Colorado Decision Support System for Prediction of Wildland Fire Weather, Fire Behavior, and Aircraft Hazards

Stakeholder Meeting #2
26 January 2016
CoE, Rifle, CO
Introduction of research comparing CAWFE® accuracy to current decision support systems

Dr. Janice Coen, Project Scientist

Presented by:
Bill Mahoney, Deputy Director, Research Applications Laboratory
Status of operational fire behavior models

- Weather is the wildcard in a wildland fire event.
- Current models (FARSITE, NTFB, FSPro) similarly:
  - Estimate how fast the leading edge of the fire will spread, based on effects of wind speed, terrain, & fuel properties or fire spread probability
  - Use station measurements, simple approximations, or coarse weather forecast grids (e.g., 5-km NDFD grids)
  - Frequently require calibrating inputs to capture observed fire behavior
  - **Do not include how the fire creates its own weather**
  - **Current tools are weak in these (and other) events below:**

    - Plume-driven fires (fire-induced winds)
    - Mountain airflows
    - Cloud gust fronts
    - Fire whirls (Missionary Ridge)
    - Backfires (Spade Fire)
    - Splitting/fire-induced + wind-driven heads
    - Chimney effect
CAWFE® Testing and Verification Cases

Simulated large wildfires in many fuel & weather conditions:
- Little Bear Fire, NM
- High Park Fire, CO
- Esperanza Fire, CA
- Real-time simulation of CO fires during 2004
- Simi Fire, CA
- Troy Fire, CA
- Spade Fire, MT
- Big Elk Fire, CO
- Hayman Fire, CO
- Yarnell Hill Fire, AZ
- King Fire, CA

MODELED WILDFIRE 

CAWFE SIMULATION

Modeled weather, fire extent, shape, intensity, and land surface effects can be validated.

Airborne or space borne infrared data reveal fire properties through smoke.

ESPERANZA WILDFIRE

INFRARED DATA

FireMapper, USDA Forest Service
Data sources for verifying simulated fire growth

Infrared data from USDA Forest Service research aircraft (not routine)

Since 2012: Visible Infrared Imaging Radiometer Suite (VIIRS) Satellite Active Fire Detection infrared data (at least two times daily at 375 m resolution)

USDA Forest Service National Infrared Operations (NIROPs) airborne mapping of high priority fires (once per night)

Colorado’s MMA will be an excellent source of verification data!
Windstorm Event

Many of the most destructive fires in recent history have been associated with June windstorms. The airflow patterns in the mountains of Colorado vary significantly in time and space and sparse weather station data are often not representative of the local conditions.
2019 UTC 9 June (2:19 P.M.), the time of the 1st VIIRS data (brick red, in figure above). (X is the ignition point.)

Comparison: Simulated fire & mapped fire are both 4 km long wedges.

0412 UTC 10 June (10:12 P.M. 9 June), the time of the NIROPS map (red, in figure above) and near the time of the incident team map (yellow).

Comparison: Simulation underestimated the leading edge by 2 km but showed the wide (5 km in simulation, 7 km in map) north-south burning area mapped by the incident team.

0837 UTC 10 June (2:37 A.M.), the time of the 2nd VIIRS data (dark orange, in figure above).

Comparison: The fire grew north to Poudre Canyon and east in the next 4.5 h. This was captured by the simulation, although it lagged the observations by 2–3 km.
Gust Front Event

Sudden changes in wind direction (for example, thunderstorm-produced gust fronts) are firefighter safety hazards and can result in a fire spreading rapidly (as occurred in Waldo Canyon).

Current tools are challenged by erratic wind conditions.

The fatalities occurred between 4:30 P.M. and 5:00 P.M.
Yarnell Hill fire progression from the Serious Accident Investigation Report (below) and CAWFE simulation (at right)

Gust front hits southern edge of the fire at 16:30 (in report and CAWFE model simulation) driving fire to the south.
Plume Driven Fire

The King Fire grew over 40,000 acres in one day. Fires such as this (e.g., the Missionary Ridge Fire, near Durango CO) are called “plume-driven” fires and are driven by fire-induced winds, which the current tools are not designed to handle.

The prediction made during the event by fire managers (shown in next slide) uses the Near Term Fire Behavior tool within WFDSS.
King Fire growth  Sep 14 at 22:17 to Sep 18 at 22:02 LT

a) NIROPS Infrared fire map

Courtesy of USDA FS and CAL FIRE

b) Growth prediction from Wildland Fire Decision Support System (WFDSS) Near-Term Fire Behavior (NTFB) tool, the current Federal operational tool, during the event

The operational tool missed the 10-mile run to the northeast during the afternoon of 9/17/14.

Courtesy of L. Hood, USDA Forest Service

c) CAWFE simulation

Progression Up to 9-18-2014

9/14  10:17 P.M.
9/16  2:00 A.M.
9/16  9:49 P.M.
9/18  12:16 A.M.
9/18  10:02 P.M.
Comparison of CAWFE® to the FARSITE fire behavior model (using a variety of weather inputs)
The 5-fatality Esperanza Fire
Riverside County, CA. Oct. 2006
15-30 min. after the fatalities (location shown by o)
6.8 h after ignition – arson (location shown by x)
Incident team assessment of fire extent:

Simulation with the Coupled Atmosphere-Wildland Fire Environment (CAWFE)

CAWFE modeled the airflow with very high resolution (grid points 123 m apart) and included the feedback of the fire’s heat upon the weather.

Heat intensity is colored according to the color bar at right, with more intensely burning regions in yellow, and less intensely burning regions in dark red.

Simulation using current methods:
4 different weather sources used as input into the FARSITE fire behavior model (another current tool)

The methods that use nearby weather station data, (a) and (b), or those that use weather model data, (c) and (d), as input into current modeling tools (without considering the fire’s impact on the weather) did not predict that the fire would be anywhere near the fatality site.

Reproduced from Weise et al. (2007) 7th Symp. Fire & Forest Meteor. Dots indicate location of or spacing between weather data points.
The next slide shows how CAWFE® will be applied as a forecasting tool with regular updates (model cycles)
MMA data will be used to update fire line boundaries between model runs.
CO-FPS Benefits Summary

• CAWFE® improves upon current tools as illustrated here

• CAWFE® predicts how weather varies in time and space at very high resolution, including the complex airflows that occur in Colorado’s mountains

• CAWFE® includes the feedbacks that fire has on winds, i.e., how the fire creates its own weather, and thus captures fire growth in “plume-dominated” fires.

• CAWFE® has captured critical fire behavior changes in fire behavior

• CAWFE® complements existing fire management tools by addressing situations where they are weakest.
Discussion of current fire behavior analysis practices
Discussion of Current Practices

• How do various decision makers use current fire behavior analysis products?
• Where do you get the tools/information (sources)?
• What are the pros and deficiencies in current tools?
• What are the pros and deficiencies in current practices?
Break
Review of CO-FPS fire behavior prediction products
But first, a brief review of the weather prediction (modeling) process
The forecasting process

1) Collect worldwide weather, ocean, lakes, and land surface observations (including vegetation state)
2) Perform quality control on all data
3) Assimilate worldwide observations into weather models – balance the physics
4) Create global weather analysis
5) Ingest analysis data into numerical weather prediction model(s)
6) Run the forecast modeling system
7) Statistically correct forecast results (using history)
8) Disseminate forecast (human-in-loop or otherwise)
Weather Observations

Upper Air
- Balloons
- Aircraft

Surface
- Airport Observations
- Road weather sensors
- Local networks
- Volunteer observers
- Agriculture sensors
- Ships and Buoys

Remote Sensors
- Satellites
- Radar
- Lidar
USA Upper Air Observation Sites
USA Upper Air Observation Sites

A lot of details are missed between observations!
Data Void Areas - Impacts

Lack of data over the Pacific Ocean results in poorer mid-range forecasts for U.S.

Figure 1. The Pacific Data Void.
Model Resolution - Impacts

Resolution makes a large difference.

Climate models are run with coarse resolution (~1000 km) predicting 10s to 100s years.

A NWS weather model is now run hourly at 3 km across CONUS out to 18-hours
Model Resolution - Impacts

NWS global model (GFS) now running at 12-km grid spacing (as of 2015)!

Mountains resolved better than before, but still smoothed.
The HRRR model will be used as the input model for CAWFE®
HRRR Weather Model Inputs

Data input examples, not exhaustive

<table>
<thead>
<tr>
<th>Data Type</th>
<th>Number Per Day (USA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weather balloons</td>
<td>150 twice per day</td>
</tr>
<tr>
<td>Wind Profilers - RASS</td>
<td>60</td>
</tr>
<tr>
<td>Radar winds</td>
<td>120 - 140</td>
</tr>
<tr>
<td>Commercial aircraft</td>
<td>3500 - 10000</td>
</tr>
<tr>
<td>Regional aircraft</td>
<td>200 - 3000</td>
</tr>
<tr>
<td>Buoy/ship</td>
<td>200 - 400</td>
</tr>
<tr>
<td>Satellite winds</td>
<td>4000 - 8000</td>
</tr>
<tr>
<td>GPS precipitable water</td>
<td>300 - 12000</td>
</tr>
<tr>
<td>Surface Observations</td>
<td>8000 - 10000</td>
</tr>
<tr>
<td>Satellite radiances</td>
<td>Tens of thousands</td>
</tr>
<tr>
<td>Radar reflectivity (intensity)</td>
<td>Every 1 km</td>
</tr>
</tbody>
</table>
Weather Model Nesting

Scale Interactions are Critical

Global Scales: 40,000 km
Continental Scales: 5,000 km
Regional Scales: 1,000 km
Local Scales: 100 km
Urban Scales: 1-10 km

NCAR UCAR air • planet • people
CO-FPS Model Nesting

Source - NWS

CONUS Scale

High-Resolution Rapid Refresh model
- Hourly updates
- 24 hour forecasts

HRRR 3-km

3 km (1.8 mi) over Colorado
Hourly updates
1 km outer subdomain

100 meter (finest grid)
Wildland Fire Scales

CAWFE®
System Concept Diagram

Colorado - Fire Prediction System (CO-FPS)

Input Data
- Large-scale weather environment
  - Operational forecast model
  - Data assimilation
  - Observations
  - Model ensemble (future)
- Fire location specified or satellite/airborne IR active fire detection
  - Multi-Mission Aircraft (MMA)
  - VIIRS (Satellite)
- Fuels
  - Spatial map of (categorical) fuel models
  - LANDFIRE, CO databases, other supplemental data
  - Measured (RAWS) or diagnosed dead and live fuel moisture
- Terrain Elevation
  - 1-30 arc-sec

Core Technology
- CAWFE® Model
  - Coupled Atmosphere—Wildland Fire Environment
  - 18 hour prediction of coupled weather (100s of m) + fire behavior
- Product Generation
  - Fire extent
  - Spread rate
  - Sensible heat
  - Winds
  - Temperature
  - Humidity
  - Smoke concentration
  - Aviation Hazards
- Display System
  - CO-WIMS

Candidate End User Categories
- Tactical Fire Management
  - Colorado End Users: State, County, and Local Deps. of Public Safety; Wildland Fire Chiefs
  - Fire Behavior Analysts (FBANs); Long Term Analysts (LTANs);
  - Fire Weather (future)
    - Incident Meteorologists (IMETs) NWS

Performance Verification

Conceptual System Diagram - Data Processing & Flow
**Planned System Attributes**

- Real-time data ingest of weather, fuel, and active fire detection data from the MMA and Visible Infrared Imaging Radiometer Suite (VIIRS)
- Multiple fire model cycles (runs) per day (utilizing updated weather and fire mapping data)
- User ability to select fire prediction location and size (via CO-WIMS)
- User ability to input ignition information (via CO-WIMS)
- Output customized and formatted to be displayed on CO-WIMS
Initial Operating Capability CO-FPS Products

18 hour predictions (at user defined increments) of:

• Fire extent
• Rate of spread
• Heat release
• Smoke concentration
• Significant fire phenomena

• Turbulence intensity
• Downdraft and updraft regions
• Wind shear regions

• Wind speed, direction, gustiness
• Surface air temperature
• Surface relative humidity

Fire behavior product group
Will be calculated on 100 m fire scale grids when triggered

Aviation hazard product group
Could be calculated on 3 km (state scale), 1 km, and fire scale grids (100 m)

Fire weather product group
Could be calculated on 3 km (state scale), 1 km, and fire scale grids (100 m)
Discussion on priorities for CO-FPS fire behavior prediction products and critical functionality
Discussion on User Needs for CO-FPS

• What are the priorities for the fire behavior products?

• What types of significant fire behavior are most critical?

• Are “alerts and advisories” or similar notices needed for certain combination of predicted hazards? If so, how should they be delivered?
  • Significant wind shifts and/or gust fronts
  • Fire line rate of spread above a threshold
  • Prediction of pyro-cumulus
  • Heat release above a threshold
  • Etc.
Discussion on User Needs for CO-FPS

• How long are you willing to wait for the system to generate its 18 hour forecast (ignition to output time)?

• The output forecast length is 18 hours in the first year? Would a longer than 18 hour forecast period be more useful? How long?

• Output forecast interval (hourly, 3-hourly, etc.?)

• How often do you want fire weather predictions to be updated? Every hour, 3 hours, other? How much is too much information?

• How often do you want fire behavior predictions to be updated? Every hour, 3 hours, other?
Discussion on User Needs for CO-FPS

• Do you want to have access to the fire weather products at all grid resolutions (~3 km, 1 km, 100m) or only selected grids? How much is too much information?

• How do you want to view the fire behavior products on CO-WIMS? Presentation of output options.
  • Polygons (shapes)
  • Filled polygons
  • Animations
  • Other
How much information is too much information w.r.t. gridded data?

Do you need to see the fire weather data on the 100 m grid, 1 km, and/or 3 km?

Note: the fire behavior output will be created on the 100 m grid
Reference Slides
1. Represent & track the (subgrid-scale) **interface** between burning and nonburning regions (the ‘flaming front’)

2. Rate of spread (ROS) of flaming front calculated as function of **fire-affected** wind, fuel, and slope using Rothermel (1972) semi-empirical equations

3. Post-frontal heat & water vapor release. Once ignited, the fuel remaining decays exponentially, acc. to lab experiments.

4. Heat, water vapor, and smoke released by surface fire into lowest layers of atmospheric model
1. Represent & track the (subgrid-scale) interface between burning and nonburning regions (the ‘flaming front’).

2. Rate of spread (ROS) of flaming front calculated as function of fire-affected wind, fuel, and slope using Rothermel (1972) semi-empirical equations.

3. Post-frontal heat & water vapor release. Once ignited, the fuel remaining decays exponentially, acc. to lab experiments.

4. Heat, water vapor, and smoke released by surface fire into lowest layers of atmospheric model.

5. Surface fire heats and dries canopy. Does the surface fire heat flux exceed the (empirical) threshold to transition into the tree canopy (if present)?

6. Calculate the rate of spread of the crown fire using empirical relationships to surface fire ROS.

7. Heat, water vapor, and smoke released by crown fire into atmospheric model.