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STORM PREDICTION CENTER'S FIRE WEATHER VERIFICATION

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1. INTRODUCTION

The National Weather Service's (NWS) Storm Prediction Center (SPC) has been forecasting Day One and Day Two Fire Weather Outlooks for the contiguous United States since 1998. The Fire Weather Outlook is formulated in both graphic and text formats and disseminated each day at 4:00 AM CDT/CST. The SPC forecast product is intended to delineate areas where the forecast weather conditions for the upcoming 24 to 48 hour period combined with the pre-existing fuel conditions would result in a significant threat for wildfires. The SPC is responsible for forecasting those meteorological conditions, which when combined with the antecedent fuel conditions, favor rapid growth and spread of a fire, should a fire ignition occur. The outlook categories for forecast areas of fire danger include critical fire weather conditions and extremely critical fire weather conditions. In addition, forecasts for areas of dry thunderstorms producing less than 0.10 inch of rainfall are included in the outlook. Determining the type of outlook category depends upon the severity of both the forecast weather and antecedent conditions relative to the given geographic region.

Since the start of this national fire weather program at the SPC, the criteria and forecasting techniques have evolved through internal review of the product, year-end surveys of NWS fire weather forecasters, and interaction with the NWS field and regional offices and other fire weather customers. During the summer months of the 2001 Fire Season, the SPC has developed a verification scheme to determine the accuracy of this product. The intention of the new verification scheme is to determine the overall accuracy of the daily fire weather forecasts from a meteorological standpoint. The focus of this paper is to describe the parameters used in the new SPC Fire Weather verification scheme and illustrate the use of those features developed so far. The methodology will be discussed first along with the varying types of data that are utilized in the scheme. This will be followed by several case studies involving both dry lightning events as well as Critical and Extremely Critical Fire Weather area forecasts for strong winds and low relative humidity. A summary section will follow explaining some of the results of the verification scheme for a portion of the 2001 fire season as well as some planned future enhancements.

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2. METHODOLOGY

The development of the SPC verification digital database has incorporated temperature, humidity, wind, precipitation and fuel observations into several different terms which provide objective measures of forecast skill for the fire weather forecast product. This paper shows examples of the initial manual verification of the outlooks using that database.

All of the fire weather outlook areas are delineated by a closed line-segment. Consistent with other SPC forecast products, the area is always to the right of the line with an arrowhead showing "direction" of the line. The set of points that define each area are archived for future use in an electronic/automatic verification along with the digital database (40 by 40 km grid resolution) of fire weather parameters.

Table 1 shows the digital database. Precipitation and lightning cover the same time period as the outlooks (12 to 12 UTC). RAWS precipitation data was converted to hourly and 24 hourly precipitation data. The other data is designed to represent conditions near the time of maximum heating and lowest humidity (21 UTC) during the 12 to 12 UTC time period. Special objective analyses and other software have been developed to produce the verification weather and fuel gridded data, incorporating all METAR, WIMS, RAWS, and COOP observations.

The SPC verification efforts include the development of gridded data for the following 7 main categories:

1) Weather conditions - The SPC Fosberg Fire Weather Index (Fosberg, 1978) (weather conditions of temperature, relative humidity and wind speed)
2) Fire danger class ratings - computed by USFS (high, very or extreme fire danger)
3) Dead fuel moisture values - computed at SPC using software routines supplied by USFS Fire Sciences Lab
4) Station Precipitation (analyzed to 40x40km grid) plus 4x4km resolution WSR-88D nationwide precipitation estimates.
5) Lightning flashes (analyzed to 40x40km grid)
6) 4km resolution images of all fires detected during 24-hour (12 to 12UTC) time period using bio-mass burning algorithms.
7) High resolution fuel model map (1km resolution)

The SPC Fosberg Fire Weather Index (SFWI) is defined by a quantitative model that provides a nonlinear filter of meteorological data which results in a **linear relationship** between the **combined meteorological variables** (temperature, relative humidity and wind speed) and **the behavior of wildfires**. Thus, the SFWI deals only with the weather conditions, not the fuels. The filter, originally used by Fosberg was developed by first transforming the temperature and relative humidity into the equilibrium moisture content. Then the equilibrium moisture content was transformed into the combustion efficiency. These filters are then combined with the influence of the wind on rate of spread to provide an index of flame length. The SPC index (SFWI) as developed by Fosberg is:

$$([(\text{Rate of Spread})(\text{Energy Release})]^{0.46})/0.3002$$

Several sets of conditions have been defined by Fosberg to apply this to fire weather management. The upper limits have been set to give an index value of 100 if the moisture content is zero and the wind is 30 miles an hour. Thus, the numbers range from 0 to 100. Note that if any number was larger than 100, it is reset back to 100. The index can be used to measure changes in fire weather conditions. The use of the objectively analyzed data (temperature, relative humidity and wind) at 40km resolution gives SFWI values every hour of the day across the U.S.. Over several years of use (and based on sample calculations), SWFI "units" of 30 and higher generally appear significant. At each grid point, using METAR, WIMS, RAWS and COOP data in objective analysis, are calculated and shown in Table 1.

Max temperature for day (21UTC)
Min Relative Humidity for day (21UTC)
Min temperature for day (12UTC)
Max humidity for day(12UTC)
U and V wind component and wind gusts
Mean Sea Level Pressure
Precipitation Duration (number of hours per day)
Twenty-four hour precipitation
Twenty-four hour lightning flashes.
Best CAPE-Convective Available Potential Energy computed from lowest 50 mb average or maximum CAPE if above the lowest 50 mb
Cloud base (using the most unstable parcel)
Average sub-cloud humidity (surface-cloud base)
Lower level lapse rate-surface to 10,000ft-agl
Inches of Precipitable Water
Fuel moisture (100 and 1000 hr)-computed at SPC using same method as USFS
At each grid point, using WIMS data where available, the following are computed.
Ten, 100, and 1000 hour dead fuel moisture
Fire Danger (low, moderate, high, very high, extreme)
Keetch-Byram Drought Index (KBDI)
WIMS 24 hour precipitation
SPC Fosberg **F**ire **W**eather **I**ndex (**SFWI**)
Fire da**N**ger Fosberg **F**ire **W**eather **I**ndex (for fire danger Class high, very high or extreme, plus wind .GE. 25 mph, humidity .LE. 25%, and temperature .GE. 60F) (**NFWI**)*
Fuel based Fosberg **F**ire **W**eather **I**ndex (for 100 and 1000 hour dead **F**uel moisture .LE. 10%, plus wind .GE. 25 mph, humidity. LE. 25%, and temperature .GE. 60F) (**FFWI**)*
Precipitation based Fosberg **F**ire **W**eather **I**ndex (.LE.2 hours of Precipitation, wind .GE. 25 mph, humidity .LE. 25%, and temperature .GE. 60F) (**PFWI**)*
Average Fosberg **F**ire **W**eather **I**ndex (00-23UTC) (**AFWI**)
Normalized (**Z**-score) Fosberg **F**ire **W**eather **I**ndex (21UTC SFWI minus Average SFWI and divided by standard Deviation of SFWI) (**ZFWI**)
**humidity of 35 percent and wind of 20 mph used for Southeast U.S. including Florida*

TABLE 1. VERIFICATION DATA AVAILABLE at SPC (40x40 km grid resolution). NOTE: Data is from 21UTC unless otherwise specified.

3. CASE STUDIES FOR JULY 2001

3.1 Case Study 1: July 15-16

The first of three case study periods will be from Sunday July 15th through Monday July 16th for the southeastern Great Basin and much of southwestern/western Utah. The study will focus on the issuance of a Critical Fire Weather area in the southern Great Basin as a ridge over the central U.S. weakened and a strong trough surged through the Pacific Northwest/southwestern Canada. At the beginning of the period, a large ridge axis was in place from southern New Mexico/southwestern Texas northward into eastern Montana/western North Dakota with 500mb heights between 594 dm to 597 dm in southwestern Texas and New Mexico at 14/00 UTC. Between 14/12 UTC and 15/12 UTC, the LKN 500mb heights fell 88 meters with a distinct height fall axis at 15/12 UTC from southern California northward through the Great Basin into northwestern Washington. A "See Text" area was issued on Saturday, July 14th for the Day Two forecast period valid from 15/12 UTC to 16/12 UTC for southern Nevada, southwestern Utah, and northwestern Arizona. The potential for an increase to Critical Fire Weather conditions was mentioned in the discussion for strong winds and low relative humidity. During the Day One period (15/12 UTC to 16/12 UTC), the 500mb low center moved south from southwestern British Columbia to along the British Columbia/Washington border as the 500mb height dropped 100 meters during this 24hour period. 700mb analyses from the same period revealed that a short wave trough/wind shift line was apparent across eastern Nevada/western Utah at 16/00 UTC, but it then shifted northeastward into the northern Rockies by 16/12 UTC. The Day One Fire Weather outlook on the 15th was upgraded to a Critical Fire Weather area for extreme northwestern Arizona, south/southeastern Nevada, and southwestern Utah. This Critical Area was issued for the combination of low minimum relative humidity values generally between 10-15% and sustained southwesterly winds from 20-30 mph.

The SFWI verification index (Figure 1) indicated that most of the Day One outlook area had either 40 to 50 SFWI values including a large 50 or greater area in the southern portion (srn NV, nwrn AZ, swrn UT) of the Day One outlook. The NFWI verification index (Figure 2) indicated that the axis of highest values were either inside the Day One outlook area or right alongside the Outlook lines. The exception to this was a small area of higher NFWI values along the Nevada/Utah border area just east of Elko. The NFWI is useful in excluding areas that do not have fire danger values of high, very high or extreme (i.e., eliminating the areas with low to moderate fire danger class). This scheme favors areas that not only have experienced dry and windy weather, but also have fuels that are determined to be dry enough to possibly cause fire difficulties. In addition, the 15/12 UTC Critical area discussion called for minimum relative humidity values from 10-15 percent. An inspection of the RMIN (Figure 3) field (15/21 UTC minimum relative humidity field) indicated no areas in the outlook area had minimum relative humidity values above 30 percent while some parts of the southern portion of the Day One outlook area had minimum values of 10 percent relative humidity or lower. In fact, the afternoon minimum relative humidity values and high temperatures via the SPC Fosberg Fire Weather Index reveal that minimum relative humidity values were primarily less than 15 percent except in western Utah where some values were between 15 and 30 percent. Afternoon high temperatures were mostly between 90 to 100 degrees except for 100 degree plus readings over the extreme southern portion and 80 to 90 degree temperatures over the northern portion. After inspection of these various verification statistics, it is relatively apparent that the 15/12 UTC Day One Critical area was accurately placed where the combination of pre-existing fuel and forecast weather conditions both suggested a Critical Fire weather threat.

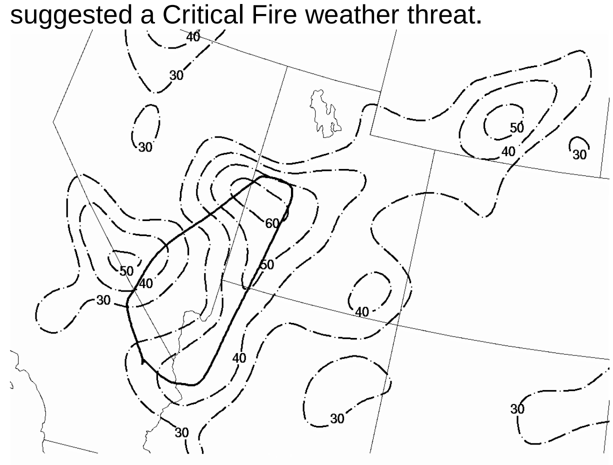

Figure 1. Day One outlook period, 15/12 UTC to 16/12 UTC. Critical Fire Weather Area shown by thick solid line. SPC Fosberg Fire Weather Index (SFWI), dashed line for 21 UTC 15 July, 2001. SFWI is shown for units of 30 and above.

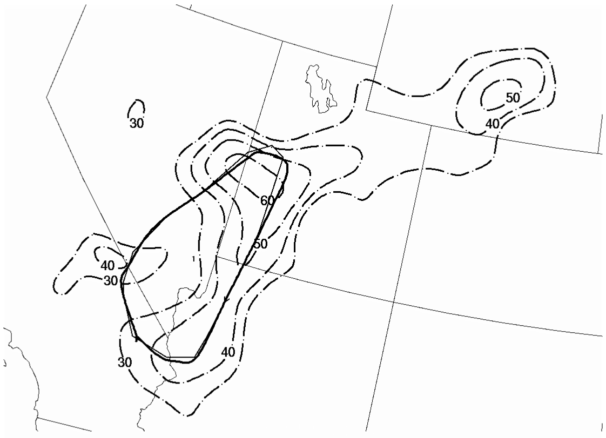

Figure 2. Same as Figure 1 except SPC Fosberg Fire Weather Index only shown within areas where fire daNger class at high, very high, or extreme (NFWI units of 30 and above), dashed line for 21 UTC 15 July, 2001.

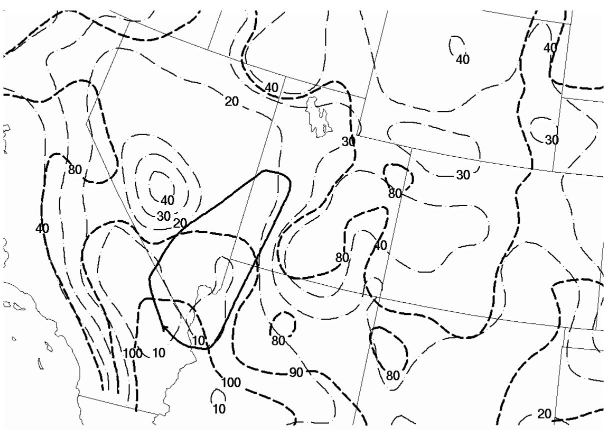

Figure 3. Maximum temperature and minimum relative humidity (at 21UTC) for 15 July, 2001.

3.2 Case Study 2: July 26-27

The next case study that will be examined is for July 26th-27th and will focus on the Critical Areas that were issued for dry thunderstorms in parts of Utah. Specific attention will be paid to the number of lightning strikes in/around the Critical areas as well as underlying weather conditions during these two forecast periods. The 500 mb pattern leading into this period was mainly zonal along the U.S./Canadian border, with a trough of low pressure over southern California. On July 25th, the 500 mb center associated with the southern CA trough moved slowly northeastward to extreme northwestern Arizona while the counter-clockwise wind regime around the low center became more discrete. At 700mb, moisture increased at GJT, FGZ, and SLC as more humid air moved into Utah from the south-southeast. The main concern on July 25th was how much mid-level moisture would advect northward into the region via the strong southerly flow in advance of the mid-upper level low center. This would affect the placement and areal coverage of dry thunderstorms for the next day.

The Day Two forecast issued on July 25th and valid for 26/12 UTC to 27/12 UTC had a Critical area for dry thunderstorms in much of eastern and central Utah as the amount of mid-level moisture throughout the region was expected to increase. The forecaster also noted to expect greater coverage of dry thunderstorms during this Day Two period than had been forecast for July 25th over southern UT, southeastern NV, and extreme northern AZ. Lightning activity was expected to be most active from the late afternoon to early evening.

For the Day One forecast period (26/12Z to 27/12Z), the 500 mb low began to weaken considerably as it moved from northwestern Arizona to west-central Colorado. As a result, the corresponding 700mb maps indicated the axis of mid-level moisture was forced east from the four corners region to the central/southern high plains. SPC's Fire Weather Forecast for this Day One period had a Critical area for dry thunderstorms across central/north-central Utah. This area was smaller than the previous Day 2 outlook and was shifted further west-northwest. The forecaster noted that sufficient moisture through a deep layer would result in mainly wet storms across western Colorado/eastern Utah. However, further west-northwest, the atmospheric moisture profiles would be more conducive for dry thunderstorms along and west of the Wasatch Mountains in central/north-central Utah.

An initial verification scheme for dry thunderstorm outlooks consists of the total lightning strikes (Figure 4) combined with total precipitation for a 24-hour period (Figure 5). This scheme showed that the Day Two dry thunderstorm forecast for the period (26/12 UTC to 27/12 UTC) verified much better than the following Day One forecast issued for the same period. The Day Two area for central and eastern UT had 25-100 lightning strikes per 40 km grid box covering fifty percent of the outlook area, with just a small portion of central UT receiving wetting rainfall of 0.10 to 0.25 inches. The Day One forecast for this same period, which was smaller and shifted to the west-northwest of the Day Two forecast, had very few lightning strikes.

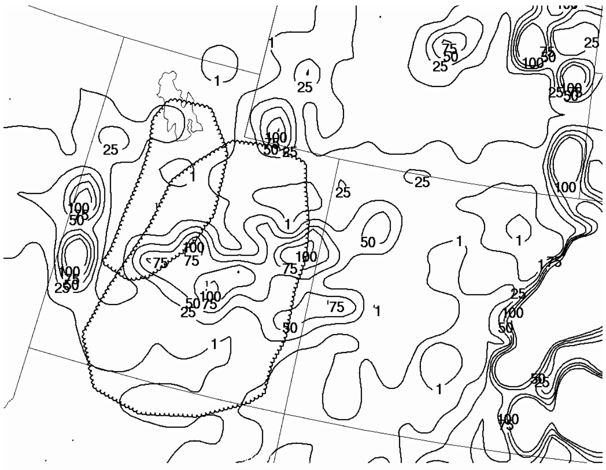

Figure 4. Day Two outlook(scalloped area central and eastern Utah and extreme northern Arizona) and Day One outlook (scalloped area over central Utah), valid from 12UTC on July 26 to 12UTC on July 27th. Lightning flashes, (1, 25, 50, 75 and 100 flashes per grid box)

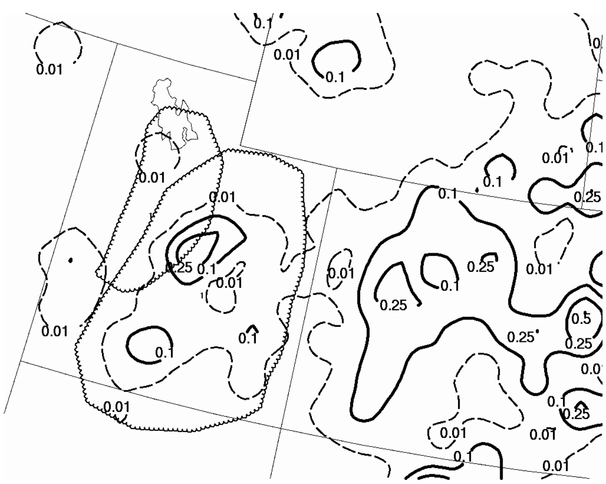

Figure 5. Same outlook areas as Figure 3 except contours of precipitation (0.01-dashed, 0.1, .25, .50, etc.-solid).

3.3 Case Study 3: July 28-29

The final case study period that will be examined is from Saturday, July 28th to Sunday, July 29th for northeastern Nevada, northern Utah, southern/southeastern Idaho, and Wyoming. On 7/27, a Critical Area was issued with the Day Two forecast valid from 28/12 UTC to 29/12 UTC for northeastern Nevada, northern Utah, southeastern Idaho, and much of Wyoming. The critical factors for this forecast were a combination of strong southwesterly winds at 20-30 mph, low relative humidity values between 10-15 percent, high Haines indices, and widespread long-term drought conditions. An abrupt wind shift to the west-northwest was also expected with a frontal passage. The upper air maps from 27/12 UTC to 28/12 UTC reveal an intensifying trough of low pressure in the Pacific northwest/British Columbia with 12-hour 500 mb height falls between 10-15 m at PDX and UIL.

During the following Day One period (28/12 UTC to 29/12 UTC), the Pacific Northwest 500 mb low center shifted from western British Columbia to eastern Alberta with a 50-65 knot 500 mb wind maximum through the northern Rockies into the adjacent plains areas. The 29/00 UTC 700 mb chart indicated a front stretching from northwestern Montana, southward through south-central Idaho, into northern Nevada with a 10 degree Celsius baroclinic zone between GTF and SPO. The Day One Forecast included an upgrade to an Extremely Critical area for much of western Wyoming/eastern Idaho and a Critical Area for northeastern Nevada, northern Utah, southern Idaho, western Wyoming, and far southwestern Montana. This upgrade to Extremely Critical was made due to an increase in the expected sustained southwesterly winds to 25-35 mph ahead of the cold front forecast to move through the area between 29/00 UTC and 29/05 UTC. Haines indices of 6 were also expected with high temperatures in the 90s F below 5000 feet. Similar wind speeds and relative humidity values were forecast for the surrounding Critical Fire Weather area as were issued in the previous Day Two for this same region.

Figures 6, 7 and 8 illustrate how the use of additional fire weather information (such as the fire danger class and/or dead fuel moisture) can help focus in on the important fire weather areas. The SPC Fosberg Fire Weather Index (SFWI) greater than 30 units (Figure 6) covers a large portion of the West. Combining the SPC Fosberg Index with the fire danger classes (high, very high, and extreme) serve to better define the potential threat area.

Verification data for this case study period (28/12 UTC to 29/12 UTC) using the NFWI (Figure 7) and FFWI (Figure 8) showed that the Day 2 and Day 1 forecasts verified well. One observation tool used at the SPC for Fire Weather forecasts are geographic regions where Fire Danger Ratings are high or greater. The NFWI for this period indicated that the placement of the Extremely Critical Area and Critical Area were excellent based on the Fire Danger Ratings combined with the observed wind speeds and low relative humidity values. Meanwhile, the FFWI showed that the upgrade to an Extremely Critical area was a good forecast. In addition to critical wind speed and relative humidity values, the FFWI focuses on calculated critical 100-hour and 1000-hour dead fuel moisture values of 10 percent or less, which can greatly enhance the fire threat.

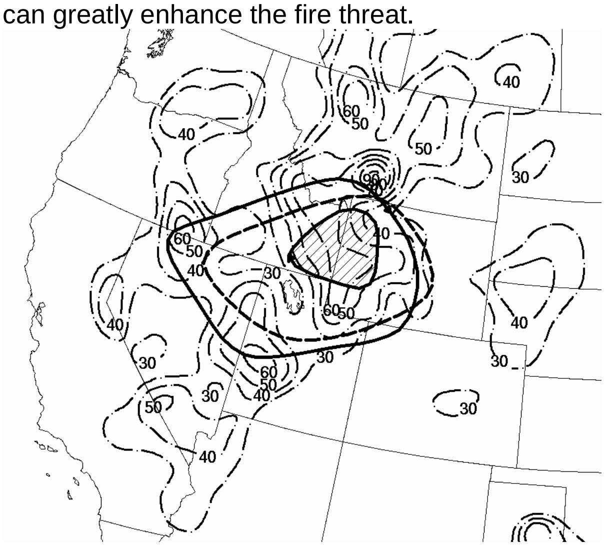

Figure 6. SPC Fosberg Fire Weather Index (SFWI- 30 units and above) for 21UTC 28 July, 2001. Thick dashed line is Day 2 forecast valid at same time, 12UTC July 28 to 12 UTC July 29, as Day 1 (thick solid line and hatched area)

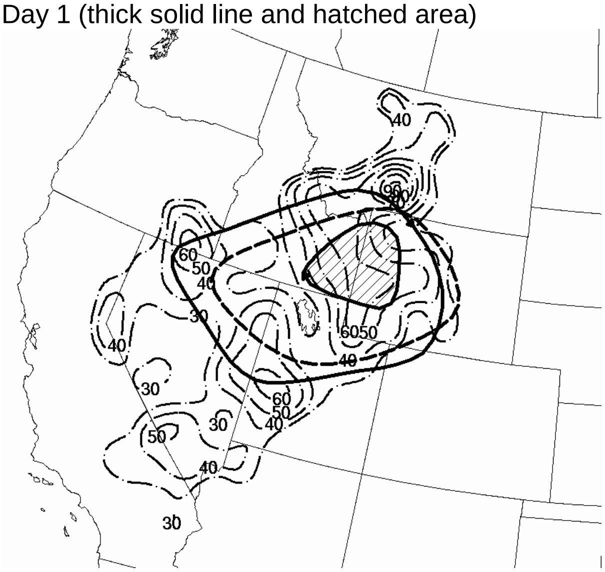

Figure 7. SPC NWFI for 21UTC 28 July, 2001

4. SUMMARY

Fire Weather forecasts are very important to those in the fire community who need to make critical life and safety decisions on a daily basis, especially during the active fire season. The SPC

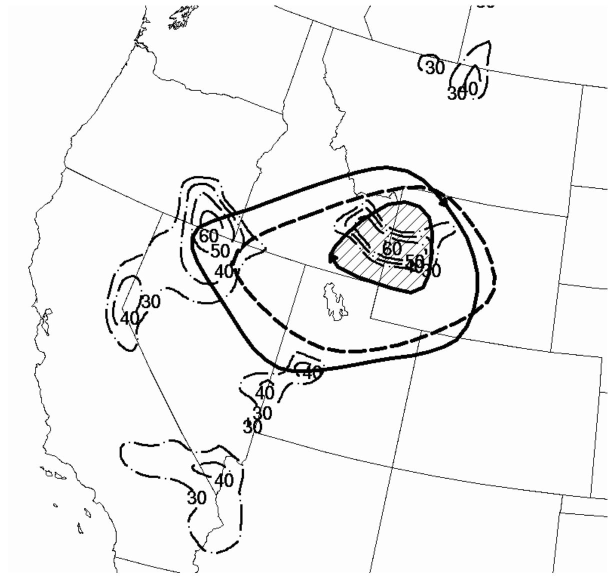

Figure 8. SPC FFWI for 21UTC 28 July, 2001.

has been issuing National Fire Weather outlooks for the last 4 years and continues to make improvements to this product. These outlooks are focused on large-scale fire weather situations. Local NWS offices and Incident Meteorologists work with local/small-scale variability.

This year the SPC has begun developing a verification scheme for the National Fire Weather Outlooks. This initial manual phase of the verification process has developed new parameters (SFWI, NFWI, FFWI), and has proven to be useful in verifying the fire weather outlooks. The usefulness of these parameters has been demonstrated in this paper through three case studies by showing how the area of fire weather concern can be focused on for a given day. The second automated phase of the verification scheme is planned to enhance the process described in this paper. A digital database will provide real-time data to the forecaster to make improvements in subsequent forecasts and allow parameter changes to be made, if fire weather criteria is changed or updated for a given geographic area.

In the future the SPC plans to make the automated verification scheme available to our partners and customers through the SPC Fire Weather web page.

References:

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Amer. Meteor. Soc., 1-4.