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INTEGRATION AND RECONCILIATION OF SATELLITE-DETECTED AND INCIDENT COMMAND-REPORTED WILDFIRE INFORMATION IN THE BLUESKY SMOKE MODELING FRAMEWORK

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1. INTRODUCTION

The BlueSky smoke modeling framework is a tool for modeling the cumulative impacts from multiple fires (Larkin et al., 2007). Developed by the U.S. Department of Agriculture-Forest Service (USFS), it combines existing models in a unified structure to predict ground-level concentrations of particulate matter less than 2.5 microns in diameter ($PM_{2.5}$). BlueSky was originally designed to assist prescribed burn and smoke managers in making burn decisions based on expected smoke impacts, but it has been expanded to predict and track smoke from wildfires and wildland fire use (WFU) fires.

Currently, BlueSky ingests wildfire incident data from Incident Status Summary (ICS-209) reports. The ICS-209 is a two-page form, the main purpose of which is to provide incident information for operational decision support and firefighting resource allocation at a regional level. ICS-209 reports are typically created daily for large (>100 acre) wildfires and WFU fires. Because ICS-209 reports were not created to provide information for smoke modeling, their use is limited in this context. Each ICS-209 report contains a latitude and longitude pair that represents the point of origin of the incident. This location does not change, even as the fire propagates several kilometers away from the point of origin after weeks of burning. Daily ICS-209 reports contain a size value expressed as acreage. This value is cumulative and represents an estimate of the total acreage burned by the fire since the beginning of the incident. For BlueSky, day-specific information on location and area burned are required to estimate daily smoke emissions.

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Satellites with infrared channels have long been used to detect actively burning fires (Dozier, 1981). There are currently several satellite-borne instruments delivering operational fire-detection products. Instruments onboard polar-orbiting satellites, such as Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Terra and Aqua satellites, are able to detect active burning as small 0.25 acre (Giglio, 2005). The MODIS active fire product (MOD14) has a 1-km nadir resolution. Large fires are detected as several pixel "hot spots". The spatial resolution of these data is significantly better than that of ICS-209-reported fires and can provide daily snapshots of the burning areas to the BlueSky framework. In addition, many fires detected by satellite do not have associated ICS-209 reports.

Unfortunately, satellite-detected fire data also have limitations. Clouds preclude fire detection. Though MODIS, for example, can detect instantaneous burning as small as 0.25 acre, this translates to a much larger area burned over 24 hours; an examination of wildfires in the western United States showed that fires less than 300 acres in size are not reliably detected. Also, because current operational algorithms only detect actively burning fires, they may miss short-duration fires.

A new system was developed to integrate and reconcile human-recorded ICS-209 data with satellite-detected fire data and provide burn area predictions to the BlueSky framework. This system is called the Satellite Mapping Automatic Reanalysis Tool for Fire Incident Reconciliation (SMARTFIRE). By reconciling both satellite-detected and human-observed fires, SMARTFIRE harnesses the advantages of both data sets. Satellite-detected fire data come from the National Oceanic and Atmospheric Administration (NOAA) Hazard Mapping System (HMS; http://www.ssd.noaa.gov/PS/FIRE/hms.html). HMS fire data are created by combining hot-spot detections from three instrument types onboard several satellite platforms and applying manual quality control by a trained satellite-data analyst.

The SMARTFIRE system was tested on data from the 2005 fire season. A handful of preliminary test cases were studied in to examine SMARTFIRE performance on representative wildfire types.

2. METHODS

The SMARTFIRE algorithm can be divided into two pieces, reconciliation and prediction. The reconciliation algorithm is responsible for merging the input fire data sets into a single cohesive data set of daily area burned. The prediction algorithm uses information in the SMARTFIRE database to provide likely burn locations and sizes for the next day. Next-day burn information is needed for BlueSky to perform its daily smoke predictions. Currently, the prediction algorithm is simple persistence. Next-day burn predictions are identical to the daily area-burn data from the reconciliation algorithm.

Ground-based, manually reported burning data sets record a different subset of fire incidents from satellite-derived data sets (Soja et al., 2005); however, many large fires are recorded by both. Therefore, when attempting to merge these two sources into a single data set, it is necessary to ensure that incidents are not double-counted. To achieve this data fusion, the SMARTFIRE reconciliation algorithm uses spatiotemporal proximity.

Figure 1a shows a reconciliation example for a single day (6/22/2005) of a large wildfire. The Cave Creek fire burned about 250,000 acres (~1000 km^2) in central Arizona between June 21 and July 4, 2005. The area burned over the course of the incident, shown on the map in yellow and orange is derived from the Burned Area Reflectance Classification (BARC; http://www.fs.fed.us/eng/rsac/baer/barc.html) developed by the USFS Remote Sensing Applications Center. BARC classifies post-fire vegetation condition using high spatial resolution satellite imagery and is used here as the "true" area burned. Both ICS-209 and HMS fire data are available on this day. The ICS-209 report shows the point of origin for this wildfire. The satellite data show several hot-spot pixels in the area. SMARTFIRE draws two buffers around the fire pixels. The first buffer is the daily FirePerimeter. The FirePerimeter groups nearby pixels into clusters of contiguous burning and provides an estimate of the daily area burned. The FirePerimeter buffer radius is currently set at 750 m. The FireEnvelope is then drawn 2000 m beyond each FirePerimeter. All FirePerimeters and ICS-209 reports that fall within a single envelope are associated as a single FireEvent. For example, in Figure 1a, all the satellite-detected points, their associated FirePerimeters, and the ICS-209 report point within the envelope are associated as a FireEvent. The ICS-209 point on the left edge of the map is treated as a separate fire.

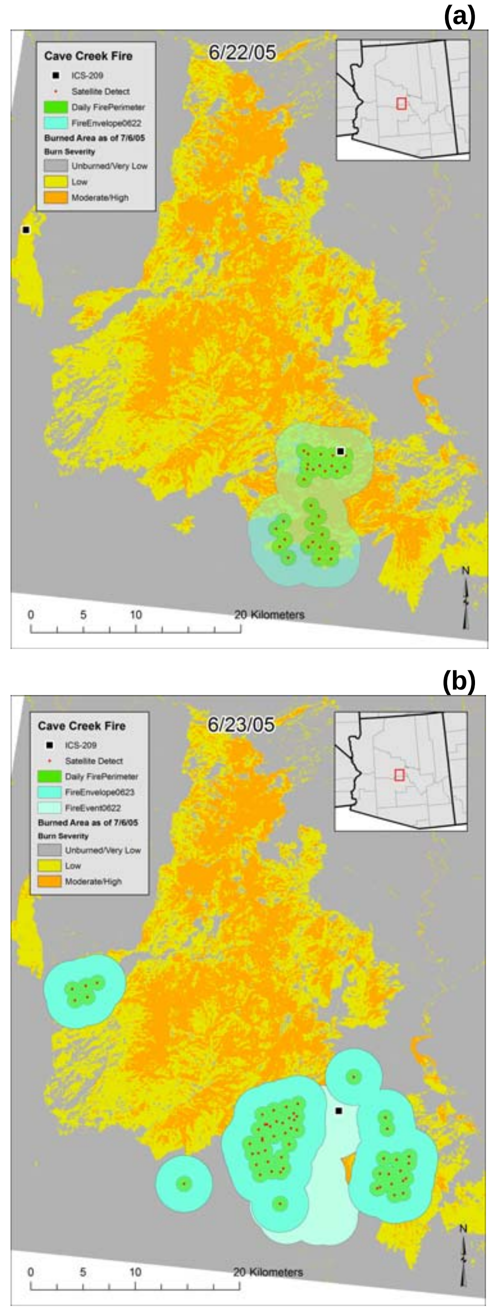

Fig 1. SMARTFIRE algorithm results for the Cave Creek wildfire on (a) the first and (b) the second day of the event.

The next day is shown in Figure 1b. The ICS-209 report has not moved, but the fire has, as seen by the HMS fire pixels. Four new FireEnvelopes were created, but two of them intersect the previous day's FireEvent. When this occurs, SMARTFIRE associates the intersecting FireEnvelopes with the preexisting FireEvent. Thus, as the fire expands away from the point of origin over time, its propagation can be tracked and recorded.

3. RESULTS AND DISCUSSION

All FirePerimeters generated by SMARTFIRE for the Cave Creek wildfire are shown in Figure 2. The total area burned according to these FirePerimeters is about 290,000 acres (1170 km2), which is about 15% higher than the estimates in the final ICS-209 report. Area is overestimated due to the overlap of FirePerimeters from different days. From these perimeters, both the daily locations and burn areas, can be extracted and fed to the BlueSky modeling framework. This improved spatial resolution is important, particularly for a large event such as Cave Creek where the fire advanced nearly 50 km from its ignition point, crossing different ecosystems and fuel types with different smoke emission characteristics.

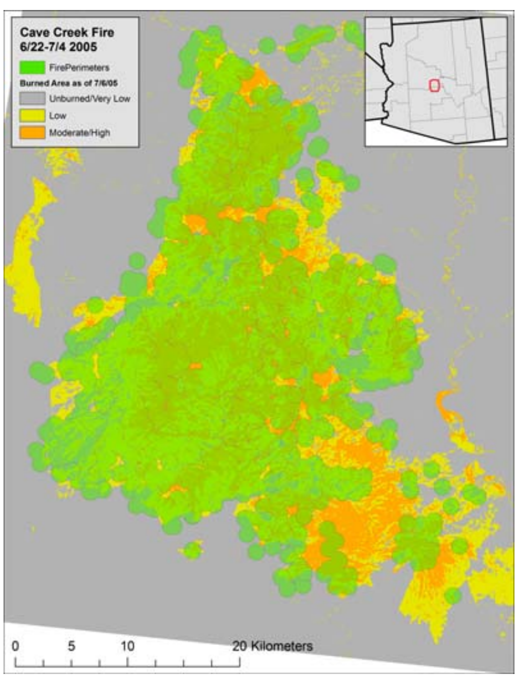

Fig 2. FirePerimeters for the Cave Creek wildfire.

The temporal profile of area burned is also important for making accurate daily smoke predictions. The School fire burned over 50,000 acres in southeastern Washington in early August 2005. Figure 3a shows the daily burned areas from ICS-209 reports, SMARTFIRE output, and the acreage modeled in the current version of BlueSky. ICS-209 reports include the total burned area of the fire up to the current day. Usually, this value increases over time as the fire spreads; however, the value sometimes decreases because the estimates of area burned are refined in subsequent days. BlueSky currently uses one-third of the area reported in the ICS-209 as its daily burn acreage. This results in both an underestimation of daily acreage during the most intense early parts of the fire, and an overestimation at the end of the burning period when the fire is dying out. The SMARTFIRE algorithm takes advantage of the daily time resolution of the satellite input data to produce a more realistic area burned temporal profile. Note that the School fire represents a best-case scenario, when ICS-209 reports are available for every day during the fire.

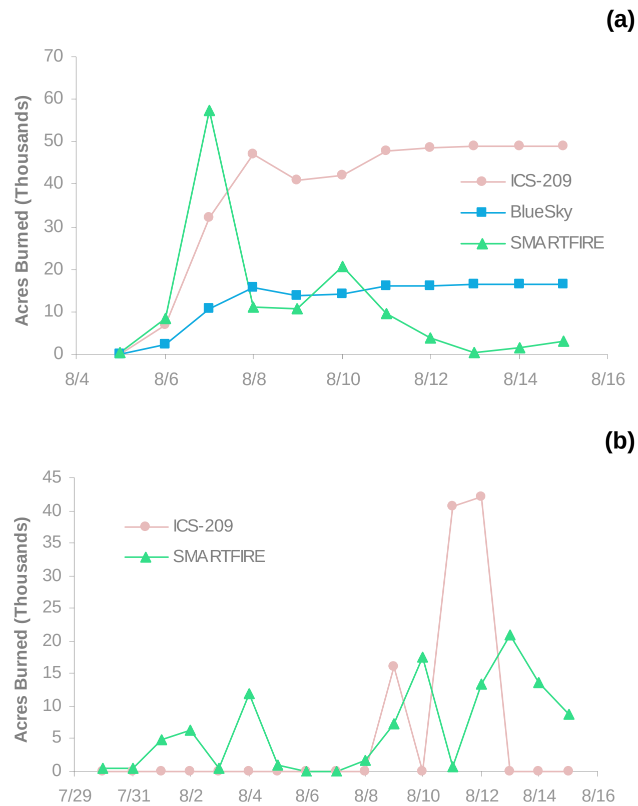

Fig 3. Time series of daily area burned for (a) the School fire and (b) the Grayling Creek fire.

Figure 3b shows the daily burned areas for the Grayling Creek fire in western Alaska, which burned in August 2005. For most of the days in the time period, there were no ICS-209 reports. The first reports on 8/9 and 8/11 represent an estimate of area burned to date, and are thus overestimates of single day burning. The current BlueSky model would predict no smoke from this fire until 8/9, though the satellites detect substantial burning several days prior.

4. SUMMARY

The SMARTFIRE algorithm provides a method for reconciling human-reported fires with satellite-detected fires for input to the BlueSky smoke modeling framework. This merging provides a more comprehensive and spatially accurate data set than either alone, while minimizing double detection. In addition, the temporal profile of area burned is more realistic. However, the algorithm has limitations. Neither data set used in SMARTFIRE reports small fires (less than 300 acres) reliably. While the largest fires account for the majority of emissions (Soja et al., 2006), small fires are important to local $PM_{2.5}$ concentrations. Due to locational errors in the ICS-209 reports, satellite pixels may not be associated with ICS-209 reports of the same incident, even with the 2000-m buffer used to associate data into FireEvents. In these cases, SMARTFIRE will report separate incidents. This is a particular problem for large WFU complexes, which may burn in several discrete areas.

SMARTFIRE currently does not make predictions about next-day burns as required by BlueSky. The algorithm keeps all inputs used to create FireEvents, along with their associated metadata, in a relational database. This database is effectively a database of fire progression. The database will be mined in an effort to develop empirical relationships for predicting next-day burn areas based on previous days' information.

SMARTFIRE results have been verified for a limited number of cases, but have not been fully validated for all regions, ecosystems, and seasons. The parameters in the algorithm have not been optimized. The SMARTFIRE system was designed to expand as other data sets become available and desirable. Prescribed-burn reporting systems are the next data class targeted to be incorporated into the system.

5. ACKNOWLEDGMENTS

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