MAPPING THE DAILY PROGRESSION OF LARGE WILDLAND FIRES USING MODIS ACTIVE FIRE DATA

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ABSTRACT

High temporal resolution information on burned area is a prerequisite for incorporating bottom-up estimates of wildland fire emissions in regional air transport models and for improving models of fire behavior. We used the Moderate Resolution Imaging Spectroradiometer (MODIS) active fire product (MO(Y)D14) as input to a kriging interpolation to derive continuous maps of the evolution of nine large wildland fires. For each fire, local input parameters for the kriging model were defined using variogram analysis. The accuracy of the kriging model was assessed using high resolution daily fire perimeter data available from the U.S. Forest Service. We also assessed the temporal reporting accuracy of the MODIS burned area products (MCD45A1 and MCD64A1). Averaged over the nine fires, the kriging method correctly mapped 73% of the pixels within the accuracy of a single day, compared to 33% for MCD45A1 and 53% for MCD64A1.

INTRODUCTION

Landscape fires release large amounts of particulate matter and trace gases into the atmosphere and global estimates of carbon emissions from fires range between 1500-3500 Tg carbon per year (1, 2). On a regional scale, wildfire emissions impact air quality and air pollution, which can have adverse effects on public health, especially when the wildfire emissions disperse into densely populated areas (3). Existing bottom-up inventories for wildfire emissions traditionally assess the emissions from the whole fire perimeter or over multiple perimeters in large areas or have coarser spatial resolutions. As a consequence, these models may not be able to capture day-by-day variations in weather and fuel moisture during fire events, which in turn may bias estimates of combustion completeness and emission factors (4), and propagate into larger emissions uncertainties.

The Moderate Resolution Imaging Spectroradiometer (MODIS) has become one of the primary instruments for moderate resolution fire remote sensing since it was launched on the Terra and Aqua platforms in 1999 and 2002 respectively (5). At the equator MODIS has four daily overpasses: at 0130 hours (Aqua ascending node), 1030 hours (Terra descending node), 1330 hours (Aqua descending node) and 2230 hours (Terra ascending node). This acquisition scheme with multiple images per day is beneficial for retrieving daily information on fire activity. Two types of fire products are consistently generated and distributed from MODIS. These are: 1) the active fire products, which give the location of the fire, 2) the burned area products which provide the extent of burn scars (5). The active fire algorithm is based primarily on the detection of an increase in brightness temperatures in the MODIS 4- and 11-μm channels when fires are active (5). The standard MODIS burned area product (6) makes use of post-fire reflectance changes in the near infrared (NIR) and short-wave infrared (SWIR) spectral regions. In addition to spatial burn extent information, the algorithm also outputs the approximate day of burning, with a nominal uncertainty of up to eight days (6). Boschetti et al. (4) assessed the temporal reporting accuracy of the MODIS burned area product by comparing the day of burning with the active fire detection time as derived from the MODIS active fire product. They found that 50% of the burned pixels had a temporal assignment accuracy of less than a single day and 75% of the burned pixels had accuracies of within four days of the actual burning date. Giglio et al. (7) describe another MODIS burned area product that combines information on post-fire reflectance changes in the NIR and SWIR spectral regions with active fire detection in the thermal infrared region. As with the burned area product of Roy et al. (6), the Giglio et al. (7) product also provides information on the day of burning.

While temporal information on the day of burning has been included in both the MODIS active fire and burned area products for many years, relatively few studies have attempted to use this information to derive data on fire progression at local to regional scales. At these scales, fire progression information can significantly enhance bottom-up estimates of emissions (4) and enables analysis of the sensitivity of fire spread rates to local environmental conditions (e.g. wind speed, wind direction, relative humidity, air temperature, topography, fuel types). In this study we use kriging (8), a well-accepted interpolation technique, for retrieving fire progression maps at moderate resolution scale using MODIS active fire data. We compared our estimates of the time of burning with high resolution fire perimeter data extracted from nighttime airborne infrared acquisitions, and with the approximate day of burning provided by the MODIS burned area products of Roy et al. (6) and Giglio et al. (7).

DATA AND METHODS

In this study the progression of nine large wildfires in the Southwestern US was calculated (Figure 1). These wildfires were selected because of the availability of high resolution daily fire perimeter data derived from nighttime airborne infrared imagery available by the US Forest Service. The timing and locations of the Terra and Aqua thermal anomalies/fire 5-min (1 km) products (MOD14 and MYD14) were used to construct the fire progression model. We used ordinary kriging to derive spatially continuous maps of the time of burning. Kriging is a geostatistical interpolation technique that calculates values at unknown locations based on a scattered set of known locations. The values at the unknown locations are calculated based on a combination of the distance to the known locations and the spatial arrangement of the known locations. The spatial arrangement of the known locations is quantified by fitting variogram curves. A variogram describes the spatial variability of a variable. A variogram is used to analyze the amount of spatial autocorrelation in a dataset. Observations that are close to each other are generally more alike than more distant observations. A variogram curve is parameterized by the range, sill and nugget. We fitted spherical models for each fire separately to derive the range, sill and nugget as input to the kriging interpolation.The resulting fire progression map was compared with the daily perimeter data from the US Forest Service and with the dates of burning reported by the two types of MODIS burned area products - both at 500 m resolution: combined MODIS Terra and Aqua monthly burned area products (500 m) MCD45A1 (6) and MCD64A1 (7).

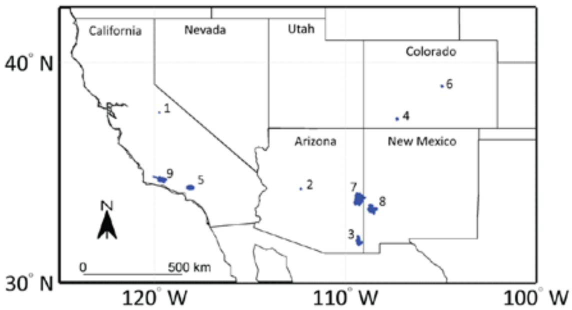

Figure 1: Fires included in this study: (1) 2009 Big Meadow fire (CA), (2) 2012 Gladiator fire (AZ), (3) 2011 Horseshoe fire (AZ), (4) 2012 Little Sand fire (CO), (5) 2009 Station fire (CA), (6) 2012 Waldo Canyon fire (CO), (7) 2011 Wallow fire (AZ-NM), (8) 2012 Whitewater Baldy (NM) and (9) 2007 Zaca fire (CA).

RESULTS AND DISCUSSION

Figure 2 shows the different data layers included in this study for the case of the Wallow fire. Table 1 summarizes the time difference between the kriging, MCD45A1, and MCD64A1 data and the fire perimeter data. On average, 34% of the data (standard deviation = sd = 15%) was assigned the correct day of the year by the kriging method, compared to 12% (sd = 6%) and 21 % (sd = 7%) for the MCD45A1 and MCD64A1 products, respectively. Averaged over the nine fires, the kriging model demonstrated a within-one-day accuracy of 73%, which outperformed the temporal accuracies of the day of burning reported by the MCD45A1 and MCD64A1 products by 40 and 20% respectively. Given the native 1 km resolution of the MODIS active fire data, the method will only be adequate for large fires with a significant number of active fire detections. In a global accuracy assessment of the day of burning reported by the MCD45A1 product, Boschetti et al. (4) found that 50% of the burned area detections occurred within the accuracy of a single day. We found that 33% of the burned pixels within the MCD45A1 product were assigned the date within a single day accuracy, when averaged over the nine fires in this study. Although the fires included in this study occurred in different ecosystems including grassland, shrub land and coniferous forest, the overall accuracy depends on the selected study and thus our results should not necessarily agree with the global accuracy assessment, e.g. the one reported by Boschetti et al. (4). It was also clear that the MCD64A1 product outperformed the MCD45A1 product. The synergetic use of post-fire reflectance changes and active fire detections in the MCD64A1 product clearly increased the temporal reporting accuracy compared to the precursor MCD45A1 product, which is based solely on post-fire reflectance changes (7).

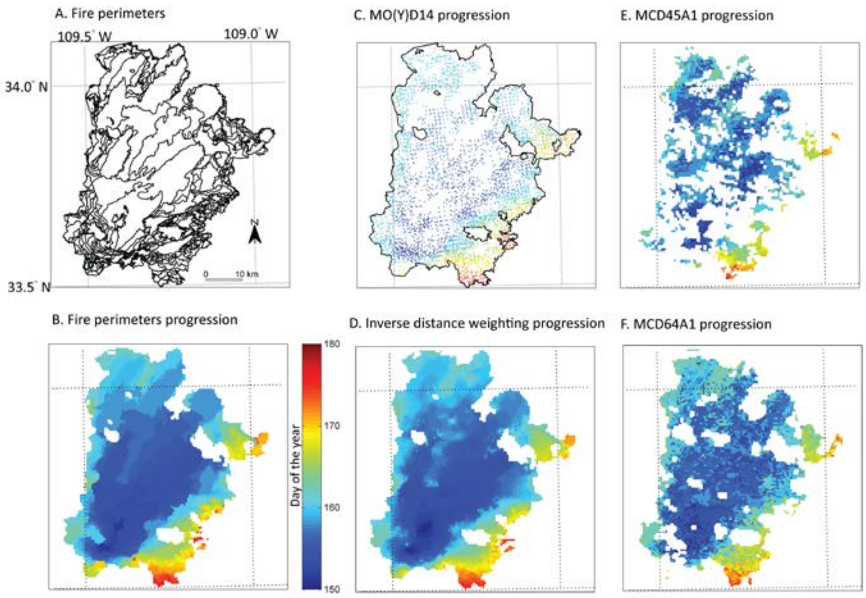

Figure 2: Observed and derived fire progression for the 2011 Wallow fire in Arizona and New Mexico.

Table 3: Average (standard deviation) reporting accuracy over the nine fires (Figure 1) within zero, one, two and three days for the comparison between daily US Forest Service (USFS) perimeter data and kriging results, and the MCC45A1 and MCD64A1 products (%).

	0 days	1 day	2 days	3 days
USFS-kriging	34 (15)	73 (15)	87 (10)	93 (7)
USFS-MCD45A1	12 (6)	33 (15)	49 (21)	63 (25)
USFS-MCD64A1	21 (7)	53 (5)	73 (5)	86 (3)

CONCLUSIONS

This study presented a kriging interpolation to construct continuous fire progression maps from MODIS active fire data at a moderate spatial scale (500 m). Overall the kriging interpolation mapped 73% of the area burned within the accuracy of a single day and outperformed the two existing MODIS burned area products (MCD45A1 and MCD64A1). Spatially explicit temporal wildfire emissions are a critical input for a variety of applications such as regional air transport models. Temporal information on burned area progression is also important to allow temporal bottom-up inventories of wildfire emissions. In addition, fuel load and combustion completeness estimates generally require weather inputs to account for the fuel moisture content. Fire progression maps allow these variables to vary temporally instead of assuming a fixed value for the whole fire event. Fire progression maps also permit studying the environmental controls such as fire weather and fuel distributions on fire behavior and fire characteristics (e.g. size, fire severity, etc.). The method presented here has potential for improving fire emissions estimates and for validating and constructing better fire behavior models.

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