METEOROLOGICAL CONTROLS ON BIOMASS BURNING DURING SANTA ANA EVENTS IN SOUTHERN CALIFORNIA

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ABSTRACT

Fires occurring during Santa Ana (SA) events in southern California are driven by extreme fire weather characterized by high temperatures, low humidities, and high wind speeds. We studied the controls on burned area and carbon emissions during two intensive SA burning periods in 2003 and 2007. We therefore used remote sensing data in parallel with fire weather simulations of the Weather and Regional Forecast model. Total carbon emissions were approximately 1800 Gg in 2003 and 900 Gg in 2007, based on a daily burned area and a fire emission model that accounted for spatial variability in fuel loads and combustion completeness. On a regional scale, relatively strong positive correlations were found between the daily Fosberg fire weather index and burned area/emissions ($p < 0.01$). Our analysis provides a quantitative assessment of relationships between fire activity and weather during severe SA fires in southern California.

INTRODUCTION

In southern California, the number of fires peaks during summer (June-August), while the burned area is highest during fall (September-November) (1). The seasonal offset between the timing of the maximum number of fires and burned area is explained by the so-called Santa Ana (SA) effect (2). SA conditions typically develop between September and April when a high pressure cell develops above the Great Basin concurrently with a low pressure cell off the southern California coast (3). Early SA events (September-November) occur when vegetation moisture is generally low after a dry and hot mediterreanean summer (2). In addition, SA events are associated with extreme fire weather (high temperatures, low humidities, and high wind speeds) and as a consequence a relatively small number of fires can rapidly spread over large areas and inflict considerable damage on nearby communities (2, 4). SA events have distinctive synoptic and local characteristics (3). During SA events relatively dry air from the high desert is blown downslope through southern California's mountain ranges. These katabatic winds are subject to adiabatic warming as they descend in altitude from the high desert. Winds gain significant speed as they are channeled through mountain gaps and canyons. As a consequence, areas downwind of southern California's mountain gaps experiencing larger fires during SA events compared to areas that are relatively more sheltered (4). The southern California firestorms of 2003 and 2007 are examples of such events (2, 5).

Between October 23 and October 30, 2003, more than 280000 ha of wildland burned in southern California, USA (Figure 1). Four years later, between October 21 and October 29, 2007, more than 190000 ha burned. As a consequence of these two relatively short duration events, total annual burned area during 2003 and 2007 were among the highest on record (Fire and Resource Assessment Program (FRAP), http://frap.cdf.ca.gov/data/frapgisdata/statewide/fire_perimeter_download.html, last accessed on July 30, 2013). Most of the area burned during the fires consisted of chaparral shrubland or coastal sage with smaller fractions of forests and woodlands. Our aim was to study the interactions between the fire weather and fire activity during the large SA events of 2003 and 2007.

METHODS

Weather variables relevant to fire danger, near-surface wind speed, air temperature and relative humidity (6), were reconstructed using version 3.3.1 of the National Center for Atmospheric Research (NCAR) Weather Research and Forecasting (WRF) model (7). The innermost nested domain of the model covered the study area (Figure 1) with a 2 km resolution. The National Center for Environmental Prediction 3-hourly 32 km resolution North American Regional Reanalysis archive (8) provided the necessary boundary conditions over the time period analyzed. The model was initialized on August 30 of each year (2003 and 2007). The model outputs are in hourly intervals. We calculated the regional Fosberg fire weather index (FFWI) which is a function of temperature, relative humidity, and wind speed (6).

Fire perimeters of fires larger than 500 ha that occurred during the 2003 (October 23-30) and 2007 (October 21-29) SA events (2, 5) were derived from the official mapped fire history from California's FRAP data. We derived daily burned area using MODIS active fire data. Terra and Aqua MODIS thermal anomalies/fire 5-min (1 km) products (MOD14 and MYD14) were downloaded for each fire through the Reverb warehouse (http://reverb.echo.nasa.gov, last accessed on July 30, 2013). We used a simple spatial interpolation method, inverse distance weighting (IDW), to derive spatially continuous maps of the time of burning. The IDW interpolation was bound within the fire perimeter. The sub-daily estimates of time of burning of the IDW model were binned into daily intervals. We created the final burned area product at a 1 km resolution, similar to the nadir resolution of the MO(Y)D14 product.

We used a multiplicative approach to estimate the emissions from the fires, following the same method as described in Veraverbeke and Hook (9). The estimation of C emissions by wildfires (CE in kg C/day) required quantification of the area burned (BA in m^2/day), the fuel load (FL in kg biomass m^{-2}), the combustion completeness (CC, unitless), and the C fraction of fuel load (CF; unitless). We used the Fuel Characteristic Classification System (FCCS, 10) to characterize the fuel load. We used the Consume 3.0 model (11) scaled by the burned fraction derived from spectral mixture analysis applied on post-fire Landsat imagery to estimate combustion completeness. Finally, for the fraction of C biomass we used a fixed value of 0.48. The C emissions model produced estimates at 30 m resolution and at a daily time step.

RESULTS AND DISCUSSION

Figure 1 illustrates the interaction between the fire weather severity and the fire activity for the peak fire day (October 22) of the 2007 firestorm. The fire locations are on or nearby the wind corridors that experienced more severe fire weather.

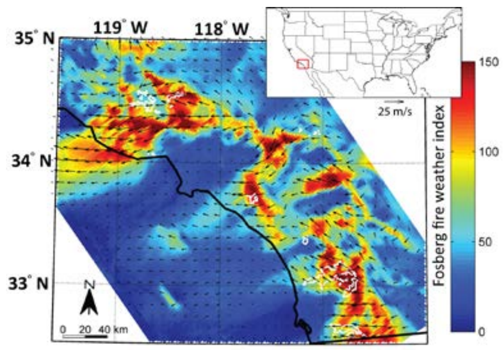

Figure 1. Fire weather severity, as indicated by the Fosberg fire weather index, and burned area (white perimeters) during the peak fire day (Day of the year 295 = October 22) of the 2007 Santa Ana firestorm in southern California. Wind speed and direction are indicated by the black arrows.

The regional daily variation in burned area and C emissions was positively correlated with the regional daily FFWI for both the 2003 and 2007 firestorms (Figure 2). For 2003, the correlation between the regional FFWI and burned area was 0.81 ($p < 0.01$), and 0.71 ($p < 0.01$) between FFWI and C emissions. Similarly, for 2007, the correlation between FFWI and burned area was 0.89 ($p < 0.01$), and 0.86 ($p < 0.01$) between FFWI and C emissions.

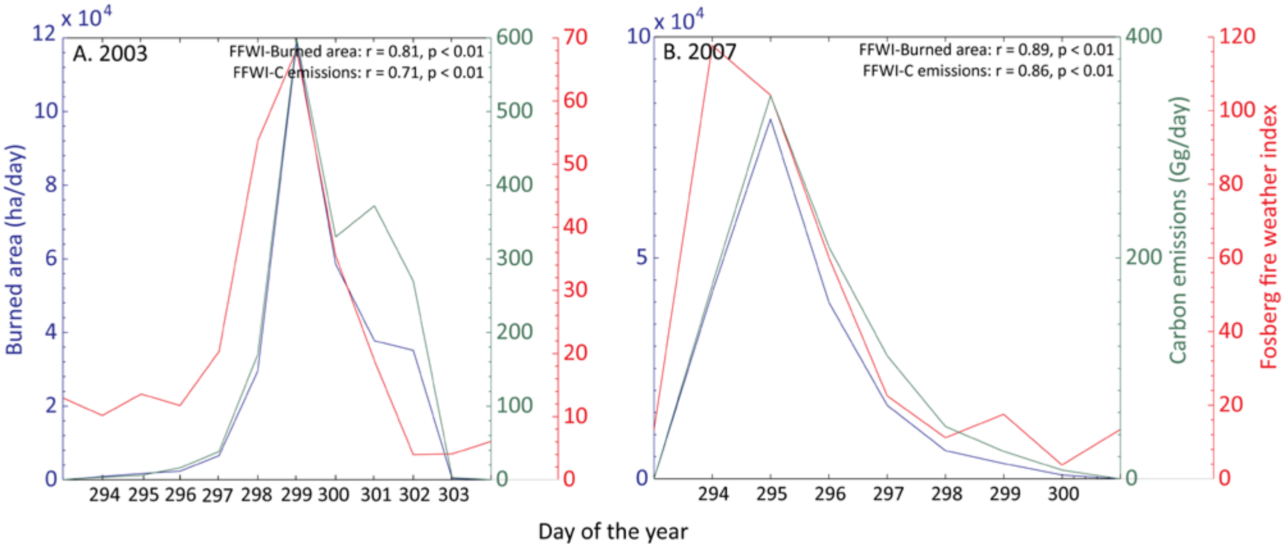

Figure 2. Time series of the total burned area/C emissions in the study area and the regional Fosberg fire weather index for (A) 2003 and (B) 2007.

The growth of fires during the 2003 and 2007 SA events was largely controlled by the timing and location of the ignitions. The timing of the ignition determines how much time a fire had to spread under severe fire weather conditions. The location of the fire sets two controls on the fire growth. First, the location of the fire relative to the main SA wind corridors determined the strength of the conditions under which the fire was able to grow (Figure 1). Second, the location of the ignition in the landscape relative to the developed areas in the direction of the prevailing westward wind direction determined the maximal growth of fires that ran into no-fuel areas. On a regional scale, there was a clear relationship between fire weather severity and fire activity (Figure 2). Under SA conditions strong offshore winds determined the direction and spread of the fires. When Santa Ana conditions weakened, an onshore ocean breeze during the day typically resulted in smaller eastwards extension of the fires. Strong and dry winds have since long been known as a key driver of fire spread (6). Due to the synoptic pressure difference between the Great Basin and the southern California coast, dry air from the inland desert areas is driven leeward over southern California's mountain ranges. This offshore flow of dry and hot wind significantly gains speeds in canyons by the Venturi effect. These combined characteristics (hot, dry and strong winds) create very severe fire weather.

CONCLUSIONS

The dry, hot and strong SA winds in southern California provide some of the earth's most severe fire weather. In 2003 and 2007, large firestorms burned more than 290000 and 190000 ha respectively, with 11 fires larger than 500 ha in each year. We used satellite observations and weather simulations to study controls on daily burned area and emissions. According to our model approximately 600 Gg carbon was emitted during the peak fire day of 2003, and approximately 350 Gg carbon on the peak fire day of 2007. We also found that at a regional scale, the daily burned area and carbon emissions were strongly related with the regional Fosberg fire weather index. The size of the other fires was controlled by the time they burned under SA conditions and the location of the fire relative to the main wind corridors in the landscape. This study gives additional evidence of the strong climatic forcing of the extreme fire activity during SA events in southern California.

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REFERENCES

1 Keeley J, & C Fotheringham, 2001. Historic fire regime in southern California shrublands. Conservation Biology, 15: 1536:1548

2 Keeley J, H Safford, C Fotheringham, J Franklin, & M Moritz, 2009. The 2007 Southern California wildfires: lessons in complexity. Journal of Forestry, 107: 287:296

3 Hughes M, & A Hall, 2010. Local and synoptic mechanisms causing Southern California's Santa Ana winds. Climate Dynamics, 34: 847:857

4 Moritz M, T Moody, M Krawchuk, M Hughes, & A Hall, 2010. Spatial variation in extreme winds predicts large wildfire locations in chaparral ecosystems. Geophysical Research Letters, 37: L04801

5 Keeley J, C Fotheringham, & M Moritz, 2004. Lessons from the October 2003 wildfires in Southern California. Journal of Forestry, 102: 26:31

6 Fosberg M, 1978. Weather in wildland fire management: The fire weather index, paper presented at the Conference on Sierra Nevada Meteorology, American Meteorological Society, South Lake Tahoe, CA

7 Skamarock W, J Klemp, J Dudhia, D Gill, D Barker, W Wang, & J Powers, 2008. Description of the Advanced Research WRF Version 3, NCAR/TN 475+STR 2008, Boulder, CO

8 Mesinger F, G DiMego, E Kalnay, K Mitchell, P Shafran, W Ebisuzaki, D Jovic, J Woollen, E Rogers, E Berbery, M Ek, Y Fan, R Grumbine, W Higgins, H Li, Y Lin, G Manikin, & D Parrish, 2006. North American Regional Reanalysis. Bulletin of the American Meteorological Society, 87: 343-360.

9 Veraverbeke S & S Hook, 2013. Evaluating spectral indices and spectral mixture analysis for assessing fire severity, combustion completeness and carbon emissions. International Journal of Wildland Fire, in press.

10 Ottmar R, D Sandberg, C Riccardi, & S Prichard, 2007. An overview of the Fuel Characteristic Classification System. Canadian Journal of Forest Research, 37: 2383-2393

11 Ottmar R, S Pritchard, R Vihnanek & D Sandberg, 2006. Modification and validation of fuel consumption models for shrub and forested lands in the southwest, Pacific Northwest, Rockies, Midwest, southeast and Alaska. Final Report JFSP 98-1-9-06, pp. 1–97