Forecasting Fire Danger Indices in the United States [1]

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Abstract

State-of-the-art forecasts of fire danger are being developed to support the need for more detailed risk-based assessments and quantitative decision-support. Much of the new development has been focused on gridded forecasts covering next day to seasonal time scales. This paper discusses five fire danger forecast products that have been developed based upon the U.S. National Fire Danger Rating System (NFDRS) for fire management decision-support. Also discussed is the value of using a single fuel model (in this case NFDRS Fuel Model G), and standardized forecast methodologies. Both of these factors allow for easier translation of information over large spatial and temporal scales since output values are based on a single fuel model and are standardized for direct comparison of deviations from normal.

Introduction

Fire danger in the United States is an integral component of fire management actions and planning. Its history extends back to at least 1916 (Hardy and Hardy 2007), and has evolved extensively to the present from continuing research efforts, advances in computing technology, and increasing data sources, amount and quality. The national fire danger system was first put in place in 1964. The current National Fire Danger Rating System (NFDRS) was implemented in 1978 (Deeming *et al* 1977) with revisions added in 1988 (Burgan 1978). Primary index outputs include:

- Energy Release Component (ERC) - a number related to the available energy (British thermal units; BTU) per unit area (square foot) within the flaming front at the head of a fire. ERC is considered a “build up” composite fuel moisture value as it reflects the contribution that all live and dead fuels have to potential fire intensity.
- Burning Index (BI) - an open-ended number related to potential flame length in feet multiplied by 10. BI represents the difficulty of control or contribution of fire behavior to the effort of containing a fire.
- Spread Component (SC) - a rating of the forward rate of spread of a headfire; numerically equal to the theoretical ideal rate of spread

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expressed in feet-per-minute on an open-ended scale with no upper limit.

- Ignition Component (IC) - a rating of the probability that a firebrand will cause a fire requiring suppression action. Expressed as a probability on a scale of 0 to 100.

Of these, ERC and BI are most utilized for an indication of daily risk, seasonal severity and for strategic planning (Scholobom and Brain 2002).

When the current version of the NFDRS was implemented in 1978, the principle objective was to provide information for pre-suppression planning. The concept was to utilize once daily "worst case" (early afternoon) weather and fuel observations and apply the outputs to "fire danger rating areas" made up of large spatial areas (up to tens of thousands hectares in size) with relatively homogeneous fuels and climate conditions, and over a period extending from several hours to several days. Weather observations taken at point locations provide the primary NFDRS input variables. These data are recorded at Remote Automated Weather Stations (RAWS), of which there are approximately 1300 observation platforms in operation across the U.S.

While the concept of fire danger rating areas remains valid for local area planning, the advent of gridded weather forecast models and climatological data have provided opportunities to extend NFDRS output observations and forecasts to national scales at finer gridded resolutions. Gridded climatological data sets for individual NFDRS index components allow standardized outputs to be displayed. Additionally, the need for more detailed risk-based assessments and quantitative decision-support is driving the development of more detailed state-of-the-art fire danger forecasts. Gridded NFDRS forecasts have enabled fire managers to analyze and compare both observed and forecasted fire danger indices across the entire country. This ability allows for a national perspective that has proved valuable to help predict fire potential and provide decision support information, especially for nationally shared resource allocation decisions. In the United States, NFDRS gridded forecasts are now available for the entire lower 48 states and Alaska.

This paper describes five NFDRS forecast models for computing fire danger. These models span daily to seasonal time horizons and produce outputs with different spatial resolutions. One of the methods is statistical based, but the others are derived from numerical weather prediction models. A discussion for each method is provided. Advantages and disadvantages of the products are also discussed. All of the forecast products presented here are considered experimental, though they are often used for operational support.

Energy Release Component and Fuel Model G

Many of the NFDRS outputs are based on underlying fuel model inputs, which vary spatially across the landscape. This makes it difficult, if not impossible, for fire managers to compare output values since output ranges vary for each fuel model, thus complicating interpretation of values over large areas. Consequently, as the analysis of fire danger indices on a national scale became more important to support resource allocation decisions, a need arose for NFDRS index values to be based on a single fuel model across the country.

Several analyses of correlations of fire business (fire days and large fire days) with NFDRS outputs show that ERC, computed for a fuel model G (ERC-G), is a good indicator of fire business across the country, even though different fuels actually exist on the ground (Larry Bradshaw unpublished report). Pat Andrews, a research physical scientist at the Rocky Mountain Research Station, studied nine drought indices at thirteen different sites across the United States to determine which worked best as a long-term dryness index (Pat Andrews, personal communication). She found that ERC using an NFDRS Fuel Model G was the best overall index. ERC-G was also ranked as one of the top three indices at all of the thirteen sites, and was the best index at all Eastern sites. Other studies and professional experience with NFDRS (Schlobohm and Brown 2001; Hall and Brown 2001; John Deeming personal communication) have also indicated that using a single fuel model provides reasonable results for large scale analyses.

ERC is a number related to the available energy (BTU) per unit area (square foot) within the flaming front at the head of a fire. Daily variations in ERC are due to changes in moisture content of the various fuels present, both live and dead. ERC does not use wind or slope as an input, and tends to fluctuate much less than other indices. Since this number represents the potential “heat release” per unit area in the flaming zone, it can provide guidance to fire managers on expected fire intensity should a fire occur. It may also be considered a composite fuel moisture value as it reflects the contribution that all live and dead fuels have to potential fire intensity. The ERC is a cumulative or “build-up” type of index. As live fuels cure and dead fuels dry, the ERC values increase, thus providing a good reflection of drought conditions and seasonal severity. The scale is open-ended or unlimited, and as with other NFDRS components, is relative. Conditions producing an ERC value of 24 represent a potential heat release twice that of conditions resulting in an ERC value of 12.

NFDRS Fuel Model G is used for dense conifer stands where there is a heavy accumulation of litter and down woody material. Such stands are typically over mature, and may also be suffering insect, disease and wind or ice damage—natural events that create a very heavy buildup of dead material on the forest floor. The duff and litter layers are deep, and much of the woody material is more than three inches in diameter. These stands represent a “worst case” situation for many of the “problematic” large fires in the U.S. Fires in these stands are prone to crown fire initiation, spotting and are very resistant to fire control efforts. Fires in these fuels often last weeks or longer, and represent the largest expenditures in terms of budget and resources.

For these reasons, ERC using a fuel model G is often used as the single index and fuel model combination for national level analyses in the U.S.

Next-Day Forecasts of Fire Danger

In 2000, the USDA Forest Service Missoula Fire Science Laboratory and the Missoula National Weather Service Forecast Office (NWS) prototyped a process to produce daily next-day national grid-based forecasts of weather variables at a 1-km spatial resolution for potential use in short-term fire management planning. In 2002, the product was updated to include experimental ERC and BI forecasts nationwide based on NFDRS fuel model G. Figure 1 shows an example of a next-day ERC-G forecast. The product was then further developed to produce all of the NFDRS indices including spread component (SC), ignition component (IC), ERC and BI based on local fuel model, and 1-, 10-, 100- and 1000-hour dead fuel moisture. All of these forecast maps can be found at http://www.wrh.noaa.gov/mso/fireweather/nfdrs.php/.

This fire danger forecast product was developed using the National Centers for Environmental Prediction (NCEP) 29-km ETA (now North American Meso or NAM) model as the basis for the 'next day' fire danger forecast using 21Z (1500 Mountain Daylight Time) as the validation time. That is, the next-day forecast is given for grid points spaced 29-km apart. NAM model forecasts of temperature, relative humidity and precipitation (among many other variables) from NCEP are given at 3-hour increments. These three primary weather variables are needed as input to compute ERC-G. Twenty-four hour maximum/minimum values of temperature and precipitation duration are also needed as input, and are estimated from the three-hour increments during the 21Z to 21Z forecast period.

The 29-km grid values are interpolated to a 1-km grid using high-resolution elevation data and a bilinear spatial interpolation scheme. This new grid is then integrated with a 1-km NFDRS fuel model map, current Normalized Difference Vegetation Index (NDVI) greenness information (to estimate live fuel moisture), calculated values of the heavy (100-h and 1000-h) dead fuel moistures and Keetch-Bryam Drought Index (KBDI) values computed for the daily Wildland Fire Assessment System (WFAS) maps.

A key advantage and desire of a U.S. map is that it provides a quick overview of the national situation, important from a national planning perspective. Using ERC-G everywhere is easier to interpret than using local fuel models, which will have varying output ranges for each fuel model. However, even ERC-G has a similar drawback in that output ranges in different regions make it difficult (if not impossible) to compare values across the country or determine how far from "normal" they are by place or date. A solution to this problem is to compute standardized values so that a standard deviation in one location is statistically the same as any other. Two forecast products discussed below provide standardized values.

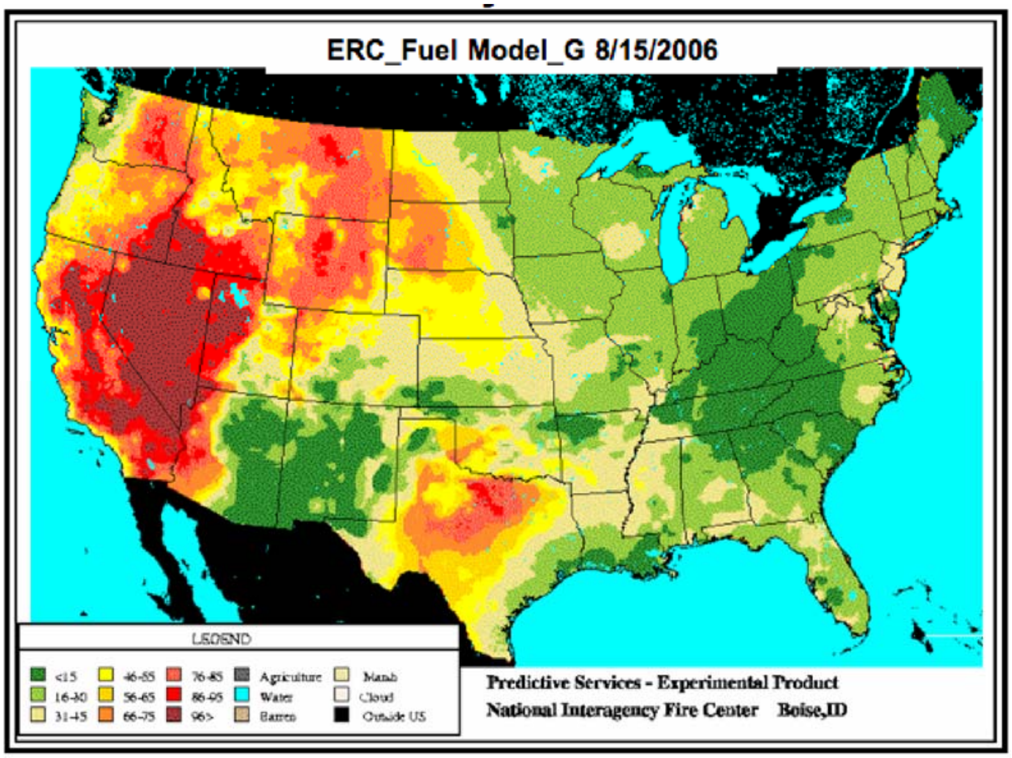

Figure 1—Example experimental next-day forecast map for ERC-G.

72-hour Mesoscale Model Forecasts of Fire Danger

The USDA Forest Service established regional modeling consortia in 2000-2001 to support the National Fire Plan. This group is called the Fire Consortia for Advanced Modeling of Meteorology and Smoke (FCAMMS). Consortia locations are in East Lansing, Michigan; Athens, Georgia; Fort Collins, Colorado; Riverside, California; and Seattle, Washington. Each consortia supports research and operational needs of their members who include land management agencies participating in the National Fire Plan, the National Weather Service, the Environmental Protection Agency, appropriate state and tribal agencies, universities and other research partners.

At each consortia, a mesoscale meteorology model (MM5) is utilized to produce value-added products for fire weather, smoke management, fire danger and fire behavior. The gridded model output is typically on spatial domains of 4-, 12- and 36-km scales, though one center produces output on a 6-km grid. Twice-daily forecasts are made up to 72-hours (three days), though there are some variations given the consortia and domain size.

A joint research project between the USDA Forest Service Missoula Fire Science Laboratory and the USDA Forest Service Pacific Northwest Research Station developed a capability to produce NFDRS output of ERC, BI, SC and IC (Hoadley *et al* 2004; 2006). Fuel model G is used for the calculation, although one consortia also produces output using varying fuel models across the domain. Figure 2 shows example output of experimental MM5 fuel model G fire danger forecasts for the western U.S. on a 6-km grid produced by the Rocky Mountain Center.

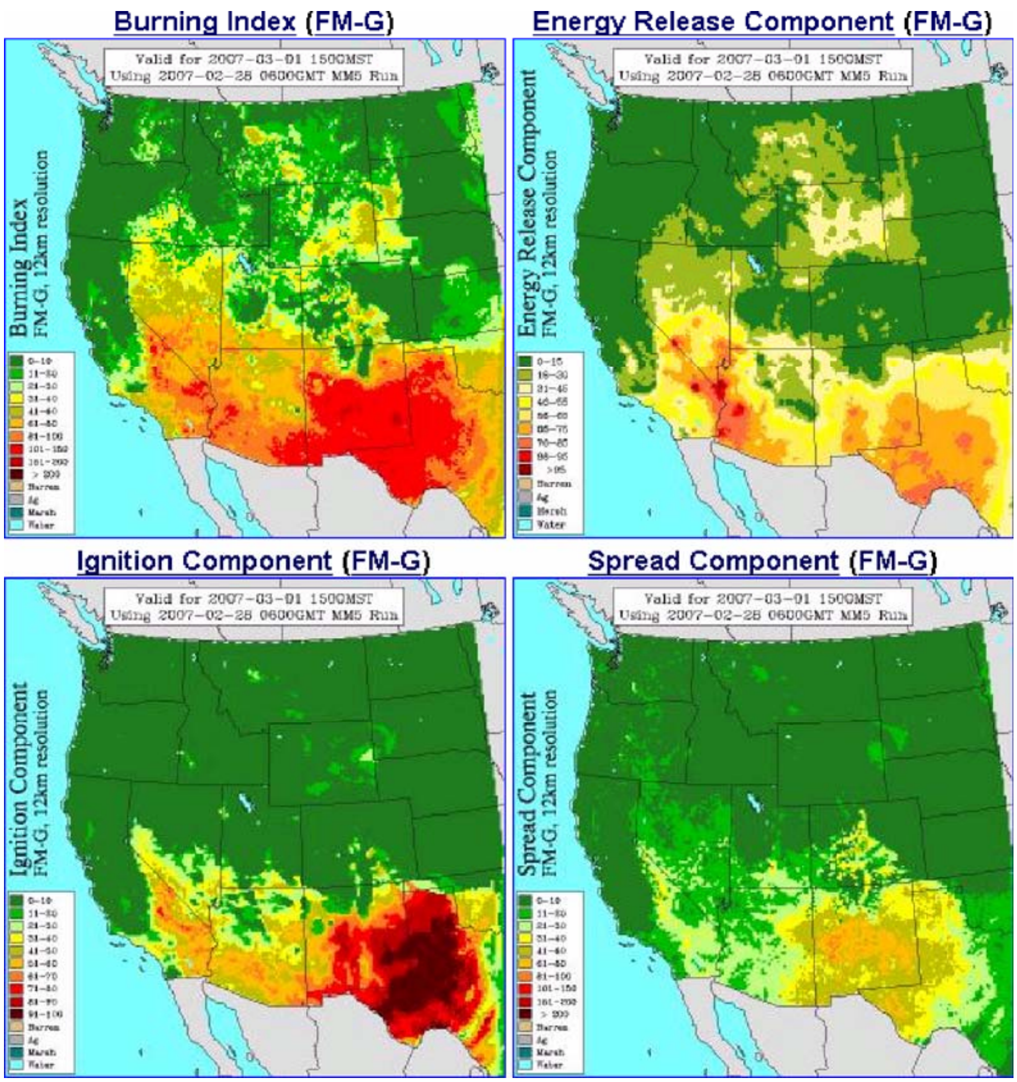

Figure 2—Example FCAMMS fire danger forecast maps from the USDA Forest Service Rocky Mountain Center (RMC).

These forecasts are considered experimental, and require further validation. However, initial feedback from users has been positive. Spatial resolution of the model is good for national and adequate for most local level planning purposes. The 3-day forecasts provide decision support information for short-term planning; however, it may not be a sufficient length of time for longer-term strategic planning where funding requests or international support may be required. The product has the same drawback as the next-day forecast previously discussed since values are not standardized. Consequently, it is difficult to compare values across the domain (and in the western U.S. there are significant elevation differences as well). Currently, no single FCAMMS is producing fire danger forecasts over a national domain. This creates boundary and computational discrepancies between domains. Also, the two eastern FCAMMS are not producing fire danger products at this time, so this product cannot be utilized across the United States.

7-Day Significant Fire Potential Forecasts

The 7-day significant fire potential forecast was developed to help determine emerging areas with a combination of dry fuels and critical weather events in order to assist managers in multi-day planning primarily for resource allocation. Significant fire potential is defined as one or more fires that require suppression resources from outside of the area that the event(s) originate. The product integrates weather, fire danger (fuels) and resource information into a single output parameter for predictive service areas (PSAs). PSAs are delineated by “significant groupings” of RAWS based upon similar climate and fuels.

Weather forecasts for the product are derived from regression equations developed between each RAWS and corresponding nearby grid points from the NCEP Global Forecast System (GFS) model. GFS is one of the current weather prediction models used by NWS. Combinations of historical weather variables from GFS were evaluated to determine how well they could predict daily weather observed from RAWS and associated derived fire danger. Model output statistic (MOS) equations were developed and implemented operationally to make 7-day forecasts of weather and fire danger for each PSA. This information translates to fuel dryness, and for each PSA is converted to a color code representing moist, marginal or dry fuels. If a significant weather trigger (i.e., lightning, wind, hot and dry) is also expected to be present, the forecast day is considered to be of ‘high risk’.

Figure 3 provides an example of the product output. A color-coded table indicates the fuel dryness for each PSA for each forecast day. If a particular day is forecast to be high risk, the relevant weather symbol is also given. A discussion is provided that covers the weather synopsis, fire potential situation and resource capabilities.

Advantages of this product are that it combines weather, fuels and resources into an integrated product that is easily interpreted by fire managers. The forecast covers 7-days, which is of sufficient length for many planning needs. There is also a national ArcIMS map product being developed that combines all of the PSA 7-day forecasts so they can be viewed simultaneously for each day covered in the outlook product. The product is standardized in that the fuel dryness thresholds and resource capabilities are defined for each PSA. Consequently, while specific data outputs may be different across the country, what is considered high risk in one PSA means the same anywhere else in the country. PSAs can be large in area, so a disadvantage is that these areas do not show the detail available utilizing a high-resolution grid.

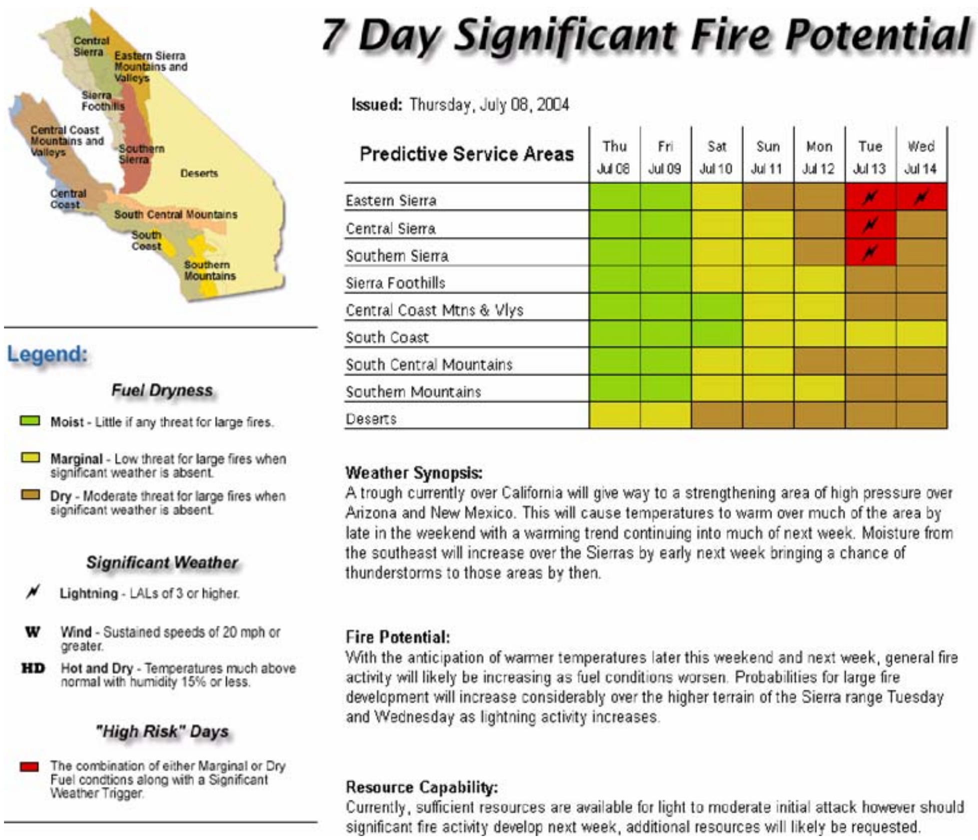

Figure 3—Example output from the 7-day significant fire potential forecast product.

15-Day Standardized ERC Forecast

In 2002, the National Predictive Service Group (NPSG) and the Desert Research Institute (DRI) worked together to develop an experimental system for producing 15-day outlook maps of ERC-G daily forecasts that included actual, standardized and anomaly values (Hall *et al* 2005). The objective behind the development of this model was to provide outputs in a standardized format so they could be compared across the country in order to determine how the forecasted values depart from average.

To facilitate the standardized ERC forecast, a gridded national climatology of ERC using fuel model G was produced at the University of Montana, Numerical Terradynamic Simulation Group (NTSG) under direction of the Fire Sciences Laboratory in Missoula. The NTSG developed fine resolution daily meteorological and climatological data (DAYMET) necessary for plant growth model inputs. The DAYMET model (Thornton 1997) generated 16 years of daily surface temperature, precipitation, humidity and radiation at 8-km resolution over complex terrain using a digital elevation model and daily observations from ground-based meteorological stations. An ERC-G climatology was developed using the DAYMET model outputs on an 8-km grid for the lower 48 states in the U.S. for the period 1982 through 1997.

The national 15-day standardized ERC forecast model uses either a 1° or a 2.5° spatial resolution (forecast days 1 through 7, and days 8 through 15, respectively) from the NCEP GFS model. Historical ERCs based on DAYMET were averaged and scaled to fit these two forecast output grids. Daily means and standard deviations of the two model resolutions were then computed, and this provided the daily climatological dataset needed to compute standardized ERC forecasts (forecast value minus mean divided by standard deviation). The Terrestrial Observation and Prediction System (TOPS) was used to integrate NFDRS equations with gridded datasets to estimate the daily ERC for fuel model G, and other sophisticated methodologies were used to estimate live fuel moisture, state of the weather and precipitation duration.

The 00 UTC GFS model run is downloaded daily, and the 18 UTC forecast time is used for the daily temperature and relative humidity values. Forecasts for times 00, 06, 12 and 18 UTC are used to determine daily maximum and minimum temperatures and relative humidity along with precipitation duration needed for the ERC calculation.

The product has been available in an operational environment for over three years and used for daily briefings at the National Interagency Fire Center (NIFC). This product offers several advantages. First, it uses a common fuel model (NFDRS Fuel Model G) allowing the product values to be compared across the country. Departure from average values can be displayed as standardized or anomaly outputs using the ERC climatology. Figure 4 shows the web page and an example anomaly (departure from average) forecast map. The user can select day and type of map for viewing, and the overall concept can be applied to other NFDRS outputs. Disadvantages include: 1) the product does not include Alaska, Hawaii or Puerto Rico; and 2) the grid resolution is considered course, especially for days 8-15.

Validation testing uncovered a significant problem that indicates DAYMET ERC climatology is not satisfactory to produce standardized values for some parts of the country. Forecasted actual and departure values generally seem reasonable. However, the standardized value is based upon a standard deviation as well as a mean, and it appears that the modeled variance does not sufficiently match the RAWS observed variance. Adjustments were ultimately needed for both the ERC climatology created from DAYMET dataset and the GFS forecast values due to biases. Even though some adjustments were made, the standardized results were still not always satisfactory. A new ERC climatology is currently being developed based upon the North American Regional Reanalysis (NARR) dataset, which is a much improved and longer-term gridded climate dataset. Utilizing the NARR climatology is expected to improve the standardized product outputs.

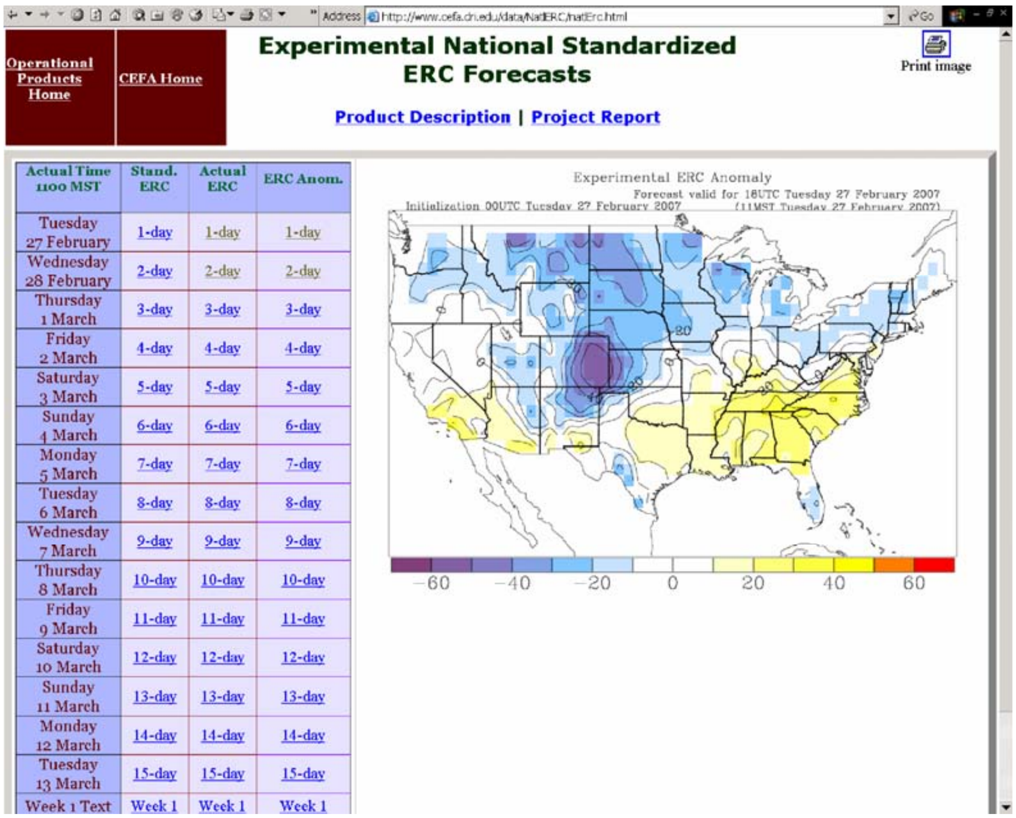

Figure 4—Snapshot of web page for the 15-day ERC forecast product. Example map shows forecast anomaly (departure from average) values.

Monthly to Seasonal Fire Danger Forecasts

In 2000, the Scripps Institution of Oceanography Experimental Climate Prediction Center (ECPC) began making experimental near real-time weekly to seasonal fire danger forecasts using the global spectral model (GSM) (Roads *et al* 2005). These models are initialized daily and produce gridded output weather that can be used for fire danger calculations. The project objective was to assess whether or not NFDRS indices could be forecast on longer time scales (monthly and seasonal) using a state of the art dynamical seasonal prediction model, and producing these forecasts automatically. Results of the analysis were positive, and forecast maps have been produced regularly to date since project initiation.

Forecasts include ERC, BI, SC, IC, fire weather index (FWI), Chandler burning index (CBI), Keetch-Byram drought index (KBDI) and a fire potential index (FPI). The grid output resolution is 50-km, though 25-km is available for two western regions in the U.S. Since the forecasts are gridded, NFDRS had to be modified to handle a grid, such as interpolating a 1-km vegetation model to the coarser GSM grid.

Considerable validation work has been undertaken on these forecasts including that by Reinbold *et al* 2004. Results indicate that there is some reasonable prediction skill given the monthly and seasonal nature of the forecasts, but there is variability of this skill given region or specific fire danger index. Figure 5 provides an example forecast of a single season ERC forecast.

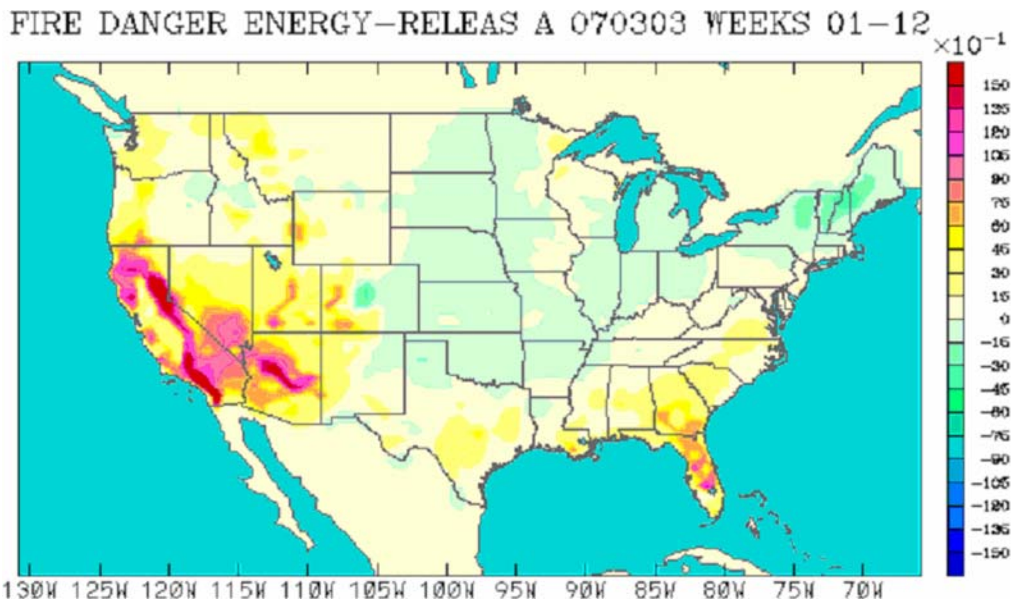

Figure 5—Example gridded Experimental Climate Prediction Center ERC seasonal forecast.

A primary advantage of this product is that it is the only one currently available that addresses the time scales relevant to long-term strategic planning. The product is also unique in that forecasts are produced on a global scale. A disadvantage of the product is that values are not standardized as discussed elsewhere in this paper and local fuel models are used rather than a single fuel model across the domain.

The Future of Fire Danger Forecasts

Gridded fire danger forecasts offer some advantages in that they can show higher spatial resolution detail, and cover areas where NFDRS weather stations do not exist. However, utilizing gridded fire danger information in the U.S. is a management paradigm shift. Point weather station data is still the primary source for fire danger information. Gridded fire danger is a new concept to fire management, but is a natural extension of gridded weather products, which have been in existence for a number of years now. Nearly all weather forecasts begin with gridded information, so forecasts for fire danger will occur (and are occurring) in the same manner. The need for more detailed risk-based assessments and quantitative decision-support is ultimately driving the development of more detailed state-of-the-art fire danger forecasts. Current science and technology is in place for this to happen, so it is highly likely that gridded fire danger forecasts will become more prevalent and commonplace over the next few years.

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