8.2 USING HIGH-RESOLUTION WEATHER DATA TO PREDICT FIRE SPREAD USING THE FARSITE SIMULATOR—A CASE STUDY IN CALIFORNIA CHAPARRAL

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1. INTRODUCTION

Since at least the 1970s, meteorologists have striven to produce fine spatial scale weather data to be used in a variety of applications. It has been long recognized that the growth of a wildfire is intimately coupled with atmospheric energy and mass flows. In the United States, operational prediction of a fire's rate of spread is facilitated by an equation developed by Rothermel (1972). This equation predicts the rate of spread of a fire spreading on the ground in wildland fuels. Several types of information are needed to make a fire spread rate prediction: 1) the size, amount, and moisture content of the wildland fuel, 2) the speed and direction of wind, and 3) the slope of the ground that the fire is spreading on. In order to produce an equation that would quickly predict rate of spread, Rothermel made several important assumptions. "The fire model is primarily intended to describe a flame front advancing steadily in surface fuels within 6 feet of, and contiguous to, the ground. Typical of such fuels are dead grasses, needle litter, leaf litter, shrubs, dead and down limbwood, and logging slash. These are the fuels in which fires start and make their initial runs and in which direct attack is usually made" (Rothermel (1983))

The Rothermel model has been implemented in several different forms to facilitate fire spread predictions. Recent research and development work has focused on improving fuel moisture dynamics in dead fuels (Nelson (2000)), wind field description using the computational fluid dynamics tool Wind Wizard (Forthofer et al (2003), Forthofer (2007)) and two-dimensional fire movement using the FARSITE model (Finney (1998)). Previous success in modeling wind flow in complex terrain for fire application resulted in the KRISSY model which was never implemented in an operational setting (Fosberg and Sestak (1986), Sestak (1984)). The KRISSY model's output was integrated into the ArcInfo GIS environment (Zack and Minnich (1991)) as Wind Wizard has been more recently.

In October 2006, the Esperanza wildfire consumed 16137 hectares of chaparral and desert scrub vegetation in mountainous terrain approximately 50 km east of Riverside, CA. Loss of life and property also resulted in this Santa Ana wind-driven fire. While tragic in outcome, the fire afforded us an opportunity to evaluate new models and technology that are being developed with the hope of preventing another such tragedy in the future. Specifically, we were able to evaluate the predictive ability of the FARSITE model when it was coupled with several different sources of weather data and compare predicted perimeters with perimeters observed by the FireMapper thermal imager which was flown over the fire area within 10 hours of the fire's start at approximately 0100 local time. We presented results from a similar opportunity that arose in 1996 with the Bee Canyon Fire which burned with 10 km of the Esperanza Fire (Gelobter et al. (1998), Weise and Fujioka (1998)).

2. METHODS

2.1 Fire Behavior Model and Fuels Data

The current version of FARSITE (4) can use weather and wind data from up to five weather stations and gridded wind data. An earlier version of FARSITE (3) can also use gridded temperature and relative humidity in

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addition to wind data. A current fuel model map produced by the Fire and Resource Assessment Program of the California Department of Forestry and Fire Protection was used to describe the fuels in the vicinity of the fire. This fuel model map contains the original 13 Northern Forest Fire Lab fuel models with 2 additional custom fuel models added for desert scrub vegetation and forest plantations.

2.2 Weather data sources.

There were several weather stations within 20 km of the point of origin of the fire. These include the Beaumont and Cranston RAWS, the Banning and Palm Springs Airports. In California, high spatial resolution weather forecasts are produced for fire behavior prediction using the MM5 model run at the Institute for Computational Earth Systems Science at UC Santa Barbara and a non-hydrostatic regional spectral model (RSM) at Riverside Fire Laboratory. These forecasts provide hourly temperature, relative humidity, wind speed, wind direction, and cloud cover on a spatial grid of 4 km in FARSITE-ready format. As part of the fire planning effort associated with the Esperanza Fire, several Wind Wizard (WW) runs were made assuming that the Santa Ana wind was blowing from 25, 45, 65, 90, 105, or 125° with input wind speeds of 64, 96, and 128 kph/hr to produce maximum ridgetop windsof 32, 48, and 64 km/hr. The input values for WW are typically twice the targeted maximum ridgetop 6m windspeeds. These CFD runs described wind speed and direction across the topography at a resolution of 100 meters.

2.3 Modeled fire spread scenarios

Several different wind and weather scenarios were run to simulate the fire spread on the Esperanza Fire between 0100 and 1200 on 26 Oct 2006. This time frame was selected because the approximate time and location of ignition were known and thermal imagery of the fire perimeter was collected by the Forest Service's PSW Research Station FireMapper thermal imager between 1115 and 1145 producing the first detailed perimeter location of the incident. Fuel moisture data were based on calculated 1- (5%), 10- (3%), 100- (5%) hr dead fuels and sampled live fuel moisture (herbaceous – 60%, woody – 60%) from chamise (*Adenostoma fasciculatum*) samples near San Bernardino National Forest's Cranston Fire Station.

Since FARSITE 4 was used, only gridded wind data produced by the various models were used with temperature, relative humidity, and precipitation data from Banning Airport which were used in four of the five simulations (Table 1). Data recorded at the Beaumont Remote Automated Weather Station (RAWS # 045617) and the Banning Airport weather station (AIRS #060650012, ARB # 33164), the 4 km resolution UCSB MM5 0Z model run initialized on 25 Oct 2006, Wind Wizard CFD model runs at 100 m resolution produced by the Missoula Fire Sciences Lab, and the RSM run at 1 km resolution at the Riverside Fire Lab were each used as inputs to FARSITE. To construct the wind files for FARSITE, the Banning Airport wind velocity and direction data were used to select the appropriate Wind Wizard run. The FARSITE simulations were run with 30 minute time steps and 60 meter distance and perimeter resolution from 0100 to 1100. Each simulation took approximately 30 minutes to complete. No modifications were made to the fuels layer and spot fire growth was not enabled.

Scenario	**Weather data (T, RH, Prec.)**	**Wind data (Dir., Vel.)**
Beaumont	Beaumont RAWS	Beaumont RAWS
Banning	Banning Airport	Banning Airport
MM5	Banning Airport	UCSB MM5
RSM	Banning Airport	Regional Spectral Model
Wind Wizard	Banning Airport	Wind Wizard

Table 1. Weather and wind data used in FARSITE scenarios to simulate fire spread from 100 to 1100, 26 Oct 2006 on the Esperanza Fire, Banning, CA.

The weather data sequences used to predict hourly fuel moistures for all of the scenarios are found in Table 2. Temperatures and relative humidity were typical of Santa Ana conditions during this time of year. The wind data from 100-1200 on 26 Oct 2006 for both weather stations can be found in Table 3. Both stations recorded the wind direction shift indicating the surfacing of the Santa Ana winds at 2000 on 25 Oct 2006 (not shown). The weather stations were both located on the valley floor so the wind velocities and directions that occurred on the fire line may have been appreciably different from those recorded.

Location	Temperature (°C)				Relative Humidity (%)	
	Min	Min Time	Max	Max Time	Max	Min
Banning Airport (1551 m)	16.1	0	27.2	1200	45	23
	14.4	2300	25.6	1200	99	22
	13.3	100	25.0	1400	99	21
	15.6	500	20.6	1200	24	19
	16.1	100	23.9	1200	24	20
Beaumont RAWS (2680 m)	15.6	200	27.8	1300	19	8
	13.3	600	27.2	1300	68	21
	10.6	600	27.2	1400	98	7
	13.9	600	21.1	1300	10	5
	16.1	0	25.0	1300	10	5

Table 2. Daily temperatures and relative humidities used to predict diurnal fuel moistures for Esperanza Incident near Banning, CA, 23-27 Oct 2006.

As mentioned above, the gridded wind sequence for the Wind Wizard simulation was assembled by using the Banning Airport wind velocity and direction to select the appropriate wind file (Table 3). The 32 kph files were used for Banning Airport wind velocities up to 32 kph, the 48 kph files were used for winds 33-48 kph, and the 64 kph files were used for winds greater than 48 kph. The WW input wind directions are also listed in Table 3.

The range in wind data resolution can be seen in Fig. 2, 4, 6, 8, and 10. The Beaumont and Banning weather stations are located 15.6 and 8.3 km to the west of the point of origin, respectively. The closest MM5, RSM and Wind Wizard grid points were located approximately 2.2, 0.13, and 0.02 km, respectively, from the point of origin. Sixteen grid points are contained in a 4 x 4 MM5 grid which covered 144 km^2. 177 RSM grid points and 14, 400 Wind Wizard grid points were contained in the same area. While Wind Wizard grids are at a much finer spatial resolution than the current operational or research weather models, it should be remembered that Wind Wizard is a static solution of flow conditions across the terrain given the boundary conditions. The weather models are dynamic predictions of weather conditions throughout the terrain.

3. RESULTS AND DISCUSSION

The fire ignited at approximately 100 Pacific Standard Time and the area within the fire perimeter at 0800 was estimated as 1571 ha (Fig. 1). The area contained within the mapped perimeter at 2000 on the 26^{th} was 9510 ha. Actual area burned was estimated by multiplying the number of pixels in the FireMapper imagery that appeared to have burned by the pixel size (25 m^2). This yielded an estimated area of 816 ha at 0800, 3064 ha at 1130, and 4384 ha at 2000. Maximum distance from the point of origin to the perimeter at 2000 was 20 km.

The fire spread simulations varied considerably in size (Table 4, Fig. 2, 3). The simulated fire spread was primarily to the west for all five simulations instead of the southwest as suggested by the actual fire perimeter location determined by FireMapper at 1100 and the 800 perimeter that was produced by the fire team. The Banning and MM5 simulations did not result in a heading fire at 0800 that spread to the southwest as the Beaumont RAWS, RSM, and Wind Wizard simulations did. Note the lobes on the simulations within the 0800 perimeter (Fig. 2). The simulated fire spread on the southern side of the fire for the Banning and MM5 weather data, while upslope, was flanking with the east wind blowing through the pass.

Time	Banning Airport		Beaumont RAWS		Input Wind Wizard Parameters	
	Speed	Direction	Speed	Direction	Speed	Direction
000	21	49	13	76	96	45
100	18	46	11	70	96	45
200	27	69	13	72	96	65
300	16	60	14	75	96	65
400	31	75	16	73	96	65
500	37	85	21	81	128	90
600	32	75	21	83	96	65
700	45	94	24	82	128	90
800	48	83	26	91	128	90
900	40	97	31	85	128	90
1000	35	92	29	89	128	90
1100	34	88	26	84	128	90
1200	37	95	27	87	128	90

Table 3. Wind speed and direction for 2 weather stations used in FARSITE simulations of the Esperanza Incident near Banning, CA, 26 Oct 2006.

Scenario	Area at 800 (ha)	Overlap at 800 (%)	Area at 1100 (ha)
Beaumont	757	21	4925
Banning	2864	57	7844
MM5	4410	23	5977
RSM	986	11	4172
Wind Wizard	716	14	1490
Estimated Actual*	1571		3064

*Area at 0800 determined from incident map of perimeter; area at 1100 determined from number of pixels burned on FireMapper image.

Table 4. Characteristics of simulated fire growth for 5 scenarios from 0100 to 1100, 26 Oct 2006, Esperanza Incident, Banning, CA.

The Banning Airport and Beaumont RAWS data were collected in the Banning Pass which is a major pass subject to strong Santa Ana winds. The east-west orientation of the pass channels wind in this direction throughout the year during normal diurnal onshore-offshore flow. As can be seen from the observed data (Table 3), the wind direction at these two locations was predominantly from the east after about 500 on the day of the fire. Because the Wind Wizard data stream was selected based on the observed data, the flow scenarios reflected the dominant flow from the east which translated to fire spread that was predominantly to the west.

In contrast, the MM5 and RSM weather predictions were resolved at each grid point using the terrain immediately below the grid point. As a result, these two simulations should have produced wind fields that would vary in direction as the wind flows over the terrain; however, the spatial resolution of the terrain for these models is much coarser than the resolution used by Wind Wizard. As can be seen in Fig. 4, the 0800 wind vectors predicted by the MM5 model were predominantly westerly in orientation. While the RSM produced some downslope flow as part of the diurnal cycle, the majority of the flow was also from the east. The distribution of wind direction for the three gridded weather scenarios at 0800 can be found in Table 5. The distributions are surprising similar. Approximately 14% of the wind vectors indicated flow from the NE and over half of the wind vectors indicated flow from the E

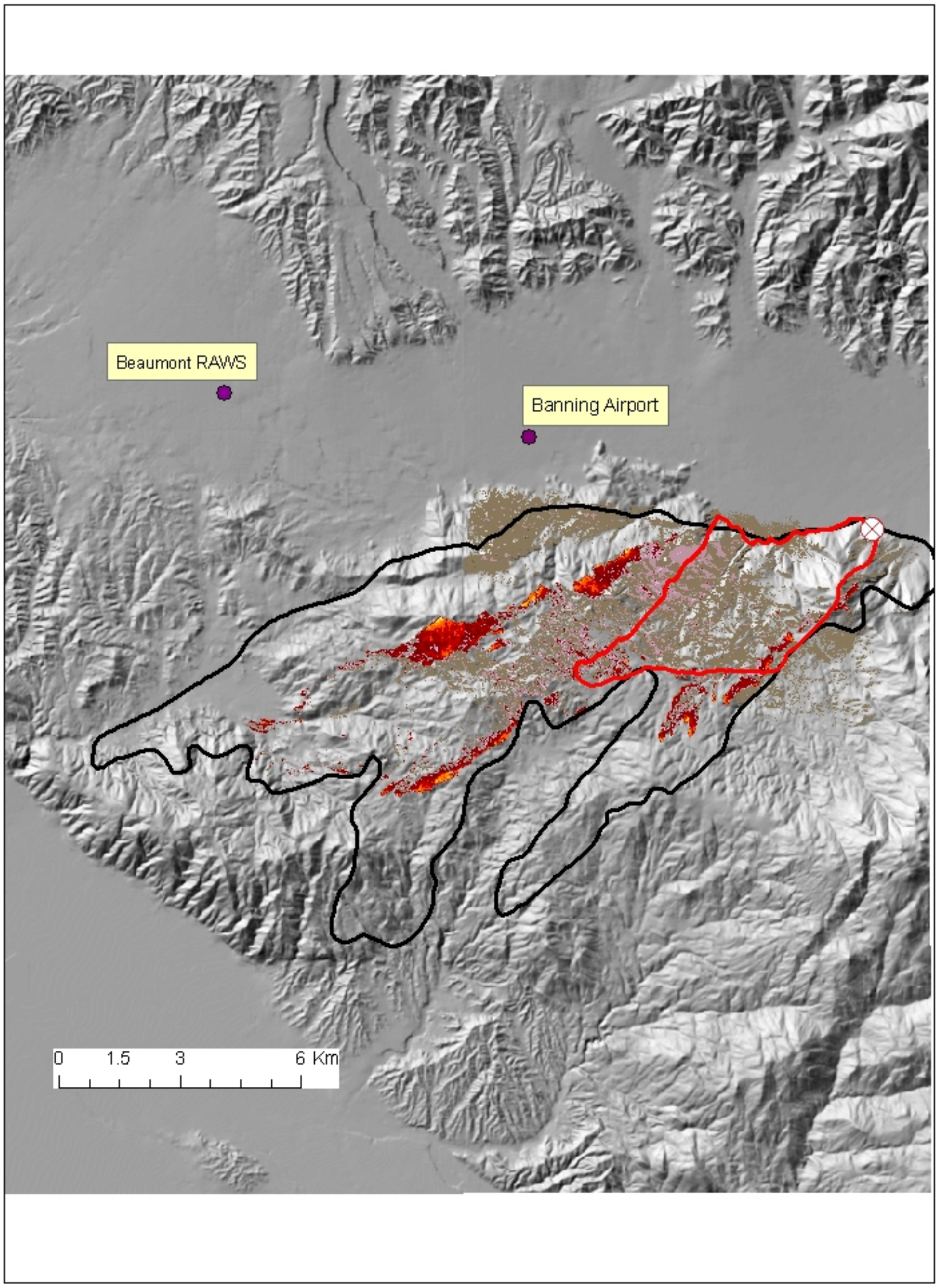

Figure 1. Fire perimeter locations at 0800 (red) and 2000 (black) provided by Incident Team and composite burned area determined by FireMapper thermal imager at 1130 on 26 Oct 2006 for the Esperanza Fire near Banning, CA.

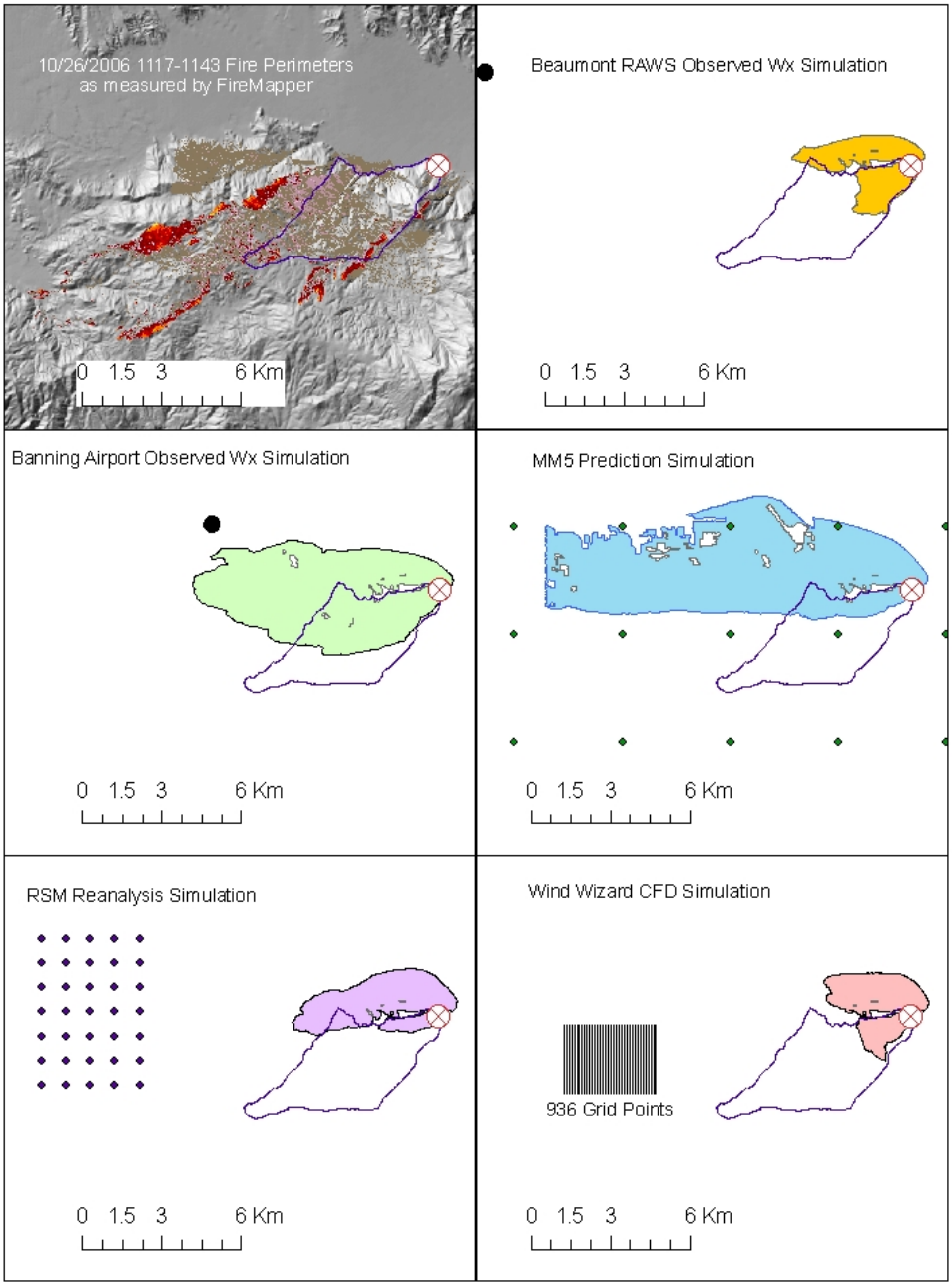

Figure 2. Actual and simulated fire line locations at approximately 800 26 Oct 2006 for the Esperanza Fire. Dots denote weather station or weather grid density.

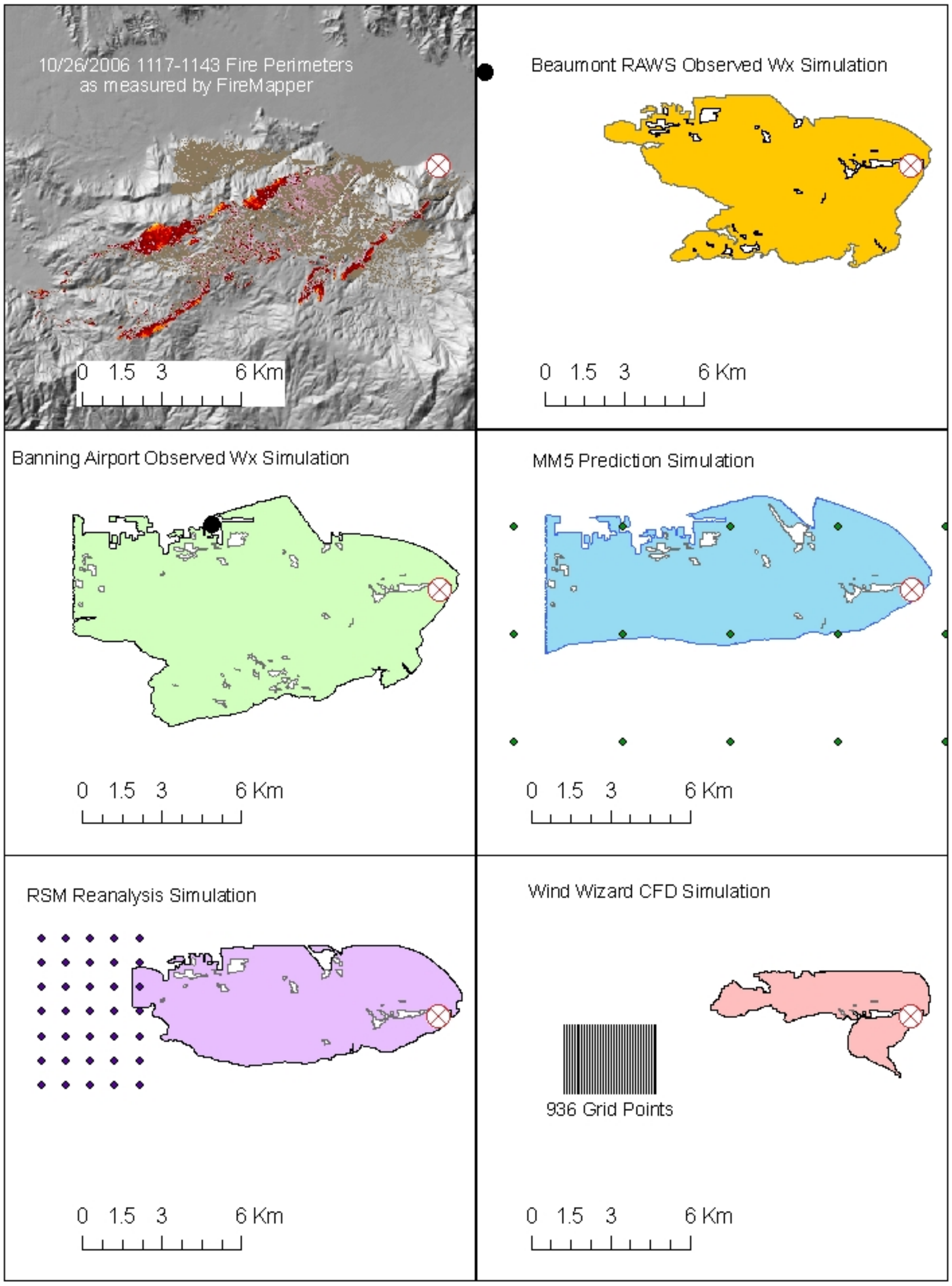

Figure 3. Actual and simulated fire line locations at approximately 1100 26 Oct 2006 for the Esperanza Fire. Dots denote weather station or weather grid density.

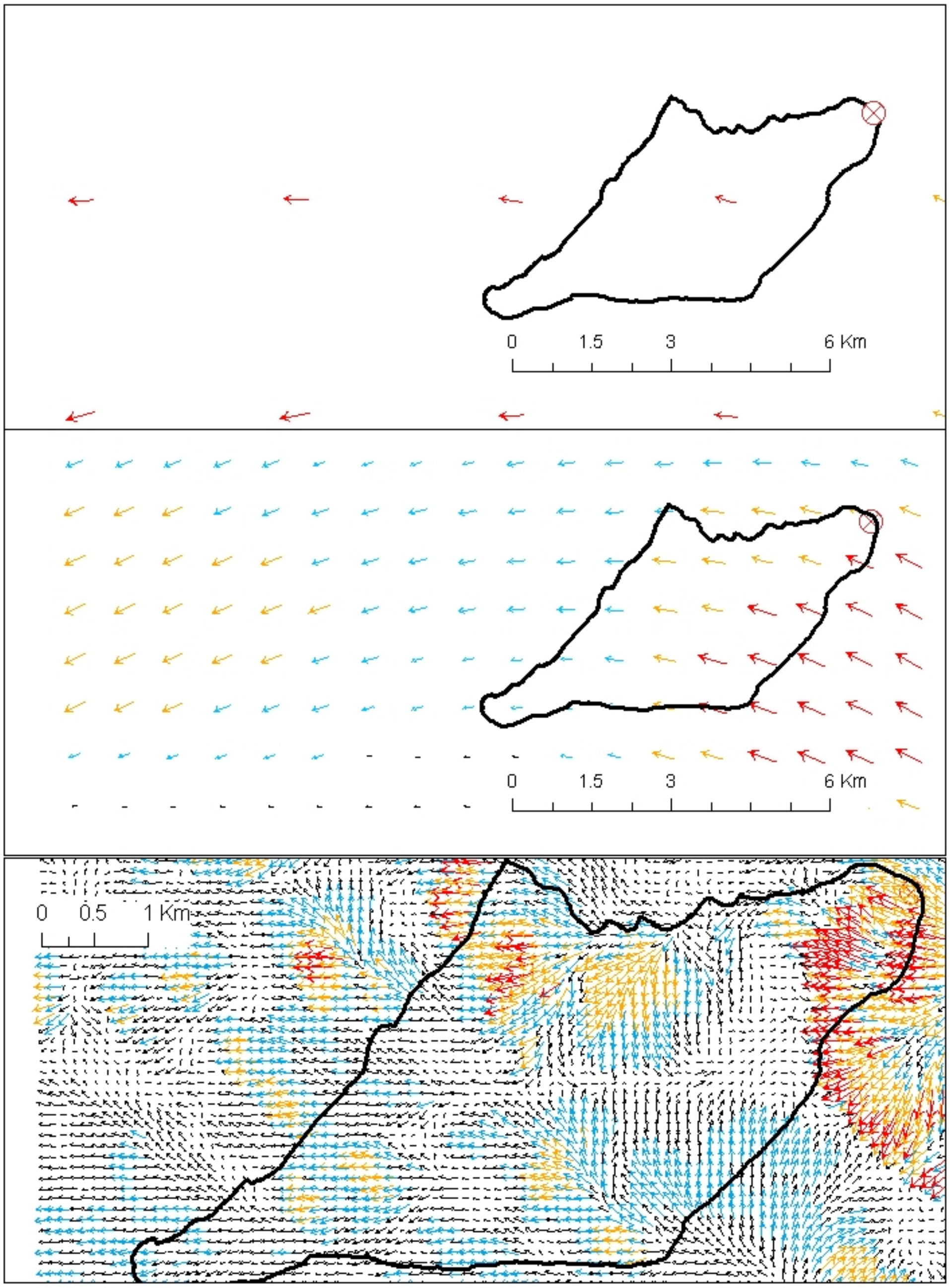

Figure 4. Gridded wind vectors produced by the MM5 (top), Regional Spectral Model (middle), and Wind Wizard models for 0800 26 Oct 2006 in the vicinity of the Esperanza Fire.

Scenario	Points	NE	E	SE	S	SW	W	NW	N
MM5	28	0.14	0.79	0.07	0.00	0.00	0.00	0.00	0.00
RSM	144	0.13	0.77	0.10	0.00	0.00	0.00	0.00	0.00
Wind Wizard 90°	4644	0.15	0.51	0.13	0.08	0.05	0.02	0.03	0.02
Wind Wizard 45°	4698	0.59	0.10	0.02	0.01	0.03	0.09	0.11	0.05

Table 5. Distribution of wind direction from three gridded weather models at 0800 26 Oct 2006, Esperanza Incident, Banning, CA.

for each of the gridded wind data sets. There was also generally good agreement in the percentage of SE winds. Note the large difference in the number of grid points represented by these data sets. In order to illustrate the importance of the initial conditions on the Wind Wizard output, the distribution of wind direction is also presented for the Wind Wizard simulation with an initial direction of 45°. For the same landscape, the dominant wind direction for the 45° simulation changed to NE (59%) with 10% occurring in the E octant. The number of grid points increased because of imprecision in selecting the same exact area (1 additional column added).

We currently do not know why the MM5 and RSM models were unable to predict winds which were predominantly from the NE. The spread of the Esperanza Fire suggests that the winds were predominantly from the NE octant; the angle of the major axis of the polygon for the 0800 perimeter is 63°. An additional FARSITE simulation using a different sequence of Wind Wizard data that is based on an initial direction of 60° may produce predicted perimeters that are closer to the actual observed perimeters. Determining the appropriate sequence of data for this new simulation must be based on “best” guesses instead of physics.

4. SUMMARY

Five simulations of the spread of the Esperanza Fire using the FARSITE simulator were performed using weather data from a range of sources – two weather stations and three gridded models. Simulated perimeters were compared with an incident mapped perimeter and imagery collected by the FireMapper thermal imager. Agreement between actual and simulated perimeters and area burned was generally poor over the 1st 10 hours of fire growth. While we are not totally certain of the accuracy of the fire spread model, the error in fire perimeter simulations were likely attributed in part to error in the wind direction, especially during the hours prior to 0800 when the fire perimeter became available. The observed weather station data and weather model predictions suggested wind direction from the east while the fire spread suggested a wind direction from the northeast. These results suggest that additional work is needed to improve predictive weather models, to develop rules in order to apply Wind Wizard model runs, , and to better understand the behavior of FARSITE under different scenarios of wind conditions in this geographic area to improve fire spread predictions.

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