Program for Climate, Ecosystem and Fire Applications

Development of U.S. Operational Fire Danger 15-Day Forecasts

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Forward

In November 2000 an Assistance Agreement 1422RAA000002 was established between the Bureau of Land Management National Office of Fire and Aviation and the Desert Research Institute. This report describes the activities at the DRI Program for Climate, Ecosystem and Fire Applications (CEFA) under Task Order 9 – Development of U.S. Operational Fire Danger 15-Day Forecasts for the period August 2002 through September 2005. Project funding and support was provided by the USDA Forest Service via the National Predictive Service Group. For further information regarding this report or the projects described, please contact either:

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Development of U.S. Operational Fire Danger 15-Day Forecasts

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1. INTRODUCTION

A primary function of Predictive Services at the National Intelligence Coordination Center (NICC) is to provide fire managers weather, climate and fuels decision support information for wildland fire decision-making, planning for resource allocations, and the determination of national preparedness levels. One of many information needs is the assessment and prediction of fire danger on national and regional scales. The energy release component (ERC) is an index from the National Fire Danger Rating System (NFDRS) that is regularly used for this purpose. However, ERC is typically a fuel model specific calculation making it difficult to assess across spatial areas or even simply between two stations using differing models. Also, when the same fuel model (e.g., fuel model G) is used everywhere, the ERC value range varies substantially across the country making it difficult to know from a national perspective how these values are related to fire business. Thus for NICC needs, it is desirable to (1) calculate ERC using a single fuel model everywhere, (2) display the index as a standardized value so that its magnitude has the same statistical meaning everywhere, and (3) provide daily predictions of standardized ERC out to two weeks. By using a common fuel model and standardized values, it is then possible for example to compare Florida and Nevada values directly. Prediction elements are readily available such as the operational weather forecasts of up to 15 days from the National Centers for Environmental Prediction (NCEP)/National Weather Service (NWS) via the Global Forecast System (GFS) numerical model.

The overall goal of the project was to develop a prototype system for producing operational daily forecasts of standardized ERC out to fifteen days. It incorporates national information needs at NICC with operational forecast products produced by NWS. In 2000, the Missoula Fire Science Laboratory and the Missoula Forecast Office prototyped a process to produce daily next-day national grid-based forecasts (ETA model) of NFDRS parameters (Bradshaw *et al.*, 2000) based on both a 1-km NFDRS fuel model map and a national G fuel model (see http://www.wrh.noaa.gov/mso/fireweather/nfdrs.php). The techniques developed in

Missoula served as a framework for national gridded predictions of standardized ERC using fuel model G by inputting forecasts of temperature, relative humidity and precipitation from the GFS model into NFDRS. To facilitate the “standardized ERC concept”, an 8 km gridded national climatology of ERC using fuel model G was produced by the Missoula Fire Sciences Laboratory (MFSL). The GFS model was chosen for the prototype as a NWS operational product meeting the 15-day requirement. Fifteen-day forecasts have been chosen for the prototype in part based upon requests for needed information by meteorologists at the Geographic Area Coordination Centers (GACCs) and preparedness level planning requirements at NICC. This project was a collaborative effort between the Desert Research Institute (DRI) Program for Climate, Ecosystem and Fire Applications (CEFA), MFSL, and NICC.

Though it is recognized that other NFDRS indices and fuel models may have high value, only ERC fuel model G was utilized in the development of the prototype system. Discussion with advanced users and developers of NFDRS, preliminary analysis at CEFA of correlating ERC with different fuel models, and some other work (e.g., Schlobohm and Brown 2001; Hall and Brown 2001) suggests that using a single fuel model for the prototype development is reasonable. However, it would be highly desirable to examine other indices, develop a verification system and evaluate other short and long-term forecast models to determine if they would improve performance.

In addition to developing the prototype 15-day ERC forecast product, validation of the method for producing ERC-G forecasts from NCEP numerical weather model output was examined. This included validation of the gridded climatology required to produce the national ERC climatology used to generate standardized values in addition to the initialization GFS model output of temperature and relative humidity.

Ensemble gridded forecasts from NCEP are also being utilized to produce standardized ERC predictions as a separate product. The ensemble forecasts provide a range of forecasts given slightly different initial conditions. These forecasts are then averaged to produce a single mean forecast.

2. DATA AND METHODOLOGY

2.1 ERC Climatology Data

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, Missoula, MT. The NTSG has been working on building fine resolution daily meteorological and climatological data stores (Daymet) necessary for plant growth model inputs. The Daymet model (Thornton, 1997) produces this particular data. This model generates daily surface temperature, precipitation, humidity and radiation over complex terrain using both a digital elevation model, and daily observations of minimum and maximum temperatures and precipitation from ground-based meteorological stations. The full

Daymet dataset contains 16-years (1982-1997) of daily temperature, precipitation, humidity and radiation estimates at an 8-km resolution.

Once all of the data were in place, it took about 15 hours of Sun server computing time to generate each day's ERC grids. The result was daily 8-km ERC values for the US for 1982 through 1997. Since the model output used for the national standardized ERC forecasts have either a 1° or a 2.5° spatial resolution (forecast days 1 through 7 and days 8 through 15, respectively), each daily, historical ERC grid was averaged and scaled to the two forecast model grid sizes. Daily means and standard deviations of the two model resolutions were then computed. This provided the daily climatological datasets needed in order to compute the standardized ERC forecasts.

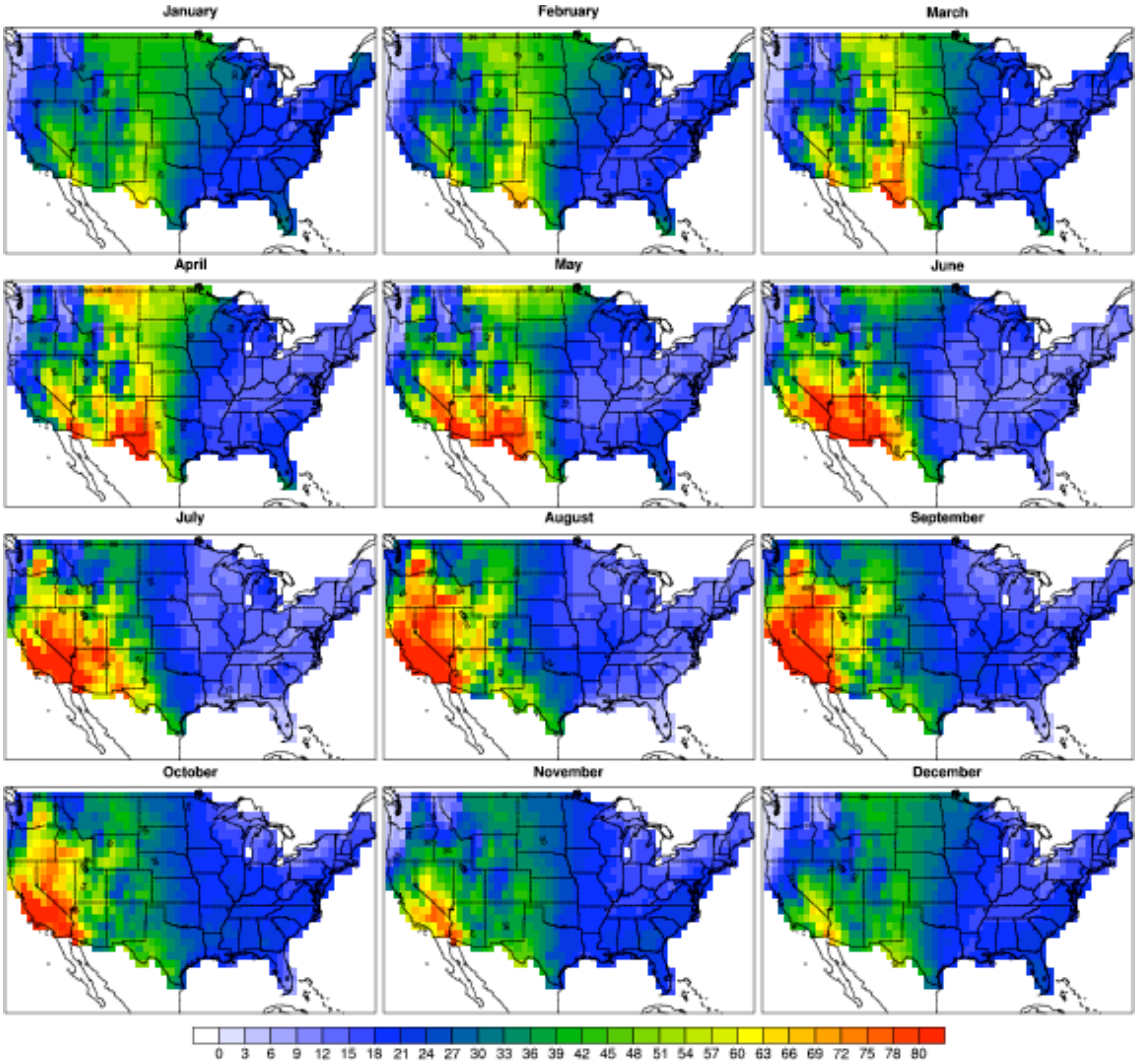


Figure 1. Monthly averaged 1º resolution ERC climatology (1982-1997) from the Daymet dataset.

2.2 ERC Derivation

The Terrestrial Observation and Prediction System (TOPS) was designed to estimate daily biospheric mass and energy fluxes for the continental US (Nemani and others 2003). TOPS was used to integrate the NFDRS equations (Cohen and Deeming 1985) with gridded datasets to estimate the daily ERC for fuel model G (short needle pine, heavy dead loads) on an 8-km grid. Fuel model G was chosen because ERC-G, despite not being very sensitive to live fuel moisture, has been considered to perform well in terms of correlation with fire activity in many locations within the US. The integration between NFDRS and TOPS required several adaptations and assumptions in four areas where NFDRS requires more explicit weather information than directly available from Daymet.

2.2.a LIVE FUEL MOISTURE

The standard NFDRS models for live fuel moisture require specification of fuel type and annual dates for greening up the live fuels. We chose to use an experimental method using satellite derived Normalized Difference Vegetative Index (NDVI) data that is used in a prototype next-day NFDRS forecasting scheme (Bradshaw and others 2000). This method uses the historical range and weekly relative greenness of a pixel to estimate the live woody and herbaceous fuel moisture. These data are provided weekly at a 1-km resolution. The values are averaged over the 1° and 2.5° spatial resolution used for the forecasts. Over 10,000 pixels typically fall within a 1° grid cell. To minimize water and other missing data influences from around the country's border, at least 7,500 pixels needed to be non-missing or on land for the grid cell to contain an averaged relative greenness or fuel moisture value. This 7,500 pixel criteria was applied to both the 1° and 2.5° resolutions.

2.2.b STATE OF THE WEATHER

NFDRS uses a state of the weather (SOW) code to estimate fuel temperature from the observation height temperature base on cloud cover, and, if it is raining or snowing at observation time, to set some parameters to coded instead of computed values.

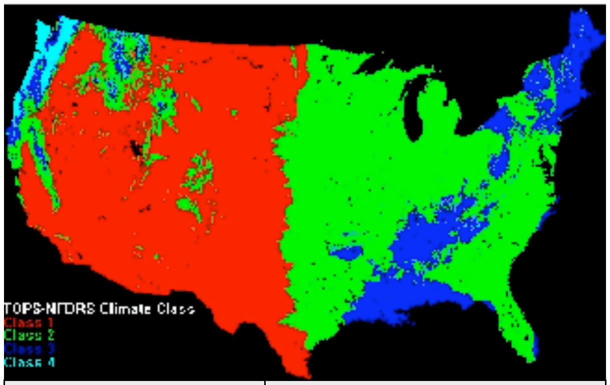
SOW was determined by the departure of daily short-wave radiation from the long-term mean radiation for that day. Using the Daymet dataset, the long-term mean and standard deviation was calculated for each 8-km grid cell for each day over the period of record. The potential radiation was then defined as the daily mean plus two standard deviations. The departures of a given day's radiation from that long-term potential radiation were used to establish SOW thresholds as shown in Table 1.

2.2.c PRECIPITATION RATE

NFDRS uses precipitation duration, not precipitation amount, to estimate the effect of rainfall (and snow cover) on dead fuel moisture. The NFDRS processing algorithms have default precipitation rates for each of the system's four climate classes. NFDRS climate classes are roughly based on Thornwaite's (1931) climate classes. However, there is no GIS layer of those climate classes available for use in this effort. Instead, an objective climate classification system was developed to determine regional precipitation rates. The Daymet dataset was used to estimate climate averages of solar radiation, precipitation and temperature for each 8-km square area. The ratio of average total precipitation and an estimate of potential evapotranspiration (PET) (Priestly and Taylor, 1972) were then used to create a four-category spatial climate classification (Figure 2).

Table 1. TOPS/NFDRS State of Weather based on percent of potential radiation.

SOW	Daily Percent of Potential
1	90 to 100
2	80 to 89
3	50 to 79
4	0 to 49



Climate Class	R
1	0.0 to 0.49
2	0.5 to 0.99
3	1.0 to 1.5
4	> 1.5

Figure 2. TOPS/NFDRS climate thresholds based on the annual precipitation/PET ratio (R).

The standard NFDRS precipitation rates were initially assigned to the four climate classes. It was determined during validation trials that computed precipitation durations for some areas, particularly in the Southeast, were too long during summer convective rains. Actual precipitation rates were assessed from hourly data from the national fire weather network and assigned precipitation rates for the four climate classes based on two season categories as shown in Table 2.

Table 2. TOPS/NFDRS precipitation rates (inches/hour) by climate class and season

Climate Class	JUN 1 - SEP 30	OCT 1 - MAY 31
1	0.25	0.05
2	0.25	0.05
3	0.25	0.05
4	0.05	0.05

2.3 ERC Forecasts

Operational ERC forecasts are computed using the Global Forecast System (GFS) model output. GFS 6-hourly output is available via internet streams at a 1° spatial resolution for forecast days 1 through 7 and at a 2.5° spatial resolution for forecast days 8 through 15. The 00 UTC model run is downloaded daily using the 18 UTC forecast times for the daily temperature and relative humidity. 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. These variables are the inputs for computing daily ERC.

2.3.a ERC Forecast Anomaly

Figure 3 shows an example map of an ERC anomaly forecast. The anomaly forecast is computed by subtracting the historical mean Daymet ERC value at each 1-degree or 2.5-degree grid cell from the GFS ERC forecast.

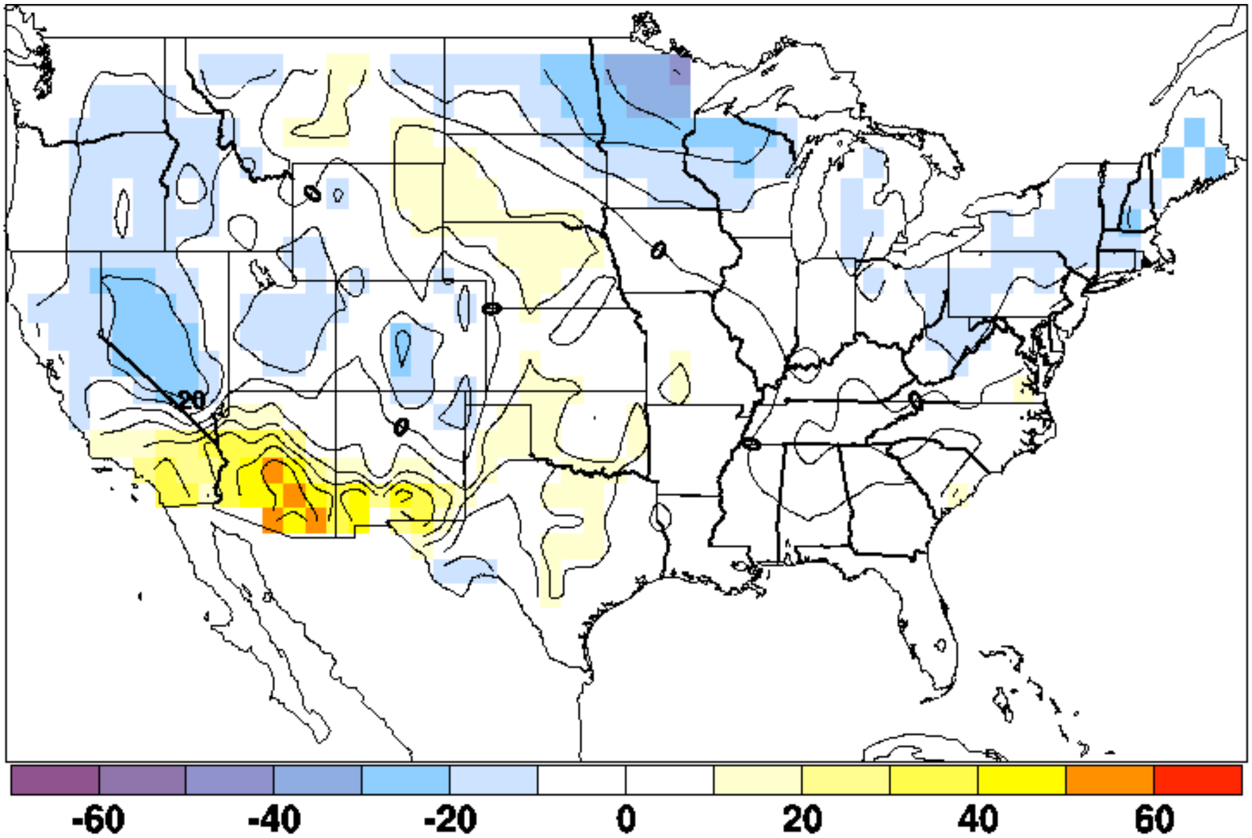


Figure 3. Example ERC anomaly forecast map at 1º resolution.

2.3.b Standardized ERC Forecasts

Once the daily forecasts for ERC have been produced, the GFS model grids are used with the historical mean and standard deviation Daymet ERC grids to compute the standardized ERC (SE) forecast using the following algorithm:

$$SE = \frac{(forecast - mean)}{st.dev.}.$$

Figure 4 is an example plot of a standardized ERC forecast using Daymet ERC climatology and GFS forecast data.

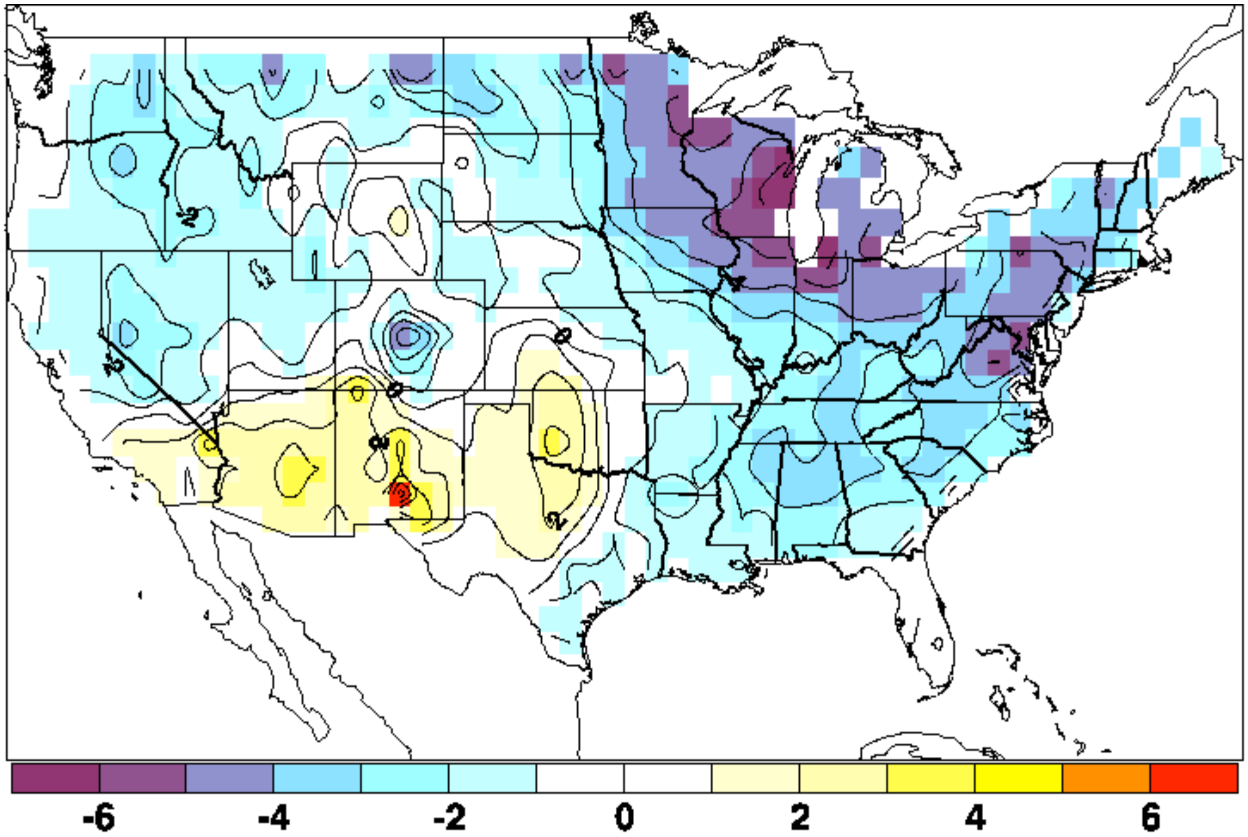


Figure 4. Example standardized ERC forecast map at 1° resolution.

2.3.c Ensemble ERC Forecasts

Ensemble forecasts of temperature, relative humidity, precipitation, and total cloud cover percentage are available from the Medium Range Forecast (MRF) model at NCEP. Only the 00UTC ensemble forecasts are downloaded to correspond to the retrieved GFS model output. Each ensemble file is an average of 12 perturbation forecast runs. The ensemble data has 6-hourly forecasts at a 2.5-degree spatial resolution. The ensemble forecast output is used as input into the ERC algorithms in the same manner as the GFS forecast output.

2.4 Method Validation

Validation of the Daymet inputs compared to surface observation data is needed to assess the accuracy of the standardized gridded national ERC forecast product. Fire managers and planners typically compute ERC based upon observations recorded at individual or special interest groupings (SIGs) of Remote Automated Weather Station (RAWS) sites. If the ERC gridded forecasts do not agree with these surface observations, it is important to know what part of the product algorithm is likely contributing to the discrepancy so that algorithm corrections can be made if possible. The two major points of potential discrepancy are the Daymet ERC climatology not matching the RAWS climatology, and the GFS forecast initializations are not in agreement with the RAWS observations.

2.4.a Historical ERC Validation

There were 882 RAWS sites located across the continental US available for this analysis. These sites were chosen by Fire Planning Unit (FPU) managers as sites they rely on the most for decision-making purposes. Daily ERC was computed for each station for the available period of record. Each one-degree grid cell across the domain was then assigned a RAWS ERC value if there was at least one station located within a grid cell. If only a single station was available then its value was used; however, if multiple stations were located within a grid cell then the average daily ERC value for all the stations was applied.

For the Daymet climatology to work well in producing standardized values, it must also sufficiently represent the climatological distribution of ERC as derived from the RAWS observations. Figure 5 shows an example of the data distribution for August Daymet unadjusted, RAWS and Daymet adjusted ERC daily values at a grid cell in southern California (centered 125°W, 35°N). The unadjusted Daymet ERC values are typically larger in this region (80 - 95 ERC units for unadjusted Daymet versus 60 – 80 ERC units for RAWS). Also, the unadjusted Daymet distribution has a much lower variance than the RAWS ERC. The middle 50% of the distributions, as represented by the shaded box, for unadjusted Daymet does not even overlap between the two datasets.

A variance adjustment (similar to what is used in remote sensing data analysis and referred to as a contrast adjustment) was applied to the Daymet data to effectively ‘spread’ the daily Daymet ERC values across a range similar to the RAWS ERC data utilizing the equations:

$$IQR_{RAWS} = Q_{3RAWS} - Q_{1RAWS}; \tag{1}$$

$$IQR_{Daymet} = Q_{3Daymet} - Q_{1Daymet}; \tag{2}$$

$$Adj.Daymet = [IQR_{RAWS} * \left(orig.Daymet - Q_{1Daymet}\right) \div IQR_{Daymet}] + Q_{1RAWS} \;. \tag{3}$$

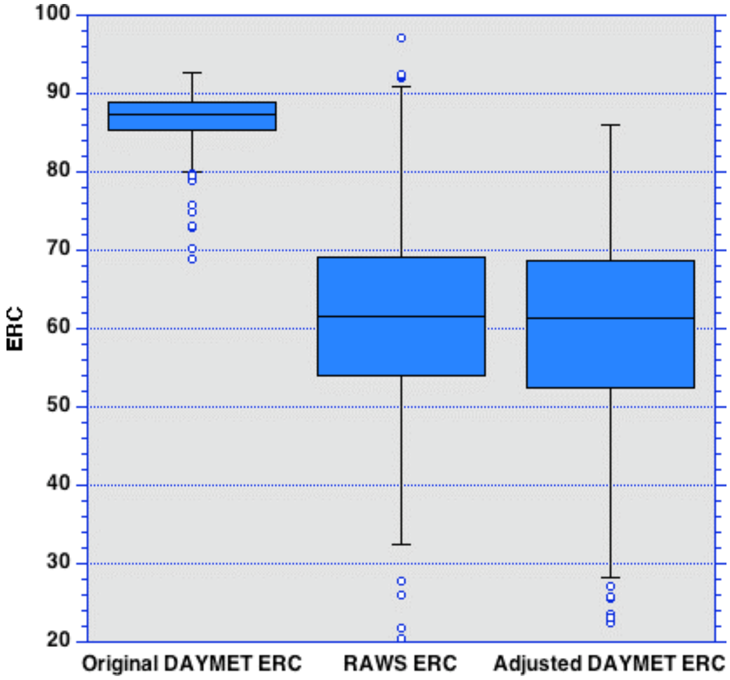


Figure 5. Box plots showing the distribution of August daily ERC values at the 120ºW, 35ºN grid cell located near the coast of southern California.

Equation 3 (Carr 2002) was used to re-distribute the original Daymet ERC values based upon their 25th percentile (Q_1) and 75th percentile (Q_3) values in order to simulate the total range distribution of the observed ERC based upon the RAWS Q_1 and Q_3 values. Applying this contrast adjustment using quartile values will cause some extreme values of Daymet to become physically unrealistic. Therefore, any adjusted Daymet value that exceeded the maximum or minimum values of the RAWS ERC was replaced with the RAWS maximum or minimum ERC values, respectively. This data adjustment was used to develop historical ERC values that better represented the data distribution of RAWS ERC based upon observations. This was done for both the 1-degree and 2.5 degree grids. The adjusted Dayment values in Figure 5 now show a distribution much closer to RAWS. The middle 50% of values overlap reasonable well with RAWS, and the more extreme values are within the range of the RAWS maximum and minimum values.

Figure 6 shows the monthly maps of the one-degree averaged RAWS ERC values subtracted from the one-degree unadjusted Daymet ERC values shown in Figure 1. Daymet ERC is typically higher (by 15 to 40 ERC units) than RAWS ERC along the Pacific coastal states, whereas the Daymet ERC in the intermountain region is typically lower than RAWS ERC. There is a substantial amount of white space in the central and eastern U.S. due to the lack of RAWS data coverage in these areas.

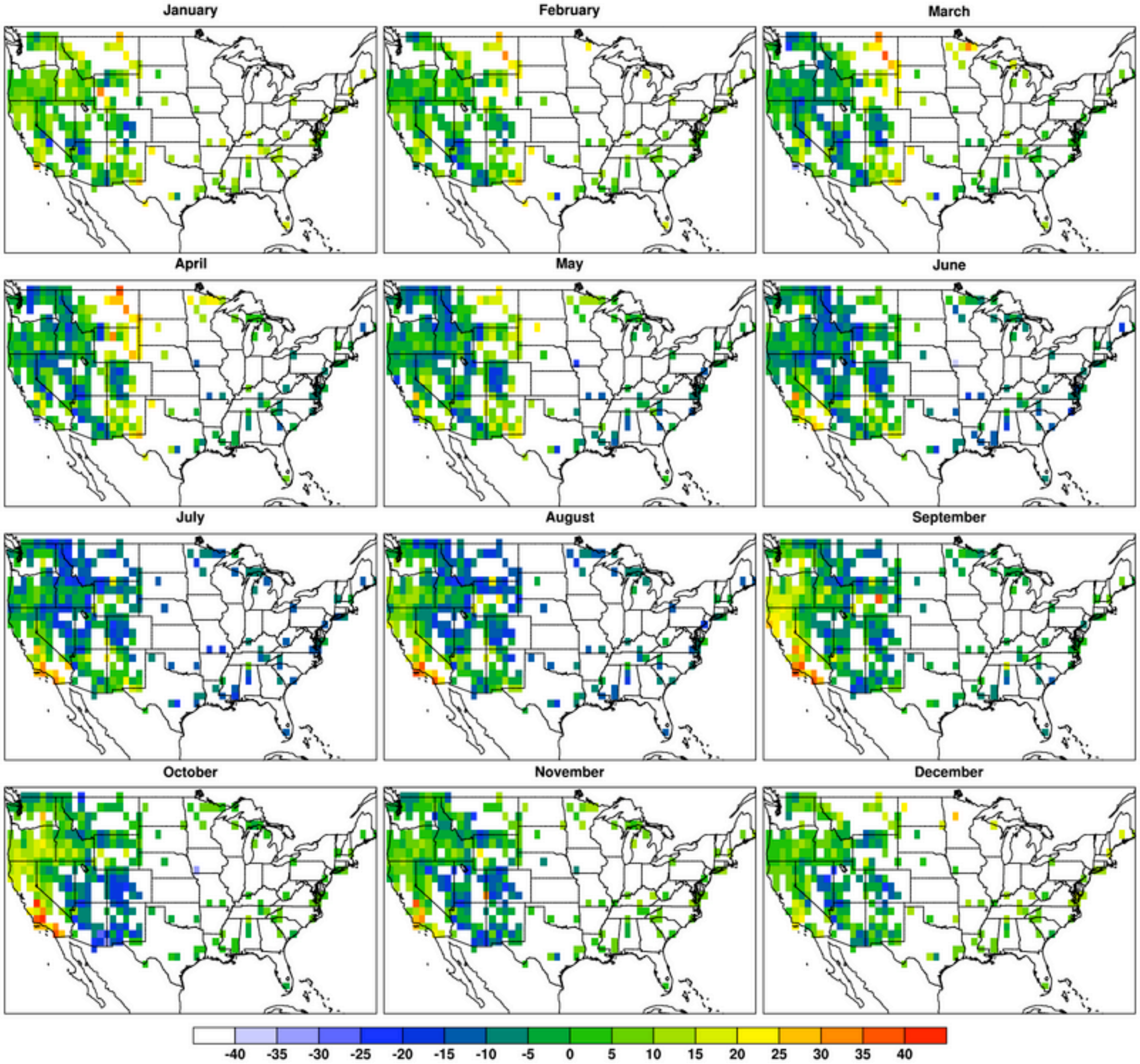


Figure 6. Monthly difference maps showing 1° averaged RAWS ERC subtracted from unadjusted Daymet ERC.

Figure 7 shows the difference between the monthly unadjusted Daymet ERC and the adjusted Daymet ERC after the data were re-distributed. Intermountain regions showing warmer (yellow, orange) colors indicate where the adjusted Daymet ERC values are now larger than the original values. Pacific coastal and northern regions are cooler colors (green, blue) indicating areas where the adjusted Daymet ERC values are now lower than the original data. Most of white area (e.g., central and eastern US, and central California) is due to the lack of RAWS data necessary to make a distribution adjustment.

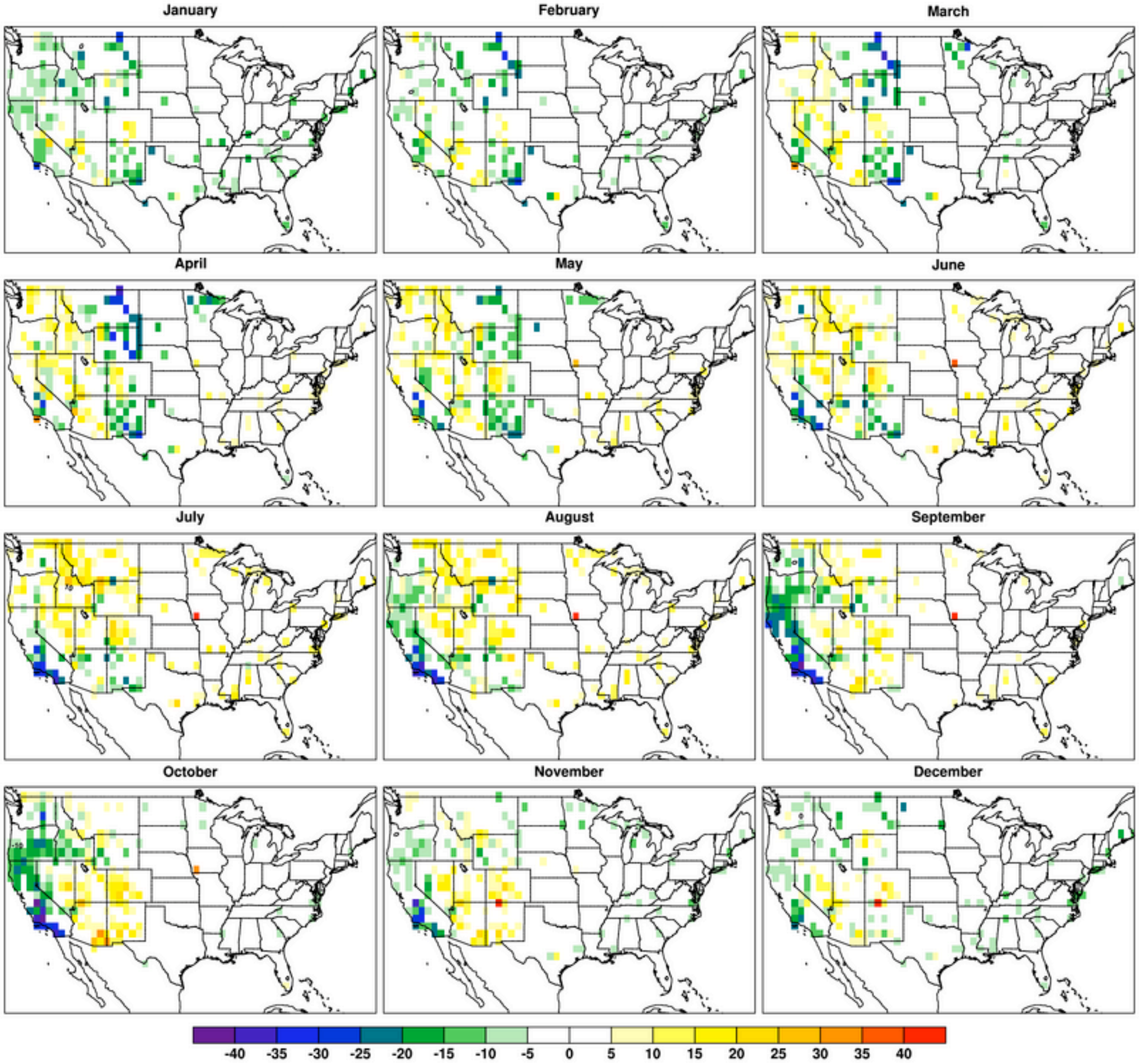


Figure 7. Monthly difference plots of the 1° adjusted Daymet ERC minus unadjusted Daymet ERC.

Figure 8 shows an example of how the re-distributed Daymet ERC affected a forecast standardized ERC plot. Cool colors (green, blue) indicate locations where adjusted Daymet decreased the standardized ERC values to be lower, and warm colors (yellow, orange) indicate locations where adjusted Daymet increased the standardized ERC values. Forecast values in California, Oregon and Washington were adjusted to higher values, the interior Great Basin values were adjusted to lower values, and other parts of the country resulted in a mix of adjustments. The white space locations did not receive an adjustment due to a lack of sufficient RAWS coverage, and hence these areas cannot be adjusted in any forecast map.

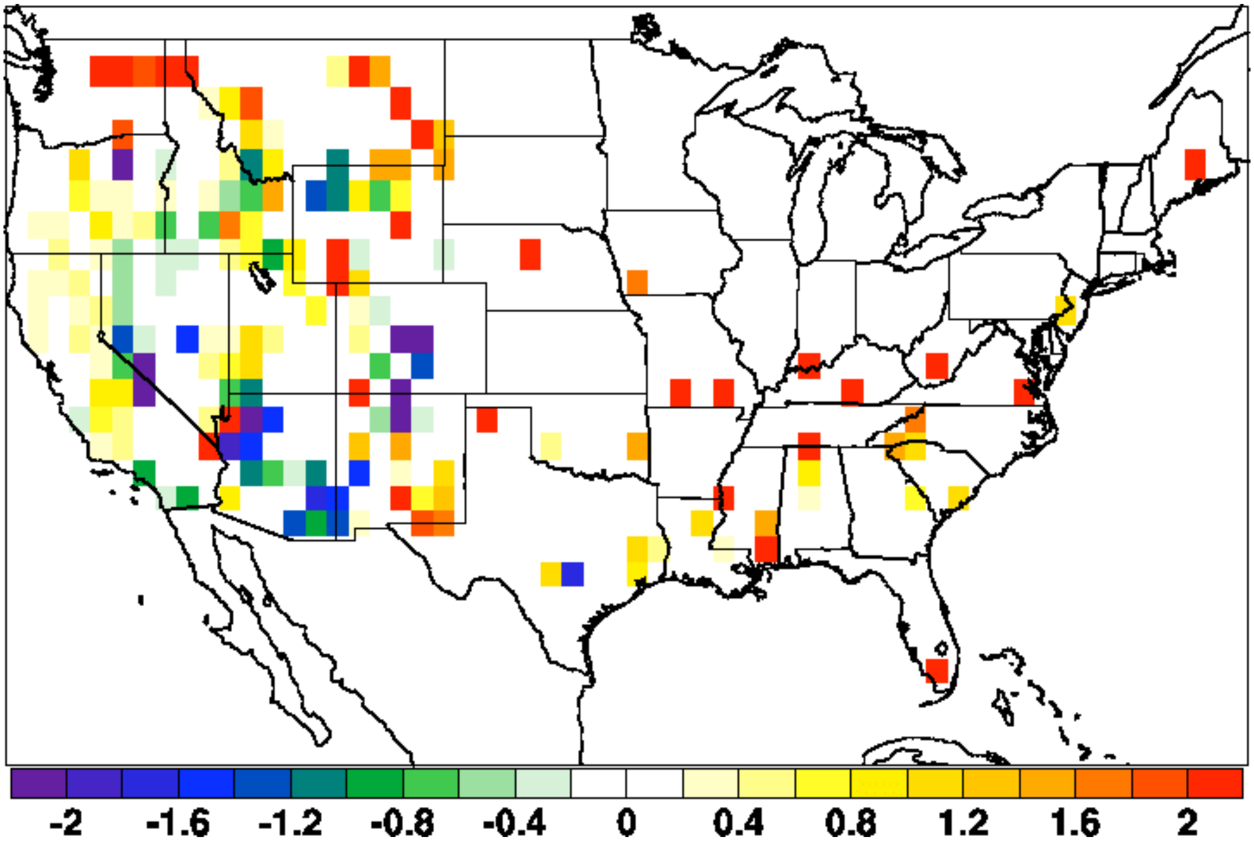


Figure 8. Example difference map of original forecasted standardized ERC values subtracted from standardized ERC values based on adjusted Daymet ERC.

2.7.1 GFS Model Validation

Another needed adjustment is the GFS forecast values to account for dissimilar distributions between GFS initialization values and RAWS observations. Model initialization values are a gridded representation of observations, but a grid cell may not correlate well to an individual station located within it depending upon how well the stations that were used as input represent a spatially large grid (e.g., one-degree). The GFS model for 2001-2003 was validated with the observations from the RAWS network using the same adjustment techniques as for the historical ERC (Daymet) validation. The 2001 and 2002 initialization grids were for a 95 km grid resolution whereas the 2003 grids were on an even 1° spatial resolution. Gridded values of RAWS temperature and relative humidity were developed similar to the gridded RAWS ERC data above.

Figures 9 and 10 show an example box plot distribution of temperature and relative humidity, respectively, between the GFS initialization values and RAWS observations at an example grid point in southern California (120°W, 35°N). For this particular location, RAWS August temperatures average about eight degrees cooler than the GFS model values. The distributions are generally similar in shape, though RAWS has a larger spread. The adjusted GFS temperature overlaps reasonably well the RAWS distribution, though the total spread is somewhat smaller and the median value is cooler. RAWS relative humidity (Figure 10) averages about 13% higher than GFS, and has a much larger spread. The adjusted values have an improved distribution overlap, but now average about 6% higher than RAWS.

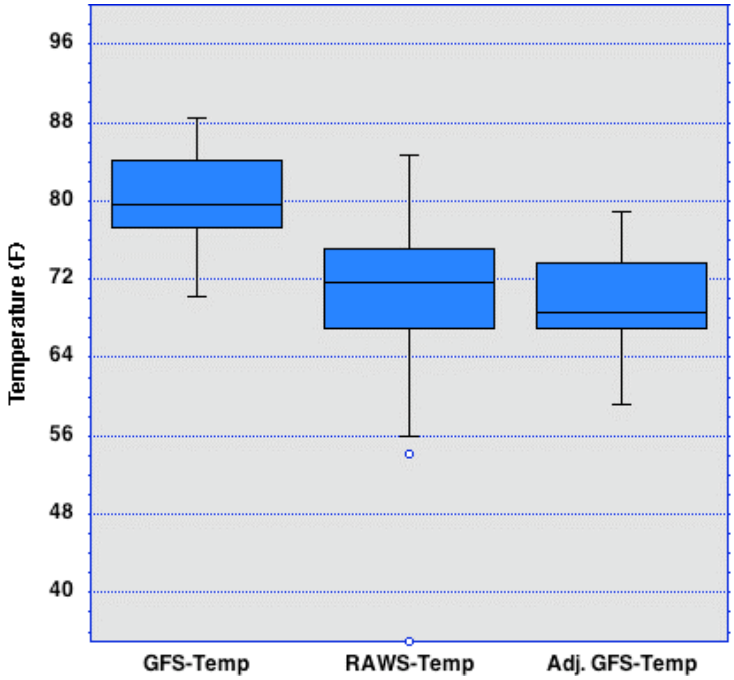


Figure 9. August temperature (2001-2003) distributions from the GFS model initialization and RAWS observations for the example grid cell located in southern California (120°W, 35°N).

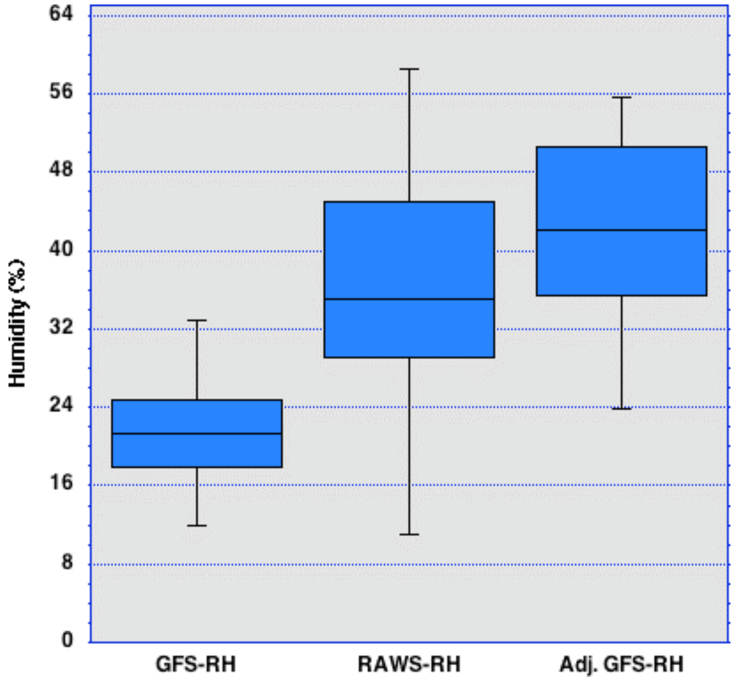


Figure 10. Same as Figure 9, except for August relative humidity.

For each 1° and 2.5° grid cell, the maximum, minimum, Q_1, and Q_3 RAWS and GFS temperature and relative humidity values were computed for each month over the 2001 to 2003 time period. These values were stored in a data file to be applied to each GFS forecast value of temperature and relative humidity (out to 15 days) to adjust the GFS values to better match the RAWS distribution. This process is similar to the one applied for the historical Daymet ERC validation, except here will be applied real-time to each once-a-day GFS forecast run.

Figure 11 shows the difference in standardized ERC values where the original, unadjusted (both Daymet and GFS) standardized ERC is subtracted from standardized ERC values computed off of adjusted GFS input. The adjusted temperature and relative humidity GFS model output has decreased the standardized ERC values by a difference of 0.8 or more units in Arizona and New Mexico. However, for most of the U.S. where GFS model output adjustments could be made, the adjustment increased the standardized ERC values ranging from 0.4 to 1.6 or more.

Note that none of the validation work in this project addresses the forecast skill of the GFS model. Model verification analysis was considered to be beyond the scope of this project.

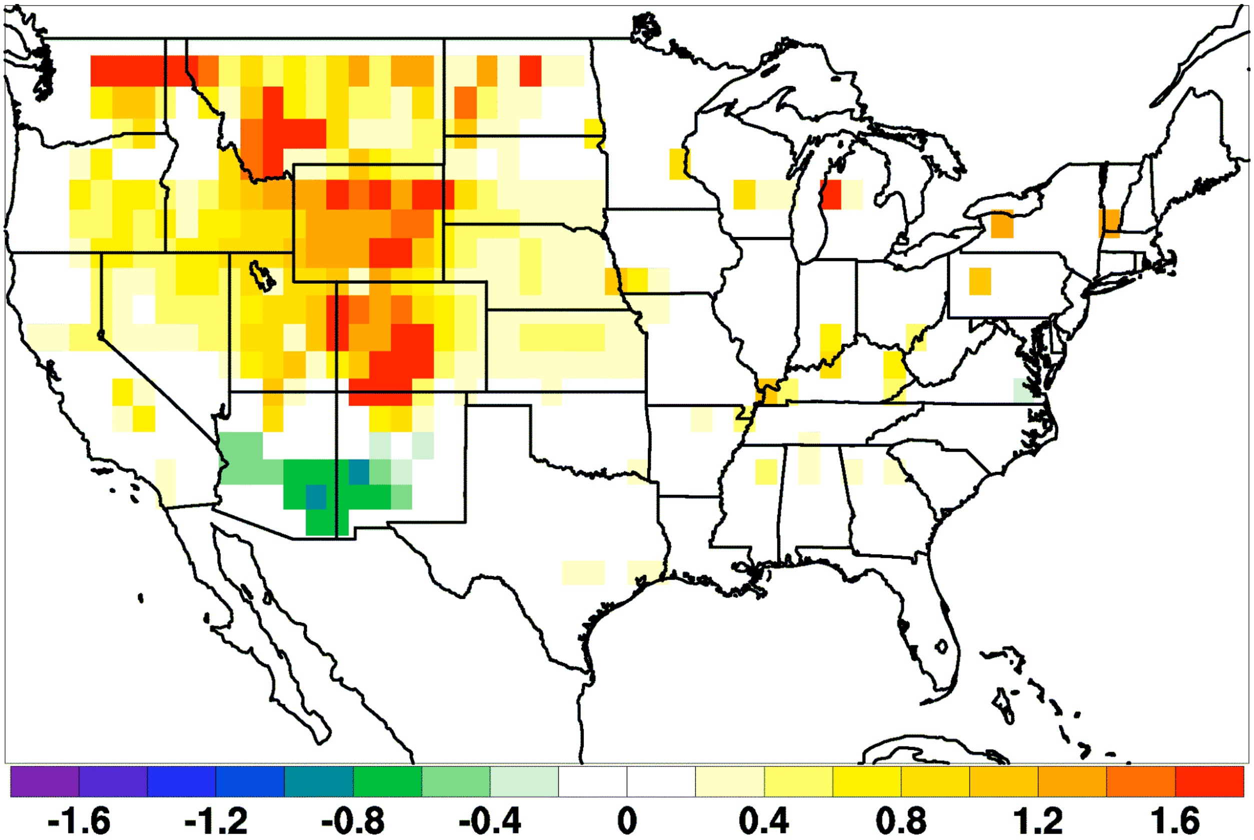


Figure 11. Example difference map of original forecasted standardized ERC values subtracted from standardized ERC forecast values based on temperature and relative humidity adjusted GFS values.

Figure 12 shows an example difference plot indicating how an original standardized ERC plot compares to a new standardized ERC plot after *both* the Daymet and GFS data adjustments have been applied. In this example map, the southwest and eastern U.S. appears to show a decrease in standardized ERC, whereas the central western US shows an increase. These regional changes will vary throughout the year in the climatology.

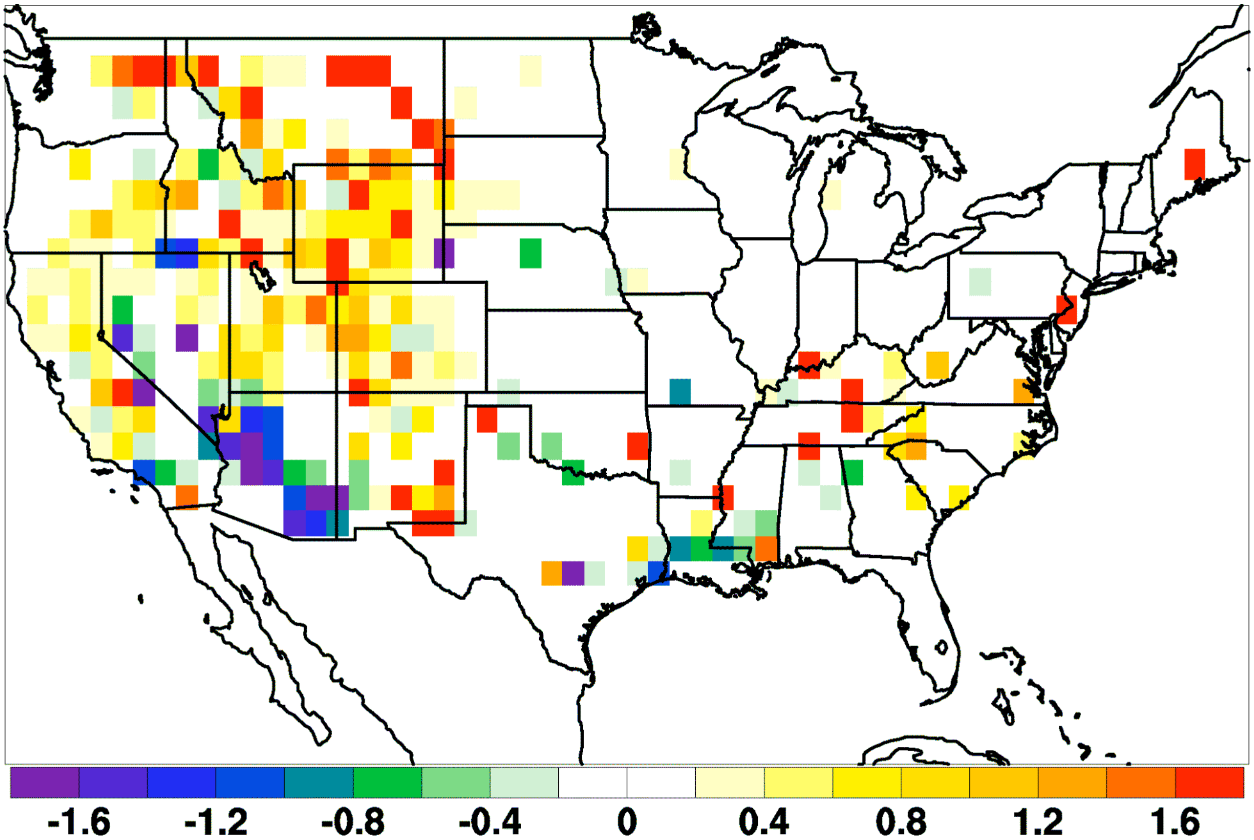


Figure 12. Example difference plot of adjusted standardized ERC minus unadjusted standardized ERC where both Daymet and GFS adjustments were applied.

2.7.2 Ensemble Forecast Validation

Equations derived from the GFS forecast model output and historical Daymet ERC validation analysis were applied to the ensemble forecasts of temperature and relative humidity. These forecasts are being provided on the deliverables web page; however, specific validation analysis for the ensemble forecasts was not undertaken.

3. DELIVERABLES

National standardized ERC forecasts maps are produced daily and made available to NICC from the Desert Research Institute (DRI) Program for Climate, Ecosystem, and

Fire Applications (CEFA) web site [http://cefa.dri.edu/data/NatlERC/natlErc.html]. ERC value, anomaly and standardized forecasts are provided daily out to 15 days based upon the 00 UTC GFS model run.

4. NEXT STEPS

Though validation analyses have been undertaken and data adjustments made, at present, the ERC forecasts are considered experimental and work in progress. It is recommended that users of this product continue evaluation regarding its usability, and provide feedback to CEFA. Despite the adjusting attempts, some areas may still be experiencing problematic output due to either or both Daymet and/or GFS distribution issues.

For future work, it is desirable to improve the ERC climatology such that bias and variance adjustments would not be needed, though these would still be appropriate for the GFS forecasts. One possibility that is being considered is using the National Centers for Environmental Prediction (NCEP) North American Regional Reanalysis (NARR) dataset to compute an ERC climatology. NARR output is based upon running a fixed numerical meteorological model with fully coupled physics between the atmosphere, ocean and land along with state-of-the art data assimilation. Output is available for a large number of meteorological variables for both the surface and upper atmosphere. The spatial resolution is 32 km, and output is produced at 3-hourly intervals for the period 1979 to present. This dataset basically provides the necessary weather input needed for NFDRS computation.

The current spatial resolution of the GFS forecasts is 1-degree (and 2.5 degree for days 8-15). It will be of interest to utilize finer spatial scale forecast grids as they become available (such as produced in the shorter-term 32 km Eta forecasts, or even the NWS gridded forecasts in the 2-4 km range should they become operationally available as two-week forecasts). It may also be desirable to perform statistical downscaling on current models to increase spatial resolution.

Finally, ensemble forecasts allow for indication of prediction uncertainty, and often exhibit skill improvement over single model output. Though ensemble forecasts of ERC are provided as a deliverable in this project, they have yet to be fully assessed for their utility in addressing agency forecast needs. However, they too are dependent upon a satisfactory ERC climatology, and so until this becomes available, further work on ensembles would be limited.

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