MODELING WILDFIRE EMISSIONS USING GIS TECHNOLOGY AND SATELLITE DATA

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1. INTRODUCTION

Emissions from biomass burning (prescribed fires, wildfires, and agricultural burns) episodically impact visibility and air quality at regional scales. A GIS-based approach to modeling emissions from fire events was developed to support assessments of these impacts. The approach was originally applied to planned burning events in the central United States to support a regional haze plan being developed by the Central Regional Air Planning Association (CENRAP). A refined version of this GIS-based approach is now being applied to wildfires in New Mexico and surrounding states to support an assessment of ozone episodes in the Albuquerque area during the summers of 2003 and 2005. For the New Mexico inventory, satellite-detected fire locations are being incorporated into the model.

2. TECHNICAL APPROACH

Within the GIS-based model, emission estimates are prepared using fire activity data (information about the size and location of fire events), fuel loadings for the various vegetation types being burned, fuel moisture inputs, and emission factors that provide estimates of emission rates for a given vegetation type, fuel loading, and moisture level. Figure 1 illustrates and summarizes the process by which emission estimates are developed.

2.1 Activity Data

For the CENRAP inventory, prescribed burn activity data were collected from incident-level fire reports in which the beginning date, duration, location, and size of the fire were generally reported. Activity data for agricultural burns were obtained through systematic surveys of county agricultural extension offices.

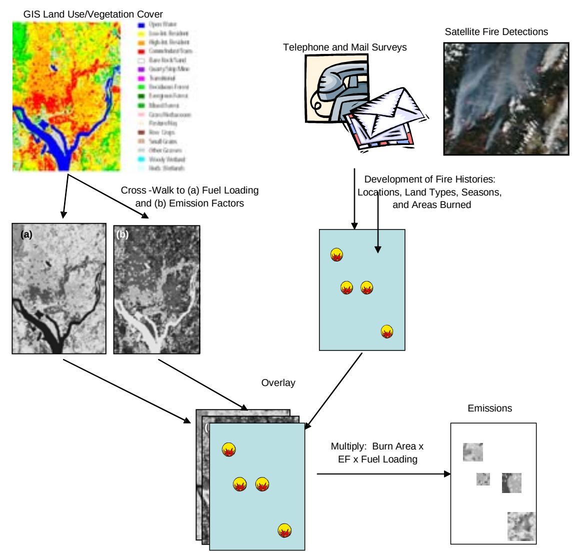

Fig. 1. Illustration of the processes used to develop emission estimates for planned and agricultural fires.

For the New Mexico inventory, activity data collection methods were refined by deriving daily fire locations and size estimates from satellite data. The Moderate Resolution Imaging Spectroradiometers (MODIS) onboard the National Aeronautics and Space Administration's (NASA) Terra and Aqua satellites detect thermal anomalies ("hot spots") on the earth's surface twice per day. Most often, these hot spots are actively burning fires. For large fires, the hot spots were compared with available estimates from Incident Status Summaries (ICS-209) prepared by the incident teams at the individual fires and helicopter-derived cumulative fire perimeters from the Geospatial Multi-Agency Coordination (GeoMAC). These comparisons were used to validate the MODIS fire locations and derived size estimates. Figure 2 shows a comparison between the fire pixels detected by MODIS and the fire location reported in ICS-209 reports for the Frank Church wildfire in Idaho in August and September 2005.

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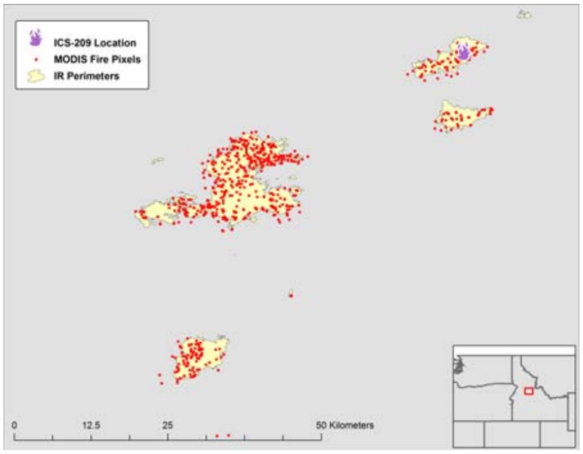

Fig. 2. Comparison of fire reporting and detection methods for the Frank Church fire complex.

2.2 Fuel Data

The GIS-based model requires information on the types of vegetation being burned and the fuel loading factors for each vegetation type. For the CENRAP planned-burning inventory, these data were acquired from the EPA's Biogenic Emissions Landcover Database (BELD) Version 3 (U.S. Environmental Protection Agency, 2001), which provides spatial distributions of vegetation types. However, the BELD database does not contain information on fuel loadings by vegetation type, so the default fuel loading factors contained in the First Order Fire Effects Model (FOFEM), a computing tool developed through the Joint Fire Science Program (JFSP), were utilized (Reinhardt et al., 2006). This methodology was refined for the New Mexico inventory by incorporating fuel loading data from the Fuel Characteristic Classification System (FCCS)(Ottmar et al., 2004).

2.3 Emission Factors

Emission factors (estimates of the quantity of various pollutants emitted per acre burned) were prepared by running the FOFEM model for each vegetation type consumed in a fire event. Inputs to FOFEM include the fuel loading data described above and fuel moisture values obtained from the Weather Information Management System (WIMS), a database of daily weather observations collected from about 1,500 fire weather stations throughout the United States.

For agricultural burning, emission factors for a variety of crop types are published in the EPA's guidance document, "Compilation of Air Pollutant Emission Factors (AP-42)" (U.S. Environmental Protection Agency, 2003) and by Jenkins et al. (1996).

2.4 Emission Calculations

Emission factors generated by FOFEM or acquired from the sources described above were combined with the fire location and vegetation data to produce emission inventories of agricultural and prescribed burning for the CENRAP inventories and wildfires for the New Mexico inventories.

To be useful for air quality modeling purposes, emission estimates must be spatially distributed to the resolution required by the modeling grid (e.g. the network of 12-km by 12-km grid cells employed in the New Mexico study for air quality modeling). In the GIS-based system, emissions are spatially distributed according to location coordinates (i.e., latitude and longitude) obtained from prescribed burn reports or from satellite data.

When the specific locations of fires are not available, a spatial surrogate approach is used to spatially distribute emissions by grid cell. In the CENRAP work, prescribed burns were spatially distributed to rural grasslands and forested lands, while agricultural burns were spatially distributed to agricultural lands by crop type based on data obtained from the agricultural burning surveys.

Where satellite-based activity data are utilized (such as in the New Mexico inventory), satellite-detected hot spots can be used to produce daily estimates of fire size and location. The MODIS fire product has a spatial (pixel) resolution of about 1 km^2. Each hot spot indicates an actively burning fire within the pixel footprint at the time of satellite overpass, twice daily at about 10:30 a.m. and 1:30 p.m. local time for the conterminous United States. A detected hot spot does not mean that the entire 1 km^2 pixel area is burning. Depending on conditions, MODIS can detect fires smaller than 100 m^2. To use the satellite data to estimate burned area, a relationship between the number of hot spot pixels and the total burned area must be established. This relationship varies from fire to fire. For the New Mexico study, satellite hot spots were compared with burn-scar perimeters identified by helicopter overflights. It was found that for the study area and time period, a single MODIS hot spot represented about 0.75 km^2 of daily burned area.

3. RESULTS AND DISCUSSION

The resulting emission inventory for the CENRAP region is illustrated in Figures 3 through 5. The emission source types in the inventory that are qualitatively considered to contribute the most uncertainty to the total estimated emissions are prescribed burning performed by the USFS on publicly managed lands and, to a lesser extent, prescribed burns performed by the forestry industry and organizations such as the Nature Conservancy on privately held lands. New information will be needed to reduce emissions uncertainties. To help mitigate the effects of these uncertainties, CENRAP was provided with an inventory and data file system that can be easily updated with revised emission factors and activity data as new information becomes available.

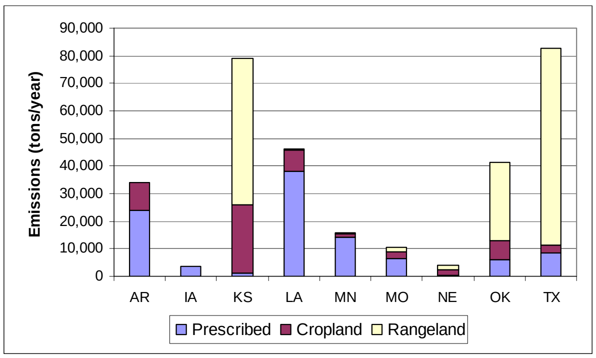

Fig. 3. Total annual $PM_{2.5}$ emissions by burn type for each state of the CENRAP region.

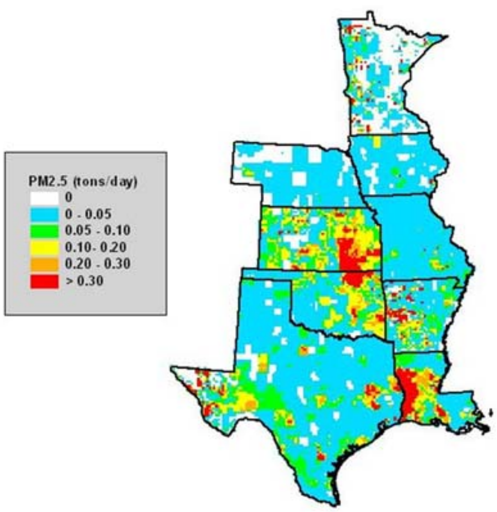

Fig. 4. Example map of daily emission densities for the CENRAP region (April 10, 2002).

Preliminary results for the July 2005 ozone episode modeled in New Mexico show that wildfires burning within the modeling domain (which has a grid resolution of 12-km by 12-km grid cells) emitted approximately 1,200 tons of nitrogen oxides (NO_x) and 39,000 tons of volatile organic compounds (VOC) from June 28 through July 2 (see Figures 5 and 6). Air quality model simulations will be used to determine the contribution of these emissions to ozone concentrations in the region during that period.

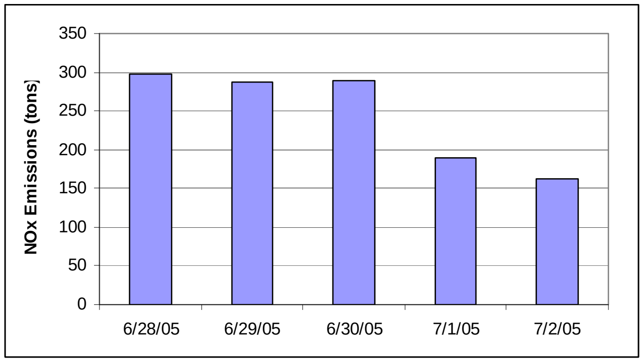

Fig. 5. Daily NO_x emissions from wildfires within the New Mexico modeling domain.

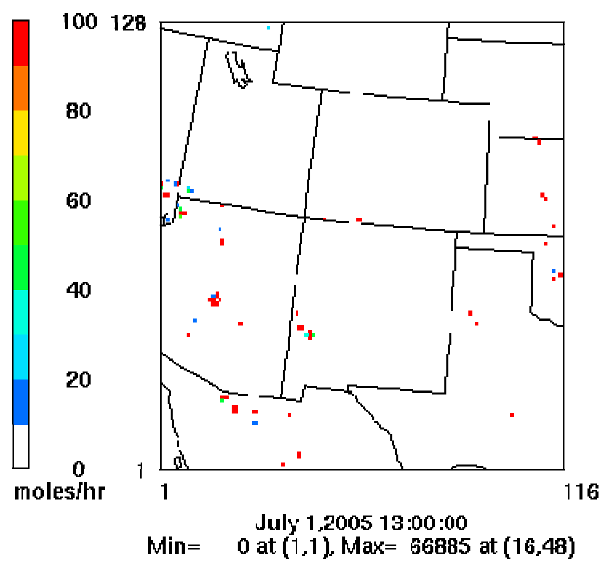

Fig. 6. Spatial distribution of NO_x emissions from wildfires within the New Mexico modeling domain.

4. RECOMMENDATIONS

The results of the GIS-based approach to fire emissions modeling depend on the quality and completeness of the fire histories and emission factors input to the system. Significant effort is required to acquire fire history data. Satellite-derived data are timely and consistent; however, MODIS cannot reliably detect fires smaller than several hundred acres. Fire histories based on human reports suffer from human errors and inconsistencies, but human reports are the only means currently available to characterize fire occurrences below the satellite detection threshold. Thus, a combination of satellite-derived and human-reported fire occurrences offers the best option for preparing the most complete fire history possible.

Emission factors for fires are the subject of ongoing research. Consequently, it is recommended that efforts be made to identify and incorporate improved emission factors related to wildfires and planned burns as they are published.

5. REFERENCES

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