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JFSP Project 11-1-7-2
Impacts of Mega-Fire on Large U.S. Urban Area Air Quality under Changing Climate

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Summary

Major research conducted

(1) Concurrence probability of large fires across the contiguous U.S. regions was analyzed using burned area data during 1980-2012, and the future trends under the changing climate were projected based on dynamically downscaled regional climate change scenarios to provide information for fire and air quality mangers to evaluate the current and future air quality impacts of wildfires that could intensify due to multiple large fires occurring simultaneously.

(2) The capacity of the dynamic land ecosystem model (DLEM) in simulating fuel and fire was enhanced by coupling improved fire module. Future fuel loading and burned area were projected using the DLEM-Fire model.

(3) An approach using the Fourier analysis was developed to fill the data gap with the dynamical downscaling produced by the North American Regional Climate Change Assessment Program (NARCCAP), which are used for this project.

(4) A burned area detection algorithm was developed that combines advantages of two commonly used approaches of more accuracy and reliability with the multi-temporal NDVI / reflectance change detection and more practicality with the empirical spectral threshold.

Major findings

(1) A large fire in a western region is likely to be accompanied by one or more large fires in another western region at the same time. Opposed to the increasing trends in future fire

potential, the concurrence probability of large fire potential is expected to become smaller in the future in most continental U.S. regions, mainly due to increased spatial variability of future precipitation.

(2) Total fuel load of the conterminous US varies from 2.54 during 1971-2000 to 2.72 Pg C/yr during 2041-2070. Interannual variations fuel load are mainly controlled by precipitation. Increases of fuel load mainly would occur in the western, northeastern and part of north-central US. Large decreases would happen in the west costal region, west of Texas, parts of Florida and the great Lakes areas.

(3) The newly developed approach using the Fourier analysis to fill the data gap with the dynamical downscaling of regional climate change scenarios showed good skills. It is a useful tool for increasing the capacity and value of regional climate change scenarios not only for forest fuel and fire projections but also for applications with various other NARCCAP users.

(4) Experimental results with the developed burned area detection algorithm were found consistent in spatial distribution for tested fire cases, and effective and accurate in quantitative analyses. The algorithm thus has the potential for monitoring and tracking spatial developments of burned areas and smoke in rapid response applications.

Accomplishments

1. Projection of concurrence probability of U.S. wildfire under changing climate

The future trends in wildfire potential for the continental United States under a changing climate were projected in the first year (2012) of this project. Future fire trends were further investigated in the second year (2013) by projecting concurrence probability of U.S. wildfire. Fire concurrences probability measures how often large fires occur at the same time in more than one region. The current status of concurrence probability of large fires across the contiguous U.S. regions was analyzed using actual burned area data during 1980-2012. The future trends in concurrence probability of large fire potential under the changing climate were projected based on dynamically downscaled regional climate change scenarios. The results should provide useful information for fire and air quality mangers to evaluate the air quality impacts of wildfires that could intensify due to multiple large fires during a same fire season.

Figure 1 shows regional averages of the current summer concurrence probability of large fires (over 50 k acres with each fire). The concurrence probability values for the four western regions are between 30-50%. This suggests that, in one out of two or three cases, a large fire in a western region would be accompanied by one or more large fire in another western region at the same time. The concurrence probability is much smaller in the eastern regions, and is very small in all regions during spring.

Figure 2 compares concurrence probability of large summer fire potential between the present and future periods. Opposed to the future trends in fire potential as found before from this project, which indicates more intense fires in the future in most continental U.S., the concurrence probability of large fire potential is expected to become smaller in the future. Large reduction is found in PS, SW, NW, and SC. This suggests that future fires would become more intense but more localized. Same concurrence analyses to temperature and precipitation indicate that this change is mainly caused by increasing spatial variability of future precipitation.

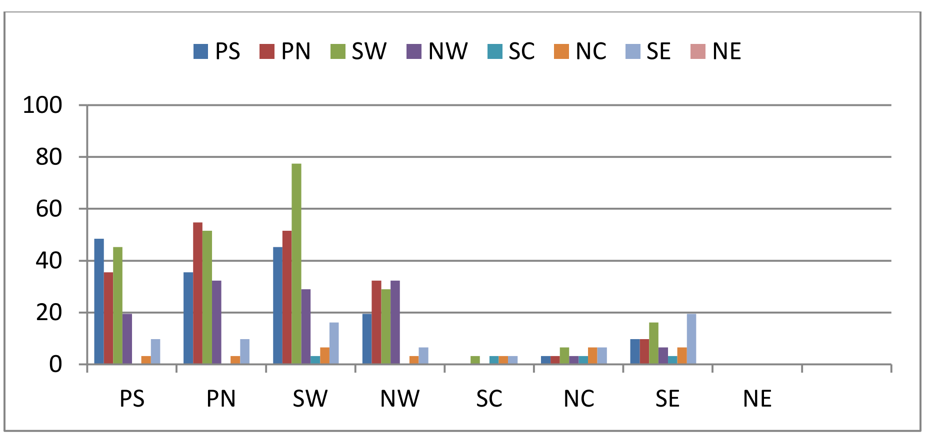

Figure 1 Current concurrence probability (%, vertical) of fires (burned area > 50k acres) during summer. The regions (horizontal) are Pacific South (PS), Pacific North (PN), Southwest (SW), Northwest (NW), South Central (SC), North Central (NC), Southeast (SE), and Northeast (NE). The bars from left to right for each region are probability between this region with all regions.

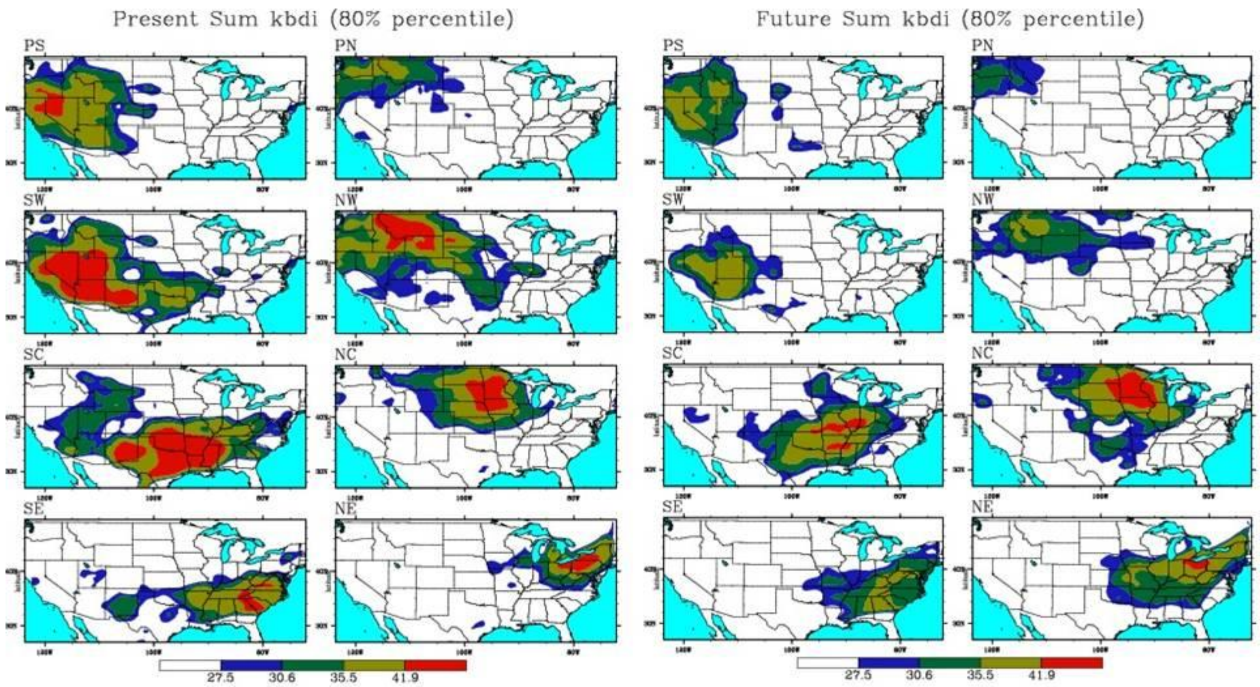

Figure 2 Concurrence probability of large fire potential (KBDI in 80% percentile) during summer. The left and right parts are for present and future period, respectively. Each panel in one part shows concurrence probability between one specific region and rest of the continental U.S. Refer to the Figure 1 caption for these regions.

2. Projections of future fuel loading with improved dynamic land ecosystem model fire module (DLEM-Fire)

In the improved DLEM-Fire model, human activities and lightning strikes are added and assumed as the two primary ignition sources and parameterized as functions of population density and lightning frequency. The ignition probability is regulated by fuel abundance and fuel moisture. Surface fire spread rate, fire intensity, flame height are estimated through a fire behavior model. The improvement of DLEM-Fire on fire impacts includes the parameterization fire consumption and fire-induced vegetation mortality. Fire consumption of vegetation, litter, and soil organic matter (duff and peat) is estimated through combustion completeness, which is related to fire intensity and fuel moisture content. Multiple gases and particles emitted from fire events (e.g. CO_2, CO, CH_4) are computed through biomass consumption and emission factors.

Before transient run, we used climate data, atmospheric CO_2 concentration, and nitrogen deposition in 2040 to run the model until equilibrium state. Land use types and land management practices were same as the year of 2010. Then, we spun the model to reach a dynamic equilibrium. The preliminary results (Figures 3 and 4) indicate that the total fuel load of the conterminous US varies from 2.54 to 2.72 Pg C/yr during 2041-2070. The averaged fuel load during this period is approximately 2.63 Pg C/yr, which would be 0.24 Pg C higher than the average value during 1971-2000. In response to changes in climate, atmospheric composition, the total fuel load would have a decreasing trend during 2041-2070 in response to precipitation decrease after 2060s. Interannual variations fuel load are mainly controlled by precipitation. While investigating spatial pattern of fuel load, increases of fuel load mainly would occur in the western US, northeast US and part of north-central US as compared to the period of 1971-2000; Large decreases would happen in the west costal region, west of Texas, parts of Florida, Minnesota, Wisconsin, and Michigan in response to warming and precipitation decrease. In addition, south-central region would experience a small decrease of fuel load.

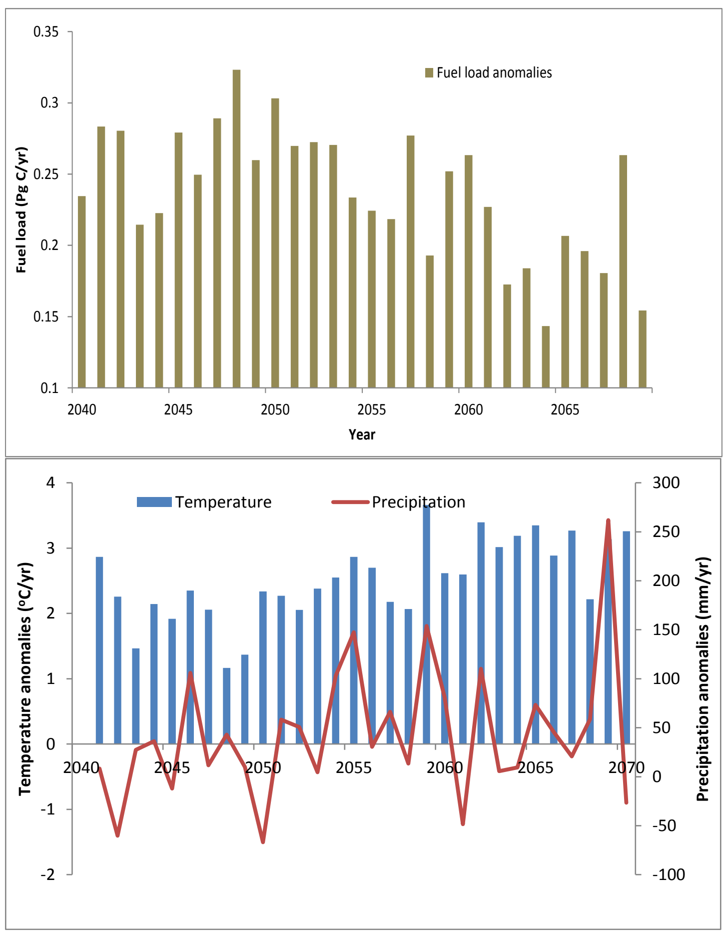

Figure 3 Anomalies of fuel load (top), temperature and precipitation (bottom) during 2041-2070 relative to the mean values of 1971-2000.

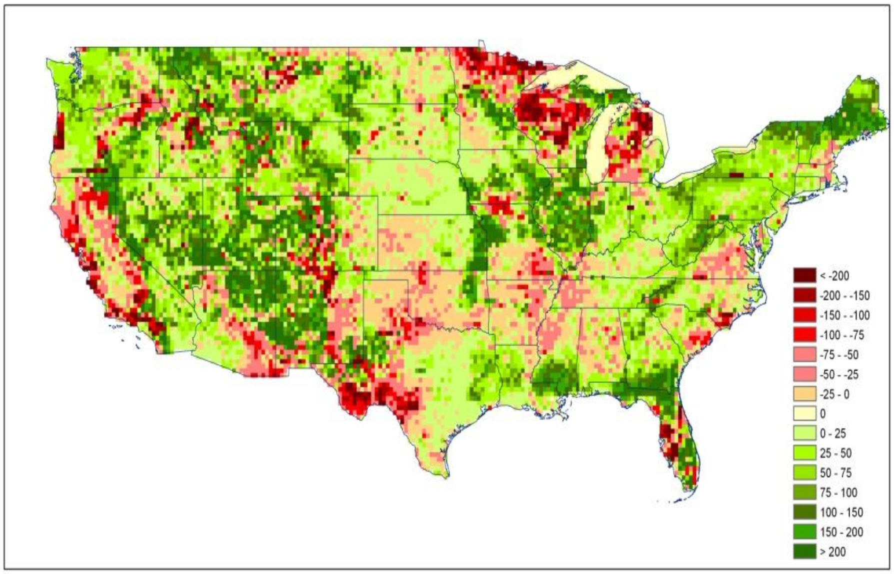

Figure 4 Changes of fuel load between 1971-2000 and 2041-2070.

3. Time gap filling of dynamical regional climate change scenarios for fire research

The regional climate change scenarios using dynamical downscaling produced by the North American Regional Climate Change Assessment Program (NARCCAP) have been used for this project. As most dynamical downscaling products, the NARCCAP regional climate change scenarios have a time gap (no data available) from 2001-2040 between the two separate periods (data available) of 1971-2000 (present) and 2041-2070 (future). While the gap does not affect mega-fire analyses and projections which are based on the climate condition at the same time, it affects fuel loading and burned area projections using the dynamic global vegetation models (DGVMs) because these models have to be run continuously from the present to future time. Filling the data time gap is valuable not only for forest fuel and fire projections using DGVMs but also for applications by various other NARCCAP users. Thus, the effort in developing time gap approach would be beneficial to JFSP by increasing its interactions with climate change research community.

An approach using the Fourier analysis was developed to fill the data gap. The available climate data for the current and future periods are expanded into the Fourier series. The expanding coefficients are the intensity spectrum of variability at various time scales. The spectrum would change in the future. For example, it is expected that the intensity for the drought scales would become larger. The moving averages of the coefficients of the two series are used to construct time series for the missing period. Figure 5 compares the errors between this approach with a linear trend approach. The new approach reduces the errors by 10-20%.

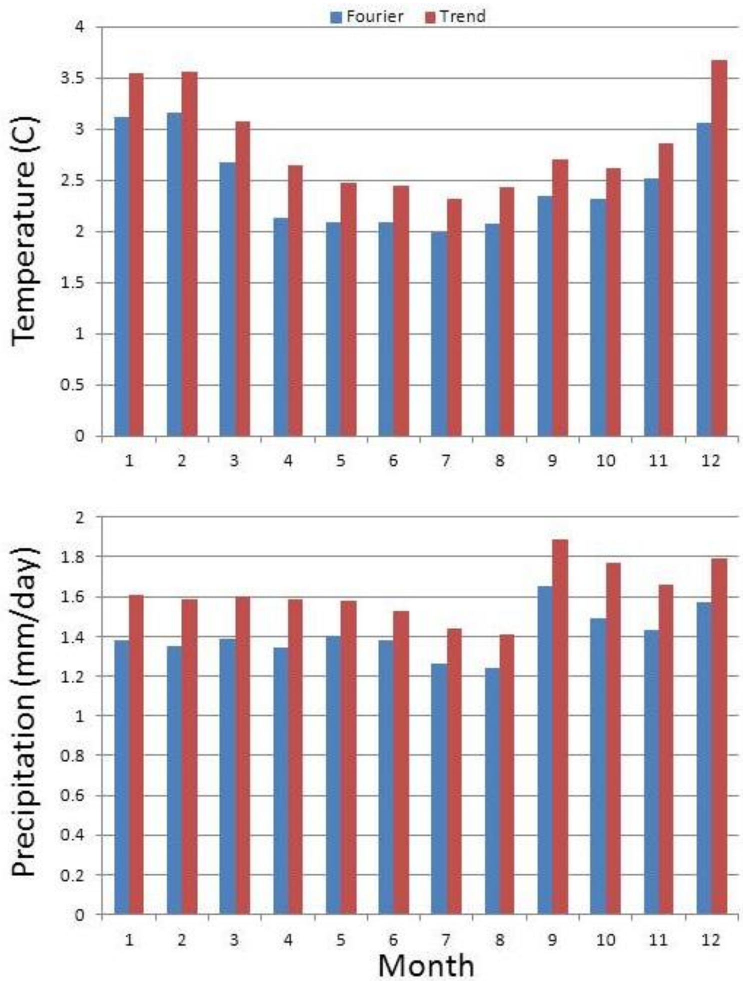

Figure 5 Errors of filled data averaged over the continental U.S. The top and bottom panels are for temperature and precipitation. The blue and red bars represent the Fourier analysis and linear trend approach, respectively.

4. Detection of smoke from mega-fires

A novel burned area detection algorithm was developed that combines advantages of two commonly used approaches, that is, more accuracy and reliability with the multi-temporal NDVI or reflectance change detection and more practicality with the empirical spectral threshold, which is based on knowledge of post-fire spectral information. The algorithm consists of four statistical differences of spectral and composite predictors and a support vector machine classification for MODIS 500-meter surface reflectance data. It is a single day burned area detection scheme, but historical statistical information is also involved in the determination of burned pixels. Therefore, it has the potential for monitoring and tracking spatial developments of burned areas in rapid response applications.

The algorithm was applied to detecting and mapping burned areas caused by several mega-fires occurred in the continental United States. Figure 6 shows the Wallow Fire case. Experimental results were validated using fire perimeter database generated by the Geospatial Multi-Agency Coordination Group or GeoMAC, and compared with the MODIS level 3 monthly MCD45 product. The algorithm was found consistent in spatial distribution for tested fire cases, and effective and accurate in quantitative analyses.

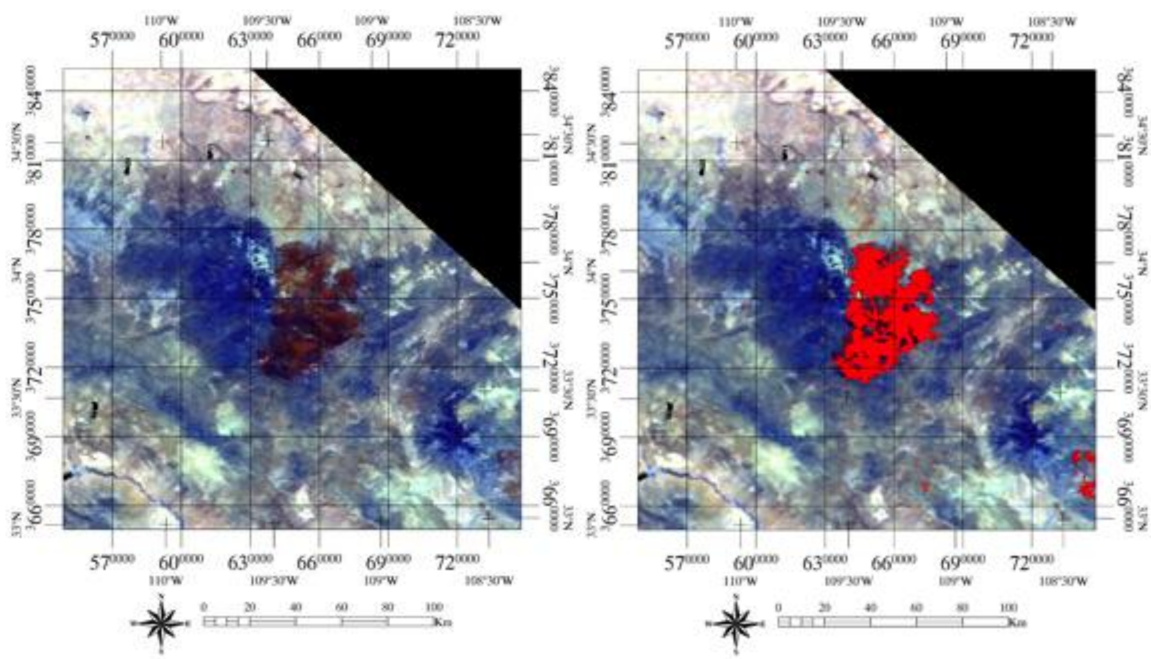

Figure 6. The Terra MODIS data acquired over Arizona, US at 17:40 UTC, Jun. 11, 2011. (a) False color image (red: 2.13 μm, green: 1.64 μm, blue: 1.24 μm). (b) Detected burned area by the proposed algorithm (overlaid in red).

Deliverables

Manuscripts

1. Liu, Y. –Q., Goodrick, S. L., Stanturf, J.A., 2013, Future U.S. wildfire potential trends projected using a dynamically downscaled climate change scenario, Forest Ecology and Management. 294:120-135. DOI: 10.1016/j.foreco.2012.06.049.
2. Liu, Y.-Q., Goodrick, S., Heilman, W., 2013, Wildland fire emissions, carbon and climate: Wildfire-climate interactions, Forest Ecology and Management (online version published).
3. Liu, Y.-Q., Prestemon, J., Goodrick, S., Holmes, T., Stanturf, J., Vose, J., Sun, G., 2013, Future Wildfire Trends, Impacts, and Mitigation Options in the Southern United States, in "Climate Change Adaptation and Mitigation Management Options in Southern United States" (to be published in November).
4. Mitchell, R. J., Y.Q. Liu, J. O'Brien, K. J. Elliott, G. Starr and C.F. Miniat, 2013, Future Climate and Fire Interactions in the Southeastern Region of the United States. Forest Ecology and Management (revision submitted)
5. Zhang, R., J. J. Qu, Y.Q. Liu, X. Hao, 2013 Detecting burned area of mega-fires using single-day and historical average MODIS surface reflectance. (to be submitted to Int'l J. Wildland Fires)
6. Yang, J., H. Tian, B. Tao, W. Ren, J. Kush, Y.Q. Liu and Y. Wang, 2013, Spatial and temporal pattern of global burned area in response to anthropogenic and environmental factors: 1901-2007. Journal of Geographical research: Biogeoscience (to be submitted).

Presentations

1. Liu, Y.-Q., L. Mearns, 2012, Analyzing and Projecting U.S. Wildfire Potential Based on NARCCAP Regional Climate Simulations, 2012 American Geophysical Union Meeting, December 3-7, 2012. San Francisco, CA (invited).
2. Yang, Jia, Hanqin Tian, Bo Tao, Chaoqun, Wei Ren, Yongqiang Liu, 2012, Global wildfire emissions as controlled by multifactor environmental changes from 1901 through 2010, 2012 American Geophysical Union Meeting, December 3-7, 2012. San Francisco, CA.
3. Liu, Y.-Q., S. Goodrick, J. Stanturf, H. Tian, B. Tao, J. Yang, 2013, Future trends in mega-fire and fuel in the United States under a changing environment, 4th International Fire Behavior and Fuels Conference Raleigh, North Carolina, USA February 18-22, 2013.
4. Liu, Y.-Q, 2013, Wildland fires under Changing climate, School of Forestry and Wildlife Sciences, Auburn University, September 6, 2013. Auburn, AL.