A Collection of

Geospatial Technological Approaches for Wildland and Wildland Urban Interface (WUI) Fire Events

Final Report

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Executive Summary

Geospatial Technology is prevalent in a wide range of applications that utilize spatial data to plan, respond, manage and operate both short term and long term tasks. Applying geospatial technology to address wildland and wildland urban interface (WUI) fire hazards has demonstrated its value. The planning, mitigation, incident response, recovery and communication to address the wildland and WUI fire hazards has become more dependent on understanding and manipulating geospatial information.

While the current availability of geospatial related data and systems is abundant and richly diverse, it is too often unavailable to the practitioners who most need it. Traditional causes for this include lack of appropriate level and relevance of guidance for practitioners, training for analysts, and the confusion caused by the abundance of overlapping options; funding to build capacity to use these resources, and standards to guide efficient implementation.

Efforts are underway to address some of these issues, such as new emerging standard documents to guide efficient implementation, e.g., NFPA 950, *Standard for Data Development and Exchange for the Fire Service*, and NFPA 951, *Guide to Building and Utilizing Digital Information*. Further, the understanding of the on-going future direction of current geospatial technological approaches for managing wildland and WUI fire is lacking clarity and deserving further attention.

The goal of this project is to compile a collection of the latest geospatial technological approaches to clarify the methodology, application and utility of various geospatial techniques and data for wildland and WUI fire events. This report is intended to improve understanding and enhance decision-making for fire preparedness, mitigation, and rehabilitation in the wildland and WUI.

The deliverables of this project collectively review the available baseline information, and identify the fundamental principles and key details involving current applications of geospatial technology to address wildland and WUI fire hazards. They provide a summary of core information regarding the features and specific use of different geospatial tools, with a primary focus on Graphic Information Systems (GIS), Remote Sensing (RS), and Global Positioning System (GPS) technologies.

Contents

1. Introduction and Background

According to a report by U.S. Department of Labor, 2005, Geospatial Technology (GST) generally refers to three primary groupings or topic areas: geographical information system (GIS), remote sensing (RS), and global positioning system (GPS). This serves as the basis for addressing the emerging technologies that assist the user in the collection, analysis and interpretation of spatial data and addressed by this study.[1] The definition of the term "Geospatial Technology Industry" is based on the report prepared by the Geospatial Workforce Development Center at the University of Southern Mississippi, and is defined as "an information technology field of practice that acquires, manages, interprets, integrates, displays, analyzes, or otherwise uses data focusing on the geographic, temporal, and spatial context." It also includes development and life-cycle management of information technology tools to support the above.[2]

Figure 1. Components of Geospatial Technology

A collection of the latest geospatial technological approaches are included in the primary sections of this study, with the intent of explaining the methodology, application and utility of various geospatial techniques and data used to address wildland and WUI fire hazards. The three primary topic areas of geospatial technology, which comprise the three main sections of this report (sections 3, 4, and 5), are defined by the U.S. Department of Labor Employment and Training Administration as the following:

Geographic Information Systems (GIS) provides users the ability to display and manipulate data with interactive mapping software. GIS allows users to query a database to perform spatial analysis or communicate specific information about a location. Data gathered and provided through GIS applications can be tailored to perform critical functions in many disciplines, such as agriculture and land management, *utility service and design, and intelligence gathering and analysis. (See reference 1)*

Remote Sensing (RS) refers to the observation and collection of data without the sensor being in physical contact with the object being studied, such as the study of the Earth from distant vantage points, via satellite or aircraft. *(See reference 1)*

Global Positioning Systems (GPS) employs a geospatial technology that enables a portable device to pinpoint a precise location almost anywhere on the Earth by processing signals with the aid of satellites. *(See reference 1)*

2. Overview of the Application of Geospatial Technology in Wildland Fire Management

Over the past decades, a series of devastating wildland fires have burned millions acres of forests, grasslands, and wildland-Urban Interface (WUI), causing inestimable environmental loss and unfavorable injuries and fatalities of fire fighters. The successful application and popularization of geospatial technology in planning and responding to emergency events has gained great interest from the wildland and WUI fire management community.

Geospatial technology includes systems such as Geographic Information System (GIS), Remote Sensing (RS), and Global Positioning System (GPS). This study focuses on identifying, evaluating, and analyzing current geospatial technological application in addressing wildland and WUI fire risk, with a focus on presenting the characteristics of each technology for wildland and WUI fire in different scale and magnitude.

The planning, mitigation, incident response, and recovery of wildland and WUI fire hazards is significantly dependent on understanding and manipulating geospatial information. The goal of this project is to compile a collection of the latest geospatial technological approaches to clarify the methodology, application and utility of various geospatial techniques and data for wildland and WUI fire events. This collection will improve understanding and enhance decision-making for fire preparedness, mitigation, and rehabilitation in the wildland and WUI.

3. Geographic Information System (GIS) Application in Wildland and WUI Fire Management

Geographic Information System (GIS) operates like an ecosystem that is mainly consisted of Hardware, Software, People, Data and Method. These components are integrated and supported to each other to perform data entry, management, analysis, visualization, and modeling activities that are tied to a specific geographic location or area.[3]

Hardware

Hardware always refers computers ranging from desktops to large servers on which GIS lunches and operates.[3]

Software

GIS software have functions and programs that can be used to manipulate geographic information, manage the database, and enable data visualization and analysis.[3]

People

People here not only include the developers of GIS technology who design and maintain the system, but also the users who utilize this technology to assist their work or support their daily life.[3]

Data

Data is the core component of the GIS technology, it means the geographic features describing a single point as well as an extensive area. Data is collected and then digitized into the GIS which can be manipulated by people.[3]

Method

Method refers to sophisticated implementation and well-developed business operation strategy that can maximize the functionality of the GIS program.[4]

GIS is a computer-based technology to spatially collect, describe, analyze, and distribute geographic information. Through integrating the geographic layers, the maps created by GIS can give the users a better understanding of the geographic component and distribution for a given area. By correlating the geographic database to the maps, GIS technology enables users to visualize, manipulate, analyze, and display spatial data on the map. Since the nature of the fire service is location oriented and information dependent (and particularly wildland fire management), GIS and its geographic information provides a great platform for fire fighting personnel to manage wildland and WUI fire hazards. [5, 6]

Nowadays, GIS continues to be an essential technology to support the wildland fire management, it provides comprehensive and advanced capabilities that enable wildland fire fighting units to manipulate and support all aspects of the entire wildland fire management mission.[6]

Typical application of GIS in wildland fire management include:

- Data Management
- Planning and Analysis
- Situational Awareness
- Field Operation
- Environmental Restoration

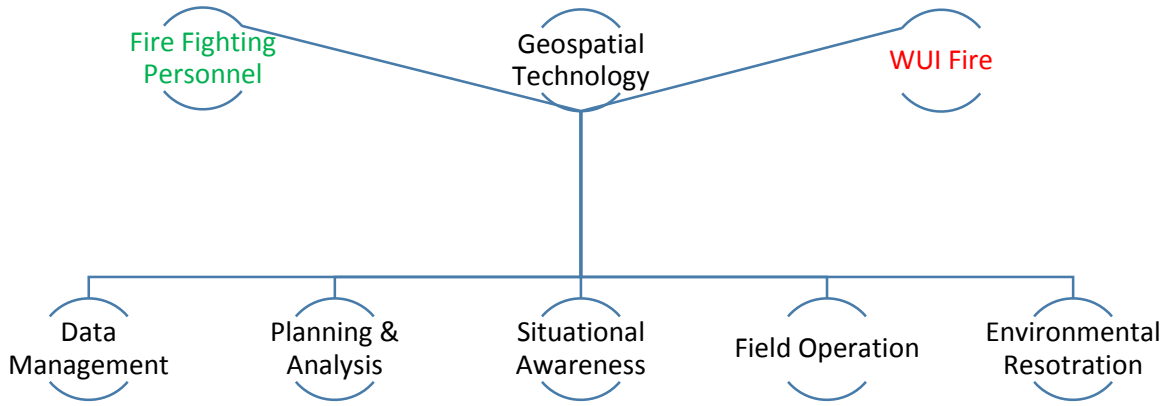

Figure 2. Geospatial Technology Application in Wildland and WUI fire Management

➢ Geographic Data Management:
The effectiveness and efficient management of geographic data by agencies addressing wildland and WUI fire events is a critical part of their normal operations. Information on wildfire and accompanying response measures may include diverse data stored in multiple information systems, as well as live feeds of data published publically or privately by various stakeholder agencies. GIS is intended to utilize a platform to integrate with other information systems, based on interoperability oriented-architecture. This allows the storage and analysis of applicable data from multiple sources to facilitate optimum response and mitigation.[7]

➢ Planning and Analysis:
Through using the GIS platform, fire managers are enabled to quickly view geographic factors, such as vegetation types, slopes, natural or man-made barriers, and weather condition that

could possibly influence the fire behavior. The possibilities of wildland fire occurrence can also be forecasted by identifying the possible ignition sources and comparing historical fire coverage. With the help of GIS technology, fire mangers can proactively respond to the wildland fire emergency by monitoring wildland system data, modifying vegetation profile, and analyzing the fire trends.[7]

- Situational Awareness
  GIS technology creates a platform that wildland fire mangers can access and analyze the geographic information that is related to wildland fire situation. The accurate and updated data regarding the current weather conditions, risk factors, fuel conditions, suppression resources, property and people at risk can be integrated and synchronized on the GIS for fire fighting professionals to visualize and the current wildland fire condition and implement response plan.[7]

- Field Operation
  Where is the fire located? What is the fuel condition? What are the risk factors and severity in this area? How does the fire spread? Where is the evacuation route? Such questions asked by the fire mangers and fire fighters now can be answered by utilizing the GIS technology, fire fighting professionals are able to access the geographic maps not only through the desktops but also with mobile GIS devices. The mobile GIS devices, such as handheld PDA, vehicle-mounted computer, or cell phone application can provide the fire fighting personnel with comprehensive information regarding the current wildland fire condition and allow the information exchange between incident mangers and first-line responders.[7]

- Environmental Restoration
  GIS enables the collection and analysis of post-fire data which is essential in estimating the property loss and recovery requirements. By synchronizing data from mobile devices, command units and central data warehouses, various stakeholders can use GIS to capture the immediate damage information from the fire scene, process and analyze it real time for operational decision making, and then this information can be uploaded and stored in the central database where data can be orderly managed for the fire mangers to perform risk estimation and develop environmental restoration plan.[8]

Currently, several GIS technologies and applications are being used to manage wildland and WUI fire hazards. Some of these technologies are developed by private GIS technology companies, while other programs are established and maintained by the government agencies. These technologies can be accessed via desktop, server, web based and mobile applications. They are typically designed and configured to meet the user requirements and system capacity. These components and applications provide the users with up-to-date mapping information, sophisticated data analysis, state of art fire behavior simulation and supplemental response plans.

In the following sub-sections, each technology identified will be presented in the alphabetic order with its background introduction and a focus on its features in terms of wildland and WUI fire risk management capabilities.

a. ArcFuels10

Introduction:

ArcFuels is a fuel management and wildfire risk analysis system which is created to meet the needs of fire service officials aimed at enhancing land management and risk control capabilities. Arcfuels is built upon a geospatial system which also provides modeling environment to conduct fuel treatments from stand to landscape scales. It offers an easy and immediate way to simulate the real time fire effects as well as provides a response treatment plan. [9]

Features:

By utilizing different models within the ArcMap user interface, ArcFuels 10 is able to process analysis for the profile of vegetation, fuel, and fire behavior with a scale range from stand to landscape. Some specific functionality of ArcFuels10 will be introduced.[9]

- Specific functionality of ArcFuels10
    - An interactive system within ArcMap to simulate treatment prescriptions with the Fire and Fuels Extension to the Forest Vegetation Simulator (FFE-FVS).[9]
    - Automated generation of Excel workbooks and stand Visualization System (SVS) (McGaughey 1997) images, showing how fuel treatments change wildfire behavior and stand conditions over time after FFE-FVS modeling.[9]
    - Scale-up of stand-specific treatment to simulate landscape changes in vegetation and fuel from proposed management activities.[9]
    - The ability to modify and reevaluate fuel treatment scenarios. [9]
    - Pre- and post-processing of files for or from FlamMap (Finney 2006) to simulate landscape-scale fire behavior and to measure fuel treatment performance in terms of wildfire probabilities, spread rates, and fire line intensity. [9]
    - Viewing and analyzing spatial fire behavior outputs in ArcMap. [9]
    - Tools to aid wildfire risk assessment. [9]

ArcFuels10 has three core applications which can provide both project planning and fuel management research:

- Modeling fuel treatments with FVS/FFE-FVS

ArcFuels10 stand-level analysis using FFE-FVS includes but not limited to fuel treatment simulation such as broadcast burns, pile burning, mastication, and tree mortality under changes of fire behavior. For users, at the stand level, they are provided with the access to digital orthophotos to observe the vegetation in stands as well as run FFE-FVS and SVS on individual stands. [9]

- Simulating landscape fire behavior and fuel treatments
  Landscape analysis of fuel treatment scenarios examines the aggregate effect of all treatments on potential wildfire behavior (Collins et al. 2010). At the landscape scale, the fuel treatment plans can be obtained in two different ways in ArcFuels10. The first method is by using FFE-FVS with treatment prescriptions to simulate all stands. The second approach is through utilizing appropriate stand-level FFE-FVS simulations, expert opinion, and geographic data to identify the treatment adjustment factors to alter raster data to determine the conditions of post treatment. [9]

- Burn probability modeling and risk analysis
  The burn probability maps can be generated by the incorporation of the minimum travel time (MTT) (Finney 2002) fire spread algorithm into FlamMap makes it feasible which is able to simulate thousands of fires. In conjunction with conditional flame length maps, burn probability maps can also be used to assess the wildfire risk. [9]

b. ArcGIS

Introduction:

ArcGIS is an integrated system that allows users to collect, organize, manage, analyze, communicate, and distribute geographic information. It has been widely used to put geographic knowledge to various disciplines, such as military, business, transportation, media, and government. The system is available everywhere using web browsers, mobile devices such as smartphones, and laptops.

ArcGIS serving as an information and tools platform enables its geographic data and products accessible and affordable to both the employees of federal agencies and end users of private parties.[10]

When it comes to fight wildland and WUI fires, mapping the real time fire condition is important. Fire fighting personnel must need to know the answers for questions such as: Where is fire? What is the fire size? How fast does it spread? What are the risks for fire fighters and residents? ArcGIS

is capable to answer these questions as well as provide data management, risk analysis, and response plan.[11]

Features:

- Desktop Application:
  ArcGIS has the capability of spatial analysis and modeling which can be used to conduct risk and hazard assessment. Common applications of ArcGIS on Desktop include but not limited to: Mapping the wildfire profile, visualizing the risk values, fire spread prediction, responding resources positioning, post fire damage documentation, environmental recovery plan. All of these features can be accessed by the fire officials using vehicle mounted laptops on the fire scene or in the situation unit during large complex fire.[12]

- Web Application
  Web-based ArcGIS is able to provide a jurisdiction with base layers information, such as surface geographic features, physical boundaries, and infrastructure. This information is a compilation of various GIS data resources. For users who are not a trained GIS professional, they can still access and utilize the operational analytics on the GIS platform by fusing base map data with dynamic data.[12]

- Mobile
  ArcGIS Mobile-based applications can significantly support the fire fighting operation and enhance the safety of fire fighters. These technologies includes monitoring the location of fire line personal in relation to the fire spread front as well as the shortest distance to a nearby safety zone, accessing the common operating picture (COP) used by Incident Commend unit, communicating immediate updates between fire line personnel and decision makers, transmitting fire behavior photos and videos footage for display within a geographic interface. ArcGIS for Windows Mobile is applicable for use in the field with short term training.[12]

- Online Maps and Data

  A key family member of the ArcGIS is the ArcGIS Online and ArcGIS.com, which provide the access to all forms of GIS data, imagery, and applications. There are various worldwide base maps available including imagery, streets, topography, community base maps and more. Fire officials can share the map data, projects, and presentations within this online service.[12]

- GIS Server

Another core component of ArcGIS system is the ArcGIS for server which is frequently used in the wildland fire management. It helps the decision making process and awareness of potential or ongoing events by creating a mechanism for organizing and managing GIS data on desktop for emergency planning and analysis. ArcGIS for server also maintains the mobile connections to utilize updates and edits which are stored in the database and published to the COP. It also enables Geographic Area Coordination Centers, agency administrators, incident managers and fire fighting personnel to stay informed on current wildland fire condition.[12]

- Solutions

  A lot current GIS applications depend on the platform created by ArcGIS to build their own programs, these applications include federal agency programs which are designed to serve the public needs as well as private parties owned programs introduced in this report that are developed for commercial purpose, such as RedZone, Timmons Group, Intterra Group, and Technosylva. ArcGIS provide solutions for emergency management by mapping and modeling potential hazards, coordinating fire fighting resources, optimizing logistics, managing situational awareness, disseminating real time information, and facilitating decision making process.[13]

- Training

  ArcGIS Online is a professional training program developed to help users to learn to utilize ArcGIS to perform their work. ArcGIS Online offers Instructor-led courses, E-Learning courses, as well as training for organizations to accommodate users with different background and knowledge level in geographic technology. Besides online courses, the Esri Press is an alternative option to again the knowledge of geographic science, application, and technology, it facilitates the geographic learning and understanding by publishing GIS workbooks, case studies, and in-depth books on GIS topics.[14, 15]

c. ArcGIS Collector (Collector for ArcGIS)

Introduction:

Collector for ArcGIS is an app on smartphones and tablets, which is used to collect and update information in the field, whether it is within a network environment or not.

Features:

Support the field operations by logging the current location, inputting the captured data, and creating maps even the devices are offline. Use maps to get the updated field data, respond to emergency events, and make onsite record.[16]

- Work offline by downloading maps to the mobile devices. [16]
- Utilize GPS to create and update map data. [16]
- Capture location profiles ranging from points to areas. [16]
- Fill out easy-to-use map-driven forms. [16]
- Search and navigate to certain location. [16]
- Monitor and analyze the sites been visited. [16]

d. Esri Disaster Response Program

Introduction:

Esri Disaster Response Program is able to provide technical assistance for disasters, such as Hurricanes & Cyclones, Wildfires, Flooding, Severe Weather, Earthquakes, Drought, and Disease. The support comes in many forms including experts, software, hardware, as well as data and the assistance are 24x7 available for the users and partners when the disaster strikes. Esri's operating platform can effectively implement the mission by facilitating information exchange, connecting local, state, national, and international agencies, allocating mitigation resources, and researching recovery plans.[17]

Features:

- Wildfires — US Wildfire Activity Public Information Map
  This Map has a user friendly interface where users are able to monitor the US Wildfire profiles, potential hazard areas, and weather conditions by incorporating geographic data from NIFC, GeoMAC, NHSS, MODIS, METAR/TAF, and the USDA Forest Service, Fire modeling institute. This maps also provide the users the access to view the map in both physical geographic layers (e.g., New Fire Locations, California Fire Locations, and US Radar) and Media Layers (e.g., Instagram, Flickr, Twitter, YouTube, and Webcams. travel)[18]

- Wildfires — Support Resources (Maps, Images, and Data)
  Fire fighting personnel are provided with the following web sites for wildfire data, maps, images, and resources.

  - ArcGIS Online[19]

- Fire Information for Resource Management System (FIRMS) [19]
- GEOMAC Wildland Fire Support[19]
- Inciweb[19]
- MODIS Active Fire Mapping Program[19]
- MODIS Active Fire Maps[19]
- Geodata.gov[19]
- National Oceanic and Atmospheric Administration[19]
- National Fire Weather[19]
- BLM Airspace Information System[19]

e. FHX2 Fire History Software (FHX2)

Introduction:

FHX2 is a program specialized in identifying the forest fire historical data through analyzing the fire scars and other damages found in a tree's rings. The software can be used to do statistical analysis and fire interval distributions modeling. FHX2 is also capable of analyzing the relationship between past fire and climate by access the superposed epoch analysis program.[20]

Features:

- Data Entry
  Historical information and record keeping are addressed by creating the format called FIRE2 ("FHX2 format" or "fire history format") which provides a means for entering, documenting, storing, and editing of fire history information. The data Entry modules allows the users to manage the fire history with multiple options such as add, move, delete and edit, and it is also capable of data integration.[20]

- Graphical Analyses
  The graphical analyses provides interpretation of the exact the year of fire occurrence by observing lines based on dendrochronological methods.[20]

- Statistical Analyses
  The statistical Module of FHX2 is able to deliver the summary information for individual trees and present the sample depth changes in a table. Additionally, FHX2 can help identify whether the fire regimes differ between two or more sites.[20]

- Superposed Epoch Analysis

Through using superposed epoch analysis, FHX2 can observe the relationship between fire and climate.[20]

f. Fire Enterprise Geospatial Portal EGP

Introduction:

The Enterprise Geospatial Portal (EGP) project was initiated in 2009 to facilitate the management, analysis, and distribution of geospatial data to support the wildland fire risk assessment and fire suppression activities. Wildland fire fighting personnel and units can access the wildland fire situational data containing up-to-date fire profile, local weather information, fire detection analysis, and resources allocation through the EGP web-based platform.

Features:

With the use of EGP, fire service personnel is able to access data from central data base, integrated the data with other data source, and exchange the information between different stakeholders.[21]

There are currently 4 components within the EGP:

- Fire Globe
  Fire Globe is developed as a common operational view which can support disseminating the 3D illustrated situational awareness of wildland fire to the EGP users. The Fire Globe can be viewed in either 3D or 2D version by utilizing three Globe Clients: Web Client, Google Earth, and Maps Engine.[22]

- Situation Analyst/GDAT (Geospatial Dashboard and Analysis Tool)
  Situation Analyst (SA) and the Geospatial Dashboard and Analysis Tool (GADT) can be considered as analytic tools that use GIS to support the wildland fire decision making process.
  While the GDTA providing highest level of analytics capabilities, the SA is a integration program of geospatial mapping, detection analysis, and the 'common operational picture'.[23]

- Fire EGP Data
  Those data are either static or dynamic that is accessible to the EGP users.[24]

- Incident Risk Console (RisC)

The Incident Control Console (RisC) is an analytic interface where data and statistics related to wildland fire are accessible for NFDRS users to conduct supplemental data analysis.[25]

g. Fire Incident Mapping Tools

Introduction:

Fire Incident Mapping Tools (FIMT) is an extension for ArcGIS ArcMap versions 10.x, 9.x, and originally in 8.3. This program is an assistive tool for Wildland Fire Incidents with its specialization for incident mapping and geographic data management. This software follows the standards and rules of Incident Command System (ICS), the GIS Standard Operating Procedures (GSTOP), and the GIS Specialist (GISS) position duties.[26]

Features:

- FIMT consists a standardized geodatabase model which provides a consistent framework for users to utilizing FIMT tools, managing fire perimeter information at national level, and archiving spatial incident data in a standard format. The FIMT geodatabase contains two feature datasets, one is capturing current incident features and the other one is for storing incident history features. Within the FIMT environment, the current incident features dataset can be converted to the history feature dataset, enabling the fire progression maps be created from archived fire perimeters.[27,28]

- The ArcMap toolbar contained in the FIMT enables users with the full version of the ArcMap tools they need in manipulating geographic data and generating maps during a fire incident. The toolbar can be used for developing incident geodatabase, opening existing datasets, managing incident metadata, and converting FIMT geodatabase to shapefile format, commanding assignments, fire points and fire lines.[27,28]

h. FSGeodata Clearinghouse

Introduction:

The USDA Forest Service Geodata Clearinghouse is a web-based platform collecting and displaying geographic information of forest resources, such as boundaries and ownership, federal and private area, roads and trails, and even insect and disease threat. It also allow users to download forest datasets, map products, raster data, and providing access to other forest information websites.[29]

Features:

- Forest Service Enterprise Data
  Users are allowed to use the Data Extract Tool to obtain the data about a specific forest or grassland. Users also have the access to downloadable datasets by topic area or theme or find and use map services published by the Agency.[30]

- Map Products
  There is a variety of map products published by the Forest Service, which include national forest atlases and wilderness maps, large scale topographic maps (FS Topo), Motor Vehicle User Maps, and Interactive Visitor Map which can help users plan their visit in the forest.[31]

- Raster Data Gateway
  The raster datasets are created by the Forest service which contain the aerial photographs, satellites images, digital pictures, and scanned maps.[32]

- Other FS Data
  Other featured datasets include fire related data and maps, boundaries, historical wilderness and wild and scenic river designation information, forest health information.[33]

i. Fuel Characteristic Classification System (FCCS)

Introduction:

The Fuel Characteristic Classification System (FCCS) is developed to meet the needs from Land managers, scientists, and policy makers to category and classify the diverse fuel beds and predict the fire hazard related to the fuelbeds.[34] FCCS contains a large database of physical parameters that can quantify the abundance, physical profile, and arrangement of wildland fuelbeds.[35]

Features:

- FCCS provides a dataset of fuel beds throughout the United States, which is a compilation of fuels images, expert opinion, research literature, and other data sources. This data will

serve as the inputs for the models which simulate the fire behavior, fire impact, carbon accounting and fuel treatment plan.[36]

- The system is able to manipulate the fuel beds data to visualize and analyze the fire profile for a given site and cover the fuel characteristics for different geographic features.[36]

- Finally, the system can provide an index of the intrinsic capacity of each fuel bed by calculating the fire potentials to model the fire spread in different condition and evaluate the fuel beds treatment effectiveness. [36]

j. GeoMac

Introduction:

The Geospatial Multi-Agency Coordination or GeoMAC, is an online-based mapping program developed to meet the needs of fire fighting personnel to view the current fire incidents status and profile in the United States.[37] The GeoMAC has been monitoring and storing the wildland fire data since 2000, and these data can serve as the input and resources to support the GeoMAC program for distribution the wildland fire information to the fire prevention agencies as well as public.[38]

Features:

- The fire information data in GeoMAC is updated daily based upon input from GPS data, infrared (IR) imagery data, and incident feedback sources, which provide the fire incident managers near real time information.[39]

- The GeoMAC provides a user friendly website that offers several important actions which can help fire mangers remotely and efficiently get updates on current fire conditions. Users can zoom in and out to display fire information at various scales and detail, print the online maps for use of fire information analysis, disseminate information to fire incidents related offices and personnel, view different layers and fire occurred in different years. The fire maps can provide the users with information on individual fire incidents such as name of the fire, current size and other fire condition profile through its relational databases.[40]

- GeoMAC Data

GeoMAC data collections include perimeter data gathered from incidents, fire point data extracted from National Interagency Fire Center (NIFC) downloadable data, MODIS Thermal Satellite data, and HMS Thermal Satellite data.[40]

k. Intterra Group Solutions: Situation Analyst

Introduction:

"Situation Analyst" (SA) is a program specializing in active situational awareness application, by incorporating the common operating picture with on-demand decision support tools, it enables the fire fighting personnel to coordinate efforts, share information, and optimize the decision making process. SA provides a framework for fire service agencies to implement their goals within a geographic information system (for example, ESRI-based architectures) by utilizing the user friendly interface, decision making tools, and mobile extentions.[41]

Features:

- Rapidly scale from a top-level overview to incident-level details
  - Informative view of geographic areas ranging from a single point to an extensive region. [41]
  - Support decision making process by consolidating incident oriented information. [41]
  - Customize incidents details and location profile as required. [41]

- Tailor the operational view to address incident specific needs
  - Manipulate the GIS data to accommodate different emergency stages (e.g. pre-planning and mitigation). [41]
  - Preload the authorized geographic data source to display the real time information. [41]
  - Seamless base map are available to use including Aerial Photos, Street Maps, and Topographic Maps. [41]

- Conduct analysis and decision support
  - Spatial information focused program can be processed in order to obtain the data related to different layers. [41]
  - Capable of conducting "plug-in" analysis by integrating data from within a geodataset or related data inputted into this program. [41]

- Access and use data from all potential data sources

SA can improve the incident geographic visualization and analysis by adopting data from multiple sources. The following data are provided by SA from both internal and external sources.

- OGC compliant web services. [41]
- Web Mapping Services (WMS). [41]
- Shapefiles (zipped or uncompressed). [41]
- KML/KMZ layers from Google Earth. [41]

➢ Share intelligence with partners and stakeholders

- Easy to export of any layer from within SA to Google Earth. [41]
- Compatible with Microsoft SharePoint. [41]
- Parameters of specific "view states" can be saved and shared. [41]

➢ Collaboratively map and share information

- Enable fire fighting personnel to synchronous field data and observations to central system. [41]
- Advanced editing abilities which utilize standards-based symbology (for example, Fire Incident Mapping Tools (FIMT) and FDGC Homeland Security symbology. [41]
- Spatial data editing capability which can manage incident-specific geodatabases, temporary user databases, or enterprise geodatabases. [41]
- Mobile editing supportable within the viewer on smartphones and tablets. [41]

➢ Process remote sensing and imagery data

- SA architecture accept automated imagery tools and modules. [41]

l. Landscape Fire and Resource Management Planning Tools (LANDFIRE)

Introduction:

LANDFIRE, Landscape Fire and Resource Management Planning Tools, is a collaboration program developed by the wildland fire management programs of the U.S. Department of Agriculture Forest Service and U.S. Department of the Interior. LANDFIRE is established to provide the wildland fire fighting agencies the comprehensive and integrated data describing landscape distribution, fuel, vegetation, and fire regimes in the United States. It served as a platform for wildland fire management, information exchange, resources allocation, and fire fighting operation planning.[42]

Features:

The LANDFIRE data is produced through a combination of many interdisciplinary technologies, such as the integration of geospatial tools and simulation models.[42] These data are available at different scales which can cover a wide range of fuel systems, the use of these data are dependent on the location and specific purpose.[43]

- Reference Data

  Reference data product is a data collection from public information, private sources, and authorized data from government agencies. These data are important for LANDFIRE to update maps, inform landscape changes and support other LANDFIRE products. The reference data product open for public use is also available for download. Other additional use of the reference data include mapping and analysis for plant species, input for vegetation models, fuels information management.[44]

- Disturbance Data

  Disturbance Data served as an input for LANDFIRE to update the landscape changes which are resulted from the natural disturbance and man-made activities, this process can also support the LANDFIRE to make modifications in detection analysis.[45]

- Vegetation Data

  Vegetation data is obtained from an integration of multiple pieces of information which include field-referenced data, remote sensing data, and biophysical layers. The vegetation data can be used to manipulate natural resource, monitor the ecosystem, classify wildland habitat, and support detection analysis.[46]

- Fuel Data

  Fuel data is developed to display the distribution and profile of wildland fuel, serve the fire potential awareness and analysis, support the fuel treatment strategy, predict wildland fire effects and behavior, and help the fire fighting operations.[47]

- Fire Regime Data

  Fire regimes products are applicable in evaluating the changes in landscape, comparing historical conditions, and support the management of landscape.[48]

- Topographic Data

  Topographic data serve as input to the Landscape (.LCP) file which is used in models to predict wildland fire behavior and effects.[49]

m. National Fire Danger Rating System (NFDRS)

Introduction:

The National Fire Danger Rating System (NFDRS) is a program developed to support the fire mangers to evaluate the fire risk potential for a given area. NFDRS can identify the risk factors and estimate the needed fire prevention resources of a given area by quantifying its existing and expected fire danger factors. It helps the fire fighting agencies to understand their levels of awareness and readiness in terms of pre-planning and tactical operations to the hazard potential of a fire dangerous area.[50]

Features:

- Staffing Level

  Staffing Level can be considered as classification of fire risk conditions, which can be used to indicate the danger status in given area, for instance, is the fire operation unit is in the hot end, cool end, or somewhere in between? The staffing level is derived from cumulative analysis of occurrence frequency of either Burning Index (BI) or Energy Release Component (ERC). It creates a fire operation response mechanism where for each staffing level there is a management action to be tied, which indicates the potential fire fighting operation workload needed.[51]

- Determine Daily Adjective Fire Danger Ratings

  In 1970s, a fire danger rating system of 5 levels was developed by the Forest Service to serve the public fire prevention information release. In 2000, the NWCG Fire Danger Working Team reviewed the definitions of those five fire danger levels and made slight modifications as it is currently expressed using the adjective levels and color codes described below.[51]

Table 1. 5 Levels of Fire Danger Ratings

Fire Danger Rating and Color Code	Description
Low (L) (Green)	Fuels do not ignite readily from small firebrands although a more intense heat source, such as lightning, may start fires in duff or punky wood. Fires in open cured grasslands may burn freely a few hours after rain, but woods fires spread slowly by creeping or smoldering, and burn in irregular fingers. There is little danger of spotting.
Moderate (M) (Blue)	Fires can start from most accidental causes, but with the exception of lightning fires in some areas, the number of starts is generally low. Fires in open cured grasslands will burn briskly and spread rapidly on windy days. Timber fires spread slowly to moderately fast. The average fire is of moderate intensity, although heavy concentrations of fuel, especially draped fuel, may burn hot. Short-distance spotting may occur, but is not persistent. Fires are not likely to become serious and control is relatively easy.
High (H) (Yellow)	All fine dead fuels ignite readily and fires start easily from most causes. Unattended brush and campfires are likely to escape. Fires spread rapidly and short-distance spotting is common. High-intensity burning may develop on slopes or in concentrations of fine fuels. Fires may become serious and their control difficult unless they are attacked successfully while small.
Very High (VH) (Orange)	Fires start easily from all causes and, immediately after ignition, spread rapidly and increase quickly in intensity. Spot fires are a constant danger. Fires burning in light fuels may quickly develop high intensity characteristics such as long-distance spotting and fire whirlwinds when they burn into heavier fuels.
Extreme (E) (Red)	Fires start quickly, spread furiously, and burn intensely. All fires are potentially serious. Development into high intensity burning will usually be faster and occur from smaller fires than in the very high fire danger class. Direct attack is rarely possible and may be dangerous except immediately after ignition. Fires that develop headway in heavy slash or in conifer stands may be unmanageable while the extreme burning condition lasts. Under these conditions the only effective and safe control action is on the flanks until the weather changes or the fuel supply lessens.

(Reference: Gaining an Understanding of the National Fire Danger Rating System, http://www.nwcg.gov/pms/pubs/MasterGaining.pdf, National Wildfire Coordinating Group, July 2002)

NFDRS processors automatically calculate the adjective class rating. The actual determination of the daily adjective rating is based on the current or predicted value for a user selected staffing index and ignition component using the table below.

Table 2. Adjective Fire Danger Rating

Staffing Levels	Adjective Fire Danger Rating				
1-, 1, 1+	L	L	L	M	M
2-, 2, 2+	L	M	M	M	H
3-, 3, 3+	M	M	H	H	VH
4-, 4, 4+	M	H	VH	VH	E
5	H	VH	VH	E	E
Ignition Component	0-20	21-45	46-65	66-80	81-100

(Reference: Gaining an Understanding of the National Fire Danger Rating System, http://www.nwcg.gov/pms/pubs/MasterGaining.pdf, National Wildfire Coordinating Group, July 2002)

- Guide Restrictions of Industrial Activity

  Industrial operations such as timber harvesting activities and natural resource exploration are contributing factors to result in the large devastating wildland fires. NFDRS can support and regulate these activities through its system thus to reduce the risk of large wildland fire.[51]

- Guide Public Use Restrictions

  In order to implement wildland public use restrictions, it is important to establish a relationship between human activity and fire occurrence. In NFDRS, this relationship is designed as each specific type of human activity is corresponded to a NFDRS index or component, thus, via observing the changes in those component or indexes, fire manger can manipulate the restrictions to human involvement in the wildland area.[51]

- Determine Regional Preparedness Levels

  Fire danger information is of great importance in coordinating, allocating, and dispatching fire fighting resources to fire risk areas. In NFDRS, the fire danger rating data in conjunction with weather information can be used to evaluate the regional fire risk potential. This evaluation is then combined with factors affect the fire fighting operations to identify if the preparation and resources are able to meet the expected fire fighting workload needs.[51]

- Assist in Wildland Fire Use Go/No Go Decisions

  Usually, there are two choices for fire mangers to choose when a wildland fire occurred, one is to take the suppression operations, and the other option is to allow the fire to burn in a controlled area and damage level. NFDRS components and indices and historical data can be served as baseline for decision makers to base their evaluations. Typically, fire mangers can utilize NFDRS to monitor up-to-date fire danger rating values, and then make comparison with historical values and seasonal trends, thus to estimate the fire risk potential for a given site at a specific time period.[51]

- Facilitate Briefings
  Inadequate briefings regarding the fire scene conditions has been identified as a factor resulted in fire fighting fatality on wildland fire. In 1997, the "Fire Danger Pocket Card for Fire fighter Safety" has been developed by the National Advisory Group for Fire Danger rating to standardize the briefings, this card has information describing the current fire conditions, seasonal trends, and comparisons with historical data which can be accessed and manipulated through a computer program. NFDRS components and indices related to wildland fires in a given site are presented in this card.[51]

n. National Significant Wildland Fire Potential Outlook

Introduction:

The National Significant Wildland Fire Potential Outlooks are developed to provide the fire service decision makers with the comprehensive fire potential information, thus to optimize the fire management fire prevention resources, improve life and property safety, and enhance fire fighting operation efficiency. The product is able to provide outlooks for seasonal and monthly durations.[52]

Features:

- 7-Day Significant Fire Potential
  Maps are compiled for Geographic Area in fire season with 7 Day Significant Fire Potential Outlooks. These maps are updated daily. [52]

- Geographic Area Outlooks
  Fire weather, danger rating, and fire potential reports are tied to each Geographic Area. [52]

- Fire Occurrence Density by Month[52]

o. Rapid Data Distribution System (RDDS)

Introduction:

The Rapid Data Distribution System is developed to support the wildland fire management agencies and professionals with both vector and raster datasets of the United States. The Viewer section allows the users to manipulate the geospatial maps and display hazards information which are available in

several geographic layers. Additionally, The RDDS offers downloadable data for the users' particular needs.[53]

Features:

- Viewable Incident Layers[53]
  - Earthquakes (> 4 magnitude) [53]
  - Active Volcanoes[53]
  - Active Fires[53]
  - Active Fire Perimeters[53]
  - Hurricanes[53]
  - Stream Floods[53]
  - Thermal MODIS[53]
  - Remote Automated Weather Stations[53]

- Viewable Base Map
  - ESRI World Imagery[53]
  - ESRI World Street Map[53]
  - U.S. Federal Lands[53]

- Downloadable Raster Products
  - Ortho Imagery[53]
  - Digital Raster Graphics (24K/100k topo) [53]
  - Shaded Relief[53]
  - Digital Elevation Models[53]
  - Terrestrial Ecosystems (U.S./Africa) [53]

p. RedZone Software

Introduction:

Redzone Software has developed a suite of GIS products that are utilized by government and commercial clients to assist them in increasing the risk awareness, protecting life and property safety, and mitigating disasters. RZAlert, RZRisk, and RZMobile offered by RedZone provide the users with real-time emergency notification, integrated risk assessment, and comprehensive incident management applications that can facilitate the decision making process as well as reduce life and property loss.[54]

Features:

- RZAlert
  RZAlert is specialized in monitoring and tracking catastrophic events, such as wildland fire, earthquakes, floods, tornadoes, and hurricanes. Based on the up to date emergency information and advanced analytical program, RZAlert is able to support the fire fighting units to enhance the situational awareness, optimize response plans, and minimize the loss from fire.[55]

  - Intelligence
    RZAlert's dataset is based on a wide range of authorized data sources, for instance, US Forest Service Wildfire Predictive Services, while frequently collecting geospatial information from those data source, RZAlert is also able to input, analyze and associate those data with the event occurrence potential, magnitude, and severity.[55]

  - Notifications
    RZAlert notifications are developed to meet the needs of users, notification forms are related to different bases, such as incident geographic location, size, severity, and etc.[55]

- RZRisk
  RZRisk is capable of analyzing wildland fire risk through evaluating the contributing factors resulting in large damage and loss, for example, immediate ignition sources, areas contain large ember showers, and areas with redundant fuel sources. RZRisk manage the wildland fire risk potential from three different perspective: 1) Site Hazard, 2) Zone Hazard, and 3) Fire History.[56]

  - Site Hazard
    The "Site" refers to an area located adjacent to a property which is under the threat of spreading wildland fire. The risk level of this site can be tied to several indicators, such as the onsite ignition sources, physical configurations, and accessibilities of fire suppression force, additionally, RZRisk can score the site fire hazards by evaluating the fuel, slope, fire occurrence trends, and expected fire behavior.[56]

  - Zone Hazard

The "Zone" is described as a large fuel source covered area that could sustain a significant wildland fire. Zone hazard is amid at estimating the fuel properties, heat release, flame length, and live embers travelling along with wind based on the physical configuration of this area.[56]

- Fire History
  The Fire History dataset is a collection of occurred wildland fires perimeters, it provides all known historical fire information near the potential hazard area. Evaluating the current fire hazard through cross-checking the historical fire profile (Year, Name, Size, Damage, etc.) can provide an insight of potential hazard in this area, such as common magnitude of wildland fires, occurrence frequency, overlap of each areas, which can be served as an alternative methodology paralleling with wildland fire modeling to support the wildland fire risk assessment decision making processing.[56]

➢ RZMobile
  While operating fire suppression activities in the wildland area is a challenging project which require the fire line responders to be well informed and prepared. RZMobile is capable of providing offline base maps which allow users to load the custom street and terrain in any area in the US, additionally, the maps are stored in the mobile devices thus fire personnel can utilize the maps without the cell network.[57]

q. Technosylva

Introduction:

Technosylva is a technology company that has a strong focus toward wildfire emergency solutions. By utilizing GIS, teledetection, remote sensing, and fire simulation models, Technosylva is able to deliver a comprehensive interpretation of the emergency situation, model fire behavior, evaluate wildfire risk potential, and support fire suppression operation. The core products in the wildland fire application are fiResponse and Wildfire Analyst, which can support the emergency response in conducting wildfire risk analysis, modeling fire behavior, and developing fire mitigation plan.[58]

Features:

- fiRESPONSE

  fiResponse is a system that can support fire fighting decision making process and incident management. It is capable of providing data synchronization between different users and devices, incident monitoring and reporting, Computer Aided Dispatch (CAD), and Incident Commend System assignment. All these functions are applicable in wildland fire pre-planning, detection analysis, emergency response, fire fighting units dispatching, suppression resources allocation, risk and hazard assessment, and post-fire rehabilitation.[59, 60]

- Wildfire Analyst

  Wildfire Analyst (WFA) is a system used on desktop providing seamless integration data, real time wildfire simulation, and fire fighting tactical plan to support the incident mangers and fire fighting personnel. Additionally, WFA is capable of providing real time weather integration with authorized and local customer weather sources including forecast data. WFA can be used in conjunction with ArcGIS server based fiRESPONSE COP.[61, 62]

r. The Wildland Urban Interface - WUI Maps and GIS data

Introduction:

WUI maps contain the geographic profile for the 50 states through the US. These maps are developed to visualize the WUI location in 1990, 2000, and 2010.[63]

WUI GIS data are created to meet the need of land management officials handling WUI and associated issues, particularly in areas effected by housing growth on the environment.[63]

Features:

- Two types of WUI maps are presented. One is intermix, which indicates areas where housing and vegetation are mixed. The other one is interface map, which are areas with housing are adjacent to the wildland vegetation.[64]

- The GIS data are downloadable in different format which are compatible to GIS software and can be utilized for mapping and analysis at national, state, and local levels.[64]

s. Timmons Group Geospatial Solutions

Introduction:

Timmons Group provides a comprehensive suite of wildland fire protection planning applications and services. There are two products of Timmons Group that provide wildland fire risk management and fire fighting support, they Wildfire Risk Assessment Portal, and Wildfire Maps The application solutions provide the information critical for mitigation and prevention planning, and real-time situational awareness. They work closely with local, state and federal fire management agencies across the nation in fuels mapping, wildfire risk assessment, and fire behavior analysis. These two products are introduced below.[65]

Features:

- Wildfire Risk Assessment Portal (WRAP)
  The Wildfire Risk Assessment Portal is developed to meet the needs of the wildland fire prevention units for the wildland risk information and planning tools. WRAP is a platform for several web-based mapping programs to be integrated which are capable of manipulating wildland fire risk profile, processing risk analysis, generating risk assessment reports, and displaying landscape maps.[66]

- Wildfire Maps
  By collecting geospatial data from authorized, private, and public data resources, the Wildfire Maps can provide up-to-date wildland fire mapping information for a given area. Wildfire Maps empowers the data distribution and collection by integrating with social media such as Twitter, Flickr or YouTube, users have the access to view the web-based mapping interface with the latest 24 hour updates.[67]

t. United States National Grid (USNG)

Introduction:

The USNG was developed by the Federal Geographic Data Committee (FGDC) to provide a more understandable environment in order to facilitate the location based service throughout the US.[68]

Features:

- Seamless plane coordinate system which is compatible with jurisdictional boundaries and maps. [68, 69]
- Referencing with GPS and maps to provide location service. [68, 69]
- Provide geo address and a universal map index. [68, 69]

u. Wildland Fire Assessment System (WFAS)

Introduction:

The primary focus of the Wildland Fire Assessment System (WFAS) is to support the fire management decision process by providing fire weather information, fuel conditions, vegetation profile, and risk information data from other authorized agencies. WFAS combines multi-spatial and multi-temporal observations and analysis into a program that is capable of operating real time risk evaluation and forecast for factors that can affect the wildland fire potential for a given site. It largely support the wildland fire management by integrating weather information, remote sensing data and risk forecasts into a single and easy to use interface. WFAS products are organized into four major categories.[70]

Features:

- Fire Potential & Danger
  The fire Potential & Danger classification is similar to the Adjective Fire Danger Classes from the United States National Fire Danger Rating System (NFDRS). Fire danger forecast service is available for current and next-day base. And Haines index maps are also provided because wildland fire spread is enhanced by atmospheric instability.[70]

- Weather
  The system provides national maps of wind speed, 24-hour precipitation, temperature and relative humidity derived from Remote Automated Weather Stations (RAWS) throughout the country.[70]

- Moisture & Drought
  The Moisture & Drought has a focus on providing the wildland fire managers live vegetation condition at the landscape scale. In the WFAS, the wetting and drying trends are described by the National Fire Danger Rating System (NFDRS)-calculated dead fuel moistures. In addition, the satellite-derived greenness are introduced into the system, such as the relative greenness and average greenness, which are used to describe the long-term minimum, maximum and average for the time of the year.[70]

v. Wildland Fire Decision Support System (WFDSS)

Introduction:

The Wildland Fire Decision Support System project is established to support the wildland fire fighting decision making processes by utilizing risk assessment tools, fire simulation models and geospatial data analysis.[71] WFDSS is capable of addressing response plan for on-going and potential fire, collecting weather information data, predicting wildland fire behavior, estimating the fire spread timeline, and assessing fire cost and impact.[72]

Features:

- Accessibility
  As WFDSS is a Web-based system that users can easily assess WFDSS with their login information under a network environment.[72]

- Consistency
  WFDSS is consistent with accepted models of risk-informed decision making.[72]

- Flexibility
  WFDSS's risk assessment tool is compatible with multiple risk characterizations and decisions making it a user friendly and wildly accepted platform.[72]

- Information assembly and consolidation
  Data that already exist from different sites are consolidated to present concise information.[72]

- Adaptability
  WFDSS provides a decision framework that is linear, scalable, progressive, and responsive to changing fire complexity. As incidents progress in size and complexity, WFDSS provides decision and documentation support to match fire management needs. Specific analysis tools can be assessed to address changes in fire conditions.[72]

- Geospatial capability
  By displaying the geospatial data information in the maps form rather than the text form, it has greatly save the time for pre-planning, detecting fire behavior, and implementing response plan.
  These maps with the multiple layers are available in different scales and resolutions.[72]

- Safety and resource availability assessments

WFDSS provides information for consideration of safety, risk, and the availability of resources as part of the decision process.[72]

w. Wildland Fire Potential (WFP)

Introduction:

The Wildland Fire Protection (WFP) map is a raster geospatial product developed by the USDA Forest Service and Fire Modeling Institute which serves as a risk assessment application for wildland fuels prioritization at different scales.[73]

Features:

- The WFP map builds upon, and integrates, estimates of burn probability (BP) and conditional probabilities of fire intensity levels (FILs) generated for the national interagency Fire Program Analysis system (FPA) using a simulation modeling system called the Large Fire Simulator (FSim; Finney et al. 2011).[74]

- The final WFP map is presented here in two forms: 1) continuous integer values, and 2) classified into five WFP classes of very low, low, moderate, high, and very high. Paired with spatial data depicting highly valued resources, it could be used to create value-specific risk maps.[74]

- Wildland Fire Potential delineates areas based on fire intensity, weather, frequency, and size, which was then classified into a relative ranking of fire potential from very low to very high.[74]

- The data is based on three primary sub-products: fuel potential, fire weather potential, and fire occurrence potential. Long-term strategic planning and fuels management.[74]

4. Remote Sensing (RS) Application in Wildland and WUI Fire Management

Remote Sensing (RS) refers to the observation and collection of data without the sensor being in physical contact with the object being studied, such as the study of the Earth from distant vantage points, via satellite or aircraft. [1] The mapping capabilities of remote sensing have been widely accepted and utilized by fire management agencies to obtain the detailed geographic information and fire profiles throughout a lot areas. There are several government developed Remote Sensing technologies and programs that will be introduced in the alphabetic order in the following sub-sections.

a. Active Fire Mapping Program

Introduction:

The Active Fire Mapping program is developed and managed by the USDA Forest Service Remote Sensing Applications Center (RSAC). By utilizing the NASA's Moderate Resolution Imaging Spectroadiometer (MODIS) data, this program is able to provide satellite-based fire detection, wildland fire activity mapping, and near real-time geospatial data that serves the United Stated and Canada. MODIS collects high temporal image data that are currently the primary remote sensing data source of this program. The primary objective of this program is to give the fire managers the access to get updated on the current regional and national wildland activities therefore to support the decision making support and fire fighting resource coordination.[75]

Features:

- Fire Detection Maps
  The Fire Detection Maps are generated from the data obtained by the MODIS, AVHRR, and GOES sensors. By clicking each state icon, users will be directed to a new page showing both current and archived fire map at the time of publication for this state, those data area downloadable in PDF and JPEG format. The update time interval of the Fire Detection Maps depends on the current fire activities in a certain geographic area. For instance, if a given area is under active and severe fire threat, maps are updated multiple times daily following satellite observations.[76]

- MODIS Satellite Imagery

Daily MODIS imagery subsets are generated from MODIS direct readout data acquired by the USDA Forest Service Remote Sensing Applications Center. This image subset is provided as a 3-band JPEG or GeoTIFF, or as a 7-band BSQ (band sequential) image. Users are provided both with latest updated data and previously acquired imagery by simply clicking the data in the calendar.[77]

- Fire Detection GIS Data
  - MODIS Fire Detection GIS Data[78]
  - VIIRS-AF Fire Detection GIS Data[78]
  - VIIRS I Band Fire Detection GIS Data[78]
  - AVHRR and GOES Fire Detection GIS Data[78]

- Fire Data in Google Earth
  It enables geospatial datasets relevant to fire management in Keyhole Markup Language (KML/KMZ) format to be used in Google Earth and other virtual globe applications.[79]

- Fire Data Web Services
  It links the OGC web maps services, geo-referenced images, and streaming geographic features.[80]

- Latest Detected Fire Activity
  The fire activities featured by various geographic themes are updated every 12-hours, and the data based on the data obtained by MODIS, AVHRR and GOES.[81]

- MODIS Burn Scar Data
  MODIS burn scar data are provided at a spatial resolution of 500 meters and attributed with the approximate day of burning on a per pixel basis.[82]

b. Burned Area Emergency Response (BAER)

Introduction:

The Burned Area Emergency Response (BAER) project is established to meet the needs from wildland fire fighting personnel in securing life and property safety as well as reducing environmental and economic cost. The primary focus of the BAER program is to identify the wildland fire associated emergency treatment plans in order to prevent untenable conditions to wildland resources and minimize the risk of life and property loss resulted from the wildland fire hazard.[83] Additionally, BAER provides delivery of Burned Area Reflectance Classifications (BARC), and other geospatial data to Forest Service and DOI BAER teams.[84]

Features:

- Burned Area Reflectance Classifications (BARC) data
  A Burned Area Reflectance Classification (BARC) is a satellite derived map of post fire condition. The BARC has four classes: high, moderate, low and unburned. It is available in both raster and vector format.[85] In the immediate aftermath of a wildland fire, a BAER team is sent to the site to conduct the damage evaluation and restoration analysis through identifying the soil burn severity and future negative effects on other natural hazards. In order to address the soil burn severity, the Burned Area Reflectance Classifications data should be used as a major input in finalizing the soil burn severity map.[86]

c. Monitoring Trends in Burn Severity (MTBS)

Introduction:

Monitoring Trends in Burn Severity (MTBS) program is established to provide consistent information for wildland fire burn severity and post-fire effects throughout the United States from 1984 to current. Regarding the burn severity, these information are used to describe the location, extent, magnitude, and national trends of the burn areas. The post-fire effects analysis and assessment are derived from a dataset comprised of high spatial and thematic resolution data.[87]

Features:

- Fuel Management
  MTBS data can be used to track changes in fuel layers, calculate parameters related to fire behavior model. MTBS burn severity data can also be used to conduct assessment of pre-fire fuels treamtments.[88]

- Tactical Fire Suppression Planning
  MTBS burn severity data can be utilized in constructing and validating the fire risk models of crown fire and lethal surface. The use of MTBS data for past fires can be used to determine fire fighter safety zones during the wildland suppression operations.[89]

- Post-fire assessments
  By tracking and mapping all significant fire information along with utilizing fire severity assessment strategies, MTBS is able to help capture the post-fire severity data immediate aftermath the target fire incident.[90]

- Fire policy implementation and effectiveness
  The mapping capabilities of MTBS can be well used in assessing and monitoring trends in fire threatened areas. In addition, the information gathered by the MTBS mapping activities can also be used to inform the decision makers about the policy implementation condition.[91]

- Ecosystem/Landscape level monitoring
  MTBS burn severity data can be converted to probability distribution curves which indicate the damage level that certain fire might bring. The probability curves then can be used to compare the historical fire regimes to current fire regimes, assess the fire management strategies, and analyze the distribution of fire severity by vegetation types after a certain period of time after fire damage.[92]

d. National Infrared Operations

Introduction:

The primary goal of the National Infrared Operations is to provide the wildland fire professionals with near real time high-quality thermal infrared imagery and accurate fire detection capabilities. The advantages of utilizing the National Infrared Operations for fire detection and imaging in wildland fire management are 1) ability to detect fire accurately with a low false report rate. 2) Wide Fire Coverage 3) Timely delivery of information.[93]

Features:

- Detect fire accurately with a low false report rate
  An accurate fire detection requires identifying small fire hot spots among an extensive land area that are potentially not within the fire boundary. In order to achieve this goal, the National Infrared Operations utilize a dual waveband, or two color fire detection that has the advantage of sub-pixel fire detection, this approach can avoid the weakness of the single waveband scanner in detecting large warm area as fire hot spot.[94]

- Wide Fire Coverage
  The National IR Operations Unit monitors and collects thermal infrared imagery for hundreds of fires each year. The scanner system is equipped with a wild field of view: 86 degrees (FireFly/Daedelaus ABS 3500) and 120 degrees (Flame and Phoenix, using the Kennedy RS-25 scan head). Plus the accurate fire detection feature, it empowers the system to cover more than a half million acres per hour and those information is ready for interoperation without post processing.[95]

- Timely delivery of information:
  The product is produced on a Raytheon TDU-850 Thermal Printer in real time and is delivered to the interpreter within an hour of production via hand, air drop, or digital transfer using RF data link.[95]

5. Global Positioning System (GPS) Application in Wildland and WUI Fire Management

The Global Positioning System (GPS) is a U.S. owned utility that provides users with positioning, navigation, and timing (PNT) services.[96] Global Positioning Systems (GPS) employs a geospatial technology that enables a portable device to pinpoint a precise location almost anywhere on the Earth by processing signals with the aid of satellites.[1] The use of GPS in wildland fire management are diverse and important, which includes improved preplanning, facilitated fire detection, and support for fire suppression operations. There are several Global Positioning System (GPS) technologies and programs have been identified which will be introduced in the alphabetic order in the following sub-sections.

a. ESRI ArcPad

Introduction:

ArcPad, by taking the advantages of advanced GIS and GPS capabilities, this mobile field mapping and data collection software is able to capture, edit, and display geographic information. The wildland fire communities are allowed to check in and extract out the critical data from the shared geodatabase. ArcPad is part of an enterprise GIS platform and integrates directly with ArcGIS for Desktop, ArcGIS for Server, and ArcGIS online.[97]

Features:

- Mobile GIS software that supports integrated GPS data capture. [98]
- Data storage format: ESRI shapefile with a spatial reference defined either by the user, or by ArcPad's default. [98]
- Spatial reference settings: Establish the spatial reference of stored data. [98]
- Point at which coordinate projection and transformation occur: When ArcPad receives incoming GPS data. [98]
- Accepts GPS input from a Trimble GPS receiver, or any NMEA-based GPS receiver. [98]
- Post-processing differential correction: Trimble GPSCorrect, plus Trimble Pathfinder Office or Trimble GPSAnalyst. [98]

b. Magellan (Mobile Mapper)

Introduction:

Mobile Mapper 6 is a mobile GPS/GIS receiver which is user friendly and affordable. It supports the mapping activities by providing a suite of required features that help users to collect and manage field data.[99]

Features:

- GPS data collection and navigation capabilities. [99]
- Raw data collection for post-processing. [99]
- Support for vector layers in 2D/3D shapefile format for point, line and area collection. [99]
- Area and perimeter calculation in the field for real-time area determination. [99]
- Structured attribute information definition for each feature, including text, numeric, date, area, perimeter, picture or voice-tag attributes. [99]
- Nesting, allowing additional points collection while mapping a line or area. [99]
- Support for raster data geo-referenced images in TIFF, JPEG and Bitmap formats. [99]
- Geo-referencing of raster images in the field. [99]
- Navigation and guidance to an existing feature for the purpose of GIS data maintenance. [99]
- Microsoft ActiveSync communication feature for data transfer and synchronization between the GPS receiver and a PC platform. [99]

c. Minnesota Department of Natural Resources Garmin GPS Application (DNRGPS)

Introduction:

DNRGPS is capable of transferring data between GIS software and Garmin handheld GPS receivers. Users are allowed to use the real-time tracking function to monitor their ground operation activities within an ArcView Document, ArcMap Data Frame, or Landview map.[100]

Features:

- Real Time Tracking. [100]
- Upload/Download Waypoints, Tracks, Routes which can be saved as .gdb, .shp, .txt, etc. [100]
- Calculate shape attributes, calculate area, perimeter, length. [100]
- Calculate CEP (Circular Error Probability) rings for Error estimation. [100]
- Covert points, lines, polygons. [100]
- Image Hot linking. [100]
- Set projection. [100]

- USB Connectivity. [100]

d. Rockwell Precision Lightweight GPS Receiver, Rockwell PLGR

Introduction:

The Rockwell Collins Precision Lightweight Global Positioning System (GPS) Receiver (PLGR) is a handheld device which as five channels and one frequency, it depends on satellite to provide three – dimensional positioning, global navigation, and data calculation to both individual and integrated users.[101]

Features:

- Delivers precise three-dimensional position, speed and time information to users. [102]
- Provides multiple user-definable NAV screens and waypoints. [102]
- Simultaneously track five satellites. [102]
- PLGR can be integrated into any operation scenario. [102]

6. Summary Observations

By reviewing and compiling the information of geospatial technology with a particular interest in the application in Wildland Fire and Wildland Urban Interface (WUI) Events, we observed that a significant amount of technologies and programs have been developed by both governmental and private agencies. These technologies can be categorized into Geographic Information System (GIS), Remote Sensing (RS), or Global Positioning System (GPS), which provide the fire fighting service personnel with various important capabilities, such as data management, geographical visualization, fire activities monitoring, information integration and distribution, and risk assessment. By taking the advantages of these state of art technologies, fire fighting personnel are able to conduct pre-fire planning, conduct emergency notification, enhance situational awareness, optimize decision process, coordinate fire suppression resources, and address post-fire environmental restoration. Effectively using geospatial information and technology can significantly reduce the loss from wildland and WUI fire disasters and better protect both life and property safety.

References

1) “Identifying and Addressing Workforce Challenges in America’s Geospatial Technology Sector”， The U.S. Department of Labor Employment and Training Administration, March 15, 2005 Revised November 2nd, 2005
2) Annulis and Gaudet, “Strategies—Outcomes—Support: A Geospatial Workforce Development Seminar.” May 24th, 2005
3) “The Component of GIS”, website: http://www.essex-countynj.org/GIS.pdf, cited: 20 November, 2014
4) “COMPONENTS OF A GIS”, website: http://bgis.sanbi.org/gis-primer/page_12.htm, cited: 5 Dec, 2014
5) “GIS Technology: Supporting the Wildfire Mission”, An Esri ® White Paper, April 2011, website: https://www.esri.com/library/whitepapers/pdfs/gis_supporting_wildfire_mission.pdf, cited: 5 May, 2014
6) “GIS for the Fire Service”, An Esri® White Paper June 2012, website: http://www.esri.com/library/whitepapers/pdfs/gis-for-fire-service.pdf, cited: 5 May, 2014
7) “How GIS is Used in Wildland Fire Management”, website: http://www.esri.com/industries/public-safety/wildland-fire-management/gis-used, cited: 5 May, 2014
8) “GIS Solutions for Wildland Fire Suppression”, Esri, website: http://www.esri.com/library/brochures/pdfs/wildland-fire-suppression.pdf, cited: 6 May, 2014
9) Nicole M. Vaillant, Alan A. Ager, and John Anderson, “ArcFuels10 System Overview”, United States Department of Agriculture, Forest Service, Pacific Northwest Research Station, General Technical Report PNW-GTR-875, March 2013
10) “What is ArcGIS?”, website: http://resources.arcgis.com/en/help/getting-started/articles/026n00000014000000.htm, cited: 5 May, 2014
11) “Wildland Fire Management”, http://www.esri.com/industries/public-safety/wildland-fire-management, cited on May 7th, 2014
12) “ArcGIS as a System forWildland Fire Management”, website: http://www.esri.com/industries/public-safety/wildland-fire-management/arcgis-system, cited: 10 May, 2014
13) “ArcGIS for Emergency Management”, website: http://solutions.arcgis.com/emergency-management/, cited: 22 Nov, 2014
14) “ESRI Trainning”, website: http://www.esri.com/training/main, cited: 22 Nov, 2014
15) “ Esri Press”, website: http://esripress.esri.com/display/index.cfm?CFID=15877867&CFTOKEN=63652964, cited: 23 November, 2014

16) “Collector for ArcGIS”, website: http://doc.arcgis.com/en/collector/, cited: 21 Nov, 2014
17) “Esri Disaster Response Program - GIS for Emergency Management”, website: http://www.esri.com/services/disaster-response/disaster-relief, cited: 19 Nov, 2014
18) “Esri Disaster Response Program – Wildfires-Public Information Map”, website: http://www.esri.com/services/disaster-response/wildlandfire/latest-news-map, cited: 20 Nov, 2014
19) “ Esri Disaster Response Program - Wildfire Support Resources”, website: http://www.esri.com/services/disaster-response/wildlandfire/resources, cited: 20 Nov, 2014
20) Henri D. Grissino-Mayer, “FHX2 - Software for the Analysis of Fire History from Tree Rings - USER’S MANUAL”, Department of Geography, University of Tennessee, Knoxville, Tennessee, USA, 1993–2006
21) “Enterprise Geospatial Portal INFORMATION BULLETIN”, National Interagency Fire Enterprise Geospatial Portal, April 14, 2014, website: https://egp.nwcg.gov/egp/assets/docs/public/egp_infobulletin.pdf, cited: 22 June, 2014
22) “About EGP – 3D Fire Global”, website: https://egp.nwcg.gov/egp/default.aspx, cited: 22 June, 2014
23) “ About EGP – Situation Analyst/GDAT”, website: https://egp.nwcg.gov/egp/default.aspx, cited: 22 June, 2014
24) “About EGP – Fire EGP Data”, website: https://egp.nwcg.gov/egp/default.aspx, cited: 22 June, 2014
25) “About EGP – Incident Control Console (RisC)”, website: https://egp.nwcg.gov/egp/default.aspx, cited: 22 June, 2014
26) “USDA Forest Service Fire Applications Support - Fire Incident Mapping Tools”, website: http://gacc.nifc.gov/rmcc/fire_incident/, cited: 19 Nov, 2014
27) John Varner, “A Better Way to Support Wildland Fire Suppression”, USDA Forest Service, website: http://gacc.nifc.gov/rmcc/fire_incident/pdf/Better_Wildland_Support_020106_a.pdf, cited: 19 Nov, 2014
28) Tim Clark, “Extension Supplies Fire Incident Mapping Tools”, website: http://www.esri.com/news/arcuser/0205/firemapping.html, cited: 19 Nov, 2014
29) “FSGeodata Clearinghouse”, website: http://data.fs.usda.gov/geodata/, cited: 25 May, 2014
30) “FSGeodata Clearinghouse - Forest Service Enterprise Data”, website: http://data.fs.usda.gov/geodata/edw/index.php, cited: 25 May, 2014
31) “FSGeodata Clearinghouse - Maps”, website: http://data.fs.usda.gov/geodata/maps/index.php, cited: 25 May, 2014
32) “FSGeodata Clearinghouse - Raster Data Gateway”, website: http://data.fs.usda.gov/geodata/rastergateway/index.php, cited: 25 May, 2014
33) “FSGeodata Clearinghouse - Other FS Data”, website: http://data.fs.usda.gov/geodata/other_fs/index.php, cited: 25 May, 2014

34) "FRAMES Resource Cataloging System (RCS)", website: https://www.frames.gov/rcs/1000/1249.html, cited: 27 May, 2014
35) Roger Ottmar, "The Fuel Characteristic Classification System (FCCS 3.0)", USDA Forest Service Pacific Wildland Fire Sciences Lab, March 12, 2014, website: http://www.fs.fed.us/pnw/fera/publications/factsheets/factsheet_fccs.pdf, cited: 27 May, 2014
36) Roger D. Ottmar, David V. Sandberg, Cynthia L. Riccardi, and Susan J. Prichard, "An overview of the Fuel Characteristic Classification System – quantifying, classifying, and creating fuelbeds for resource planning", website: http://ordvac.com/soro/library/Fuels%20Literature/fuels%20modeling/Ottmar%20et%20al%202007%20FCCS%20overview.pdf, cited: 27 May, 2014
37) "About GeoMAC", website: http://www.geomac.gov/about.shtml, cited: 2 June, 2014
38) Sandra P. Walters, Norma J. Schneider, and John D. Guthrie, "Geospatial Multi-Agency Coordination (GeoMAC) Wildland Fire Perimeters", U.S. Department of the Interior, U.S. Geological Survey, 2008
39) "How GeoMAC Works", website: http://www.geomac.gov/, cited: 5 June, 2014
40) "GeoMAC Viewer", website: http://www.geomac.gov/viewer/viewer.shtml, cited: 6 June, 2014
41) "SituationAnalyst - the first responder's ultimate awareness tool", website: http://www.intterragroup.com/specs.pdf, cited: 20 Nov, 2014
42) "About LANDFIRE", website: http://www.landfire.gov/about.php, cited: 8 June, 2014
43) Matthew G. Rollins, "LANDFIRE: a nationally consistent vegetation, wildland fire, and fuel assessment", International Journal of Wildland Fire 2009, 18, 235–249
44) "LANDFIRE-Data Products-Reference", website: http://www.landfire.gov/reference.php, cited: 8 June, 2014
45) "LANDFIRE-Data Products- Disturbance", website: http://www.landfire.gov/disturbance.php, cited: 8 June, 2014
46) "LANDFIRE-Data Products-Vegatation", website: http://www.landfire.gov/vegetation.php, cited: 8 June, 2014
47) "LANDFIRE-Data Products-Fuel", website: http://www.landfire.gov/fuel.php, cited: 8 June, 2014
48) "LANDFIRE-Data Products-Fire Regime", website: http://www.landfire.gov/fireregime.php, cited: 8 June, 2014
49) "LANDFIRE-Data Products-Topographic", website: http://www.landfire.gov/topographic.php, cited: 8 June, 2014
50) "National Fire Danger Rating System", website: http://www.fs.usda.gov/detail/cibola/landmanagement/resourcemanagement/?cid=stelprdb5368839, cited: 12 June, 2014
51) Paul Schlobohm and Jim Brain, "Gaining an Understanding of the National Fire Danger Rating System", A Publication of the National Wildfire Coordinating Group, July 2002

52) “National Significant Wildland Fire Potential Outlook”, website: http://www.predictiveservices.nifc.gov/outlooks/outlooks.htm, cited: 2 Dec, 2014
53) “Rapid Data Distribution System (RDDS) 4.0 – Overview & Data Content”, website: http://firedata.cr.usgs.gov/, cited: 16 June, 2014
54) “About RedZone Software”, website: http://www.redzonesoftware.com/about, cited: 18 June, 2014
55) “What's at stake, in real-time”, website: http://www.redzonesoftware.com/products/rzalert, cited: 18 June, 2014
56) “Don’t be caught unprepared by the next catastrophic wildfire”, website: http://www.redzonesoftware.com/products/rzrisk, cited: 18 June, 2014
57) “RZMobile is a secure e-class mobile solution”, website: http://www.redzonesoftware.com/products/rzmobile, cited: 18 June, 2014
58) “Technosylva – Service – Wildfire”, website: http://technosylva.com/services/wildfires/, cited: 5 Dec, 2014
59) “Technosylva – Products – fiResponse”, website: http://technosylva.com/products/firesponse/, cited: 5 Dec, 2014
60) “fiResponse – enterprise wide incident management & resource tracking decision support system”, website: http://firesponse.com/download/fiResponse-brochure.pdf, cited: 5 Dec, 2014
61) “Technosylva – Products – Wildfire Analyst”, website: http://technosylva.com/products/wildfire-analyst/, cited: 5 Dec, 2014
62) “Wildfire Analyst – tools for more informed decision making”, website: http://wildfireanalyst.com/download/WFA-brochure.pdf, cited: 5 Dec, 2014
63) “The Wildland Urban Interface - WUI Maps and GIS data”, website: http://silvis.forest.wisc.edu/maps/wui_main, cited: 7 Dec, 2014
64) “United States Maps and Data”, website: http://silvis.forest.wisc.edu//maps/wui/2010/download, cited: 7 Dec, 2014
65) “Timmons Group Geospatial Solutions - Wildland Fire”, website: http://www.timmonsgis.com/industries/wildfire-management/, cited: June 26, 2014
66) “Timmons Group Geospatial Solutions - Wildfire Risk Assessment Portal”, website: http://www.timmonsgis.com/products/wrap-wildfire-risk-assessment-portal/, cited: June 26, 2014
67) “Timmons Group Geospatial Solutions – WildfireMaps”, website: http://www.timmonsgis.com/products/wildfiremaps/, cited: 26 June, 2014
68) “United States National Grid (USNG)”, website: http://www.arcgis.com/home/item.html?id=dc352c5f18854d82b32bce92c0b6656b, cited: 7 Dec, 2014
69) “United States National Grid”, website: http://www.fgdc.gov/usng, cited: 7 Dec, 2014
70) William M. Jolly, Patricia L. Andrews and Larry S. Bradshaw, “The Wildland Fire Assessment System (WFAS): A web based resource for decision support”, USDA Forest Service

71) “About Wildland Fire Decision Support System”, website: http://wfdss.usgs.gov/wfdss/WFDSS_About.shtml, cited: 1 July, 2014
72) Morgan Pence and Thomas Zimmerman, “The Wildland Fire Decision Support System: Integrating Science, Technology, and Fire Management”, Fire Management Today
73) “Wildland Fire Potential (WFP) for the conterminous United States”, website: http://www.firelab.org/project/wildland-fire-potential, cited: 15 July, 2014
74) “Mapping Wildland Fire Potential for the conterminous United States”, website: http://www.firelab.org/sites/default/files/images/downloads/wfp_methods_041813.pdf, cited: 15 July, 2004
75) “Active Fire Mapping Program, RSAC”, website: http://data.fs.usda.gov/geodata/maps/active-fire.php, cited: 3 Aug, 2014
76) “Fire Detection Maps”, website: http://activefiremaps.fs.fed.us/activefiremaps.php, cited: 3 Aug, 2014
77) “Daily Georeferenced MODIS Image Subsets”, website: http://activefiremaps.fs.fed.us/imagery.php, cited: 4 Aug, 2014
78) “Fire Detection GIS Data”, website: http://activefiremaps.fs.fed.us/gisdata.php, cited: 4 Aug, 2014
79) “Fire Data in Google Earth”, website: http://activefiremaps.fs.fed.us/googleearth.php, cited: 4 Aug, 2014
80) “Fire Data Web Services”, website: http://activefiremaps.fs.fed.us/wms.php, cited: 4 Aug, 2014
81) “Latest Detected Fire Activity”, website: http://activefiremaps.fs.fed.us/current.php?op=info, cited: 4 Aug, 2014
82) “MODIS Burn Scar Data”, website: http://activefiremaps.fs.fed.us/burnscar.php, cited: 4 Aug, 2014
83) “Burned Area Emergency Response, BAER – Background”, website: http://www.fs.fed.us/biology/watershed/burnareas/background.html, cited: 19 Aug, 2014
84) “Burned Area Emergency Response (BAER) Imagery Support”, website: http://www.fs.fed.us/eng/rsac/baer/, cited: 19 Aug, 2014
85) “What is a BARC”, website: http://www.fs.fed.us/eng/rsac/baer/barc.html, cited: 19 Aug, 2014
86) “Burned Area Emergency Response Image Support”, website: http://www.fs.fed.us/eng/rsac/baer/DocumentsAndPosters/posters/10045POS-gs-test1.pdf, cited: 19 Aug, 2014
87) “Monitoring Trends in Burn Severity (MTBS) – Background and Partners”, website: http://www.mtbs.gov/background_partners.html, cited: 26 Aug, 2014
88) “Applying MTBS Data – Examples of how MBTS can be used – Fuels Management”, website: http://www.mtbs.gov/cooperators.html, cited: 1 Sep, 2014
89) “Applying MTBS Data – Examples of how MBTS can be used – Tactical Fire Suppression Planning”, website: http://www.mtbs.gov/cooperators.html, cited: 1 Sep, 2014

90) “Applying MTBS Data – Examples of how MBTS can be used – Post-fire assessments”, website: http://www.mtbs.gov/cooperators.html, cited: 1 Sep, 2014
91) “Applying MTBS Data – Examples of how MBTS can be used – Fire policy implementation and effectiveness”, website: http://www.mtbs.gov/cooperators.html, cited: 1 Sep, 2014
92) “Applying MTBS Data – Examples of how MBTS can be used – Ecosystem/Landscape level monitoring”, website: http://www.mtbs.gov/cooperators.html, cited: 1 Sep, 2014
93) “National Infrared Operations – about us”, website: http://nirops.fs.fed.us/pages/about, cited: 15 Sep, 2014
94) “National Infrared Operations – Fire Detection”, website: http://nirops.fs.fed.us/pages/about-more, cited: 15 Sep, 2014
95) “National Infrared Operations – Fire Coverage & Information Delivery”, website: http://nirops.fs.fed.us/pages/about-more, cited: 15 Sep, 2014
96) “What is GPS?”, website: http://www.gps.gov/systems/gps/, cited: 29 Sep, 2014
97) “ArcGIS for Mobile - ArcPad”, website: http://www.esri.com/~/media/Files/Pdfs/library/brochures/pdfs/arcgis-for-mobile.pdf, cited: 3 Oct, 2014
98) Carl Beyerhelm, “Basic GPS Data Capture Using ArcPad 7.1 - A Quick Start Guide”, website: http://www.fs.fed.us/database/gps/documents/ArcPad71.pdf Coconino National Forest, Revised 15-August-2008, cited: 3 Oct, 2014
99) “Mobile Mapper6 - Affordable GIS/GPS with Nothing Missing”, website: http://www.kansastag.gov/AdvHTML_doc_upload/MobileMapper6.pdf, cited: 15 Oct, 2014
100) “DNR Garmin Application”, website: http://www.dnr.state.mn.us/mis/gis/tools/arcview/extensions/DNRGarmin/DNRGarmin.html, cited: 27 Oct, 2014
101) “Rockwell PLGR”, website: http://www.ion.org/museum/item_view.cfm?cid=7&scid=9&iid=13, cited: 5 Nov, 2014
102) “The PLGR Family Precision Lightweight GPS Receivers”, website: http://www.ion.org/museum/files/PLGR%20brochure.pdf, cited: 5 Nov, 2014