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SPATIAL AND TEMPORAL ANALYSIS OF FIRES IN SERBIA FOR PERIOD 2000-2013

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Abstract: Spatial and temporal analysis of fires in Serbia for period November 2000-August 2013 has been performed to investigate whether spatial relationships exist among fire data. MODIS active fire data were used as fire locations. On such data, different tools of spatial analysis and spatial statistics were used, to determine if there is any spatial relationship. Analysis included data screening, identification of land cover of fire locations, aspect, slope, elevation and solar radiation for each location. Later, different spatial statistics tools were executed against fire locations data, including Getis-Ord Gi* Hot Spots, Global Moran's I Spatial Autocorrelation, Anselin Local Moran's I Cluster and Outlier, Ordinary Least Square linear regression and Geographically Weighted Regression. Fire radiative power was used as dependant variable, while terrain morphology and solar radiation were used as explanatory variables. Results shows hot spots of fires in Serbia, and indicates that there is strong relationship between fire radiative power on one side and terrain morphology, land cover, solar radiation and spatial distribution on other side. These analysis have highlighted areas with very intensive fire use associated with land management practices.

Key words: fires; MODIS; spatial analysis; temporal analysis; spatial statistics; Serbia

Introduction

Fires occur widely in spatial and temporal window. They have important environmental and climatic impact on different spatial levels - global, regional and local (Oom and Pereira, 2013). Fires control landscape and diversity of species (Swetnam and Betancourt, 1997); have influence on availability of resources, nutrient cycling, water yield, mass wasting and erosion (Agee, 1993); affect air quality (Sampson et al., 2000). Exploratory geography of fires and their temporal characterization can be of a great importance to explain relationships between natural systems and fires.

In last decades there has been strong development of different sensors and algorithms used for collection and exploration of consistent fire information.

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Satellite remote sensing platforms include different type of multi-spectral and hyper-spectral sensors of different spatial resolution, operated by different national and international organizations and institutes. For fire information collection and analysis, several sensors are being used: Advanced Very High Resolution Radiometer (AVHRR) with spatial resolution of 1 km, Geostationary Operations Environmental Satellite (GOES) with 4 km spatial resolution, European Space Agency (ESA) Along Track Scanning Radiometer (ATSR) World Fire Atlas (WFA), NASA/Japan Aerospace Exploration Agency (JAXA) Tropical Rainfall Measuring Mission (TRMM) Visible and Infrared Scanner (VIS), and widely used active fire product from the Moderate Resolution Imaging Spectroradiometer (MODIS). These sensors provide data that can be used for exploratory analysis of the burned area and active fires at different scales and years. Such datasets can be used for estimation of atmospheric emissions of trace gases (Duncan et al., 2003) and burned area (Pereira, 2003). Although they represent very important source of fire information on global level, they also have known limitations, which subsequently lead to use these datasets with some reserves. For example, after performing data screening, near 25% of WFA observations were removed which were not corresponding to vegetation fires (Oom and Pereira, 2013; Oom, 2008). Since year 2000, NASA is developing global active fires datasets, using sensors on Aqua and Terra satellites, as a part of MODIS remote sensing platform. With constant improvement of sensors and detection methods and four daily overpasses over Earth, this dataset provides more accurate information about active fires, but also not error-free. Validations of MODIS active fire products were performed by several authors and results presented commission errors between 2 and 3 % (Oom and Pereira, 2013).

Exploratory spatial and temporal data analysis represents set of algorithms used in different descriptive and statistical tools, with aim to find patterns in data, especially in spatial and temporal domain. They tend to find patterns of features and their attributes that occur in space and time, suggesting hypothesis concerning the causes of observed patterns. One of most used tools is spatial autocorrelation, explained as propensity for observations in geographical proximity to have similar values (Oom and Pereira, 2013). Spatial autocorrelation is measured with Moran's I ranged within values from +1 as perfect correlation and -1 as perfect dispersion (Moran, P. A. P., 1950). Global spatial autocorrelation (Global Moran's I) assesses overall clustering of data and does not inform on the type, extent and location of spatial clusters and outliers (Anselin, 1995). Local indicator of spatial association, usually referred to as Anselin Local Moran's I, allows assessing the significance of local spatial patterns, classifies them into four types of association, with distinction to local clusters (high–high or low–low) or local spatial outliers (high–low or low–high) (Mitchell, 2005). Certain studies have applied these techniques to spatial fire data and have identified spatial autocorrelation patterns in burned areas, based on global and local indicators of spatial association (Pereira et al., 1998). Other tool used is represented with hot-spot analysis tools, such is Getis-Ord Gi* statistics (Getis and Ord, 1992). It identifies statistically significant hot spots and cold spots within a set of weighted features within a context of neighbouring features (Mitchell, 2005). At the end, descriptive and statistical spatial and temporal analysis of used datasets has been performed to help determine correlation between fires occurred and geographical characteristics of territory of Serbia.

Material and methods

Data

For purpose of this research, several datasets have been used: MODIS active fire data, ASTER Global DEM, CORINE Land Cover data, borders of Serbia, and their derivatives, according to used methods.

MODIS datasets consists of nearly 13 years (November 2000 till 14th of August 2013) of the MCD14ML Collection 5.1 active fire product obtained with data acquired by the Moderate Resolution Imaging Spectroradiometer (MODIS) on board NASA's Earth Observing System (EOS) Terra (since February 24, 2000) and Aqua satellite (since May 4, 2002), processed by LANCE using the standard MODIS MOD14/MYD14 Fire and Thermal Anomalies product. Each active fire location represents the center of a 1 km pixel that is flagged by the algorithm as containing one or more fires within the pixel (NASA, 2013). Algorithm exploits the strong emission of mid-infrared radiation from fires and is based on brightness temperatures derived from the 4 and 11 µm channels (Giglio et al., 2003), enhancing the sensitivity to smaller, cooler fires and decreasing the occurrence of false alarms (Oom and Pereira, 2013). This dataset is missing some data, from June 16th to July 2nd 2001, March 20th to 27th and April 15th of 2002. Dataset includes attribute of longitude and latitude of fire, brightness temperature of the fire pixel measured in Kelvin (K), satellite scan, track and name information, data and time of acquisition, confidence measured in percent (%) to gauge quality and confidence of fire location, version of product, brightness temperature of fire pixel for channel 31 measured in Kelvin (K) and fire radiative power (FRP) of fire pixel measures in MegaWatt (MW). Dataset has been clipped to represent border of Serbia with 10 km buffer.

ASTER (Advanced Spaceborne Thermal Emission and Reflection) Global Digital Elevation Model (ASTER GDEM) is joint product of The Ministry of Economy, Trade, and Industry (METI) of Japan and the United States National Aeronautics and Space Administration (NASA). For this research, enhanced version 2 of ASTER GDEM was used, with 30 m spatial resolution. Dataset has been clipped to represent border of Serbia with 10 km buffer. Derivatives from this dataset include aspect raster, slope raster and hillshade raster, all processed with Esri ArcGIS for Desktop software.

CORINE Land Cover seamless vector data from European Environment Agency (EEA, 2013) for year 2006 have been used as source of information about land cover. Dataset has been clipped to represent border of Serbia with 10 km buffer.

Other vector data used in this research include border of Serbia and border of Serbia with 10 km buffer have been obtained from GDi GISDATA LLC Belgrade (GDi GISDATA, 2013). All datasets have been clipped to represent border of Serbia with 10 km buffer.

Methods

Methods used in this research refer to methods of data screening, methods of spatial statistics, spatial analysis, temporal analysis, description and visualization. All of them were performed using Esri ArcGIS for Desktop software version 10.1 with additional extensions.

Data screening refers to selection of MODIS data used in analysis. Nearly 13 years of daily based MODIS data clipped to spatial domain of 10 km buffered border of Serbia have 21623 identified fires. Oom and Pereira (2013) in first stage of screening divide fires into three categories: false alarms, non-vegetation fires and vegetation fires. Such division is needed to select which MODIS data actually represents fires burning vegetation fuel, and which represent hot-spots with other way of genesis. Using CORINE Land Cover data, intersection has been performed with MODIS data, which resulted in assigning land cover class to each fire location. Later selection of MODIS data according to land cover level 2 class resulted in 20647 locations that were not classified as industrial, commercial and transport units, waters, wetlands, mine, dump and construction sites and urban fabric. This means that about 5% of all fires in given time frame (November 2000 till 14th of August 2013) have been detected on land cover classes that represent artificial or water surfaces. They were classified as false alarm and non-vegetation fires, and were not used in analysis.

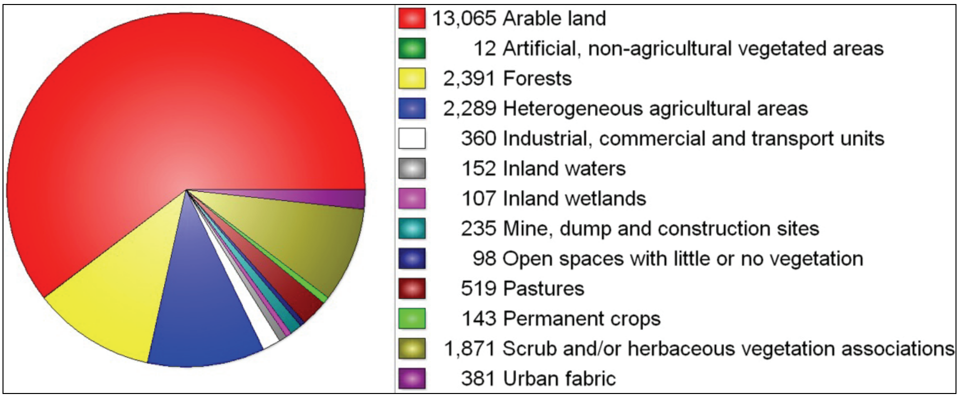

Figure 1. Number of fires per CORINE Land Cover level 2 for period November 2000 – August 2013

Spatial analysis methods were used to perform analysis of vector and raster spatial data, and to create derivatives from. Tools of spatial overlay, such intersect is, have been used to assign attributes of certain data to MODIS fire data. Such attributes included: CORINE Land Cover classes of level 1, 2 and 3, elevation values, aspect values, slope values. Elevation values were obtained from ASTER GDEM with 30 m of spatial resolution. Using Aspect and Slope tools from Esri ArcGIS for Desktop software, rasters of aspect and slope were created with ASTER GDEM. Frequency of fires per land cover, elevation, aspect and slope has been analysed and visualized. Using Temporal Analyst extension for Esri ArcGIS for Desktop, temporal frequency of fires has been investigated and visualized, both as data clock graph and as video animation of fire occurrences. With interpolation tools, results of spatial statistic tools have been interpolated into continuous raster, indicating fire “hot” areas in Serbia. For each fire location, total solar radiation has been calculated for august month, for further use in regression analysis.

For investigation of patterns in data, several spatial statistics tools were used. As first, spatial weights matrix has been generated using space-time window type of conceptualization of spatial relationships. Space-time in time interval of one month has been chosen because it defines relationships amongst features in terms of both their spatial and their temporal proximity, while Euclidean distance has been chosen as method for calculating distance between neighboring features. Resulting spatial weights were later used in other spatial statistic tools. Fire radiative power (FRP) has been used also in other spatial statistic tools as weight attribute for each MODIS fire location. Measured in MegaWatts (MW), it provides information on the measured radiant heat output of detected fires. It has been demonstrated in small-scale experimental fires that the amount of radiant heat energy liberated per unit time is related to the rate at which fuel is being consumed (Wooster et al., 2005). This is a direct result of the combustion process, whereby carbon-based fuel is oxidised to CO2 with the release of a certain "heat yield". Therefore, measuring this FRP and integrating it over the lifetime of the fire provides an estimate of the total Fire Radiative Energy (FRE), which for wildfires should be proportional to the total mass of fuel biomass combusted.

Hot Spot analysis using Getis-Ord Gi* statistics has been performed on MODIS fire data, with fire radiative power as weight attribute. This analysis tells if features with either high or low values are clustered spatially. Conceptualization of spatial relationship has been gained from spatial weights matrix. Spatial autocorrelation analysis using Global Moran’s I statistics has been performed on same data, using same weight attribute and conceptualization of spatial relationship. It indicates tendency of data towards clustering or dispersion. Finally, Cluster and Outlier analysis using Anselin Local Moran’s I has been performed over same data with same weight attribute and conceptualization of spatial relationship, resulting with identification of statistically significant hot spots, cold spots and spatial outliers, distinguishing clusters of high (HH) or low (LL) values, outliers in which a high value is surrounded primarily by low values (HL), and outlier in which a low value is surrounded primarily by high values (LH). Ordinary Least Square (OLS) linear regression analysis and Geographically Weighted Regression (GWR) analysis have been experimentally tested on data, to show future steps in research.

Results and interpretation

Data screening resulted in identification of approximately 5% of 21623 fires distinguished as false alarm or non-vegetation data. Other fires, 20647 of them, have been identified as vegetation fires. They have rather regular frequency per day during period from November of 2000 till August 2013, as shown in Figure 2. High peaks of frequency are regularly noticed during month of October for each year. This is when fires are most occurring per day. Other peaks can be noticed during month of March for each year. These highest values are geographically and anthropologically connected to agriculture: after spring or autumn harvest, agricultural workers rather illegally burn the remains of crops on agricultural land. The constant frequency noticed before each October peak represents fires during summer months.

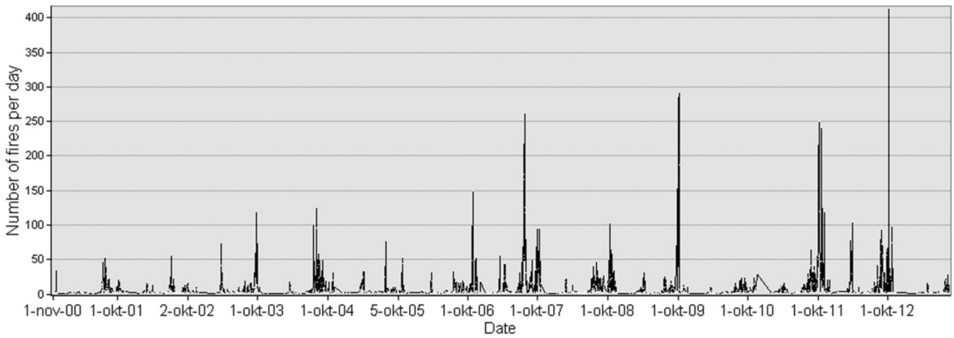

Figure 2. Frequency of fires per day for period November 2000 – August 2013

Years with highest number of fires are those in which the highest daily temperatures and temperature extremes were measures: 2007, 2011 and 2012, each with over 3000 fires, followed with year of 2009 with something over 2000 fires, while all other have less or significantly less number of fires. Most of fires have been spotted between 09:00 and 12:00 hours of day-time, as shown in Figure 3, with highest frequency of detection in first and last week of month. Months with highest number of fires are August, September and October, while least fires have been identified in December and January.

Most of fires occur on south, south-eastern and south-western slopes, during whole time of year, but with greater frequency in summer months. Eastern and western slopes follow in number and frequency, while north-eastern and north-western have also large number of fires. Northern slopes count several hundreds of fires.

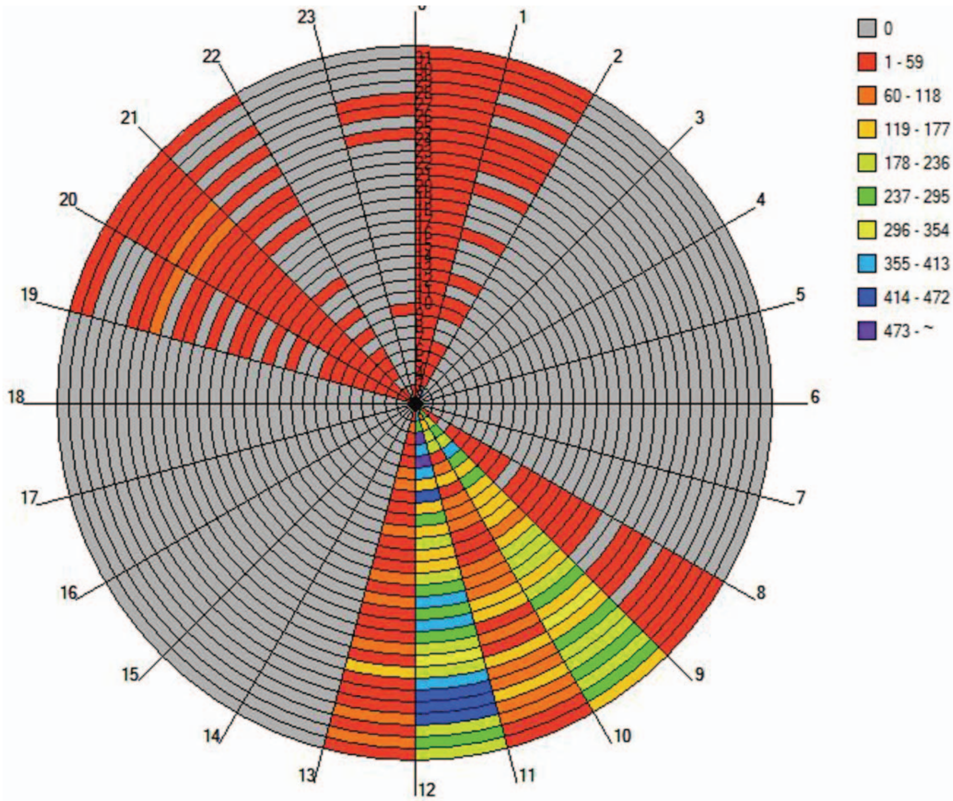

Figure 3. Data clock of MODIS fires for period November 2000-August 2013 representing frequency of fires on certain hours per day per month

Geographically, fires are unequally distributed in Serbia. Most of them, over 60%, are detected in province of Vojvodina, about 10 % in province of Kosovo and Metohija,, and rest in Central Serbia. In Central Serbia, fires are most detected in Eastern Serbia and in valleys of large rivers; such are valley of Dunav, Sava, Velika Morava and Južna Morava. In terms of elevation, fires have been detected dominantly in low-lands: 82% of them are detected on heights below 500 meters above sea level.

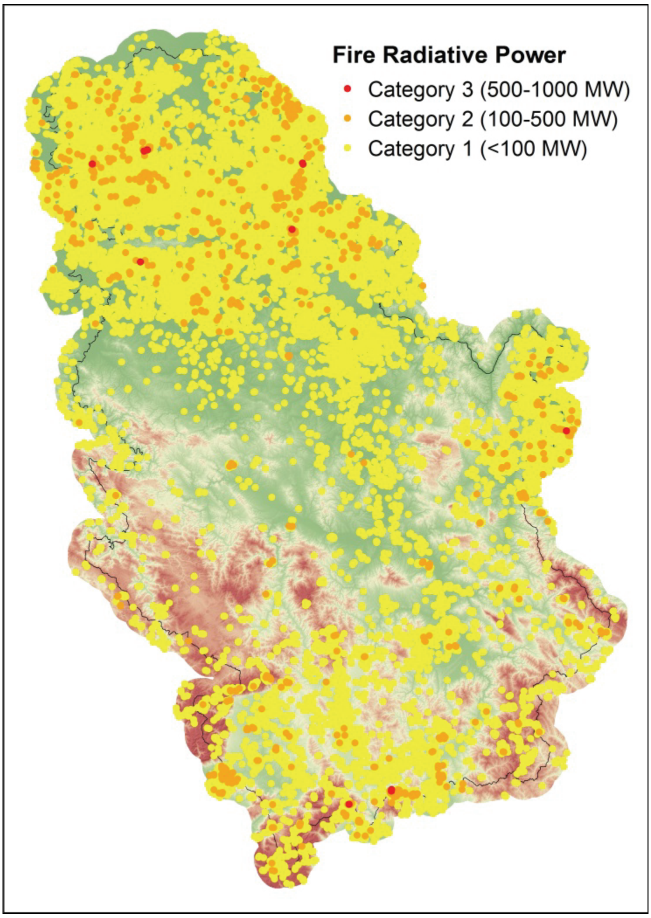

Figure 4. Geographical distribution of fires and Fire Radiative Power in Serbia for period November 2000-August 2013

Hot spots gained from Hot Spot Getis-Ord Gi* statistics with FRP as weight clusters of high and low values. Clusters of high FRP are located in mountainous area in Central Serbia and province of Kosovo and Metohija, and in lowlands of Eastern Serbia and agricultural land of province of Vojvodina. Clusters of low FRP are located mostly in province of Vojvodina, and in confluence of Drina, Kolubara and Velika Morava River into Sava and Dunav.

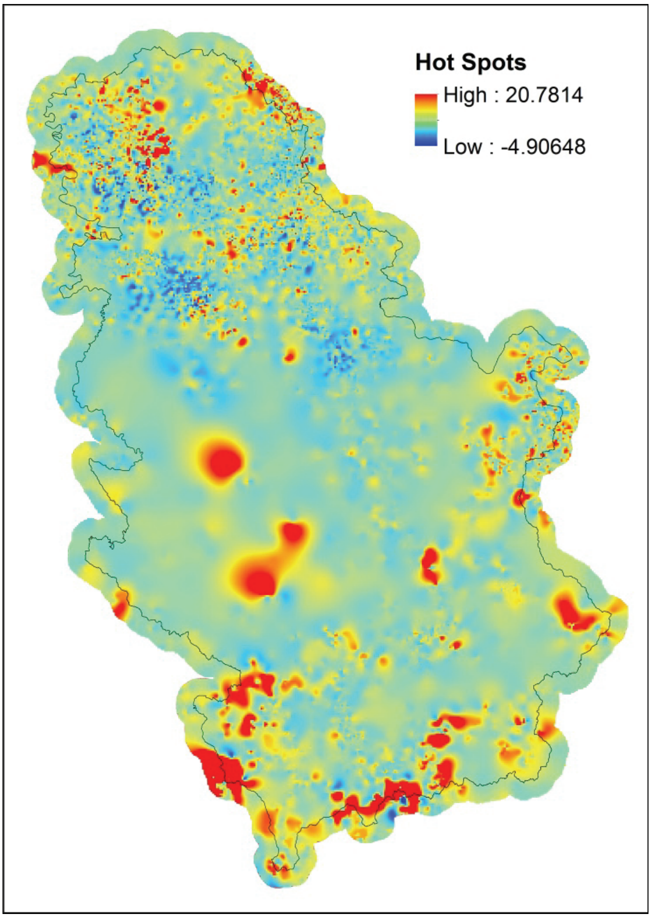

Figure 5. Getis-Ord Gi* Hot Spots of FRP interpolated to surface

Spatial autocorrelation from Global Moran's I statistics with FRP as weight field resulted in general evaluation of fire data to be clustered, as shown in Figure 6. Tool reported that given the z-score of 40.21, there is less than 1% likelihood that this clustered pattern could be the result of random chance. Average Nearest Neighbor tool also reported that clustered pattern is not result of random choice.

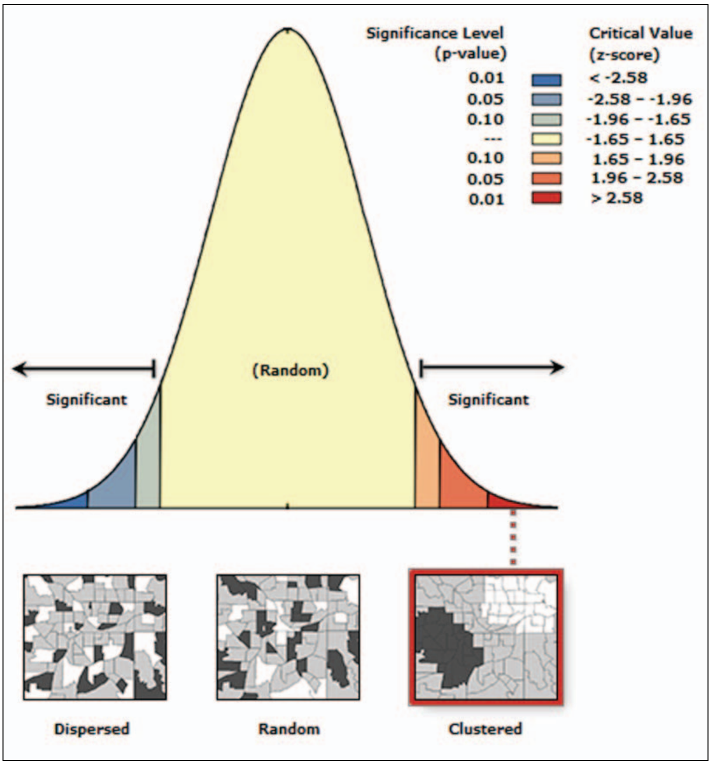

Figure 6. Global Moran's I Spatial autocorrelation results

Cluster and Outlier analysis from Anselin Local Moran's I statistics have determined clusters of high (HH) or low (LL) values, outliers in which a high value is surrounded primarily by low values (HL), and outlier in which a low value is surrounded primarily by high values (LH). Results are in direct correlation with Getis-Ord Gi* Hot Spot analysis, confirming hot spots as clusters of high and low values of FRP.

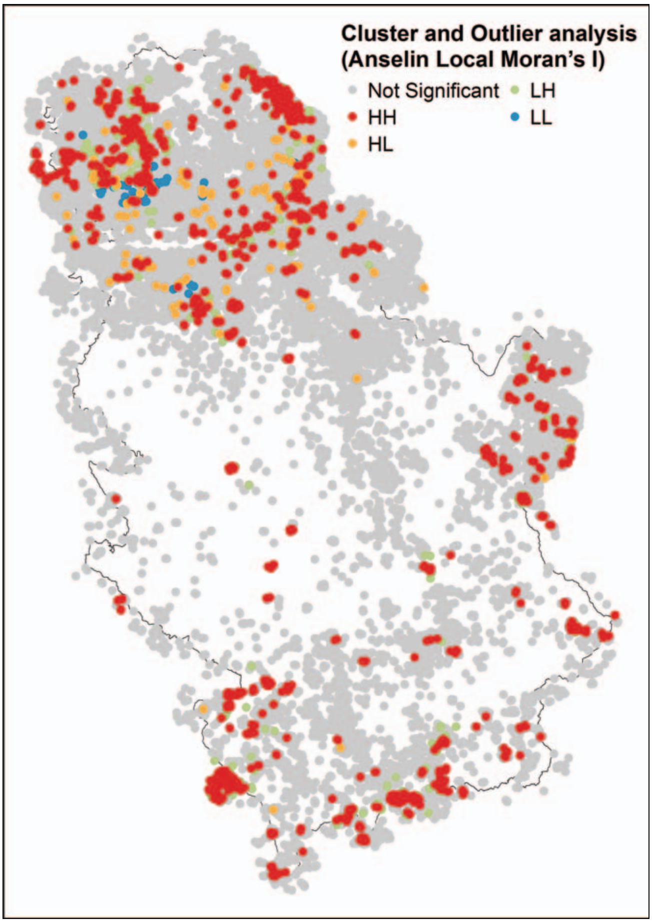

Figure 7. Anselin Local Moran's I Cluster and Outlier analysis results

During research, several experiments were conducted using two other spatial statistics tools: Ordinary Least Squares (OLS) linear regression, and Geographically Weighted Regression (GWR). These tools have been executed against MODIS fire data, with FRP as dependent variable, and aspect, slope and elevation values as explanatory variables for OLS, and aspect values as explanatory variables for GWR. They were tested to try to explain if aspect, slope and elevation have influence on FRP. Results of OLS are shown in Figure 8, and they indicate that there is strong relationship between FRP and aspect, slope and elevation values, which should be taken into consideration for future researches. Due to character of distribution of values of aspect, slope and elevation, GWR tool strongly suggested to use OLS as there exists sever local multicollinearity – redundancy among model explanatory variables.

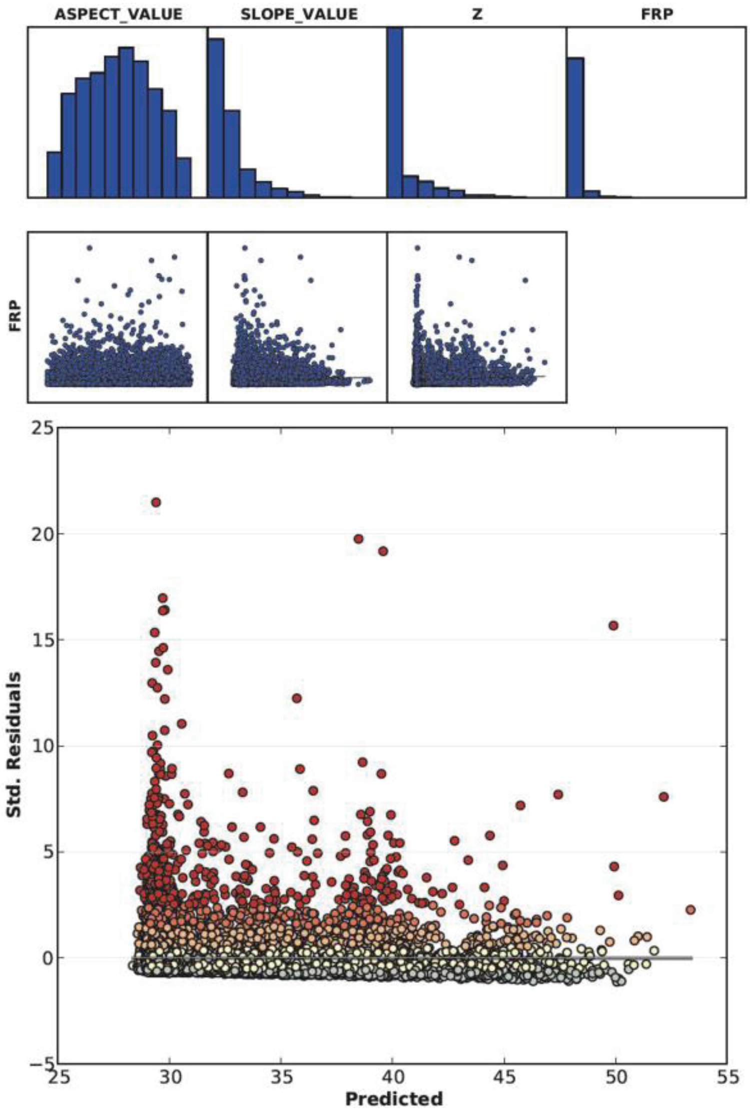

Figure 8. Histograms and Scatterplots of Ordinary Least Square linear regression showing variable distribution and relationships, and residual vs. predicted plot for FRP as dependant and aspect, slope and elevation as explanatory variable

OLS linear regression has been performed also using total solar radiation (direct and diffuse) for fire locations as explanatory variable for FRP as dependant variable. Total solar radiation has been calculated for august month, as it is the month with highest air and surface temperature. Results in Figure 9 shows strong relationship of values of FRP to total solar radiation for respective point, all together spatially correlated with hot spots cluster distributions.

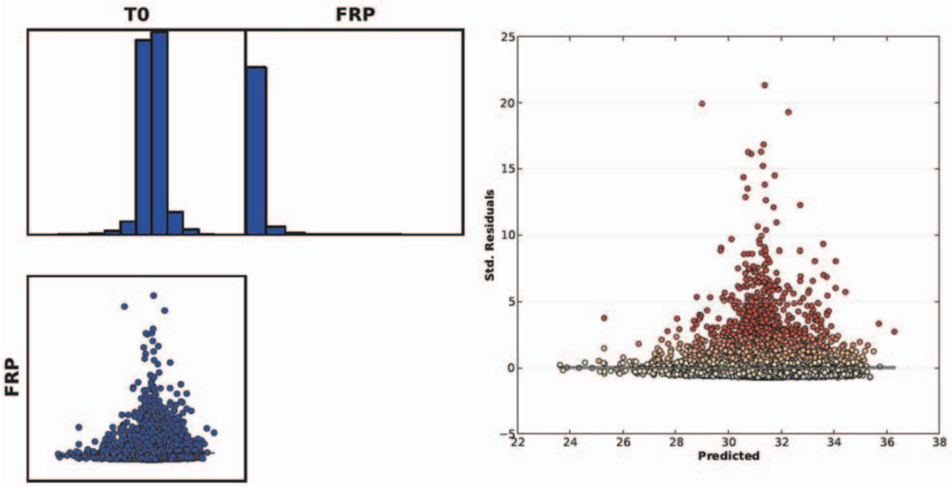

Figure 9. Histograms and Scatterplots of Ordinary Least Square linear regression showing variable distribution and relationships, and residual vs. predicted plot for FRP as dependant and total solar radiation as explanatory variable

Future researches should also include air and surface temperature as variable for such analysis, and also more detailed classification of land cover in manner of better biomass determination. Such analysis can be used to explain whether FRP is spatially and statistically related with terrain morphology and solar radiation.

Conclusion

The NASA MODIS active fire data for period of November 2000-August 2013 were collected and screened as preparation for explanatory spatial and temporal analysis. After screening, 95% of data have been used in various spatial and temporal analyses. Spatial analysis have been performed using various spatial statistics tools, such are: Getis-Ord Gi* Hot Spots, Global Moran's I Spatial Autocorrelation, Anselin Local Moran's I Cluster and Outlier, Ordinary Least Square linear regression and Geographically Weighted Regression. Fire Radiative Power (FRP), as quantification of fuel combustion and identifier of which fuel is burning, has been used as weight attribute and dependant variable in such analysis, while terrain morphology, solar radiation and spatial distribution were used as explanatory variables. Results indicate strong relationships between FRP on one side, and terrain morphology, land cover, solar radiation and spatial distribution on other side. Temporal analysis and frequency of distribution indicate that most fire events have been detected during agricultural season peaks, such early autumn and spring are. These analysis have highlighted areas with very intensive fire use associated with land management practices.

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