On the Use of Fire Behavior Models for Decision Support Part I: Model Survey and NWS Capabilities

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1. INTRODUCTION

Over the course of the last few decades, wildland fire management has grown increasingly more complex in nature, scale and impact. In response to this growing complexity, wildland fire managers have looked to technological advances to increase the availability and usefulness of fire-specific information used to manage and respond to developing incidents. In particular, the US Forest Service recently implemented a Wildland Fire Decision Support System (WFDSS, see citation), which helps fire line officers make informed tactical and strategic management decisions for long-term (7-14 day), unplanned ignitions. Field requests to accelerate the deployment of this tool underscore the need for advanced support in the execution of daily wildland fire management decisions.

Parallel advances in fire behavior modeling, the availability of geospatial data sets, and mobile communications technology, have created an opportunity for National Weather Service (NWS) forecasters to provide advanced decision support information to agencies responding to developing wildland fire incidents. In particular, fire spread calculations based on current and forecast conditions could prove critically useful to first responders and fire managers who need independent, localized, and timely data to make life-saving decisions during the initial 12 hours of a rapidly evolving urban-wildland interface fire (e.g. Cedar Fire (2003); Laguna Beach Fire (1993); Oakland Hills Fire (1991)).

The intent of this paper is to introduce two commonly used fire behavior models (FARSITE and FlamMap) and the data sets required to support the modeling efforts specific to each application. In addition, a case study utilizing these models will be used to explore the potential for NWS forecasters to provide decision support services to fire line officers and emergency support personnel (e.g. local fire department, sheriff, etc.) in the field during the initial stages of a developing wildland fire.

2. FIRE BEHAVIOR MODELS

Development of simple fire growth models began in the late 1960s (Van Wagner, 1969) with modest improvements occurring throughout the 1980s. Concomitant with the increase in computing power, modeling efforts have rapidly expanded and improved during the past decade. Stratton (2006) described a number of wildland fire models commonly used by land managers today. This paper will focus on fire spread simulations utilizing the FARSITE (Finney, 2004) and FlamMap (Finney, 2006) fire behavior models.

FARSITE is a two-dimensional deterministic *fire growth* model that utilizes a vector propagation technique to simulate fire perimeter expansion over a heterogeneous landscape. It accounts for the variability of fuel moisture, wind speed, and wind direction over time and space which makes it an ideal tool for simulating fire spread across a landscape.

FlamMap is a spatial *fire behavior* mapping and analysis model that computes fire behavior characteristics over an entire landscape at one instance in time. All fire behavior calculations assume that fuel moisture, wind speed, and wind direction are held ***constant*** which makes it a useful tool for examining the spatial variability of fire behavior across a landscape and for identifying hazardous fuel and topographic combinations.

The Minimum Travel Time (MTT) fire growth algorithm contained within FlamMap is used to simulate fire spread in the absence of time-varying wind and fuel moisture. The algorithm calculates the minimum fire travel time between adjacent nodes over an arbitrarily gridded landscape relying upon the spatial variability of fuels and topography to drive fire growth. Consequently, the FlamMap MTT algorithm is not considered to be a complete fire growth simulation model like FARSITE. Despite this limitation, FlamMap will be evaluated to determine if it might offer computational efficiencies over FARSITE in an operational forecast setting.

For a complete description of the structure and performance of each model see Finney (2004, 2006).

3. SUPPORTING DATA SETS

Nearly all modeling efforts require a set of initial conditions in order for the model to perform its designated function. Although FARSITE and FlamMap perform uniquely different functions, the initial data sets that support each modeling effort overlap. Tables 1-3 provide the overarching data requirements for each model.

The quality and accuracy of the initial data set has a profound impact on the outcome of the modeling effort. Subsequently, a detailed guide identifying the information needed to create quality data sets for use in FARSITE and FlamMap was made available through the National Interagency Fuels, Fire and Vegetation Technology Transfer (NIFTT) website (see citation for Fire Behavior and Effects Assessment: A Guide to Understanding and Creating Weather, Wind, and Fuel Moisture Files) to support fire behavior modeling efforts in the field.

a. Landscape File (LCP)

Obtaining geospatial data for fire modeling has improved dramatically over the course of the past five years. The Landscape Fire and Resource Management Planning Tools Project (LANDFIRE, see citation) was organized to provide national level, landscape-scale geospatial products to support fire and fuels management planning operations. A web portal was created to allow fire managers access to this data with relative ease. The geospatial data used in this project was accessed via this portal using the

LANDFIRE Data Access Tool (LFDAT, see citation) developed by the U.S. Forest Service (USFS) (Stratton, 2009) for ArcMap.

The FARSITE Landscape (LCP) file (Finney, 2004) is a common data format used in fire behavior modeling that consists of five required landscape themes including elevation, slope, aspect, fuel model and canopy cover. Optional themes include stand height, crown base height, canopy density, duff loading, and coarse woody debris. The standard practice (Stratton, 2009) is to create an LCP file that includes the five required themes along with the three optional canopy characteristic themes. The LCP is built by importing each theme as an ASCII Raster file (a common GIS file format) and assembling the pieces into a single LCP file using LFDAT.

b. Weather File (WTR)

The Weather (WTR) file is an ASCII text file that contains daily observations of maximum and minimum temperature, maximum and minimum humidity, and precipitation. A sine wave is used within FARSITE to interpolate between these datum to simulate the diurnal variation in dead fuel moisture as a function of time of day, topography and shading.

c. Wind File (WND)

The Wind (WND) file is an ASCII text file that contains wind speed, direction and cloud cover for user-defined periods covering the entire extent of the simulation at a height of approximately 6 m above the fuel canopy. Wind speed and direction values associated with this file are referred to as *broadscale winds* in this study. Computationally these broadscale winds are evenly distributed throughout the model domain with **no** adjustments for topographical effects.

d. Initial Fuel Moisture File (FMS)

The Initial Fuel Moisture (FMS) file is an ASCII file that contains 1-hour, 10-hour, 100-hour, Live Herbaceous, and Live Woody fuel moisture values representing conditions prior to the start of the simulation. Three references were used to clarify plant phenology as well as the process of generating appropriate values for input into this file: *Fire Behavior and Effects Assessment: A Guide to Understanding and Creating Weather, Wind, and Fuel Moisture Files* (see citation); the *Moisture Scenarios* section found in *Standard Fire Behavior Fuel Models: A Comprehensive Set for Use with Rothermel's Surface Fire Spread Model* (Scott and Burgan, 2005); and *Fuel Moisture Sampling Guide* (Pollet and Brown, 2007).

Two important considerations need to be weighed during the preparation of the FMS file based upon suggestions enumerated within the *Fire Behavior and Effects Assessment* guide noted above. First, fuel moisture values that are a product of the National Fire Danger Rating System (NFDRS) are **not** specifically designed to support fire behavior modeling efforts such as those found in FARSITE and FlamMap. The NFDRS values may be referenced in a qualitative sense but are not explicitly intended to be used quantitatively as input for the fire behavior models. Second, FARSITE provides for an optional fuel conditioning routine that adjusts the initial fuel moisture settings at the grid level to reflect the influence of local conditions. The technical documentation that accompanies FARSITE recommends the use of this conditioning routine for improved results, particularly when a simulation is initiated with a large perimeter in complex terrain for a short duration.

e. Gridded Wind Files (ATM)

Wind is a significant factor that exacerbates wildland fire behavior and is a primary determinate of fire spread and prediction. Broadscale wind patterns can be significantly modified in mountainous terrain generating complex speed and directional variations. In an effort to increase the responsiveness of FARSITE to these complexities, a gridded microscale wind input option was added to the model.

Forthofer (2007) tested the performance of two microscale wind-prediction models to evaluate their suitability for generating gridded wind inputs in the field. He concluded that a mass-consistent scheme, although not as accurate as a computational fluid-dynamics approach, would be more feasible for fire managers given the limited computing resources available at fires. The mass-consistent (WindNinja) and computational fluid-dynamics (WindWizard) models are both available through FireModels.org (see citation).

Forthofer also demonstrated that predicted fire growth improved when gridded microscale wind inputs were used in the simulation by enabling the model to reproduce terrain influenced details that were not previously possible using the broadscale uniform wind inputs. Finney *et al.* (2006) also concluded that fire growth and fire behavior prediction accuracy increased when gridded microscale wind inputs were used in fire modeling efforts.

4. CASE STUDY: RATTLESNAKE FIRE – SEPTEMBER 4, 2005

a. General Description of Event

On the morning of September 4, 2005, a wildland fire ignited along the east side of the Arbon Valley Highway approximately 15 miles due south of the Pocatello Regional Airport (PIH, Fig. 1). The fire made an initial upslope run to the east during the morning, followed by an explosive run to the north-northeast throughout the afternoon hours. By late afternoon, the head of the fire shifted to the east-northeast and weakened. The preponderance of acreage consumed occurred during the initial burn period (first 12 hours of the fire) razing approximately 4050 hectares along the west slope of the Bannock Range between 1430 m and 2130 m MSL. On September 12, 2005, the fire was classified as controlled with a total of 4320 hectares burned.

b. Geospatial Fuel Distribution

The fuel distribution across the Rattlesnake Fire was strongly stratified by elevation, aspect, and growing season moisture availability, which is consistent with much of the arid regions of the intermountain west. Following the fuel model classifications provided through LANDFIRE, much of the lower elevation (1430-1675 m MSL) fuels (Fig. 1) were composed of a moderate load of dry-climate grass (GR4, Fuel Model 104) and dry-climate grass-shrub mix (GS2, Fuel Model 122) (see Scott and Burgan, 2005). Mid and upper slopes (1675-1980 m MSL) were composed of a high load of dry-climate shrubs (SH5 and 7, Fuel Model 145 and 147) while high elevation (>1980 m MSL) fuels were dominated by a low load of dry-climate timber-grass-shrub mix and Dwarf Conifer (TU1 and 4, Fuel Model 161 and 164).

c. Temperature and Precipitation Trends

An analysis of the temperature and precipitation trends leading up to the fire did not show any abnormal *seasonal* trends. In fact, the accumulation of summertime precipitation (Fig. 2) and the daily temperature trace (Fig. 3) were fluctuating near normal throughout most of the summer. While seasonal trends appeared to be representative of normal late summer conditions, afternoon highs were approaching record levels just prior to the ignition date and measureable rainfall had not been recorded in over two weeks (dashed vertical lines Figs. 3 and 2, respectively).

d. Fuel Conditions

The Energy Release Component (ERC) is commonly considered to be a composite fuel moisture value that reflects the contribution of live and dead fuels to potential fire intensity. The ERC represents the available energy per unit area within the flaming front of the head of a fire and is typically utilized by fire managers to quickly assess fuel conditions and potential fire severity. As live fuels cure and dead fuels dry, ERC values increase and provide a good reflection of drought conditions. Figure 4 represents the ERC values for the Bull Canyon Remote Automated Weather Station (RAWS), which was situated 25 miles south-southwest of the fire in similar terrain. The ERC values for September 4 (dashed vertical line), reached extreme levels in the 97^{th} percentile compared to the 1990-2008 historical record. In addition to the extreme ERC readings, the Observed Fire Danger Class for September 4, 2005 (Fig. 5) was rated as extreme for southeast Idaho.

e. Synoptic Developments

On September 3, one day prior to the fire, a broad ridge of high pressure (Fig. 6) extended north from Texas into the northern tier states. The corresponding water vapor satellite imagery (Fig. 7) clearly showed a low pressure system anchored over western British Columbia while an ill-defined Pacific short-wave trough (depicted by the red X) lifted northeast toward the California coast along the northwest periphery of the high pressure ridge. Over the course of the next 36 hours, this short-wave trough would become much more pronounced as it pushed northeast through California (Figs. 8 and 9) and into southern Idaho (Figs. 10 and

11), driving a surface cold front through the fire area between 1700 and 1900 MDT on September 4, 2005 (Figs. 12 and 13).

A sharp increase in the daily high temperatures (Fig. 3) occurred several days prior to the fire, consistent with the expected surface response preceding the approaching system. A review of temperature data from mid-August through mid-September suggests that as many as four similar events may have occurred during the late summer period.

An analysis of available surface observations from sites surrounding the fire (not shown) indicated that wind speeds remained light as the ridge of high pressure developed over the region. On the afternoon of September 3, a four hour period of modest south winds occurred at several locations, consistent with diurnal convective mixing of enhanced winds from aloft in advance of the approaching system. By September 4, moderate winds were observed at PIH as early as 0900 MDT, which increased in strength throughout the day in the pre-frontal environment.

5. MODEL RESULTS

a. Supporting Data Sets

i. Landscape File (LCP)

The LCP file was created utilizing LFDAT and the standard mix of required and optional landscape themes (see section 3.a) with a raster cell size of 30 m^2.

ii. Weather File (WTR)

Observations from PIH for September 1 through September 6, 2005, were used as the basis for preparing the weather file.

iii. Wind File (WND)

Observations from four sites (Crystal RAWS, Bull Canyon RAWS, Scout Mountain RAWS and the PIH Automated Surface Observing System (ASOS)) located within 65 km of the fire perimeter were used to prepare the initial wind file. The file was further refined to reflect the expected local response to the developing synoptic scale weather pattern for the area immediately surrounding the fire. The refinements resulted in a depiction that featured an upslope flow regime during the early daylight hours followed by moderate pre-frontal south-southwest winds mixing into the fire environment by mid morning. The strongest winds began around 1300 MDT and continued until the simulated frontal passage and accompanying wind shift from the west-northwest at 1900 MDT on September 4, 2005. The process used to refine the wind file was consistent with current methodologies used to complete a spot forecast for land managers.

iv. Initial Fuel Moisture File (FMS)

Creating an Initial Fuel Moisture (FMS) file was by far the most subjective exercise encountered during the study. Only one data source was identified which contained actual fuel moisture measurements (see citation for National Fuel Moisture Database). The remaining input was garnered from a mix of reference tables (Scott and Burgan, 2005), local knowledge, and/or the Nelson Dead Fuel Moisture model available through FireFamily Plus (see citation for FireModels.org).

Dry-climate grass and shrub fuel models and the 1- and 10-hour dead fuel classes dominated the low and mid level elevations. The moisture values for these fuel classes were objectively skewed toward the drier end of the seasonal fuel moisture spectrum in accord with the late summer timing of this event. The higher elevation timber models and 100-hour dead fuel classes were held near moderate stages of moisture content as defined in the tabular references cited above. These values were then cross checked against output generated from the Nelson Dead Fuel Moisture model and Live Fuel Moisture measurements from nearby sites (Sagebrush from Pocatello; Juniper from Jim Sage, Utah).

v. Gridded Wind Files (ATM)

WindNinja was utilized to generate gridded (approximately 100 m^2) wind files. The broadscale uniform wind sets used in the WND file were used to initialize the WindNinja model for each previously defined time period. The resulting gridded winds were then substituted into FARSITE, with the subsequent impacts on fire spread prediction provided below.

b. FARSITE Simulations

FARSITE fire spread simulations (Fig. 14) were produced using the supporting data sets noted above. The first run utilized the broadscale uniform wind regime (yellow) while the second run (cyan) relied upon the gridded WindNinja data set.

Neither simulation accounted for ground or air suppression efforts that likely occurred along the western and southern flanks of the fire during the initial burn period. However, the Arbon Valley Highway (green line, Fig. 14) constituted a significant natural fire barrier and was portrayed as such on the FARSITE landscape prior to model initiation.

The simulated fires were initiated from a point source at 0700 MDT on September 4, 2005 (see Ignition Point stickpin Fig. 14), following a 3-day fuel conditioning period. The results of each model run spread the fire upslope (east-southeast) from 0700 through 0900 MDT. Between 0900 and 1100 MDT, the predicted fire spread north-northeast reaching Lower Rattlesnake Road around 1100 MDT. After 1100 MDT, explosive growth to the north-northeast was observed, which continued throughout the remainder of the afternoon. Intermediate fire perimeters at 1100 MDT and 1300 MDT (Fig. 14, thin cyan) were included to highlight the initial direction of spread as well as the significant change in direction and growth of the fire between 1100 and 1300 MDT.

At 1900 MDT, the model-simulated cold front moved through the landscape driving the head of the fire east into larger, less receptive fuels where the rate of fire spread diminished rapidly. Each model run was arbitrarily terminated at 0200 MDT on September 5.

c. FlamMap Simulation

For comparison purposes, a FlamMap model run (Fig. 15, white lines) was produced using the Minimum Travel Time (MTT) algorithm found within the model. Due to the static limitations associated with FlamMap, which were discussed in Section 2, a rough fire perimeter (orange) approximating expected conditions at 1300 MDT was used to initiate the model. The stronger 1300 to 1900 MDT broadscale winds utilized in the FARSITE simulation were then used as input for the FlamMap simulation, which was arbitrarily terminated at 0200 MDT on September 5.

6. DISCUSSION

a. Model Comparisons

i. Overall Model Performance

In the absence of simulated fire suppression activities, the models performed remarkably well in characterizing the overall spread of the observed fire. The explosive growth to the north-northeast during the heat of the afternoon was also depicted well in each simulation. In secondary model simulations using FARSITE (not shown), modest suppression efforts on the western and southern flanks of the fire resulted in a simulation that nearly replicated the final observed fire perimeter.

ii. Broadscale Versus Gridded Wind Results

Unlike Finney *et al.* (2006) and Forthofer (2007), it is extremely difficult to determine whether the gridded microscale wind set enhanced the modeling effort over the broadscale simulation in the absence of detailed fire progression observations. The two simulations were remarkably similar with the only noteworthy deviations occurring on the western and northern perimeter of the fire. In these regions, the gridded simulation consumed a modest amount of additional acreage extending the overall fire perimeter further west and north. The similarities appear to be a reasonable expectation given that the stronger pre-frontal winds were nearly parallel to the main ridge axis located to the east of the fire with minimal terrain induced wind modification occurring. Perhaps under a different set of wind conditions (e.g. strong west wind), the gridded microscale wind set may have provided better results.

iii. FARSITE Versus FlamMap Results

The FlamMap MTT model simulation (Fig. 15, white) provided a fairly good estimate of the observed fire perimeter and was similar to the FARSITE results. However, a preliminary FlamMap simulation (not shown) initiated at 0700 MDT at the identified point of ignition using the stronger 1300-1900 MDT afternoon wind speed and terminated at 0200 MDT on September 5, produced a simulated fire perimeter that was nearly three times the size of the observed perimeter, encompassing both the west and east slopes of the Arbon Valley north of the ignition point.

A critical limitation of FlamMap was exposed during these simulations resulting from the static nature of the wind variable. In the comparative case between FlamMap and FARSITE, a rough fire perimeter encompassing both the early morning upslope spread of the fire and the initial wind shift toward the northeast was required to initiate the model. This effort was an attempt to accurately replicate the explosive growth to the northeast during the afternoon hours. Without the use of this rough fire perimeter to initialize the model, an unrealistic outcome resulted. Even a simple change in wind speed during the initial burn period presented a significant obstacle in terms of model initialization. Finally, had the frontal passage occurred earlier in the afternoon, it would have been impossible to objectively simulate the expected change in fire spread direction utilizing FlamMap. In short, the positive FlamMap results presented in Figure 15 appear to be entirely due to the generous efforts used to initiate the model with information that may not be realistically known in an operational forecast setting.

b. Mission Considerations

i. NWS Mission

Arguably, wildland fire is the severe weather of the west (see citations for Billion Dollar Weather Disasters 1980-2008; Billion Dollar U.S. Weather Disasters; Historically Significant Wildland Fires). The preponderance of overtime incurred by NWS forecasters in the west is either directly or indirectly the result of performing fire management decision support activities. These activities help fire managers and community leaders make sound weather related *decisions* that save lives and benefit the nation's commerce, commensurate with the NWS's mission.

ii. NWS and Decision Support

The NWS has made a concerted move toward all-hazard decision support services (Bradshaw, 2010) in recent years. This move is firmly supported by the NWS's expertise in science, knowledge of local weather impacts, strong sense of mission, presence in and commitment to local communities, and the value placed on supporting core partners. The job does not end after a forecast is produced. NWS forecasters are challenged daily to *interpret* and *communicate* the meaning of weather impacts in a context and manner that society and core partners can understand and use.

iii. **Urban-Wildland Interface Fires**

One of the most complex situations for fire managers is the urban-wildland interface fire. Decisions made during the first 12 hours of these incidents are critically important to the protection of life and property. In many cases, the action or inaction of local government agencies and citizens can mitigate or exacerbate the developing situation. The NWS is uniquely trained, equipped, and positioned to provide not only decision support services to fire managers in the field but also short-fused warnings to individuals sitting in the comfort of their living rooms.

c. **Operational Considerations**

i. **Model of Choice**

Based upon the modeling results presented within this study, FARSITE appears to be the most appropriate platform to use for generating fire spread predictions. The increased flexibility and accuracy associated with FARSITE and the lack of computational constraints found within an NWS forecast office setting should offset any perceived shortcomings associated with file preparation time or model use.

ii. **Timeliness**

It took approximately 85 minutes in a timed reconstructive exercise to assemble the required data sets, produce a FARSITE fire spread simulation for the Rattlesnake Fire, and export the results into Google Earth. This included numerous inefficiencies associated with data collection and the manual formatting of text files identified previously. Nearly all of these inefficiencies have recently been resolved and/or streamlined within the latest version of the WFDSS, allowing users to produce fire spread projections in as little as 15 to 30 minutes.

iii. **Fuels Assessment**

NWS forecasters would be required to expand their base of scientific knowledge and expertise to include an assessment of fuels in an effort to provide timely decision support. Given modest instruction, forecasters should be able to accomplish the basic fuels assessment needed to prepare the Initial Fuel Moisture file. In an ideal setting, fuels specialists from land management agencies could work collaboratively with local NWS personnel to produce an appropriate Initial Fuel Moisture file for subsequent use in the model.

d. **Technological Considerations**

The idea for this study came from a discussion with a local fire department supervisor who desired fire spread projections to support operational decisions when responding to urban-wildland interface fires within his community. The key to the discussion was the fact that mobile internet capability was now available in the cabs of their trucks. The widespread use of digital and mobile communications technologies has created an **opportunity** for NWS forecasters to provide real-time data and decision support *directly* to first responders and fire managers positioned in the field so that they can make timely and life-saving decisions (Jans and Keen, 2007).

7. CONCLUSION

Wildland fire management has grown increasingly more complex in nature, scale, and impact, requiring timely and enhanced decision support services. Expanding mobile communication technologies have created an opportunity for land managers and first responders to leverage NWS expertise and decision support services to effectively manage developing wildfires.

The use of FARSITE would enable NWS forecasters to capitalize on knowledge of short-term weather and fuel conditions to generate fire spread projections covering the initial 12 hours of a developing wildland fire. These projections would help decision makers identify immediate threats and weigh potential impacts. With the use of the latest version of the WFDSS, fire spread projections can be produced in about the same time it currently takes to prepare a spot forecast.

Through the use of mobile communication technologies, NWS forecasters could provide direct and timely decision support services and warning capabilities to first responders, emergency support personnel, and government agencies in the field. This information would allow them to make sound, life-saving decisions during rapidly developing urban-wildland interface fires.

8. ACKNOWLEDGMENTS

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Wildland Fire Decision Support System
http://wfdss.usgs.gov/wfdss/WFDSS_Home.shtml

File Name	**File Type**	**Required**	**Optional**
Landscape	**Raster**	**Fuel Model** **Slope** **Aspect** **Elevation** **Canopy Cover**	**Crown Bulk Density** **Crown Base Height** **Stand Height** **Duff Loading** **Course Woody**
Weather	**Text**	**At least 1 file**	**Up to 5 files**
Wind	**Text**	**At least 1 file**	**Up to 5 files**
Adjustment	**Text**	**Yes**	**No**
Initial Fuel Moisture	**Text**	**At least 1 day prior to start of simulation**	**No**
Fuel Model Conversion	Text	No	Yes
Custom Fuel Models	Text	No	Yes
Fire Acceleration	Text	No	Yes
Air Attack Resources	Text	No	Used by air attack functions
Coarse Woody Profiles	Text	No	Used by Post Frontal Combustion Model
Burn Period	Text	No	Yes
Gridded Weather and Wind	Text	No	Yes
Ground Attack Resources	Text	No	Used by air attack functions

Table 1. FARSITE required and optional data files.

File Name	**File Type**	**Required**	**Optional**
Landscape	**Raster**	**Fuel Model** **Slope** **Aspect** **Elevation** **Canopy Cover**	**Canopy Bulk Density** **Canopy Base Height** **Height**
Initial Fuel Moisture	**Text**	**At least 1 day prior to start of simulation**	**No**
Gridded Wind	Text	No	Yes – Used in lieu of Wind Direction radio button for the Minimum Travel Time feature
Custom Fuel Models	Text	No	Used in lieu of Initial Fuel Moisture file
Weather	Text	No	Used by fuel moisture [conditioning] model
Wind	Text	No	Used by fuel moisture [conditioning] model

Table 2. FlamMap required and optional data files.

GUI Section	Required Selections
Wind	• Wind Blowing Uphill and Wind Speed, or • Wind Direction and Wind Speed, or • Gridded Winds
Canopy Characteristics	• Height (if not in Landscape file) • Canopy Base Height (if not in Landscape file) • Canopy Bulk Density (if not in Landscape file) • Foliar Moisture
Fuel Moisture Settings	• Fixed Fuel Moistures from Fuel Moisture File or • Fuel Moisture Conditioning [model]

Table 3. Required FlamMap GUI selections. In order to use the Minimum Travel Time feature either "Wind Direction and Wind Speed" or "Gridded Winds" has to be utilized.

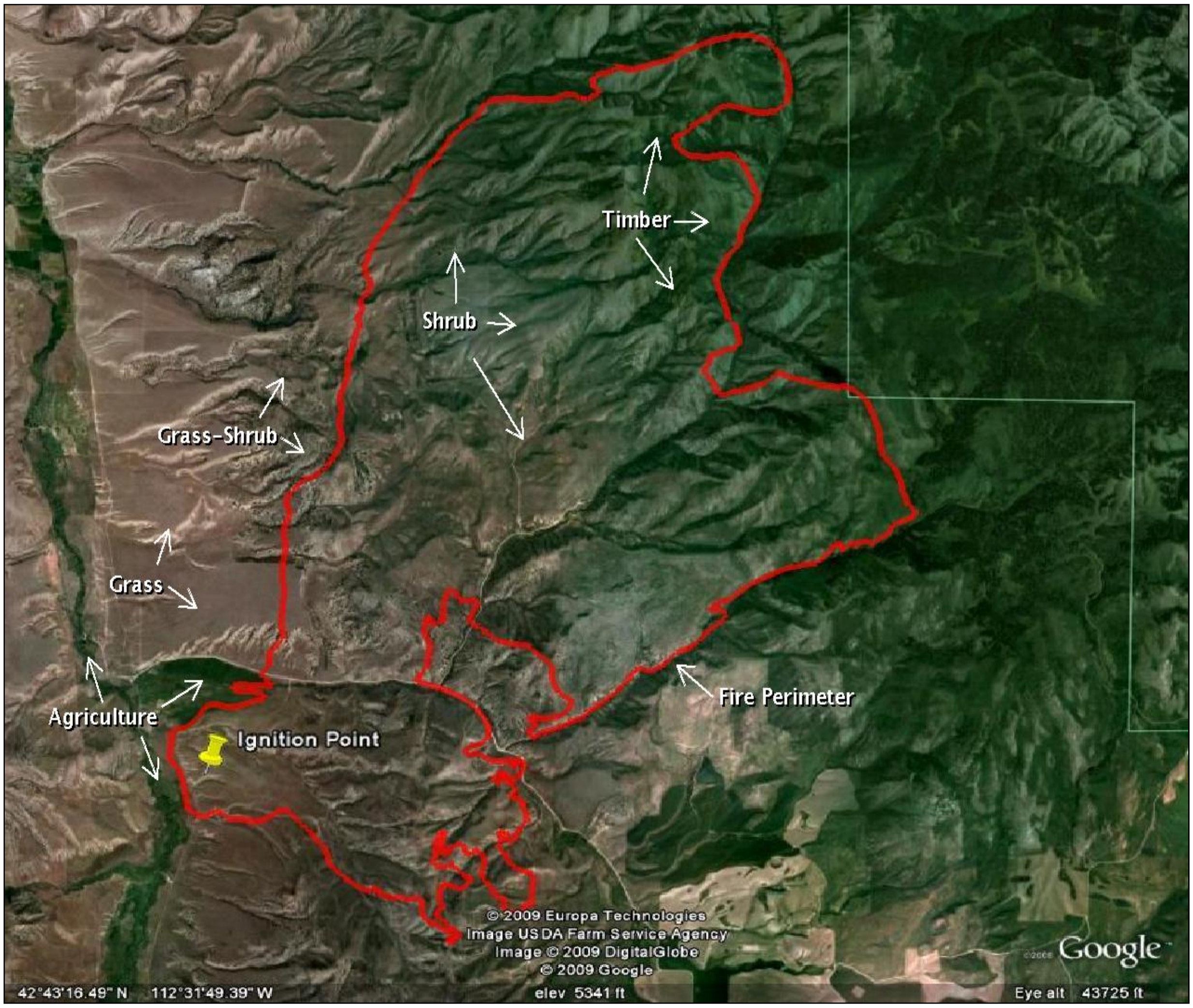

Fig. 1. Rattlesnake Fire perimeter (red) mapped on September 12, 2005. Background image from Google Earth showing geographic features with annotated geospatial fuel distribution.

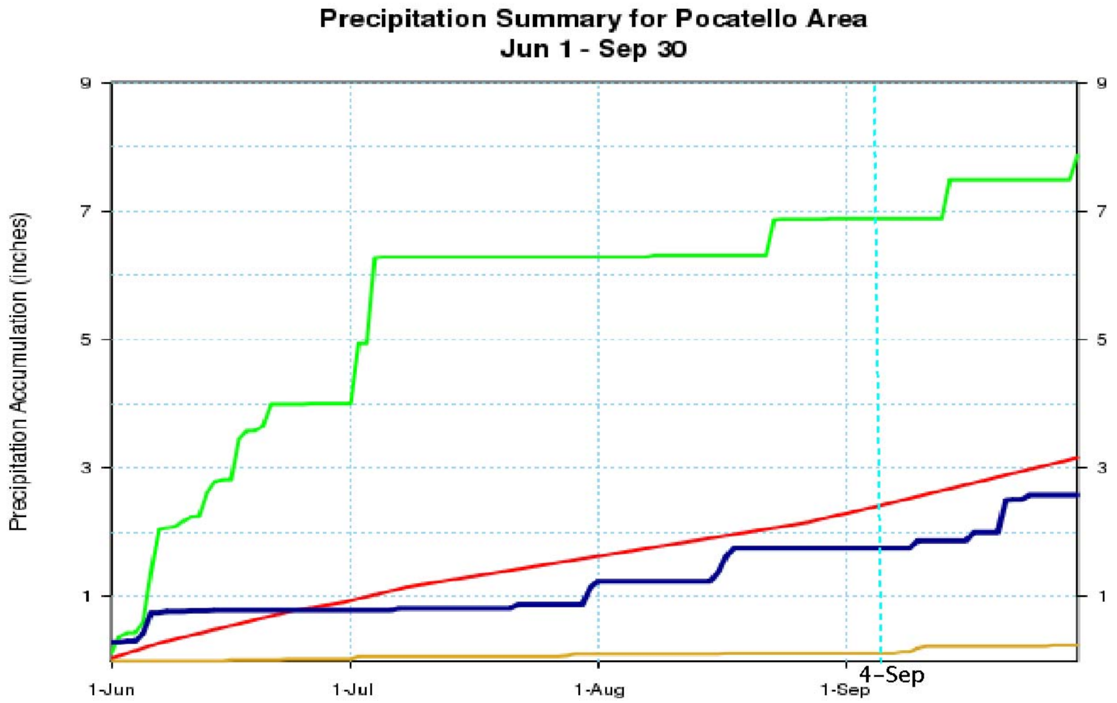

Fig. 2. Observed (blue) and Normal (red) Precipitation Accumulation for the Pocatello Regional Airport from June 1, 2005 through September 30, 2005. Wettest (2009, green) and Driest (1956, tan) Precipitation Accumulation for the Period of Record (1939-2009) provided for comparison.

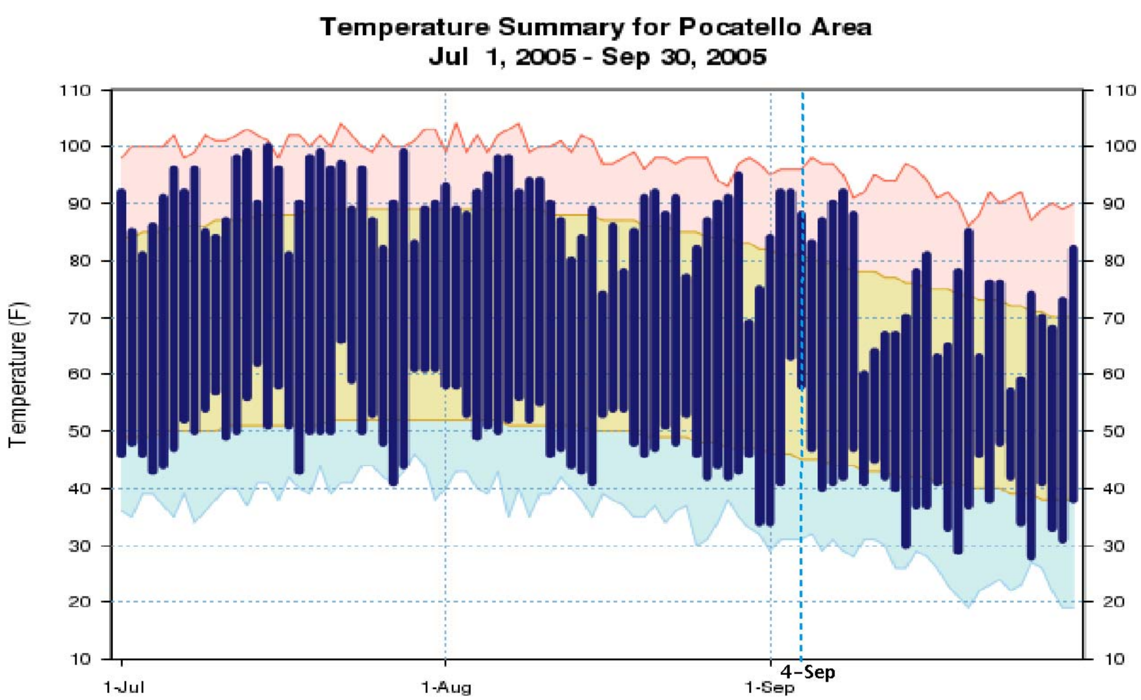

Fig. 3. Temperature Summary for the Pocatello Regional Airport from July 1, 2005 through September 30, 2005. Observed daily max and min temperatures are connected by dark blue bars. Normal max and min temperatures represented by tan shading. Record max and min temperatures represented by red and blue shading, respectively.

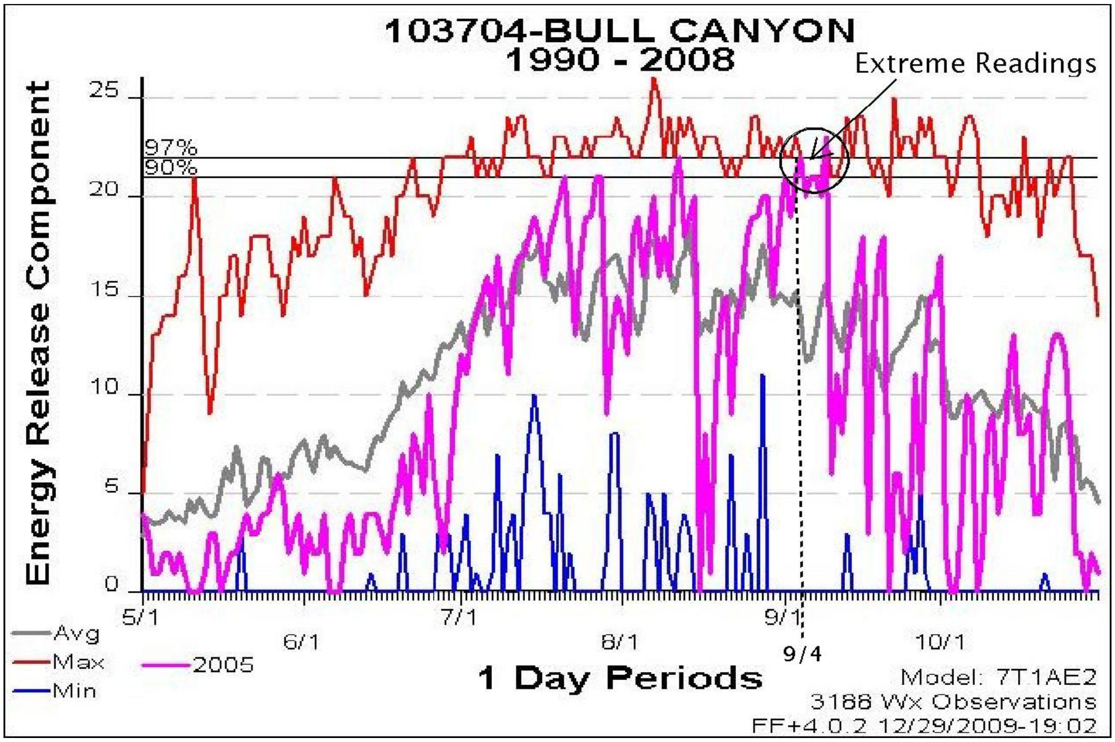

Fig. 4. Observed Energy Release Component (pink) for Bull Canyon RAWS from May 1, 2005 through October 31, 2005. Max (red), Min (blue) and Average (grey) Energy Release Component for the period 1990 through 2008 provided as a reference.

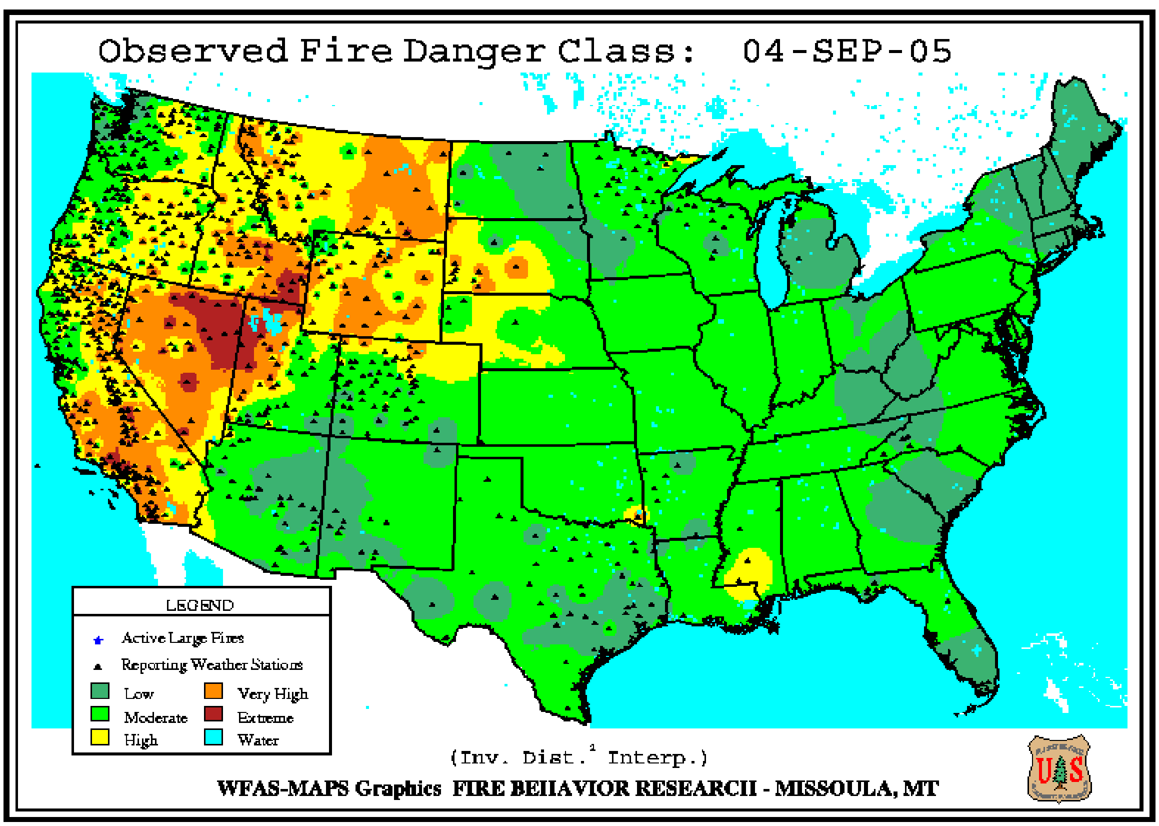

Fig. 5. Observed Fire Danger Class for September 4, 2005. Extreme Fire Danger is indicated for southeast Idaho.

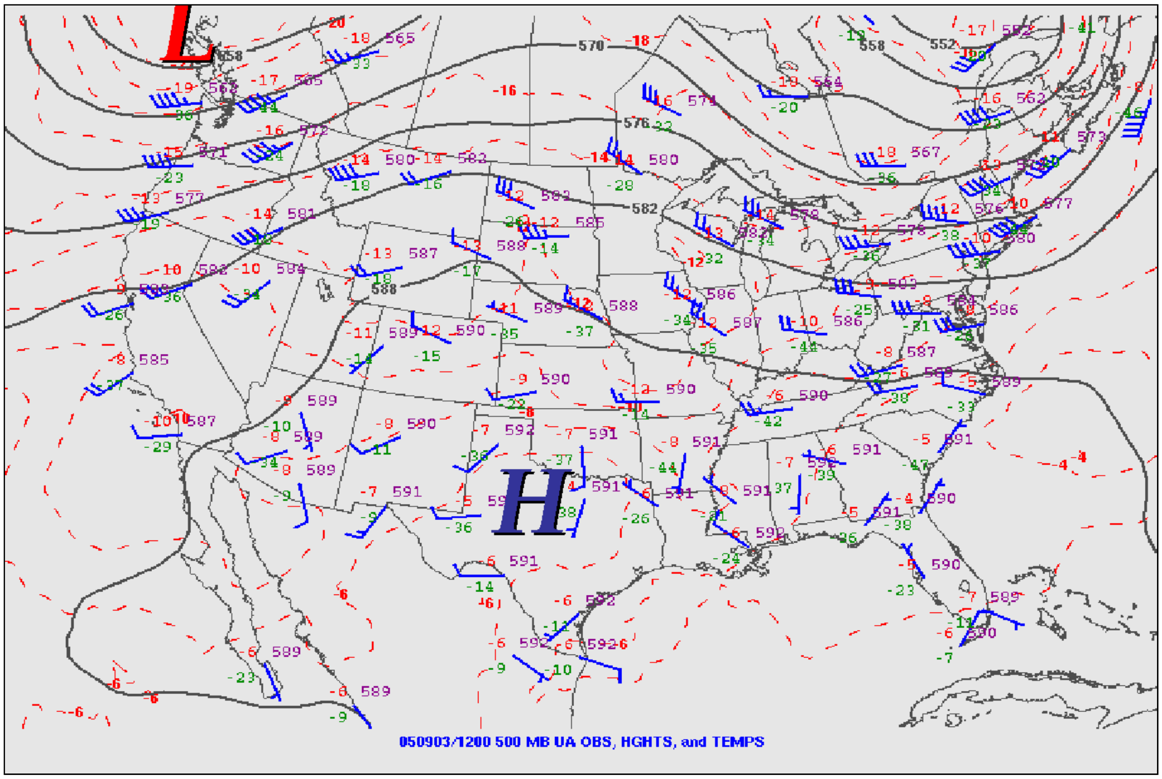

Fig. 6. Observed 500 hPa height (purple number and solid black line, 60 m contours), wind (blue wind barbs, knots), and temperature (red number and dashed red line, 2^{o}C contours) for September 3, 2005, at 0600 MDT.

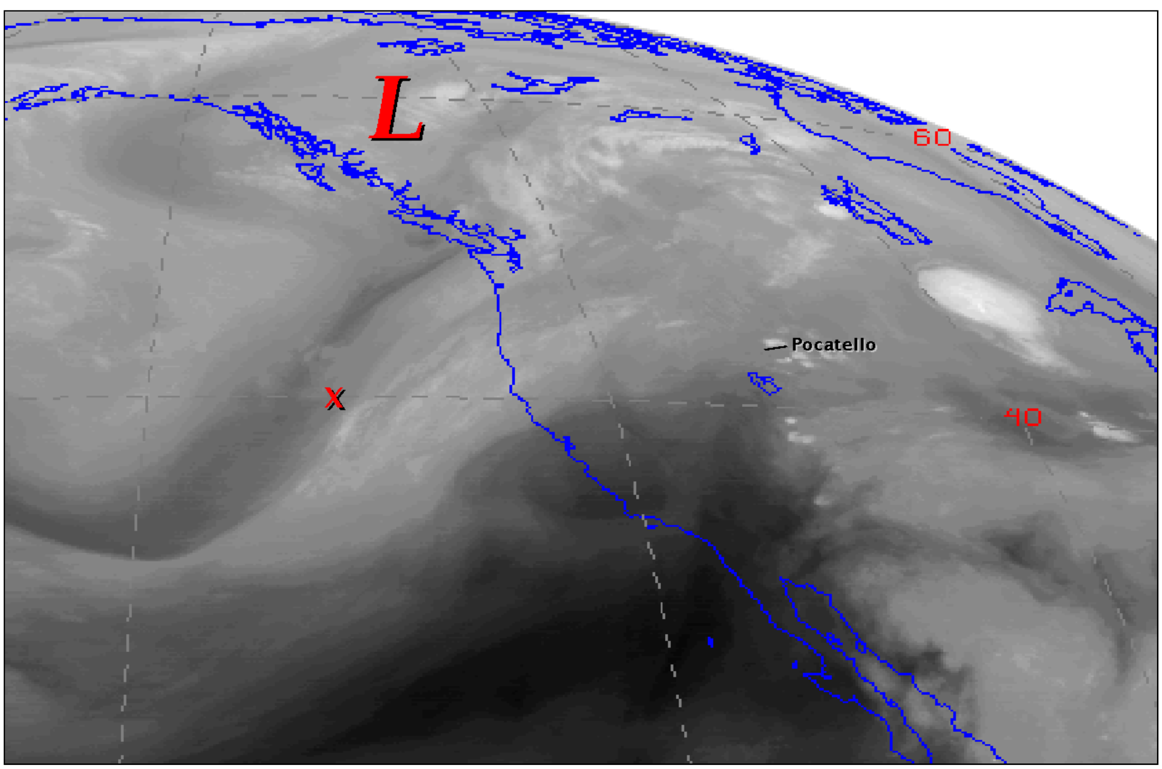

Fig. 7. Water Vapor satellite imagery. September 3, 2005, at 0600 MDT.

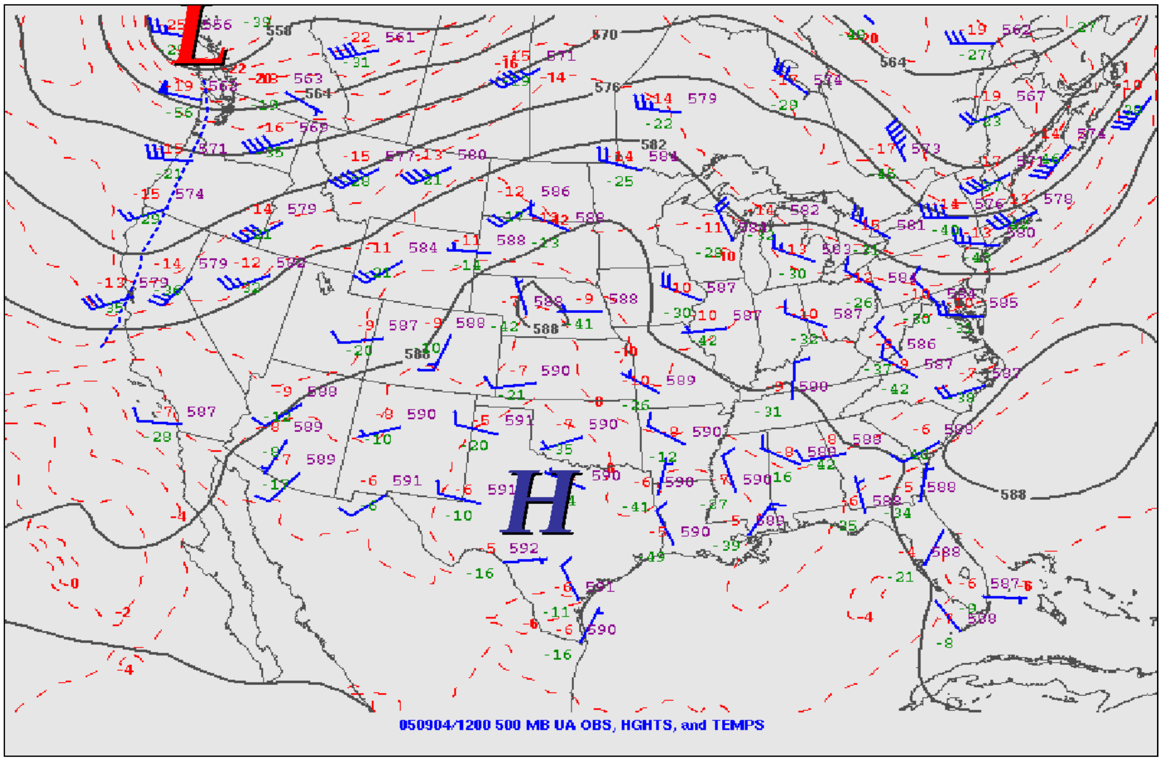

Fig. 8. Observed 500 hPa height (purple number and solid black line, 60 m contours), wind (blue wind barbs, knots), and temperature (red number and dashed red line, 2^{o}C contours) for September 4, 2005, at 0600 MDT.

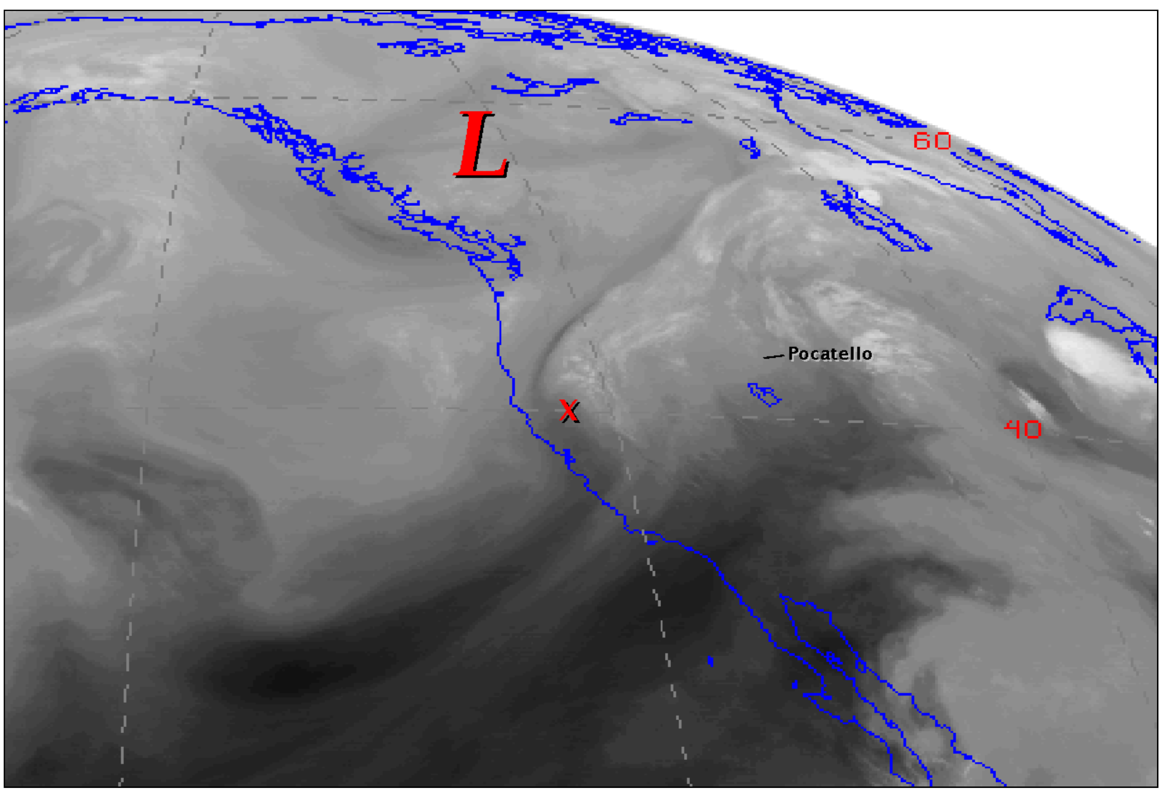

Fig. 9. Water Vapor satellite imagery. September 4, 2005, at 0700 MDT.

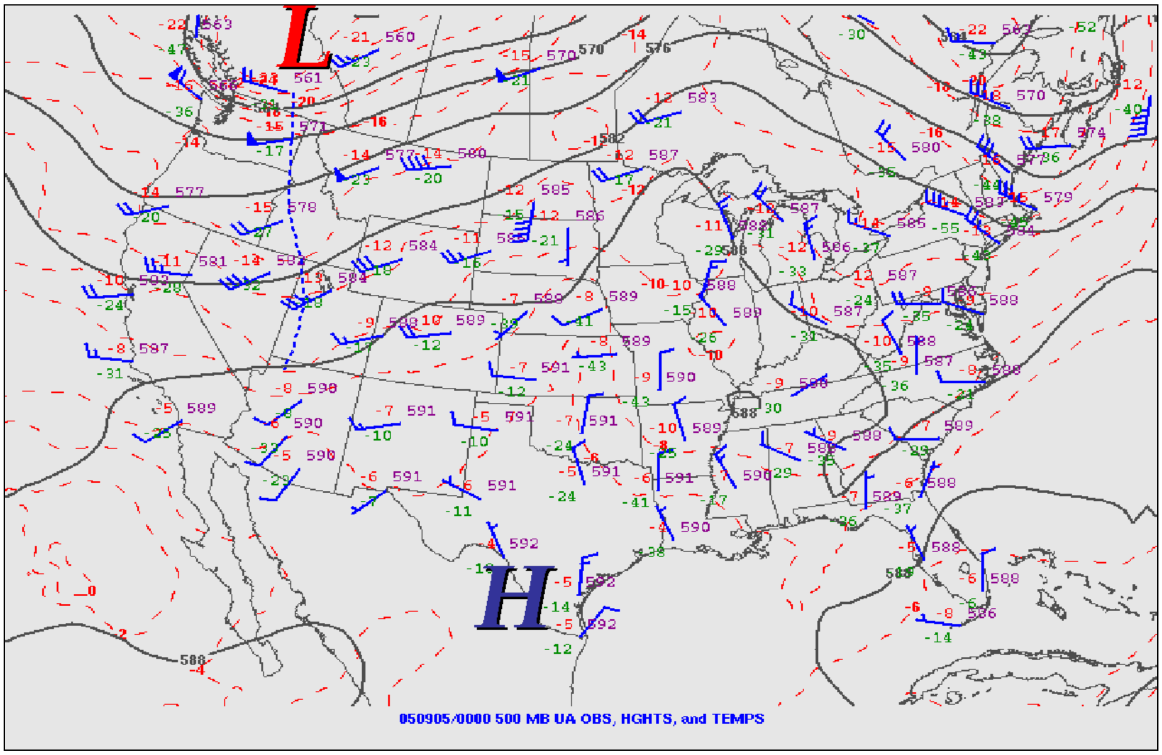

Fig. 10. Observed 500 hPa height (purple number and solid black line, 60 m contours), wind (blue wind barbs, knots), and temperature (red number and dashed red line, 2°C contours) for September 4, 2005, at 1800 MDT.

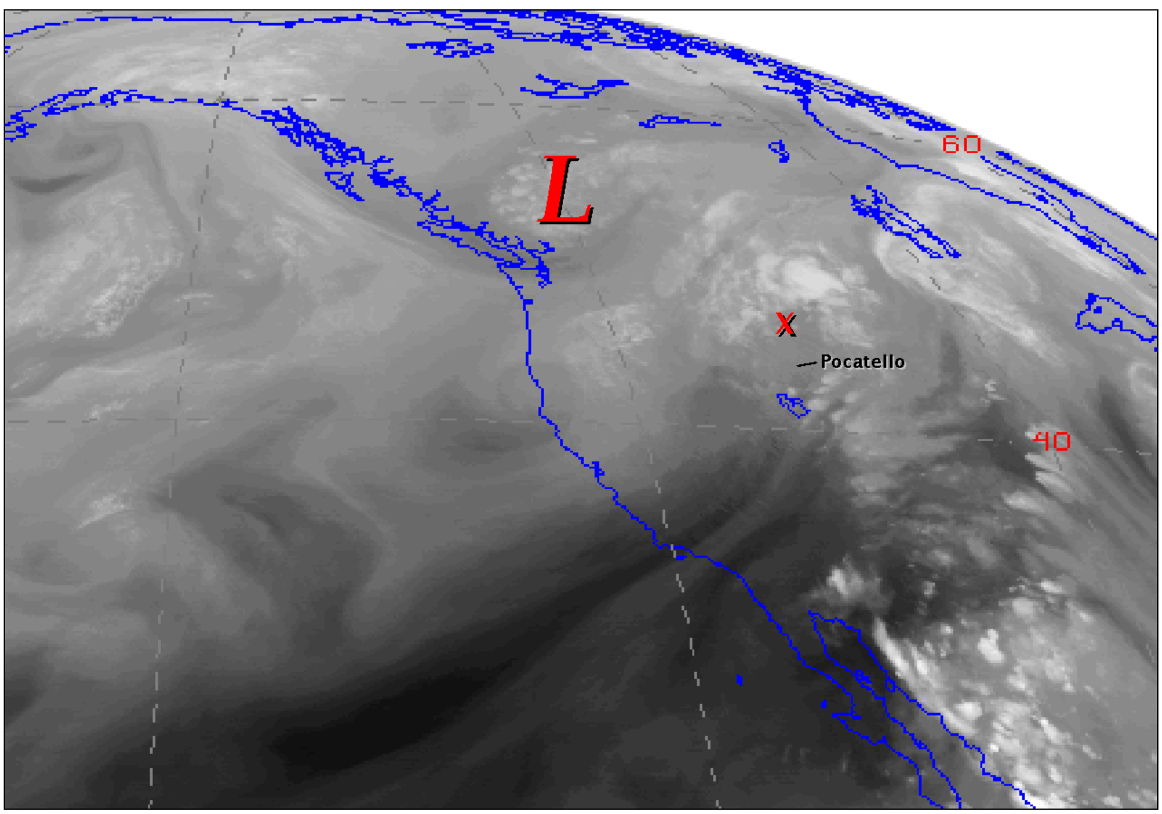

Fig. 11. Water Vapor satellite imagery. September 4, 2005, at 1900 MDT.

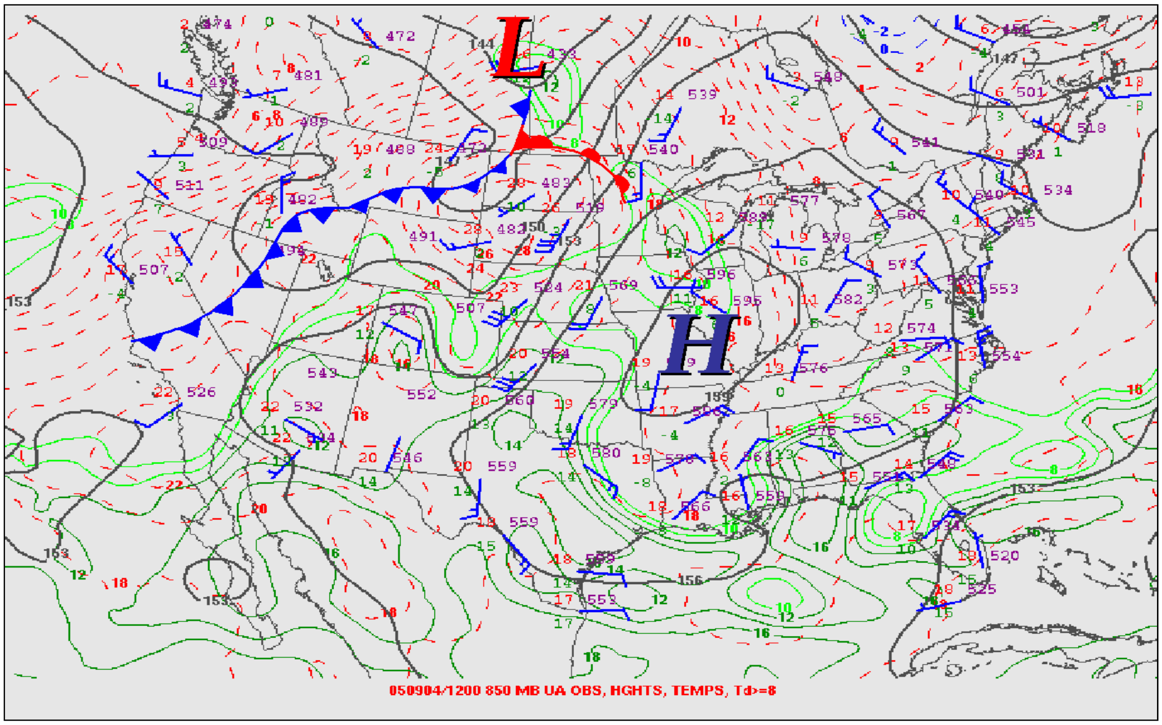

Fig. 12. Observed 850 hPa height (purple number and solid black line, 30 m contours), wind (blue wind barbs, knots), and temperature (red number and dashed red line, 2^{o}C contours) for September 4, 2005, at 0600 MDT.

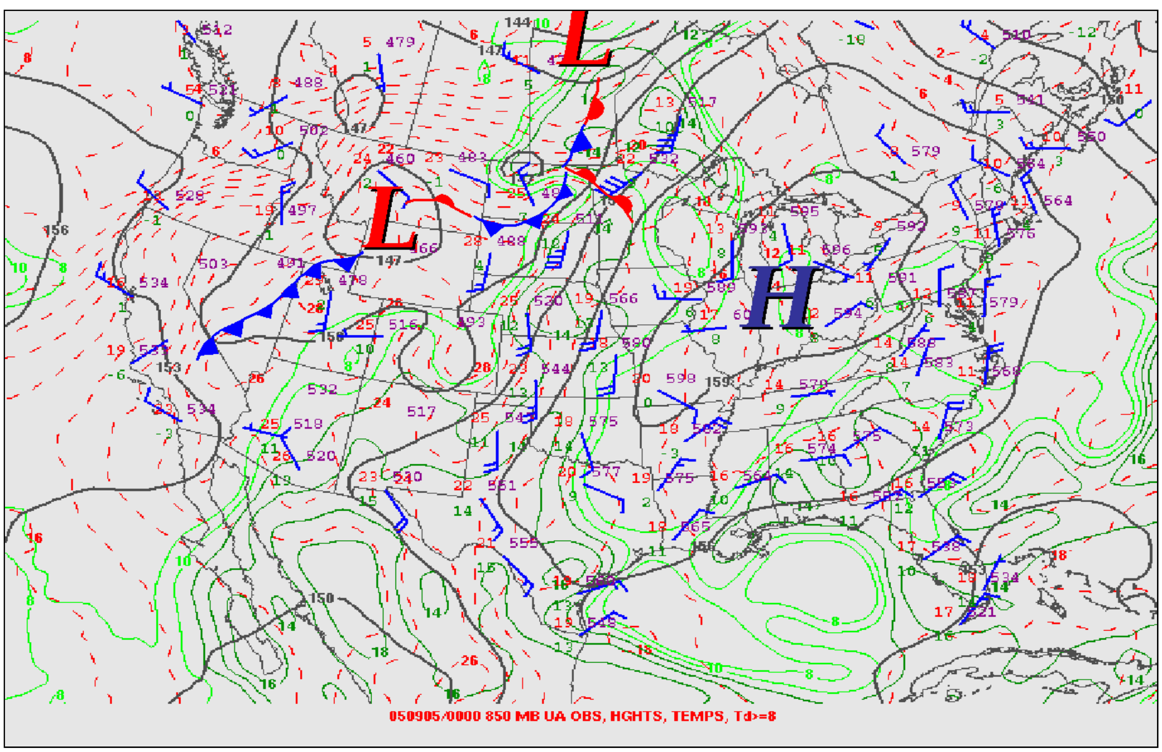

Fig. 13. Observed 850 hPa height (purple number and solid black line, 30 m contours), wind (blue wind barbs, knots), and temperature (red number and dashed red line, 2^{o}C contours) for September 4, 2005, at 1800 MDT.

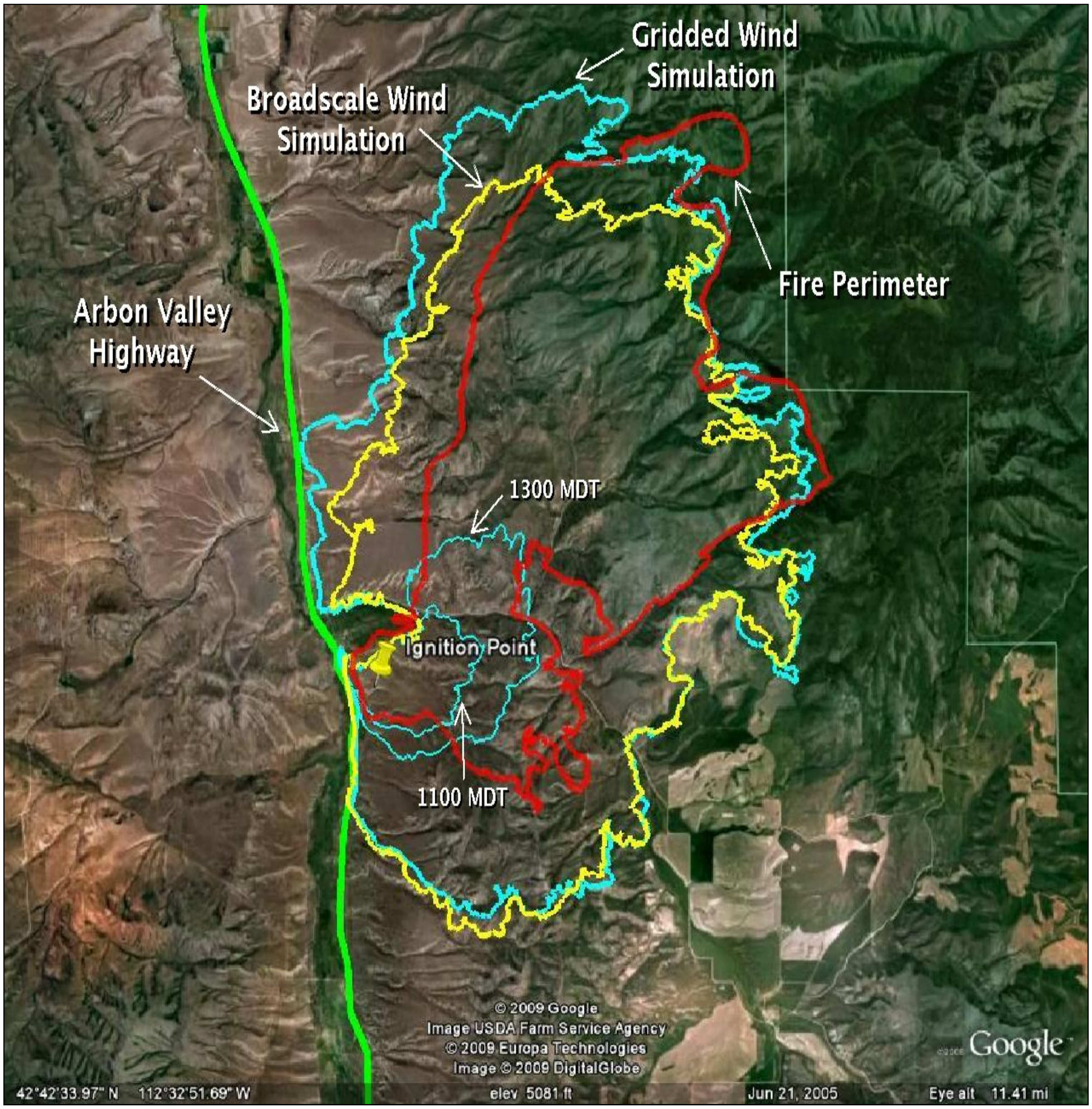

Fig. 14. FARSITE model simulation results. Broadscale wind simulation fire perimeter (yellow) and gridded wind simulation fire perimeter (cyan) after 19 hours of model simulation ending at 0200 MDT on September 5, 2005. Observed fire perimeter (red) mapped on September 12, 2005, provided for comparison. Intermediate, gridded wind simulation fire perimeter results (thin cyan) at 1100 MDT and 1300 MDT, on September 4, 2005, provided for reference.

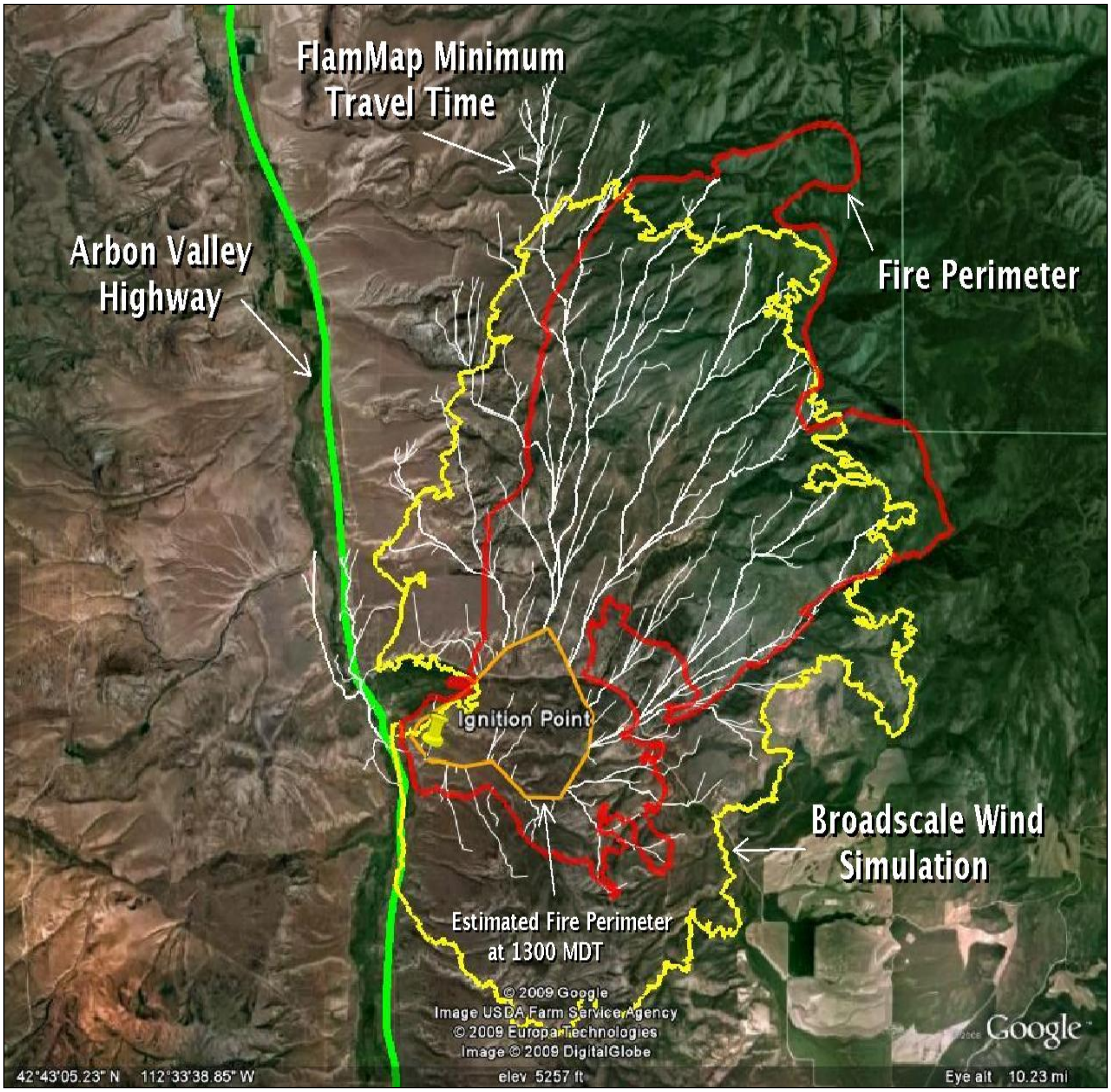

Fig. 15. FlamMap Minimum Travel Time (MTT) fire path simulation (white) after 13 hours of model simulation using the broadscale wind ending at 0200 MDT on September 5, 2005. Estimated fire perimeter at 1300 MDT (orange) was used to initialize the FlamMap simulation. FARSITE broadscale wind simulation fire perimeter (yellow) and observed fire perimeter (red) provided for comparison.