coincides with MODIS imagery, however these fires are not recorded in the ground fire data.



5a
July 20, 2002.



5b
August 5, 2002.

Figure 6. Enhanced Thematic Mapper quick look sensed near Okefenokee Swamp. The darker brown portion of these images appears to be a large fire scar. The fire scar is enlarged in the June 16th image, and the location of these scars coincides with GOES imagery, but the fire is not recorded in the ground fire data.

6a
May 15, 2002.

6b
June16, 2002.