

Visualization of Fire in Space and Time on the Basis of the Method of Spatial Location of Fire-Dangerous Areas

Andrii Havrys^{1*}, Roman Yakovchuk¹, Oleksandra Pekarska¹, Nazarii Tur¹

¹ Institute of Civil Protection, Lviv State University of Life Safety, Kleparivska Str. 35, Lviv, 79007, Ukraine

* Corresponding author's e-mail: havrys.and@gmail.com

ABSTRACT

The subject of the study is the forecasting of fires, on the example of Australian events in the winter of 2013, using the spatial location of fire-hazardous areas. To do this, several approaches were used to visualize data in space and time. A temporary map has been created showing the points of fires using a color scheme linked to the date. A series of small multiple visualizations has been developed. A time series has been created in which the regularity of the brightness of points is distributed depending on the date of origin and animated maps that allow you to view data in space and time. In this case, the geographic information system was used as the main tool when working with maps, as it is one of the best ways to process georeferenced data displayed on the map. A space-time cube is displayed, which displays data in 3D format, or rather, fire points, symbolized by the average temperature of the fire (displayed in different colors) in accordance with the day of the month. Finally, clusters of focal points were created using the space-time framework in the ArcGIS software environment. The described results of using the method of spatial location of fire hazardous zones, in addition to the direct task – localization of fire points (fires), this method makes it possible to study patterns in spatial and temporal scales, with the possibility of further visualization of the spatio-temporal cube in 3D format in the ArcScene program, which will allow more efficient predict fire hazardous periods and areas in the study area. The method of spatial location of fire hazardous areas can be used for any investigated area for which there are statistical and spatial data, both for the purpose of localizing fires, and for the purpose of studying patterns in selected space-time scales.

Keywords: fire, fire points, data visualization, fire-hazardous area, map, ArcGIS software.

INTRODUCTION

Forest fires have been a big problem for decades. Every year, governments and international organizations allocate thousands of dollars to combat them; civil protection services are constantly organizing humanitarian missions in the countries affected by this emergency. In addition to the great negative impact on the ecosystem, fires lead to human casualties and significant material losses. Therefore, it is necessary to prevent and monitor large-scale forest fires in advance, which can be done only with the help of modern information technologies and gaining new useful knowledge to prevent these emergencies. Today many methods of fire prevention are being studied: the creation of a network of wireless sensors

(Abdulsahib and Khalaf, 2018), flame identification based on photo and video (Muhammad et al., 2019), including neural networks (Li and Zhao, 2020; Luo et al., 2018). However, the most promising authors consider the direction of forecasting based on remote sensing of the Earth. To better understand the nature of the spread and possible prediction of forest fires, as well as to study the causes of their occurrence, the authors developed a method of spatial location of fire-hazardous areas based on remote sensing (Havrys et al., 2019; Nikolaevich, 2021; Yakovchuk et al., 2020, Popovych and Renkas, 2019), spatial temperature distribution in areas of fire, as shown in Figure 1.

This method has been tested on the basis of publicly available and complete information obtained from The NASA – Earth Observing System

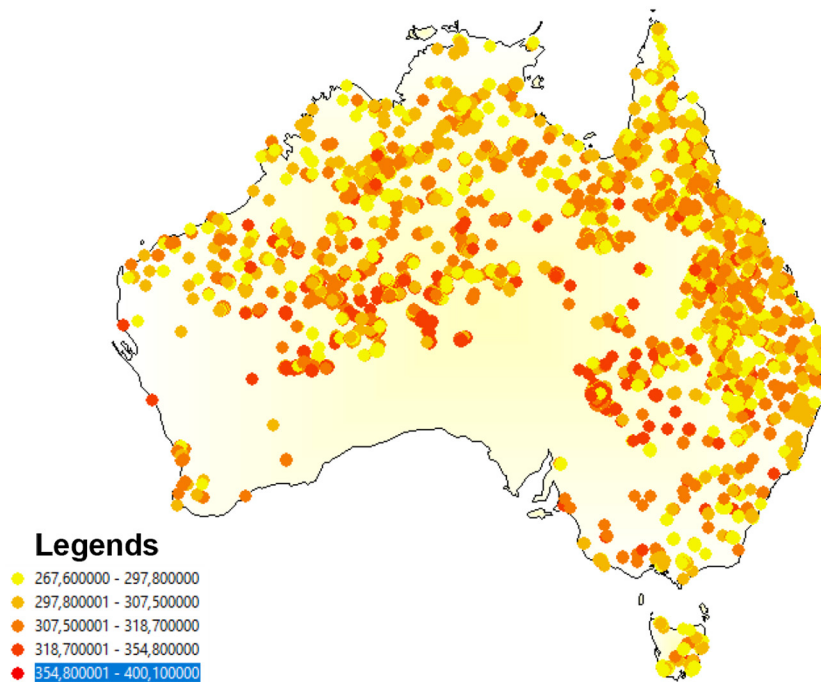


Figure 1. Map of the spatial distribution of temperature in areas of fire (Havrys et al., 2019)

Data and Information System (NASA EOSDIS) (EARTHDATA (2020)), which is based on forest fires that occurred in Australia in January 2013. However, the task of the developed method is not limited to the above use and in this article the authors will give examples of processes of deeper data analysis and versatile use of this method in the field of civil security.

METHODS AND MATERIALS

To achieve this goal and solve the problems of theoretical and experimental research used methods of system and structural analysis – to study the subject area of emergency prevention and comparative analysis of known models; software tools for simulating the occurrence of emergencies – to visually represent the emergency in a certain area and confirm the need to use these software products in the project. The purpose of this article is to develop hazard maps and predict the directions of its spread to neighboring areas using the software ArcGIS.

Satellites receive information for operational remote monitoring of forest fires on a daily basis. Monitoring forest fires makes it possible to eliminate them at an early stage. Modern GIS technologies make it possible to obtain information from all over the earth and even from space (Starodub and Havrys, 2015a; Starodub and Havrys, 2015b;

Zatserkovnyi, 2016; Popovych and Gapalo, 2021; Renkas et al., 2021; Renkas et al., 2022). The use of geographic information systems within emergency management has enhanced the ability of practitioners to plan for, respond to, and aid in recovery from natural- and human-induced hazards in a more comprehensive fashion than ever before (Grunes and Kovel, 2000; Cutter et al., 2007).

As noted by Milenković and Kekic (2016) emergency situations nowadays occur more often than before and emergency management personnel have critical tasks to protect people's lives, their property and environmental values. In solving these tasks, GIS will facilitate their work and raise public safety before, during and after some natural or other disasters. Institutions responsible for emergency management are aware of those facts and make big efforts to implement GIS in their work. Gutierrez-Martin (2020) proposes an original approach for predicting shallow translational slide hazards, which are triggered by irregular rainfall events, via the method of zonation at a regional scale in emergency situations.

The proposed model incorporates the infinite slope method in a GIS platform to assess hazard and risk associated with slope instability. Employees of the State Emergency Service of Ukraine annually carry out special measures aimed at preserving the environment before the start of the fire-hazardous period. Develop and approve operational and mobilization plans for the actions of

units in the event of forest fires. State forestry's lay mineralized strips and fire breaks, as well as take care of previously laid strips and breaks. For clear and correct interaction of the State Emergency Service of Ukraine and the Ministry of Forestry, these bodies are guided by the order № 89/132 of 12.03.2007 "On approval of the Instruction on the procedure of interaction of departmental fire protection of the State Forestry of Ukraine and fire and rescue units of the Civil Protection Service of Ukraine forest fires".

Forestry's are taking all necessary measures to reduce the risk of forest fires. Since the beginning of 2019, 115 km of firebreaks and 8.1 thousand km of mineralized strips have been installed in Ukrainian forests, 17.7 thousand km have been maintained, and 9.5 thousand unscheduled roads have been blocked. Along the roads of forests and in places of recreation of people already installed 7.8 thousand sold-outs, panels, posters on fire-fighting (State forest recourses agency, 2019).

RESULTS AND DISCUSSION

The occurrence of fires in Australia is common, but the winter of 2012–2013 seemed extremely hot. This led to a large number of fires in the south-east of the country (Australian Government, 2018) and to large losses (BBC News, 2021; Wildfires in Tasmania, Australia, 2013). This article uses several approaches to visualizing data in space and time. All the information used was obtained using the Earth Observing System Data and Information System (NASA EOSDIS), which stores a large amount of archival data in free access (Earthdata, 2020). Satellite images obtained from Earthdata show the infrared temperature spectrum in the form of fire points throughout Australia in the raw form.

For the map of fire points it is necessary to develop data visualization in different ways, namely to create: a temporary map; a series of small multiple visualizations; a timeline that can be viewed with a linked map; animated maps and space-time cube. Temporary map. Since ArcGIS focuses mainly on maps rather than time, we'll start by making a simple temporary map, showing the points of fires using a color scheme tied to the date.

From the official portal of NASA EOSDIS (Earthdata, 2020) download the archived file "Australia_Wildfire_Geodatabase.zip" and unzip

the data to a working folder. "Australia.gdb" includes:

- a few simple vector base maps of Australia for the Natural Earth 1: 50m data set;
- a point vector file of Australian forest fire forms from 1 January to 29 January 2013;
- "EODIS_wildfire_shapefile.pdf", which provides metadata for this dataset.

The map below, where the dates of localized fire points are compared, shows that the earlier points of the local clusters are located on the west side, while the later points are located on the east (Figure 2). To apply additional attributes of fire points, such as brightness (layer "BRIGHT_31") and temperature measurement, it is necessary to use other graphical measurements: size, shape or labeling (layer "ACQ_DATE" - date field DD / MM / PP). The day of the month helps to improve the appearance of the map and make it clearer, because all data relate to one month and year. However, the density of the applied data makes it difficult to create a successful map even on the scale of a single cluster (Figure 3). To fix this problem, use the tool "Convert Time Field" and enter the value of the day "ACQ_DATE" as an integer. We change the labels so that only the day of the month is displayed, which will allow us to better see the spatial-temporal distribution (Figures 4).

A series of small multiple visualizations

Small sets are created using the ArcMap program of the ArcGIS software package. We place them on one layout of the data frame, which contains time-sliced data on a single layout. For example, the cluster below shows fires that occur over a period of 7 days in one area.

Creating a time series

Geographic information systems are the main tool when working with maps, because it is where people spend most of their time working with georeferenced data displayed on the map. However, the fact that the data is spatial does not mean that cartography is always the best way to study the data for a sample. To confirm this fact, create a map that displays the value of the layer "BRIGHT_31" for each point. Using the Graph Wizard tool of the ArcGIS software package, we create a graph of overlapping layers "BRIGHT_31" and "ACQ_DATE"



Figure 2. Map of the location of localized fire points ranked by date of occurrence in the ArcGIS software environment

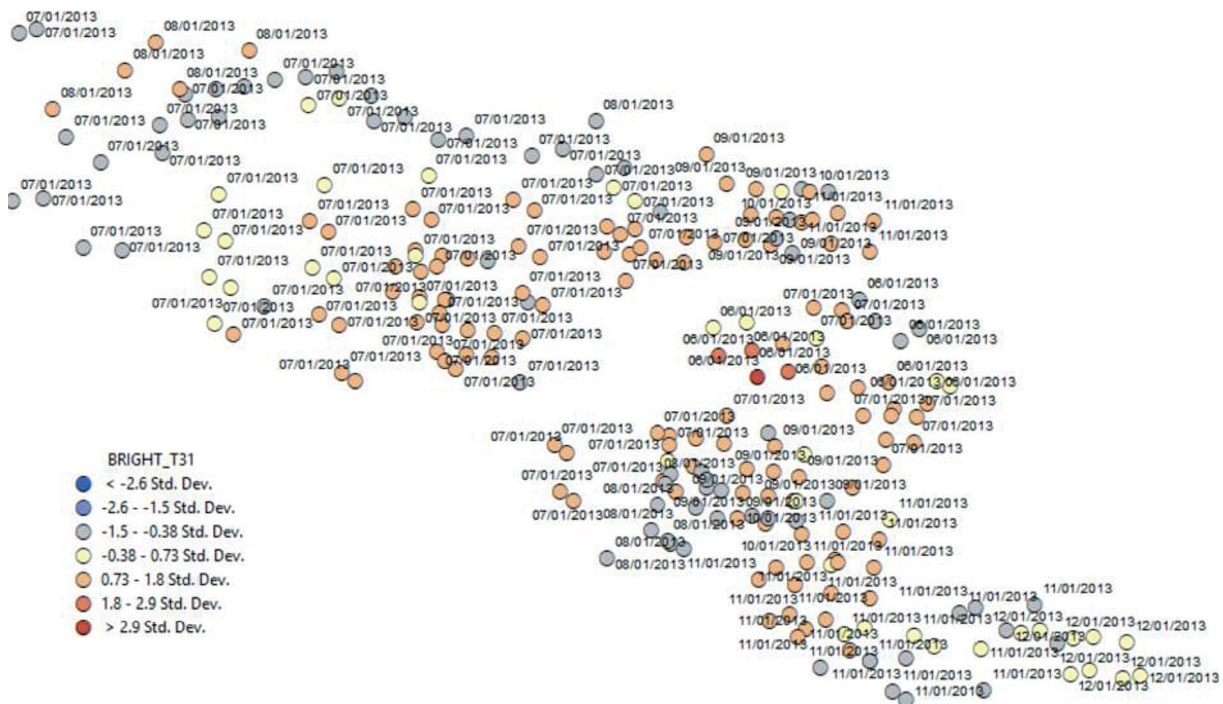


Figure 3. Map of the applied attribute of brightness of fires

from the map data layer to investigate how the brightness of fire points changes over time. The distribution of the regularity of the brightness of the points depending on the date is shown in Figure 6. This graph reveals a number of patterns. There are some deviations with respect to the “BRIGHT_31” layer. To automatically update the map and graph, eliminate these

deviations from your layer, as shown in Figure 7. As can be seen from Figure 7, the events of 2013 have a certain tendency to appear as hot and cold spots during the month, as well as decrease in variation. We add a trend line to the graph (Figure 8) to understand whether there is a tendency to cool (ArcGIS Resources, 2012). The general trend line confirms the

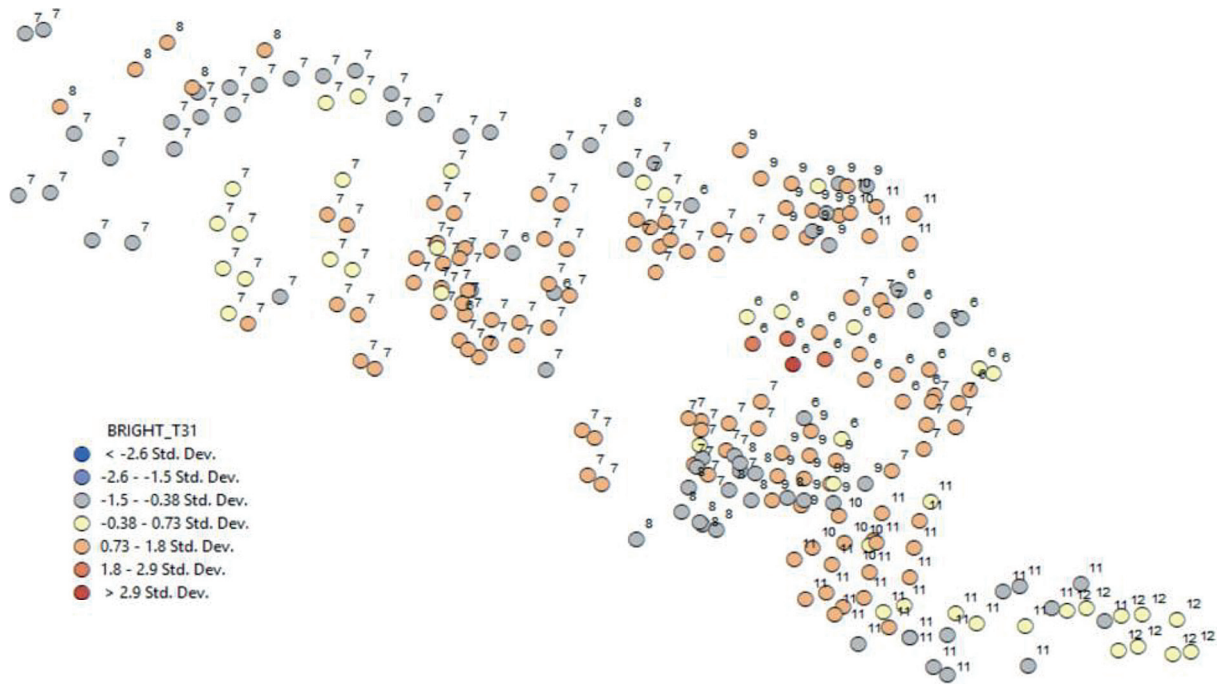


Figure 4. Spatial-temporal distribution of fire points (indicating the day of occurrence)

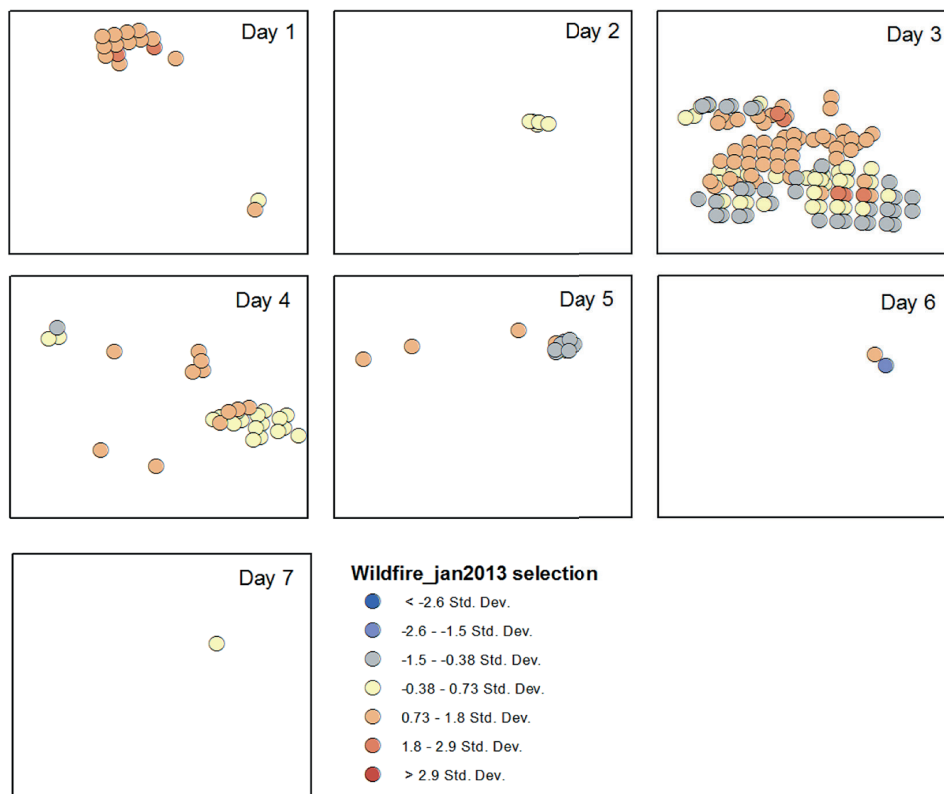


Figure 5. Clusters of fire points in one territory with distribution by days during January 2013

hypothesis that there is a tendency to cool, however, this must be verified by statistical analysis. Smoothing is an appropriate approach for identifying a cyclic pattern, but the ArcGIS local graph function tool requires that a pair

of attributes be unique, although our data set does not meet this criterion because many observations are made per day. However, we can calculate the average temperature of fires that occur daily and add this as a time series. Use

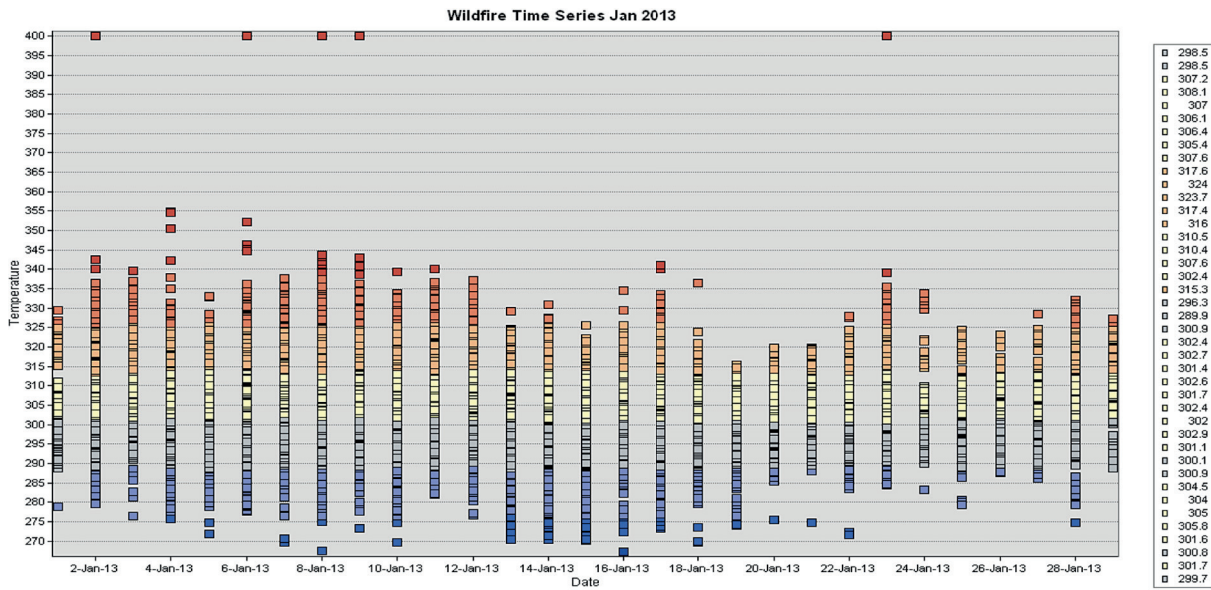


Figure 6. Graph of the dependence of the brightness of fire points on time

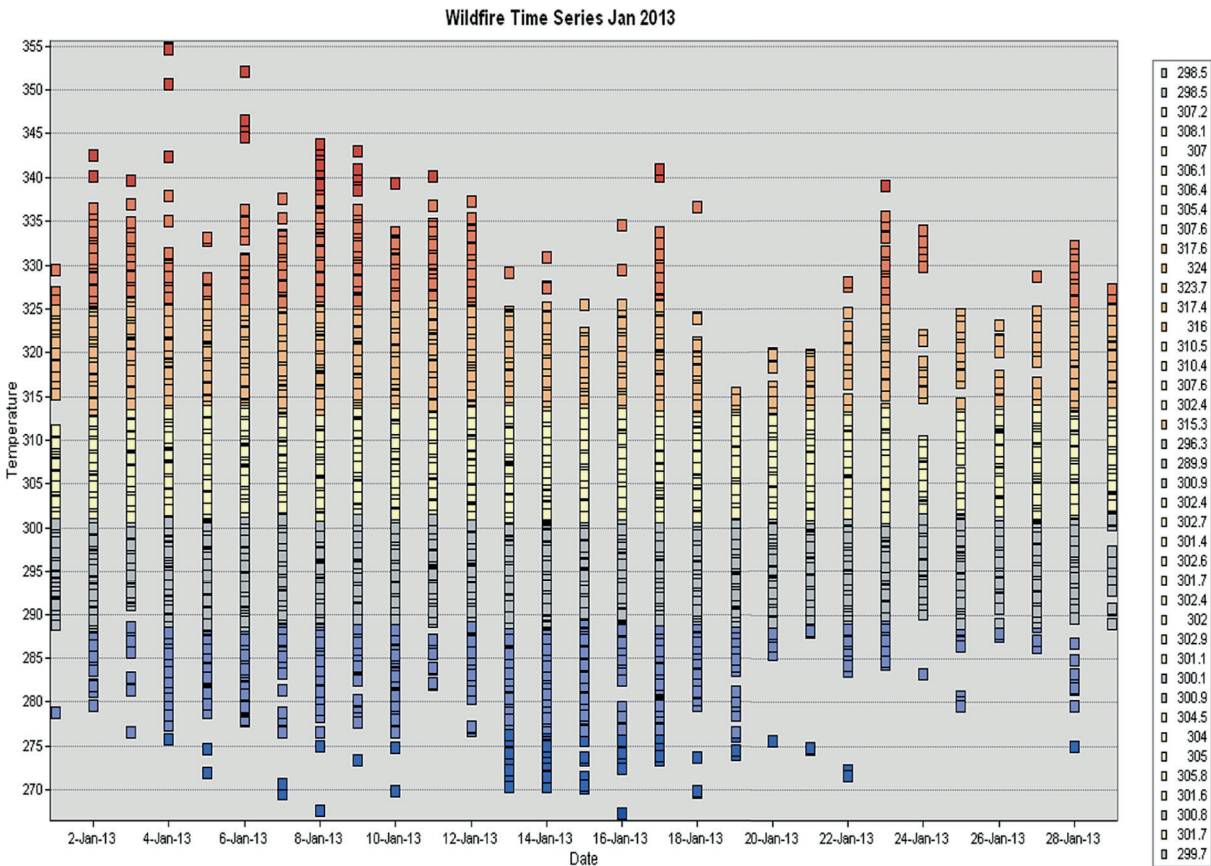


Figure 7. Graphic dependence of the brightness of fire points on time with the deviations of the layer "BRIGHT_31"

the tool "The Summary Statistics" to calculate the average value of the layer "BRIGHT_31" to "ACQ_DATE". We can now add a new feature that displays the smoothed trend line of the average temperature. To achieve an obvious

cyclical trend, it is necessary to experiment with different smoothing factors. Keep in mind that for an accurate estimate, you need to use more than one possible way to analyze events. After all, with just one analysis it is not always

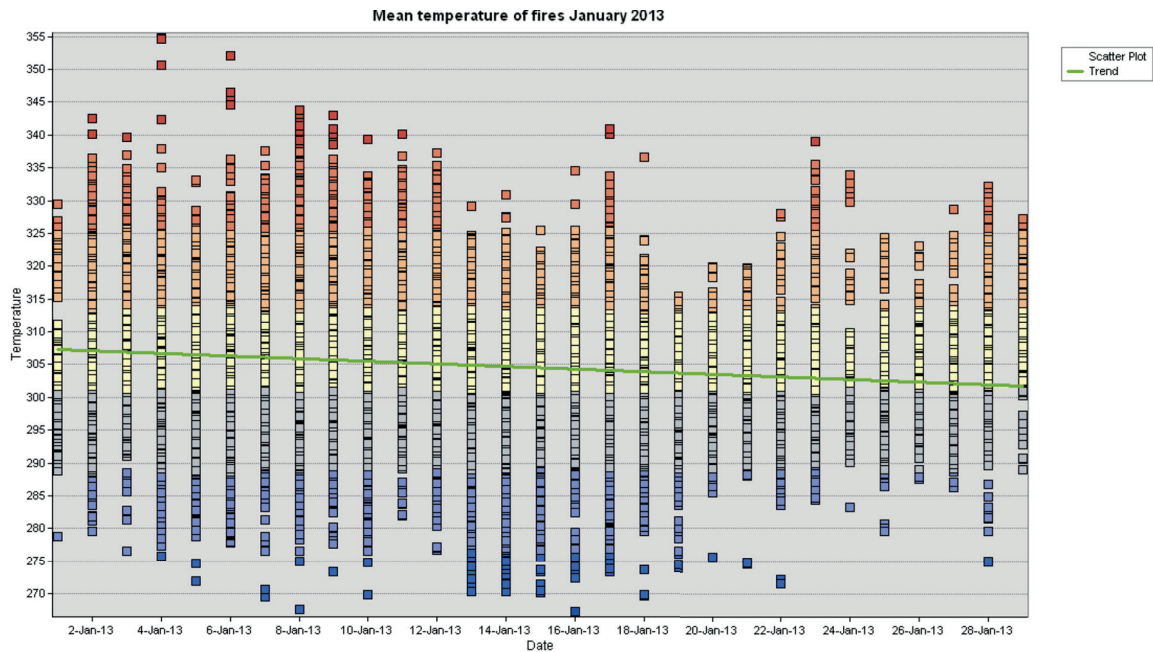


Figure 8. Graph of the brightness dependence of fire points on time with a linear trend

possible to get a complete picture of the situation. Therefore, the graph will be more accurate the more different visualization methods will be used in it. Graphs derived from map layers support dynamic linked brushing. The user selects objects on the map or graph, and all windows containing this data are automatically updated to show the selection. Using the “linked brush” tool, we will determine the location of the hottest fires by selecting it in the graphics window.

Animated cards

Animated maps can be a useful way to view data in space and time. The time slider in ArcGIS provides a quick tool for studying spatial and temporal changes in the spread of forest fires and their brightness (ArcGIS Resources, 2012). In the layer properties include the layer “Time” on the layer “wildfire”, using “ACQ_DATE” as a time field (Figure 9). The next step is to create an

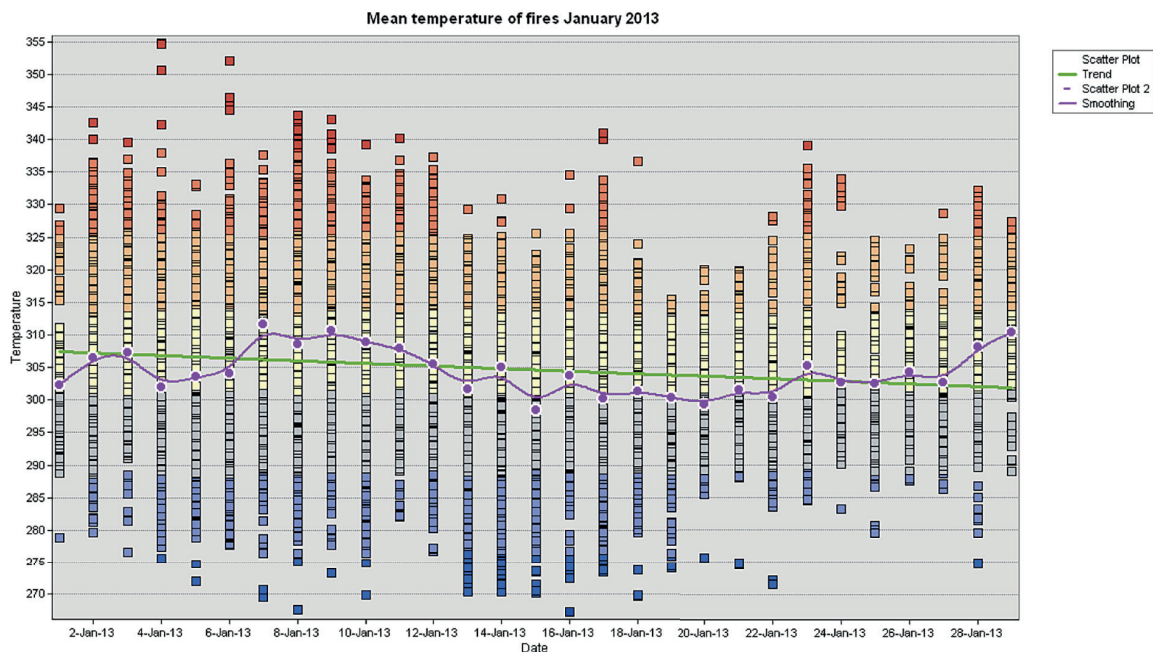


Figure 9. Graph of the brightness dependence of fire points on time with the plot of the trend line

animated time map of the forest fire temperature in time and export the video in MPEG format. We increase the length of time to understand the dynamics of changes in our sample.

Spatial-temporal cube

ArcGIS software supports the creation of (space time cubes, which are stored in NetCDF format. Voxel values can then be exported to a function class for display in ArcMap or ArcScene. Displaying data in 3D is expensive to compute, so we will use a small subset of the data. For this work, we select a sufficiently large cluster of fire points and export as a new class of functions. Next, selecting the tool “Create Space Time Cube By Aggregating Points”, create a space cube in NetCDF format, which saves the calculation of the number of fire points and the average temperature of fires in each cell of the grid.

To export cell values to a class of objects in which the ordinal value of the time dimension is assigned to the value of z of each voxel centroid, use the tool “Visualize Space Time Cube”. The next step is to review the 3D cube function class in ArcScene, and to get a good visualization, you need to work with the symbols. Figure 10 shows the clusters of fire points, symbolized by the average temperature of the fire. The location of the cube corresponds to the day of the month – the lower the cube, the correspondingly the earlier day of the month. Pay attention to the location

of the cubes: as a cluster in the left foreground appeared at the beginning of the month and was cool (green), and then a hotter fire at the end of the month, on the right.

Clusters of firing points

Points from EODIS data are obtained from pixels measured remotely from the MODIS satellite. Each dot is a centroid of a pixel that has been identified to contain forest fires. The pixel resolution is approximately 1 km². Fires of large bushes can unfold for many kilometers and last not days but months, so individual “fires” can be modeled as groups of pixels, close in space and time. This can be done by defining spatial-temporal clusters using the “Grouping Analysis” tool using the spatial weighing matrix created using the “Generate Spatial Weights Matrix (Spatial Statistics)” tool (ArcGIS Resources, 2012). The spatial weighing matrix is a conceptualization of the “proximity” of the location in space and, in this case, in time.

The strictest criterion is that the points must be “adjacent” in space and time to be considered part of a single fire, but the spatial adjacency in the raster can be defined rectilinearly or diagonally. In any case, the data are vector points obtained from several images, so you should choose the radial distance. The time scale is expressed in days, so strict temporal adjacency would be following days. More liberal spatial and temporal criteria increase the probability of points being classified

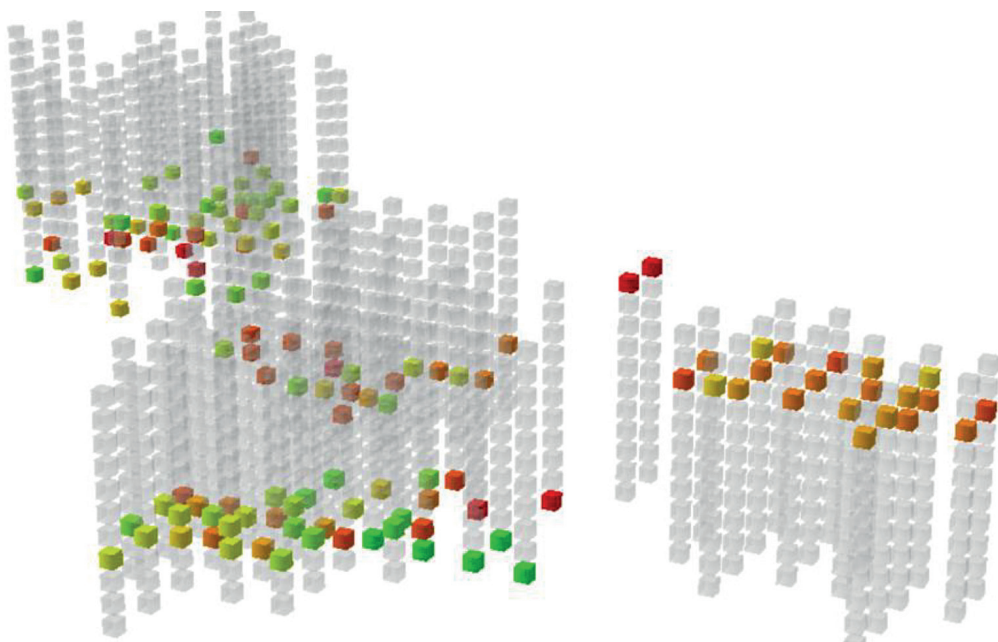


Figure 10. Visualized space-time cube with the designation of the average temperature of the firing points

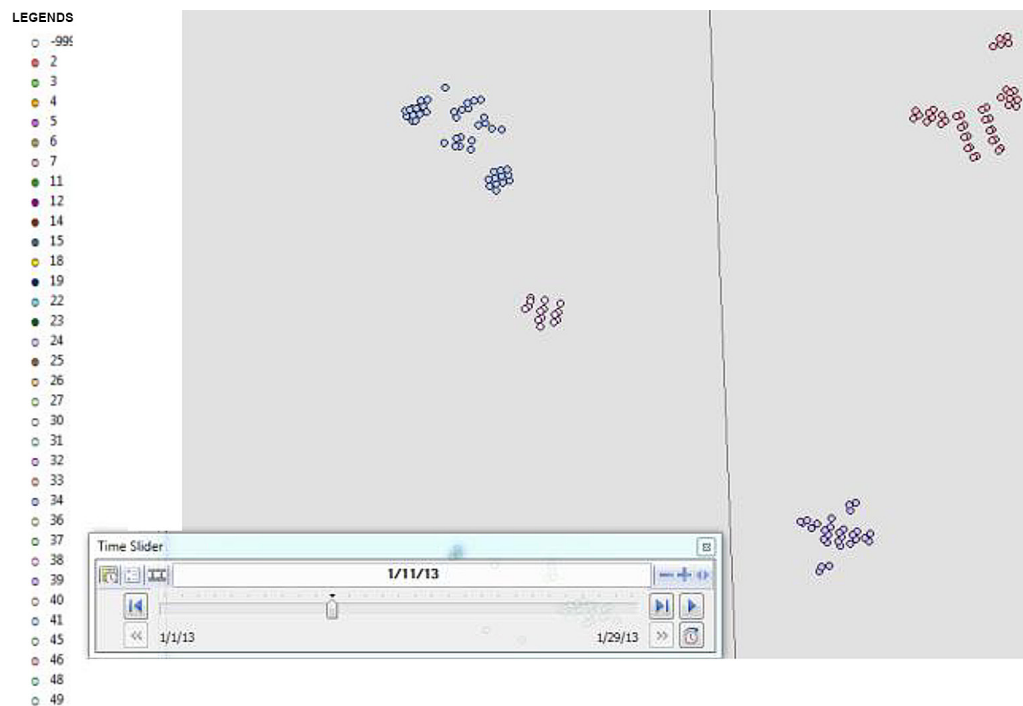


Figure 11. Map of fire points location in the study area using space-time frameworks in the software environment ArcGIS

as part of a group, i.e. “fires”. Using the time slider, let’s explore the local spatial and temporal pattern of the ignition pixels. Noticing several points of fire, we choose our spatial and temporal thresholds. It should be borne in mind that smaller values will create more clusters of space and time, which will lead to slower data processing. Because rendering is very intensive, the number of clusters also affects process performance. Next, we use the Grouping Analysis tool to allocate points between spatial-temporal groups based on the spatial coordinates and conceptual-spatial time defined by the spatial weighing matrix. We set the time properties of the grouped layer and scale the size of the grouped pixels to see how the fires increase and decrease in space and time in the study area (Figure 11).

CONCLUSIONS

Phenomena such as fires occur both due to local causes (availability of fuel, source of ignition) and regional (climate, land use), and, therefore, can show character on different scales. Therefore, it is necessary to be able to predict and identify patterns in certain spatial and temporal scales. For this purpose, the method developed by the authors of the spatial location of fire-hazardous

areas based on remote sensing data of the Earth is used. Since, in addition to the direct task – the location of fire points (fires), this method makes it possible to explore patterns in spatial and temporal scales, with the possibility of further visualization of space-time cube in 3D in ArcScene, which will more effectively predict fire periods and areas the study area. In addition, based on this method, several different visualizations of forest fires in Australia were developed, namely: a temporary map; a series of small multiple visualizations; a graph of the brightness of fire points on the time that can be viewed with the associated map; animated cards. The method of spatial location of fire-hazardous areas can be used for any study area for which statistical and spatial data are available, both for the purpose of localizing fires and for the purpose of studying patterns in the selected space-time scales.

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