2.5 **CASE STUDY OF AN INTEGRATED WEATHER/FIRE SPREAD MODELING APPLICATION**

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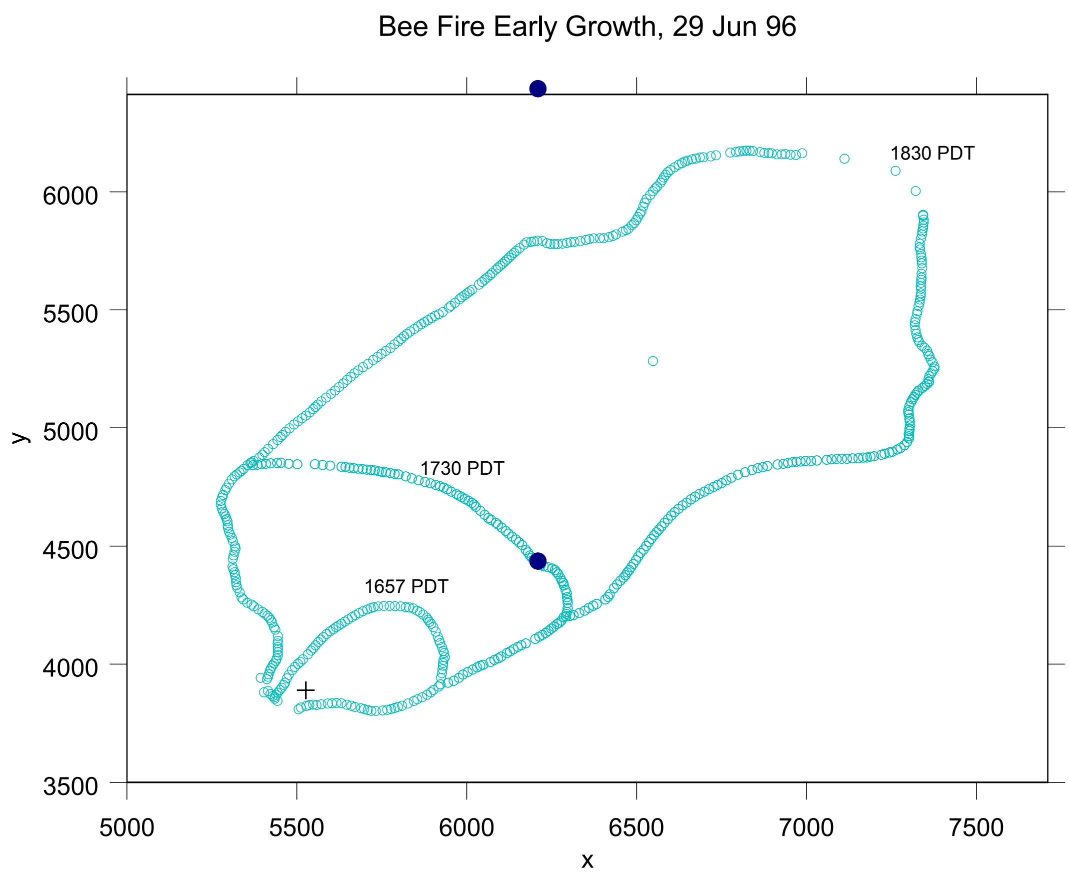

Figure 1. Plots of the first three perimeters recorded for the Bee Fire, San Bernardino National Forest, California. Axis units are in meters relative to local UTM coordinates. The plus sign indicates the ignition point of the fire. The solid dots are wind model grid points

1. INTRODUCTION

The increasing accessibility of mesoscale weather models makes them highly desirable for use in wildland fire spread simulations, particularly where small-scale features affect surface wind speed and direction. Some fire behavior modeling systems, such as FARSITE (Finney, 1998), accept gridded weather fields in anticipation of such usage. The FARSITE system simulates two-dimensional fire spread, given terrain, fuel and weather conditions. It is designed to run on personal computers, reasonably user-friendly, and thus a likely candidate for field implementation. However, the accurate simulation of fire spread is still a substantial scientific challenge.

This paper examines the accuracy of fire spread simulations of the Bee Fire, which burned a portion of the San Bernardino National Forest in southern California, in summer 1996 (Figure 1). The study focused on the incipient

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stages of the fire, when fire growth measurements were most frequent, and suppression efforts were minimal to absent. A mesoscale model was used to describe the surface weather variations over the region at a grid interval of 2 km. The next section describes the data used for this study. The third section describes a new and improved method of analysis of fire spread simulation errors, which was applied to the Bee Fire. The final section summarizes the main points of the study, and ends with conclusions and recommendations.

2. BEE FIRE DATA

A fire behavior team, consisting of a fire behavior analyst, two trainees, two field observers, a geographic information systems (GIS) specialist and a fire meteorologist, assembled data describing terrain and fuels in the Bee Fire area. The team obtained weather data for the burn period from Pine Cove, a nearby remote automatic weather station (RAWS). Through interviews, the team documented the sequential growth of the fire in a GIS dataset that described the position of the fire at 28 different times, from 29 June to 3 July 1996.

Because the weather data coverage was inadequate, a Forest Service study was initiated, well after the fire, to provide weather data on a 2 km grid spacing for the fire episode (Figure 2), using a mesoscale meteorological model (Weise and Fujioka, 1998). The weather model is a high resolution extension of the global spectral model used by the National Center for Environmental Prediction (NCEP) in Washington, DC (Juang and Chen, 1998).

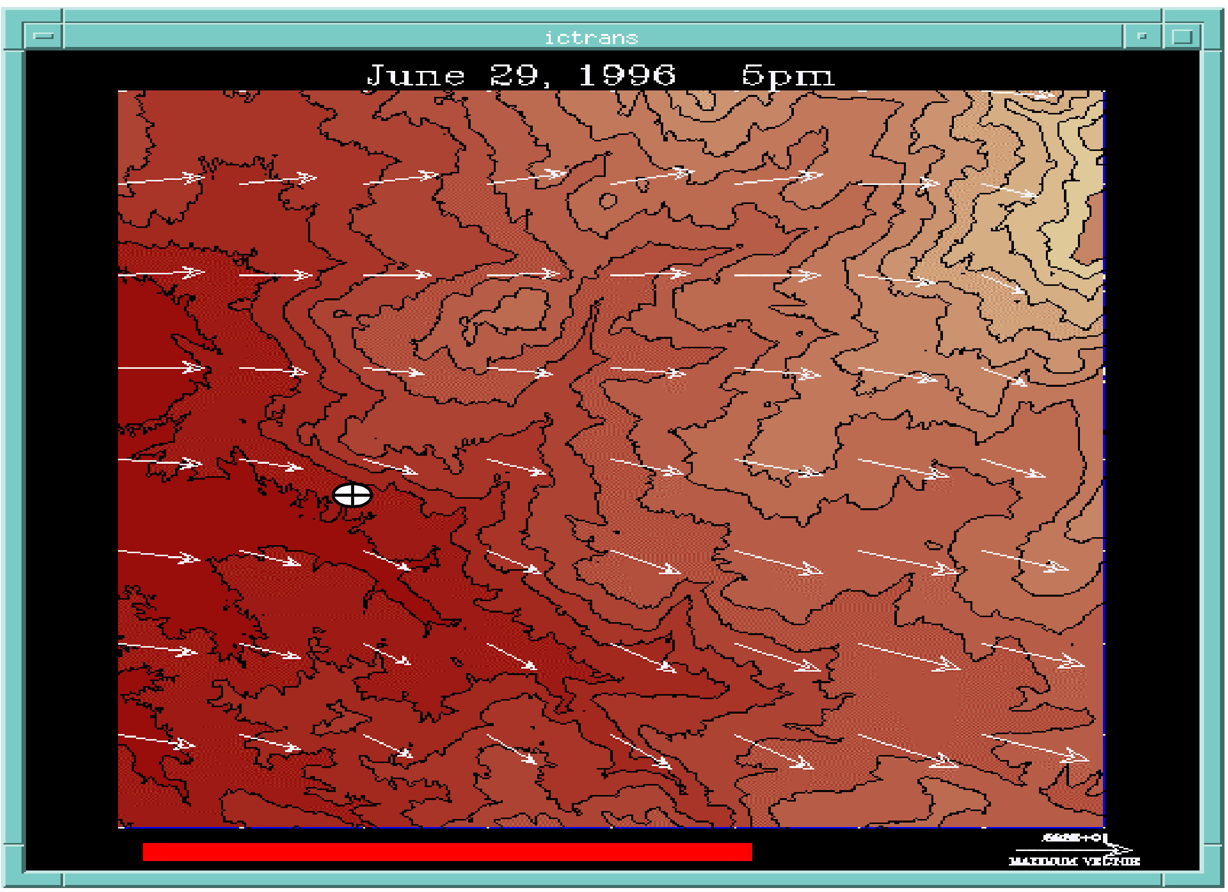

Figure 2. Mesoscale model forecasted winds over the Bee Fire area, at 1700 PDT, 29 June 1996. The ignition point is on the west side, approximately at the position indicated by the circle. The vectors show the wind flow at 10 m above the surface.

This Mesoscale Spectral Model (MSM) solves the primitive equations on terrain following sigma coordinates, and includes non-hydrostatic terms for the mesoscale field.

We will concentrate our analysis on the first two hours of the fire, due to limitations of the fire growth data. Within this time span, we have perimeter data at approximately 10, 45, and 105 minutes after ignition. These are the shortest sampling intervals of the perimeter growth compiled by the fire behavior team. The next perimeter would not be reported until 4.5 hours later. Beyond the period that we consider, the fire does not exhibit the free burning character simulated by our spread model. This may be due to suppression effects on the fire, faulty documentation of fire growth, modeling deficiencies, or a combination of the above.

3. FIRE ENVIRONMENT

The 1996 Bee Fire event started on the afternoon of 29 June, at the base of the San Jacinto Mountains, approximately 1.6 km north-northwest of the Cranston Ranger Station, in the San Bernardino National Forest, California. The ignition point lay in Bee Canyon (Figure 2), approximately 680 m above sea level. The north fork of the San Jacinto River cuts through the eastern portion of the burned area, while Indian Creek runs through its western extent. The San Jacinto River bounds the south side of the fire. The predominant fuel type is chamise (*Adenostema fasciculatum* H&A). Over its life, the Bee Fire covered 3,848 ha.

On 29 June 1996, the air temperature at the time of ignition, 1647 PDT, was approximately 29° C, relative humidity 19%. Winds blew out of the southwest to northwest at approximately 2 m/s. Less than two hours later, the temperature dropped to 24° C, and relative humidity increased to 24%. The wind speed held relatively constant at 2 m/s, until 1830 PDT, when it became virtually calm.

4. METHOD OF ANALYSIS

I used MSM simulations of the weather conditions at the time of the fire, in conjunction with FARSITE, to try to replicate the actual two-dimensional growth of the fire from the model weather, fuel and terrain conditions. The FARSITE simulations yield UTM perimeter points that are converted to polar coordinates $R(\Theta, t)$. The observed perimeter is similarly converted to polar coordinates $r(\theta, t)$.

I define the error of a fire simulation by the difference, *D*, and the ratio, *G*, of the radials of observed and simulated fire perimeters, relative to the ignition point:

$$D(\theta_j, t) = r(\theta_j, t) - R(\theta_j, t)$$

$$G(\theta_j, t) = r(\theta_j, t) / R(\theta_j, t)$$

This provides a two-dimensional spatial measure of error, in difference and ratio form. The evaluation at different times yields the temporal evolution of the error.

Once the fire location is recorded, we can correct simulation errors by various means. The observed perimeter can serve as the initial fire position for the next iteration. A correction can be applied to compensate for model bias on the basis of the error information from the preceding step. First, compute the incremental growth in the fire simulation:

$$\Delta R(\theta, t+1) = R(\theta, t+1) - R(\theta, t).$$

Next, calculate the corrected growth:

$$\Delta R_c(\theta, t+1) = \Delta R(\theta, t+1)\, G(\theta, t).$$

The next step prediction is the sum of the observed perimeter at the previous step, plus the corrected growth:

$$R_c(\theta, t+1) = r(\theta, t) + \Delta R_c(\theta, t+1).$$

I ran fire growth simulations both with and without error corrections. The results are given in the following section.

5. RESULTS

5.1. Error analysis at 1657 PDT

Figure 3 shows actual and simulated perimeters at 1657 PDT on 29 June 1996. At this time, the Bee Fire is about 10 minutes old. The simulation marked “Original” used weather data from the Pine Cove weather station, while the “MSM Winds” simulation used the predicted wind field from the MSM model, initialized by data from 1700 PDT of the previous day. The simulated fires are approximately elliptical. The actual fire perimeter, on the other hand, is somewhat more complex, pinched near the ignition point, and fanning out to the northeast. Even at this early stage, it is apparent that the simulations head the fire more east than north, relative to the actual fire. The simulation with

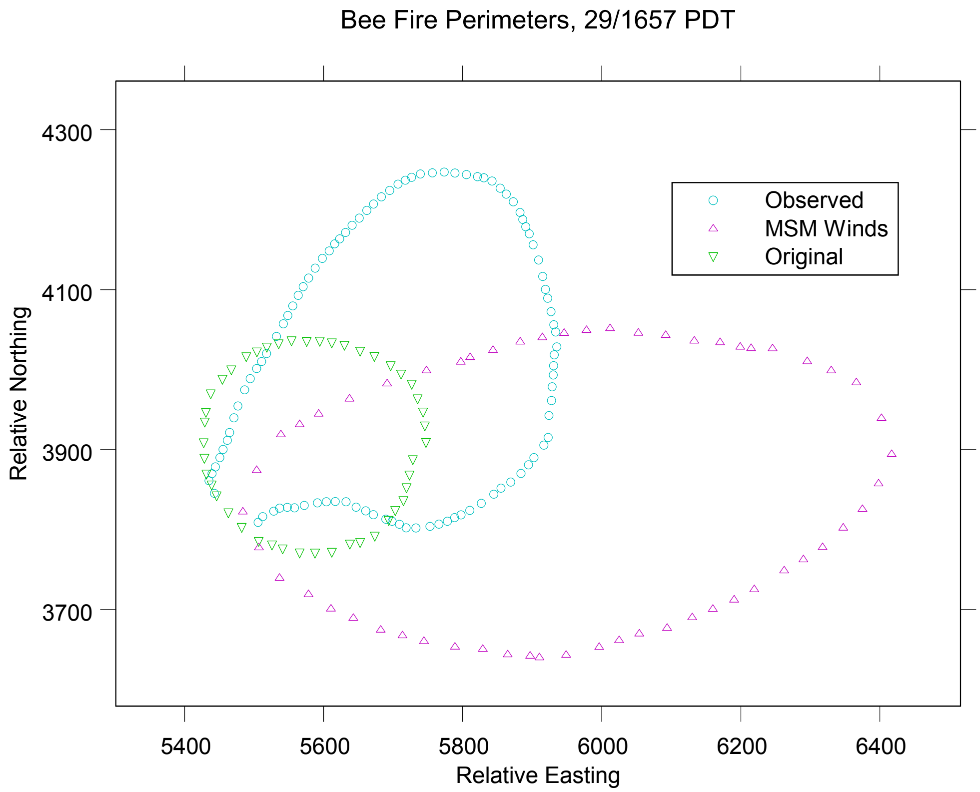

Figure 3. Observed and simulated Bee Fire perimeters on 29 June 1996, 1657 PDT. The perimeter plot marked “MSM Winds” resulted from wind input from a mesoscale weather model with initial data from 28 June 1996, 1700 PDT. The “Original” perimeter was simulated with winds from the Pine Cove RAWS.

the weather station observation was better, in the sense that it did not grossly overpredict the actual fire growth, as the MSM Winds simulation did. Figure 4 shows the ratio error function of the “Original” simulation. An ideal simulation would have ratio values near unity.

5.2 Error analysis at 1730 PDT

Using the error analysis from 1657 PDT, we apply the correction specified in section 4 for the next fire spread prediction. We restart the simulation at 1657 PDT, with the observed perimeter set as the initial fire location. The target prediction time is 1730 PDT, when we have the next observed fire perimeter.

In addition to the observed perimeter at 1730 PDT, Figure 5 depicts three alternative predictions. The “Uncorrected” perimeter is obtained from the simulation starting at the ignition point, with the observed wind direction modified slightly to align the simulated and observed head fire direction. The “Position Corrected” perimeter is from the simulation beginning at 1657 PDT, initialized by the perimeter observed at that time. Every other input is the same. The “Position + Error Corrected” simulation utilizes not only the updated perimeter information, but also the ratio form of the error function, $G(\theta$, 1657 PDT$)$. The correction is intended to compensate for consistent overestimates or underestimates by the spread model. In this case, none of the corrected simulations seemed to improve upon the “Uncorrected” one. All of the simulations overestimated the spread to the east, and underestimated the spurt to the northwest.

If we fail to predict perimeter growth, as is evident in Figure 5, we might attempt to describe a region of space wherein the true perimeter might lie, with specified probability. This requires knowledge of the distributional properties of the spread model error. Figure 6 is

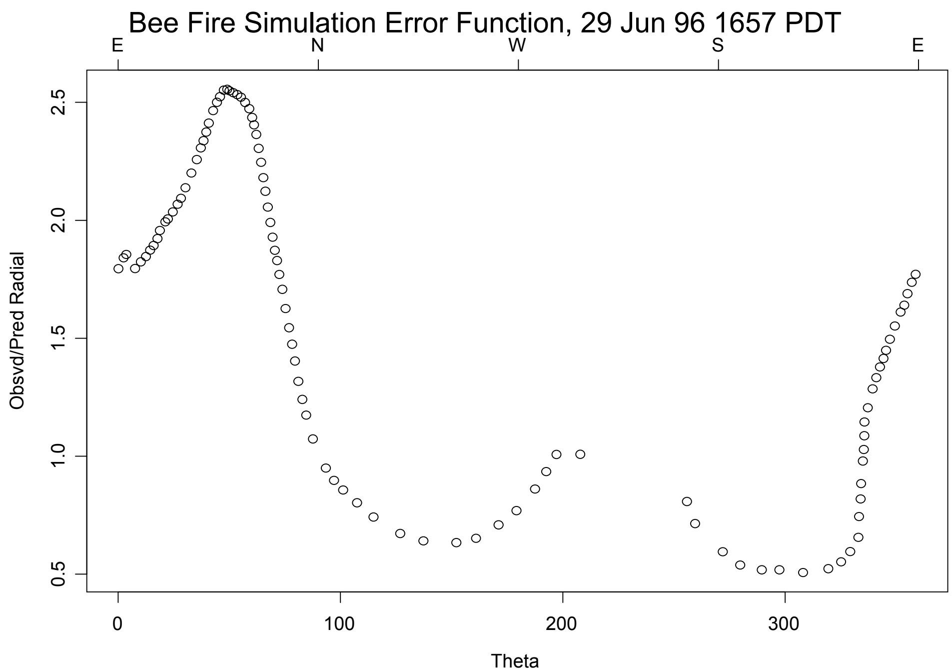

Figure 4. Errors in the "Original" simulation for the Bee Fire, 29 June 1996, 1657 PDT, expressed as the ratio of observed to predicted radial around the ignition point. Theta points to the east at zero, and increases counterclockwise. Top axis marks corresponding compass points.

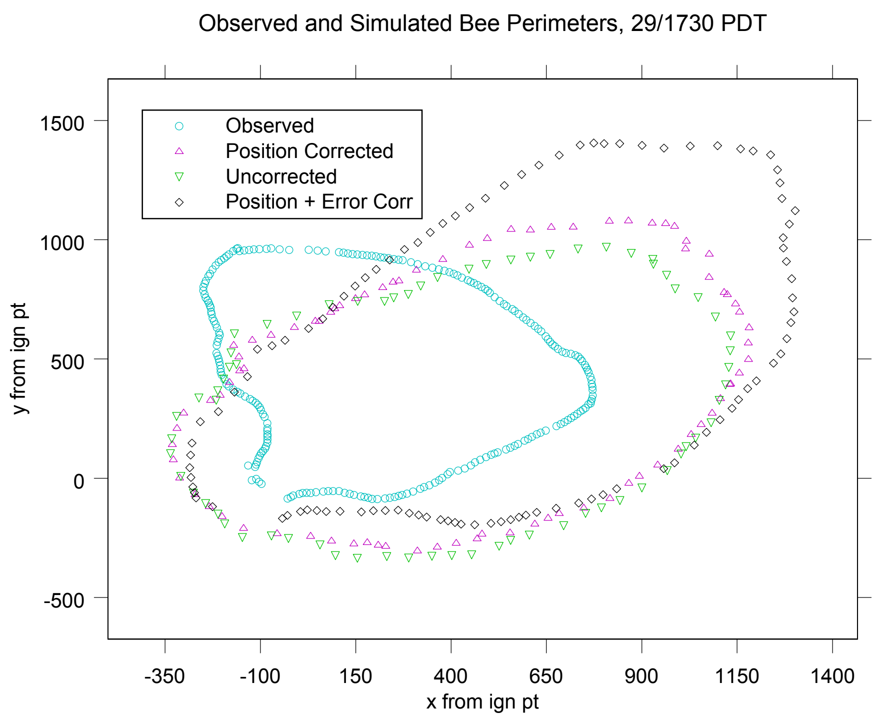

Figure 5. Observed and simulated Bee Fire perimeters, 29 June 1996, 1730 PDT. Corrected perimeters use error information from the analysis for 1657 PDT.

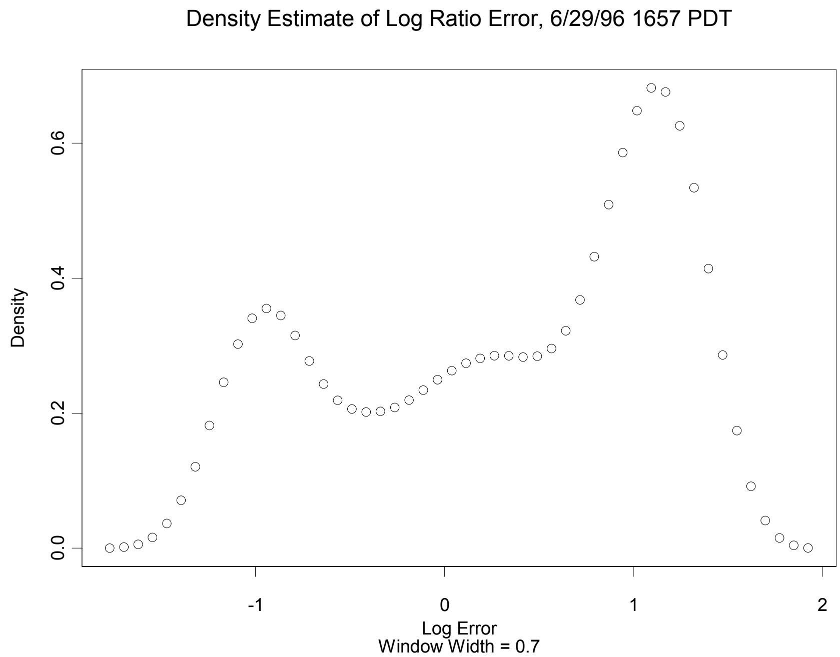

Figure 6. Non-parametric density estimate of the log ratio of observed to predicted radials for the Bee Fire simulation with modified wind direction, 29 June 1996, 1657 PDT.

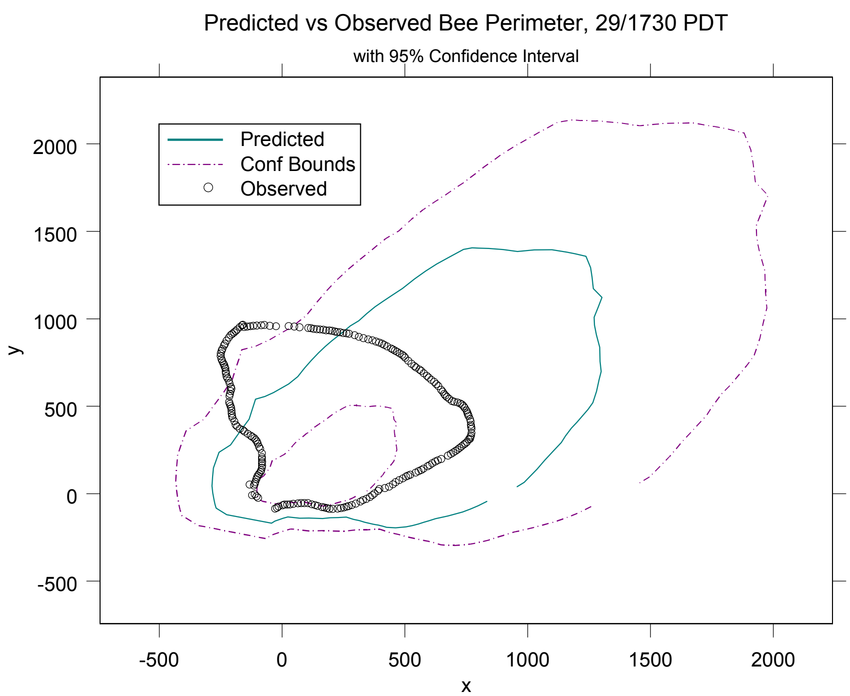

Figure 7. Position and error corrected perimeter prediction for the Bee Fire, 29 June 1996, 1730 PDT, and approximate 95% confidence interval for the true perimeter.

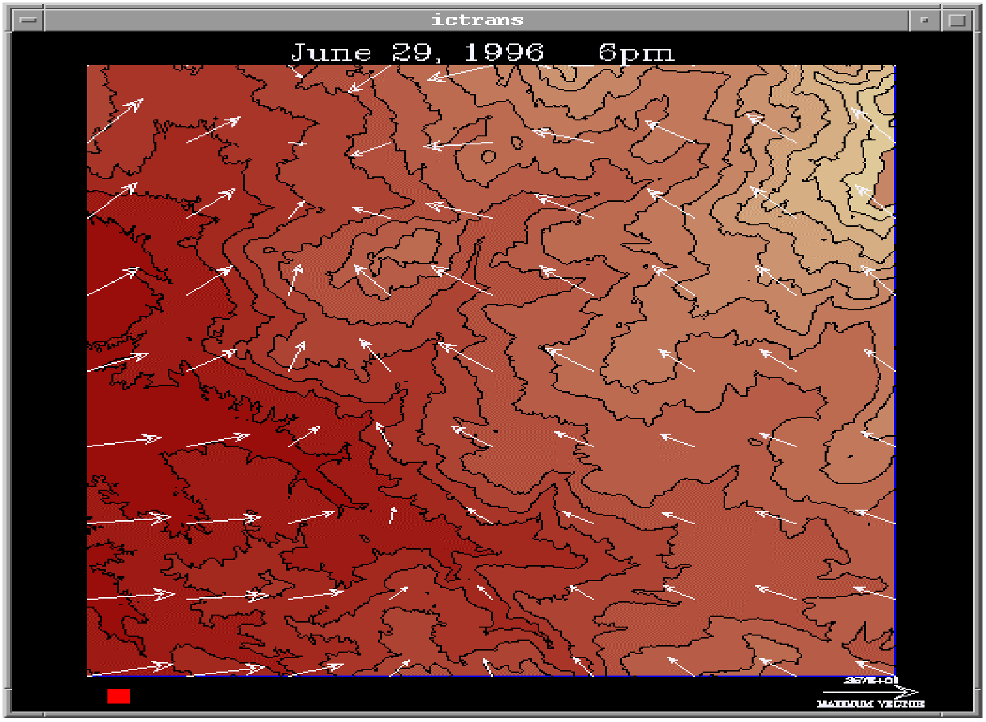

Figure 8. Mesoscale model analysis of Bee Fire winds on 29 June 1996.

a non-parametric density estimate (Silverman, 1986; Venables and Ripley, 1994) of the log ratio measure of error for the Bee Fire simulation at 1657 PDT. As the name implies, this is an estimate of the underlying probability density, $\hat{f}(x)$, of the data, computed from

$$\hat{f}(x) = \frac{1}{b}\sum_{j=1}^{n} K\left(\frac{x - x_j}{b}\right)$$

where K is a density kernel and b is bandwidth. In this case, the estimated density is non-Gaussian. We will use this to estimate the empirical distribution function of the ratio error to obtain error bounds on the predicted perimeter.

As a result, we obtain an approximate 95% confidence interval for the predicted fire perimeter at 1730 PDT, which is corrected for position and error (Figure 7). Apparently, the actual fire grew at such an unexpected rate toward the northwest that it breached the upper confidence limit there. The characteristics of the fire spread simulation errors merit closer inspection.

6. DISCUSSION

We focus on the effect of wind on the spread modeling error. Although the wind speeds observed and modeled during the Bee Fire were not great, the influence of wind direction was, or could have been significant. The slope of the terrain can enhance or suppress the wind effects, depending on whether the wind blows the fire uphill or downhill.

Figure 8 is a mesoscale model *analysis* based on data obtained on 29 June 1996 at 1700 PDT. Note that the mesoscale model *forecast* in Figure 2 predicted winds from the west to west-northwest in the burn area at 1700, while the analysis depicted winds in transition from a southeasterly flow to a westerly to southwesterly flow from 1700 to 1800 on 29 June. The mesoscale analysis provides plausible evidence, therefore, of southwesterly winds that would direct the fire toward the northeast. Using this wind dataset in FARSITE produced the simulated perimeter at 1730 in Figure 9. Also shown for reference are the simulated perimeters from the mesoscale forecast winds, a no wind simulation, and the observed perimeter at 1730.

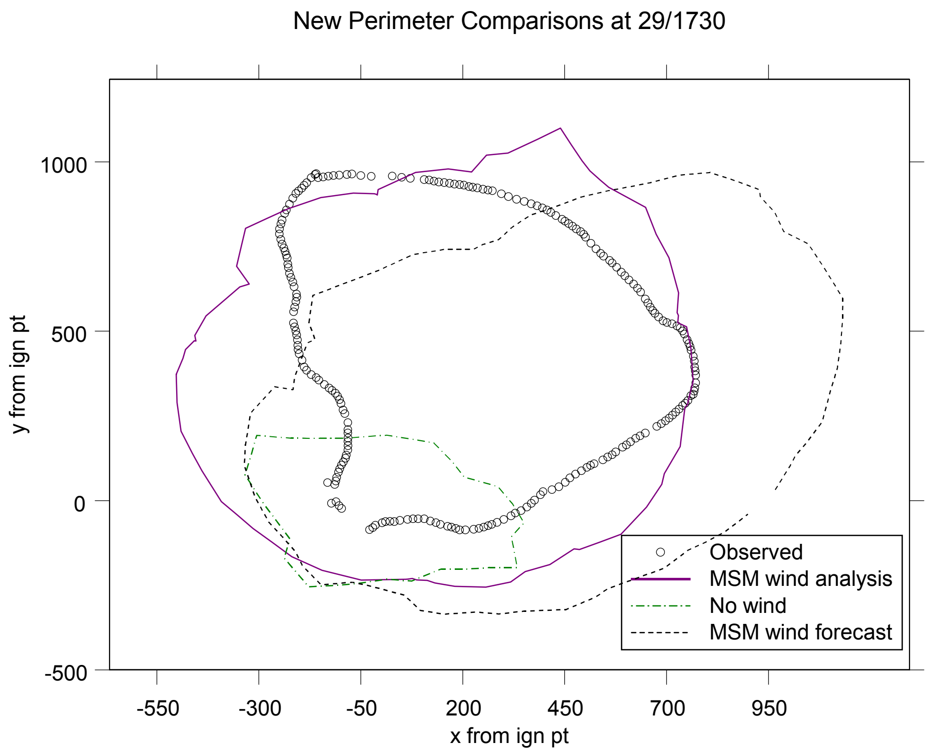

Figure 9. Observed and simulated perimeters for 29 June 1996, 1730 PDT. MSM refers to the mesoscale spectral model used in this study.

7. SUMMARY AND CONCLUSIONS

The FARSITE simulation with the analyzed mesoscale model winds did the best of all the simulations at 1730 PDT in reproducing the fire spread to the north and northeast. Errors were reduced, except in the northwestern quadrant, where the new simulation overestimated the actual growth more than the other simulations. The ratio correction did not improve the spread prediction. To the contrary, it magnified the error, when the actual fire changed its spread behavior from one time step to the next.

The grid spacing of the mesoscale meteorological model simulations was probably too coarse for this case study of the Bee Fire. More frequent observations of the actual fire perimeter are needed to test the capabilities of the weather/fire modeling system. However, the fact that a simple modification in the wind direction led to a considerable improvement in the fire spread simulations illustrates the importance of weather information to the model output.

8. REFERENCES

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