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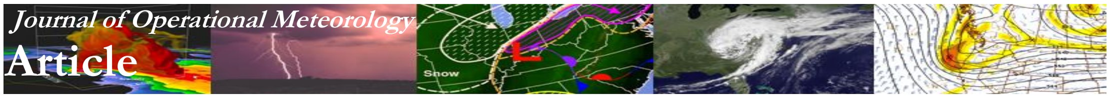

Verification of National Weather Service Spot Forecasts Using Surface Observations

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ABSTRACT

Software has been developed to evaluate National Weather Service spot forecasts. Fire management officials request spot forecasts from National Weather Service Weather Forecast Offices to provide detailed guidance as to atmospheric conditions in the vicinity of planned prescribed burns as well as wildfires that do not have incident meteorologists on site. This open source software with online display capabilities is used to examine an extensive set of spot forecasts of maximum temperature, minimum relative humidity, and maximum wind speed from April 2009 through November 2013 nationwide. The forecast values are compared to the closest available surface observations at stations installed primarily for fire weather and aviation applications. The accuracy of the spot forecasts is compared to those available from the National Digital Forecast Database (NDFD).

Spot forecasts for a selected prescribed burn are used to illustrate issues associated with the verification procedures. Cumulative statistics for National Weather Service County Warning Areas and for the nation are presented. Basic error and accuracy metrics for all available spot forecasts and the entire nation indicate that the skill of the spot forecasts is higher than that available from the NDFD, with the greatest improvement for maximum temperature and the least improvement for maximum wind speed.

1. Introduction

A 2008 National Oceanic and Atmospheric Administration (NOAA) report entitled, "Fire Weather Research: A Burning Agenda for NOAA," outlined the need for more robust forecast verification for wildland fire incidents (NOAA SAB 2008). National Weather Service (NWS) forecasters at Weather Forecast Offices (WFOs) have issued 103,370 forecasts, often at very short notice, requested by fire and emergency management professionals for specific locations, or "spots", during the April 2009 -

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November 2013 period. Spot forecasts are requested for prescribed burns, wildfires, search and rescue operations, and hazardous material incidents (Fig. 1). The Medford, OR (MFR) WFO issued the most prescribed burn forecasts while the Missoula, MT (MSO) WFO has been responsible for the most wildfire forecasts during this period. Nationwide, spot forecasts are issued twice as often for prescribed burns than for wildfires. NWS forecasters rarely receive detailed feedback from fire and emergency management professionals on the usefulness of their spot forecasts and no quantitative evaluation of spot forecasts has been undertaken nationwide.

Prescribed fires on federal or state land have operating plans that contain thresholds for atmospheric variables such as wind speed and relative humidity beyond which they should not commence burning. Spot forecasts play a central role in determining whether a burn is initiated on a given day. Of the 16,600+ prescribed burns undertaken in 2012, only 14 escaped (Wildland Fire Lessons Learned Center 2013). However, public reaction to this small number of escapes is overwhelmingly negative. Outcry from the Lower North Fork Fire, which broke out in smoldering litter four days after the prescribed burn work, destroyed 23 homes and 3 fatalities and led to modifications of the Colorado state constitution to allow victims of prescribed burn escapes to sue the state (Ingold 2012).

The nation is increasingly at risk for loss of life and damage to property as a result of wildfires (Calkin et al. 2014). During 2003, fires near San Diego, California destroyed over 3500 homes and killed 22 people (Hirschberg and Abrams 2011). Three fires (High Park, Waldo Canyon, and Black Forest) in the Front Range of Colorado in 2012 and 2013 destroyed a total of 1117 homes. Forecast guidance, issued by WFO forecasters initially and later by Incident Meteorologists as wildfires grow in extent and potential for harm, helps to determine the magnitude and placement of responding firefighters. In some circumstances, there is little that can be done to contain explosively developing conflagrations, but even when the ability to control a fire is diminished, accuracy in forecasting timing and intensity is essential. The deaths of 19 firefighters in Yarnell, AZ, caused in part by a sudden wind shift outflowing from a thunderstorm, underscore the need for capturing the wide range of possible fire weather conditions.

As reviewed by Myrick and Horel (2006), the goals of forecast verification fall into three categories:

- administrative (assess overall forecast performance for strategic planning),
- scientific (improve understanding of the nature and causes of forecast errors to improve future forecasts),
- economic (assess the value of the forecasts to the end users).

This research is focused on the first two categories. Joliffe and Stephenson (2003) and Wilks (2006) define objective estimates of forecast quality that are appropriate for administrative-oriented verification at the national level as well as scientific-oriented verification that can provide feedback directly to the forecasters. Both needs can be addressed as outlined by Murphy and Winkler (1986) either in terms of measures-oriented or distributions-oriented verification. The former is centered on statistics such as bias, root-mean squared error, or other skill scores developed to contrast forecasts with verifying data. Nevertheless, as Murphy and Winkler (1986) state regarding measures-oriented approaches, "they are not particularly helpful when it comes to obtaining a more detailed understanding of the strengths and weaknesses in forecasts or to identifying ways in which the forecasts might be improved".

The distributions-oriented method alleviates some of these concerns in part by presenting more detailed information about the relationships between the forecasts and the verifying observations. It allows for any type of forecast to be examined, whether for a discrete or continuous variable and whether done in a categorical or probabilistic manner. The locations of errors are also exposed more effectively, as breaking up the joint, marginal, and conditional distributions allows for the inspection of categorical errors that only occur under certain conditions. Horel et al. (2014) illustrate how the skill of forecasts for fire weather applications can be evaluated using both measures- and distributions-oriented statistics.

Brown and Murphy (1987) provide an excellent example of evaluating fire weather forecasts. Forecasts issued by the Boise WFO in 1984 for the Black Rock Ranger Station in Wyoming were evaluated. The forecasters were instructed to issue not only an anticipated value, but also projected 25th and 75th percentile values. They found a slight warm/dry bias in maximum temperature and minimum relative humidity forecasts. They suggest that the biases are due to the forecasters' perceptions of the consequences to fire professionals of underforecasting the maximum temperature and maximum wind speed, while overforecasting minimum relative humidity, such that fire danger calculations would then be underestimated. The forecaster does not desire to leave the fire officials ill prepared for potential curing of fuels. Brown and Murphy (1987) also suggested that difficulties in quantifying uncertainty by the forecasters (i.e., predicting the upper and lower quartile values) led to negative skill in relative humidity and wind speed relative to climatological forecasts.

The objectives of this research have been to: (1) facilitate the transfer from research to operations of methodologies to verify spot forecasts and (2) assess the degree of improvement provided by such forecasts relative to those available from the National Digital Forecast Database (NDFD) (Glahn and Ruth 2003). Forecasters require verification of their spot forecasts to help improve those forecasts, and fire and emergency management personnel need to be able to develop confidence regarding the skill of those forecasts. To demonstrate the capabilities of the tools developed, we limit this study to evaluating quantitatively maximum temperature, minimum relative humidity, and maximum wind speed. These variables are central to estimates of fire spread rates and hence affect fire management and containment activities.

Lammers (2014) describes the procedures developed to verify spot forecasts and a broader set of cases and statistics than possible here. Before summarizing national statistics primarily for prescribed burns, we illustrate validating spot forecasts using a prescribed burn case (Box Creek), and cumulative statistics from the Tucson WFO. Lammers (2014) examines additional prescribed burn and wildfire cases, statistics for other WFOs, and cumulative statistics for wildfire spot forecasts in greater detail.

2. Data

a. Spot Forecasts

Spot forecasts are issued by forecasters at NWS WFOs for four primary purposes: prescribed burns, wildfires, search and rescue, and hazardous materials (Fig. 1). Professionals submit an online request form outlining the reason for needing the forecast and other pertinent information (Fig. 2). The resulting request is stored as a text document (Fig. 3).

The spot forecast itself contains four primary sections, each of which is represented in the example product in Fig. 4. The first contains basic information: name of the fire, land ownership, time the forecast was issued, and contact information for the forecast office. The second section is a free form discussion of anticipated conditions, including wind shifts, trends, potential for thunderstorms and lightning, or simply providing context for the forecasted conditions relative to recent observed values. Detailed forecasts follow of requested values for the requested time periods. Often these periods are “Today” or “Rest of Today,” “Tonight,” and the next day. Finally, the spot forecast identifies the forecaster responsible, the requestor, and the type of request.

From the Graphical Forecast Editor (GFE) within their Automated Weather Interactive Processing System (AWIPS) workstation, forecasters can choose to populate the requested specific forecast values for each time period from the locally stored gridded fields at the WFO or enter the requested values manually (Mathewson 1996; Hansen 2001). The forecast grid files at the WFOs are often at higher spatial resolution than those stored as part of the NDFD national products. Considerable effort is spent by forecasters adjusting numerical guidance and previous forecast fields to update their local grids several times per day (Myrick and Horel 2006; Stuart et al. 2007; Horel et al. 2014). After reviewing additional information, the forecaster may then choose to adjust the values initially populated by the GFE as needed based on their interpretation of the forecast situation. Integrating forecaster experience and conceptual models with datasets available on AWIPS is a useful approach in operational forecasting (Andra et al. 2002; Morss and Ralph 2007). Whether by request or forecaster prerogative, the "Today" forecast regularly includes more detailed hourly or bi-hourly values, which can prove highly useful to end users in the case of a frontal passage or anticipated wind shift.

b. NDFD Forecasts

NWS WFOs release their forecasts for their respective County Warning Areas (CWAs) as gridded products, which are stored nationally as part of the NDFD at 5 km horizontal resolution during the majority of the period evaluated in this study (Glahn and Ruth 2003). A goal of this study is to assess the extent to which the numerical components of the spot forecasts provide improved forecast guidance relative to the NDFD forecasts. Of course, the NDFD forecasts can replace neither the critical "Discussion" section provided by the forecaster nor the valuable information on terrain-relative flows (e.g., up-slope/up-valley) often provided within the forecast guidance, broken down by time period, that take into account local knowledge of topographic features.

The online web tools developed as part of this project make it possible to compare NDFD and spot forecasts for all available forecasts. However, in order to evaluate a consistent set of NDFD and spot forecasts, the 0900 UTC NDFD forecasts for the afternoon/evening (6-, 9-, 12-, and 15-hour forecasts for 15, 18, 21, and 24 UTC) are used as a baseline for comparison with spot forecasts issued commonly in the early morning. NDFD values are extracted from the nearest neighbor grid points to the spot forecast locations.

c. Validation Datasets

Fire professionals rely most heavily on surface observing stations installed by land agencies as part of the Remote Automated Weather System (RAWS, Horel and Dong 2010). There were, as of November 2013, 2277 RAWS stations in operation from which data are archived in the MesoWest database (Horel et al. 2002). Equally relevant for this study to validate the spot and NDFD forecasts are the additional 2289 NWS/Federal Aviation Administration stations as of November 2013. As shown in Fig. 5, the density of the observations from these two networks varies across the nation, with the highest number in California. While data from an additional 25,000 surface observing stations are available in MesoWest (see http://mesowest.utah.edu), the RAWS and NWS/FAA networks are relied on most heavily by NWS forecasters issuing spot forecasts. In addition, forecasters depend on standardized equipment and maintenance standards (Horel and Dong 2010), e.g., both networks report temperature and relative humidity at ~2 m (~6.6 ft). Permanent RAWS stations report wind speed at 6.1 meters (20 ft), which has been the desired height for fire management operations, as well as the height at which wind speed is generally forecast in spot forecasts. Temporary RAWS stations are often deployed to support planning for prescribed burns and provide wind speed at 3 m (10 ft). NWS/FAA stations report wind speed at 10 m (33 ft) to meet the goals of aviation applications.

The National Center for Environmental Prediction (NCEP) has generated the Real-Time Mesoscale Analysis (RTMA) since 2006, providing hourly analyses of surface atmospheric variables (de Pondeca et al. 2011). This study used the operational 5 km gridded fields available during most of this study period, although operational RTMA grids are now available at 2.5 km resolution. While it can be generally assumed that nearly all NWS/FAA and most RAWS observations are used in the RTMA analyses, some RAWS observations are not received in time for the RTMA due to latencies in satellite data transmission. The analyses provide a point of comparison within at most a few km of the location requested for the spot forecast. We focus here on validating the spot forecasts relative to nearby observations; see Lammers (2014) for more in-depth discussion about verifying the forecasts using the RTMA grids.

3. Methods

a. Text Parsing

The mix of textual and numerical values contained in spot forecasts (Fig. 4) makes it difficult to extract pertinent information for verification. The numerical values contained within the spot forecasts are not separated and sent to a centralized online database. NWS forecasters rely on the GFE to translate quantitative information into text products for the general public and other customers. However, validating spot forecasts requires the inverse, reverting from text products back to numerical values. Hence, natural language methodologies were developed as part of this project to parse the forecast values from the freeform text of the spot forecasts. The resulting code was found to be adequate to evaluate spot forecasts for all CWAs, and minimized the number of forecasts dropped due to inability to parse the text properly (i.e., 9854 forecasts of the 71,070 forecasts issued during the study period were not able to be processed).

Development of the validation web tools has focused on analyzing those spot forecasts that are labeled “WILDFIRE” or “PRESCRIBED.” Large sections of text for those spot forecast types are ignored because they are outside the scope of the research, e.g., the “Discussion” section. Most spot forecasts for prescribed burns are issued in the morning for the remainder of the day, such that the section following the “Discussion” focuses on “Today” or “Rest of Today.” Requests for prescribed spot forecasts often are submitted the night before scheduled burn operations, but the forecasts are not required nor desired until early morning. Within the “Today” or “Rest of Today” block, relevant numerical values are obtained for maximum temperature, minimum relative humidity, and maximum wind speed.

Handling wind is more complicated than what is required for temperature or humidity. Consider the following snippets of content from spot forecasts. “LIGHT AND VARIABLE WINDS BECOMING SOUTHWEST 5 MPH EARLY IN THE AFTERNOON…THEN BECOMING LIGHT AND VARIABLE LATE IN THE AFTERNOON.” Or: “UPSLOPE/UPVALLEY 6 to 11 MPH. GUSTY AND ERRATIC IN THE VICINITY OF THUNDERSTORMS.” While an end user can glean useful information from such forecasts, the lack of specificity makes it difficult to validate against observations that are reported at typically hourly intervals. What is the wind speed corresponding to light and variable? When specifically is early or late afternoon? What direction is upslope or upvalley? What is gusty and erratic? Hence, a pragmatic approach was adopted to simply focus on the maximum wind speed forecasted, ignoring directional terms or phrases related to wind gusts. Forecasters in a specific CWA may be required to forecast winds at a single level or multiple levels using different definitions (e.g., “20 FT”, “20 FOOT,”, “EYE LEVEL,” or “GENERAL”). To obtain the most reasonable maximum wind speed forecast value for validation, 20 ft winds are preferred, since that is the height of permanent RAWS sensors. If there are two forecasts for wind speed for the day (e.g., one that is more free-flowing, and one that specifies by hour or every two hours), then the maximum of all the values is kept.

b. Verification

As described previously, the spot and NDFD forecasts are compared to RAWS and NWS/FAA observations as well as RTMA analyses. It is important to distinguish between the broader capabilities of the online web tools developed as part of this project and the more restrictive limits used to address the objectives of this study. For this study, the latitude and longitude extracted from the request form are used to define the station nearest to the spot forecast location within a horizontal distance of 50 km and vertical distance of 333 m. Only 1054 forecasts were removed from the analysis because they did not have a station within those distances. The maximum temperature and wind speed and minimum relative humidity are determined and stored from all values available between 16 UTC and 24 UTC and simple range checks are used to eliminate occasionally erroneous values. The maximum temperature and wind speed and minimum relative humidity from all RTMA values between 16 UTC and 24 UTC at the nearest neighboring gridpoint to the spot forecast location were also obtained. Similar values were also extracted from the NDFD grids for comparison to the spot forecasts.

Measures-oriented metrics that are used to evaluate the spot and NDFD forecasts are the average difference between forecasts and verifying data (i.e., the bias or Mean Error, ME) and Median Absolute Error (MAE), which is less sensitive to outliers than the mean absolute error.

c. Online Tools

As described by Murphy (1991), the large dimensionality implicit in forecast verification inhibits documenting all of the characteristics of these spot forecasts in this single study. For the April 2009 – November 2013 period, there were 44,901 prescribed burn and 16,280 wildfire forecasts that could be verified. It is important as well to be able to examine forecast skill as a function of the particular values of the forecasts or the verifying observations or analyses. Hence, a central goal of this study was to develop tools that forecasters and end users can use to evaluate the forecasts of interest to them, rather than attempting to relate cumulative statistics over a limited sample of broad categories to their needs. These tools are available at http://meso1.chpc.utah.edu/jfsp/.

In order to be able to rapidly query such a large data set that is continually updating, a comma-separated text file containing every valid forecast with the corresponding nearby observations, NDFD forecasts, and RTMA values is created. To alleviate the complexity of the multivariate nature of the spot forecasts, the open source Crossfilter code developed by Square, Inc., is used that allows for near-instantaneous slicing on each axis of a multidimensional data set. That allows users to create histograms conditioned on ranges of values in multiple dimensions, i.e., within selected elevation ranges, times of year, values of variables (for example, maximum temperature in the range 20-25^{o}C), etc. These histograms then can be adjusted dynamically by the user based on selections in other histograms. The Crossfilter object is instantiated by simply pulling in the necessary information in comma-separated format. Filters are generated on one or more of the variables so that the user can make selections based on ranges of values, but also visualize the impact of other selections on these variables.

Consider the verification data available at http://meso1.chpc.utah.edu/jfsp/statsAllWF.html for all wildfires starting 1 April 2009 and updating daily. A short description of the forecasts available for this page is provided, followed by a histogram of the number of forecasts broken down by date, a series of other tabs, and a map with red markers for accurate spot forecasts issued during that period. Black markers are forecasts that are assumed to have less skill since they deviated from the surface observation by user-selectable values that default to ±2.5^{o}C, ±5% relative humidity, and ±2.5 m s^{-1} (Fig. 6). By clicking on any of the markers, a window is displayed that contains the parsed values from each of the data sets that were used for verifying that forecast. There are also links to the spot forecast and to the MesoWest page for that station for the day of the forecast to be able to examine the observed conditions in more detail.

On either side of the histogram of forecasts binned by month are two “brushes.” Dragging them to restrict the range of allowable months adjusts the markers on the map to only reflect those forecasts that were issued during that time frame. It also modifies all of the other multivariate histograms that are initially hidden within the clickable tabs. As many of these tabs can be opened as are desired by the user, and brushes can be used on every histogram to pare down the number of forecasts to only those they wish to view on the map and see reflected in the histograms. By leveraging these web tools, basic questions about the distributions of errors and the relationships between variables can be addressed without searching endless archived figures. Since the intention is for such tools to be used operationally, they must be dynamic such that recent forecasts are constantly being provided to the forecasters and end users.

4. Analysis and Discussion

a. Box Creek Prescribed Fire

The Box Creek Prescribed Fire occurred in the Fishlake National Forest of Southern Utah in May 2012 (USFS 2012). A crew ignited a test fire on 15 May that burned for a few days under containment. According to the Facilitated Learning Analysis (FLA), spot forecasts were requested “and referenced against observed weather conditions and feedback was given to the meteorologist. The spots lined up with conditions on the ground very well. This provided the RXB2 (Burn Boss) with much confidence in the meteorologist’s forecasts” (USFS 2012). The FLA also stated that ignitions were halted for several days due to unfavorable winds and did not resume until 29 May. Mop-up and patrol operations followed until 4 June, when torching and spotting were observed to an extent that on-site resources could not contain it within the prescription boundary. Weather conditions in this area were warmer and drier on 4 June than typical for this time of year. No prescribed burn spot forecast was requested on the morning of 4 June since the fire was assumed to be contained. A wildfire spot forecast was requested later that afternoon and subsequent ones continued to be issued until June 17.

As an illustration of the web tools developed for verifying prescribed and wildfire forecasts, the sample of 23 spot forecasts and verifying data for this case are accessible via the following web page: http://meso1.chpc.utah.edu/jfsp/BoxCreek.html. Figure 7 contrasts the spot forecasts of temperature, relative humidity, and wind speed issued for the Box Creek fire to the observations from the portable RAWS (FISHLAKE PT #4, assigned MesoWest identifier TT084) deployed 3 km and 56 m above the average burn elevation, which was sited to support the prescribed fire operations. Figure 7 also contains the NDFD gridpoint values and RTMA values at the specified forecast location. Figure 8 shows histograms of differences between the 23 spot forecasts and the corresponding conditions observed at TT084 and analyzed by the RTMA. The user-controlled whisker filters available on the web page can be used to isolate, for example, which forecasts are outliers (i.e., 26 May with a ~7^{o}C temperature error, see also Fig. 7) or the date when the location requested for the spot forecasts shifted several km further south (29 May).

Using the default thresholds for accuracy for temperature, relative humidity, and wind speed spot forecasts of 2.5^{o}C, 5%, and 2.5 m s^{-1}, respectively, then Fig. 8 indicates that 18 temperature, 19 relative humidity, and 18 wind speed forecasts would be considered accurate relative to the observations for this sample of 23 forecasts. However, 3 temperature, 12 relative humidity, and 21 wind speed forecasts would be considered accurate using the same thresholds when verified against the RTMA (Fig. 8). The lower accuracy implied by the comparison to the RTMA results in this instance from the RTMA's warm, dry bias due to a lower elevation specified in the analyses for the verifying gridpoint (2690 m) compared to that used by the forecaster (2896 m) or that of TT084 (2952 m).

In order to evaluate the accuracy of the spot forecasts for the Box Creek fire relative to the values available from the NDFD, Fig. 9 tabulates the departures of the spot and NDFD forecasts from the TT084 observations into bins defined in terms of their absolute error following the approach of Myrick and Horel (2006). Note that the sample size is reduced to 19 since four NDFD forecasts are not available in the NDFD archive at the University of Utah. Columns reflect increasing error from left to right of the spot forecasts while rows indicate increasing error from top to bottom of the NDFD forecasts. Each bin is split further such that the values above (below) the diagonal line indicate forecasts for which the forecaster made no or small (large) changes relative to the NDFD guidance. The thresholds for distinguishing between small and large deviations from the NDFD guidance are set for temperature, relative humidity, and wind speed by default to 1^{o}C, 5%, and 1 m s^{-1}, respectively. It is readily apparent from Fig. 9 that 17 (7) of the 19 temperature spot (NDFD) forecasts would be considered accurate. The light shading in the left column highlights the 10 cases where the forecasters provided improved temperature guidance relative to the NDFD values. The forecasters never degraded accurate NDFD forecasts in this case (dark shading in the top row). However, only 1 relative humidity and 3 wind speed NDFD forecasts were improved to the point they would be considered accurate while the accuracy was lowered for 3 NDFD wind speed forecasts.

b. Tucson WFO

The Tucson CWA in the southeast corner of Arizona experiences, not surprisingly, hot and dry conditions (i.e., there are no spot forecasts issued for maximum temperature below 10^{0}C or minimum relative humidity above 60%). There were 214 prescribed burn forecasts issued during the 2009-2013 period and 258 wildfire forecasts. As summarized in Figs. 10a and 10b, Tucson forecasters tend to overforecast maximum temperature and underforecast minimum relative humidity. We will show later that the Tucson warm, dry bias of ~1.7^{o}C and 3% for prescribed burn forecasts differs from the majority of WFOs that exhibit a slight cool, wet bias relative to the observations. Further, only ~10% of prescribed burn forecasts (Fig. 10a) and ~20% of wildfire forecasts (not shown) called for maximum temperatures less than what was observed. NDFD forecasts exhibit less noticeable biases in temperature and relative humidity (Figs. 10c and 10d).

As summarized in Fig. 11a, 74% of the NDFD maximum temperature forecasts for prescribed burns in the Tucson CWA are considered accurate while 65% of the spot forecasts exhibit similar accuracy. Tucson forecasters modify by more than 1^{o}C accurate NDFD forecasts 60% of the time and thereby reduce the accuracy of NDFD forecasts for 24% of these cases (dark shading in the top row) while only 14.5% of inaccurate NDFD forecasts are improved (light shading in the left column). Similarly, the accuracy of NDFD relative humidity forecasts is higher than that of the spot forecasts with more reductions in accuracy than improvements. Forecasters adjust on average the temperatures to be nearly 3^{0}C warmer and relative humidity to be ~7% drier than the corresponding NDFD values (not shown). The maximum wind speed spot forecasts issued by the Tucson WFO for prescribed burns improve upon the NDFD gridded values more often than they degrade them (Fig. 11c). The marginal percentage of accurate spot forecasts is 69.8% while that of NDFD forecasts is 64.7%. For wildfire spot forecasts, this improvement is enhanced (not shown), with spot forecasts improving on 20.4% of cases while they degraded only 6.1% of them.

Hence, Tucson forecasters tend to supply temperature and humidity (wind) spot forecasts that are less (more) accurate than the gridded values they provide for general applications.

These forecasts tend to err conservatively for fire weather operations by anticipating higher fire danger via higher maximum temperature and lower minimum relative humidity forecasts.

c. Cumulative Statistics

Cumulative statistics for prescribed burns nationwide are now summarized with less information presented for wildfires due to constraints on publication length. A total of 44,901 (16,280) prescribed burn (wildfire) spot forecasts were analyzed for the afternoon forecast period between 1 April 2009 and 30 November 2013 with at least one prescribed burn forecast issued in every state as well as Puerto Rico (Fig. 12a). The months with the most prescribed burn forecasts were April 2010 and March and April 2012 (Fig. 13a). Whereas prescribed burn forecasts are spread fairly evenly throughout the country, wildfire forecasts are concentrated in the western United States with sizeable numbers in Florida as well as from Eastern Michigan through North Dakota (Fig. 12b). As shown in Fig. 13b, the months with the largest number of spot forecasts issued for wildfires are July and August with 1,043 spot forecasts that could be verified during August 2011; only 3 wildfire forecasts were verified during December 2009.

As summarized in Table 1, the temperature spot forecasts for prescribed burns have a slight cool bias (-0.5^{o}C ME) and a 1.3^{o}C MAE when verified against the observed maximum temperatures. The slight cool bias is evident in the forecast error histogram (Fig. 14). The bimodal peak surrounding zero results from binning temperature forecasts that are available frequently as integer Fahrenheit values. Comparing NDFD forecasts to the observations suggests that the NDFD forecasts are more biased (-1.7^{o}C ME), less accurate (1.7^{o}C MAE), and their errors relative to observations skewed more negatively than the spot forecasts (Table 1 and Fig. 14). Overall, the RTMA temperatures exhibit a cool bias relative to the verifying observations that leads the spot forecasts to appear to have higher temperatures than the RTMA grid values.

Focusing on WFOs with at least 100 prescribed burn forecasts (Fig. 12a), the Phoenix (PSR) and Tucson (TWC) CWAs are among the few that exhibit a warm bias in Fig. 15a, with most CWAs exhibiting cool biases (e.g., particularly Reno, REV and Grand Junction, GJT). WFOs in the western United States and those containing large sections of the Appalachian Mountains tend toward higher MAE values than those in the Great Plains and the South (Fig. 15b). Both Melbourne, FL (MLB) and Springfield, MO (SGF) provide accurate temperature forecasts with MAEs of just 1.1^{o}C. Only one forecast issued by Springfield had a temperature error greater than 5^{o}C out of 165 forecasts. The cool biases evident in REV and GJT contribute to large MAE values for temperature as well (Fig. 15b).

Figure 16 tabulates the temperature errors of spot forecasts for prescribed burns compared to those for NDFD forecasts. The values in the upper left bin are ones where the NDFD and spot forecasts were accurate and the forecaster either made only minor changes of less than 1^{o}C (40.4%) or else they made slightly more substantive changes (18.8%). Of greater interest are the sums excluding the upper left bin of: (1) the light shaded values in the left column (i.e., where the forecasters made changes relative to the NDFD gridded values that resulted in accurate forecasts) and (2) the dark shaded values in the uppermost row (i.e., where the NDFD forecasts were accurate and the manual adjustments provided by the forecasters degraded the skillful forecast available from the NDFD). For maximum temperature forecasts those values are 16.1% compared to 6.5%, which suggests that the manual intervention by the forecasters improved the spot forecast compared to NDFD forecasts by 9.6% (Table 2). Of particular note are the 2.8% of the forecasts in Fig. 16a where the NDFD forecasts deviated from the verifying observations by more than 7.5^{o}C while the forecasters adjusted those values substantively and provided spot forecasts within 2.5^{o}C.

As summarized in Table 1, spot forecasts for prescribed burns performed better than the NDFD gridded forecasts for minimum relative humidity in terms of both bias (1.5% wet bias for spot forecasts, 6.0% wet bias for NDFD) and accuracy (5.3% MAE for spot forecasts, 6.0% for NDFD). The cumulative error histograms confirm the slight wet biases of both spot and NDFD forecasts (Fig. 17). The RTMA grid values tend to have higher relative humidity than the nearest observations, leading to the apparent dry bias of the spot forecasts relative to the RTMA (Table 1).

Forecasters at most WFOs tend to have a wet bias (i.e., positive ME for most CWAs in Fig. 18a). Notable exceptions are Tucson discussed previously as well as Eureka (EKA; see Lammers 2014 for discussion of relative humidity errors in the EKA CWA). The regions with less accurate minimum relative humidity forecasts are those with generally higher relative humidity values in general: the Pacific Coastal states, the Central Appalachian Mountains, and parts of the Great Plains (Fig. 18b). CWAs in the desert southwest and other regions where relative humidity values tend to be low exhibit higher accuracy in terms of MAE, e.g., Midland/Odessa (MAF) provided overall the most accurate relative humidity forecasts.

As shown in Fig. 19, the assumption of accurate minimum relative humidity forecasts to be within 5% of a nearby observation reduces the overall accuracy of both NDFD and spot forecasts. Alternatively, one can simply assume an accuracy threshold of 10% and add the percentages in the first two columns (rows) for the spot (NDFD) forecasts. The relative accuracy of the spot vs. NDFD forecasts for minimum relative humidity forecasts is less than that for maximum temperature. Forecasters improved substantively upon 15.7% of the NDFD forecasts and degraded 11%, which suggests an improvement in accuracy of 4.7% as a result of forecasters adjusting the NDFD values for the nation as a whole (Table 2).

A smaller sample of 38,017 prescribed burn forecasts for maximum wind speed is available due to the greater difficulty in parsing the spot wind speed forecasts. As evident in Table 1, both spot and NDFD forecasts exhibit slight overforecasting errors (ME values of 0.2 m s^{-1} and 0.4 m s^{-1}, respectively). Validating maximum wind speed forecasts relative to the RTMA rather than nearby observations leads to similar ME and MAE values (Table 1). The positive biases are also evident in the histograms in Fig. 20 although the values appear slightly shifted to the left simply because the values are plotted at the lower edges of the 1 m s^{-1} bins. The positive biases apparent for the larger number of prescribed burns in the western CWAs dominate over the CWAs in the central and eastern United States with negative biases calculated from smaller sample sizes (Fig. 21a). There is less regional homogeneity in terms of MAE, although Rocky Mountain offices are slightly less accurate (Figure 21b). Jackson, MS WFO (JAN) issued the most accurate maximum wind speed forecasts, with a MAE value of only 0.85 m s^{-1} over 537 forecasts. As evident in the upper left bin in Fig. 22, accurate forecasts were provided 65.1% of the time by both the prescribed burn spot and NDFD forecasts. Adjustments by the forecasters for 11% of the poor NDFD forecasts result in accurate spot forecasts although modifications to 9.4% of the NDFD forecasts degraded them (Table 2).

Briefly summarizing the spot forecasts provided for wildfires, the maximum temperature forecasts overall have a -0.3^{o}C ME while the NDFD forecast errors are more negatively skewed with a cool bias of -1.5^{o}C (Table 1). The MAE of the wildfire spot (NDFD) forecasts versus the observations is 1.7^{o}C (2.0^{o}C), suggesting that the wildfire spot forecasts improve upon NDFD gridded values for maximum temperature (Table 1). As shown in Table 2, 66.6% (59.1%) of the wildfire spot (NDFD) maximum temperature forecasts are judged to be accurate (within 2.5^{o}C of nearby observations), reflecting a substantive improvement of accuracy for 7.5% of the wildfire forecasts. As shown in Table 1, the ME for wildfire spot relative humidity forecasts is only 0.7%, while NDFD forecasts have a ME of 4.1% with a 1.05% lower MAE for spot forecasts compared to NDFD forecasts. Forecasters provided accurate minimum relative humidity forecasts 51.3% of the time, an increase of 3.8% compared to NDFD forecasts (Table 2).

Forecasting maximum wind speed effectively is crucial for containing and combatting wildfires, especially in their early stages. As shown in Table 1, the ME for spot (NDFD) forecasts is 0.7 m s^{-1} (0.8 m s^{-1}) and corresponding MAE values of 1.5 m s^{-1} (1.6 m s^{-1}), respectively. All of the Western United States offices save San Diego have positive biases for wind speed, while the Eastern offices have varying ME values (not shown). Similar to the prescribed burn maximum wind speed forecasts, 58.2% of the wildfire maximum wind speed forecasts supplied by the NDFD grids are equally accurate to those provided by the spot forecasts (Table 2). Adjustments to the NDFD grid values by the forecasters provided only a net increase in accurate forecasts of 1.6%.

5. Conclusions

The objective of this study was to develop a framework to evaluate spot forecasts for the benefit of the forecasters who provide them as well as the fire and emergency management professionals who request them. While commercial software is available for individuals to quantify metrics and distributions of forecast errors, flexible open source web tools were developed to allow users to evaluate the cases of interest to them, which helps identify the causes and ramifications of forecast errors. To implement these verification tools is beyond the scope of this study and requires transitioning to, or developing similar capabilities in, an operational entity, such as the NWS Performance Branch.

Spot forecasts are integral to the current fire management system in place in the United States. They guide officials in prescribed burn and wildfire decision making, helping to protect life and property. As shown in this research, spot forecasts have added skill above the gridded guidance issued by forecast offices in forecasting for specific locations the daily maximum temperature, minimum relative humidity, and maximum sustained wind speed. There remain areas for improvement in both the forecasting process and our verification techniques, but we have shown that these text products can be verified in an automated and systematic manner, and that meaningful information can be extracted by such verification to help forecasters and end users alike.

a. Prescribed Burn and Wildfire Spot Forecasts

Prescribed burns are anticipated in management plans developed by wildland fire management officials at lead times of months or even years for publicly owned locations. Wildfires are spontaneous and can occur anywhere there is fuel to burn. Forecasters are called upon to provide detailed forecasts conditions for both types of fires. Because of the need for immediate assessment of potential fire danger, wildfire forecasts are turned around quickly, with 71% having lead time (the difference between the recorded receipt of the request and spot forecast issuance) less than 50 minutes. For prescribed burns, only 27% are issued in 50 minutes or less from the recorded receipt of the request, suggesting that forecasters have more time to evaluate the forecast situation.

An objective of this study was to assess the specific guidance provided by the forecasters relative to that available from the grids they develop for more general purposes that are archived as part of the NDFD. This evaluation is far from a comprehensive evaluation of the skill of the spot forecasts, since it is restricted to assessing the spot forecasts of temperature, relative humidity, and wind speed during the afternoon relative to NDFD grids available earlier in the day at 0900 UTC. Every summary metric (e.g., see Tables 1 and 2) indicates that the accuracy of spot forecasts is higher than that of the values obtained from the NDFD grids for both prescribed burns and wildfires. The improvement is largest for maximum temperature (9.6% and 7.5% for prescribed burns and wildfires, respectively) and lowest for maximum wind speed (1.6% for both categories). While forecasters often adjust their forecasts to deviate from the NDFD values, those adjustments do not display substantial improvement for maximum wind speed while adding considerable value for maximum temperature.

b. Recommendations

Forecast verification is a continual, ongoing process. Tools must be in place that make it possible for the forecasters and users of the forecasts to quickly examine cases and aggregate statistics of interest to them using their experience and local knowledge, rather than depending on bulk statistical metrics accumulated on national scales as summarized in this study. In order to develop useful verification tools for spot forecasts operationally requires minimizing some of the underlying limitations identified during this study.

The principal recommendation of this study is to leave the decisions as to what to verify and how to verify the forecasts in the hands of the forecasters and end users by developing flexible methods to explore the multidimensional nature of the forecasts. Foremost is simply the need to be able to examine the following in a centralized framework: the requests, the forecasts, geolocation information, and nearby observations and other information relevant to analyzing the forecast situation. While this may seem obvious, it has never been possible before this study developed such capabilities. Then, the user should be able to explore and control interactively key parameters (e.g., distance to the verifying observations, forecast lead times, magnitudes of the parameters, or magnitudes of the errors). Currently, much of the verification performed on the federal level centers on aggregate statistics that fail to capture the nuance necessary for evaluating spot forecasts. In order to make the tools described in this study more appropriate for operational use, several limitations need to be overcome as summarized here and detailed below:

- Isolate quantitative numerical values separately from qualitative alphabetical descriptors.
- Make forecast wind level a numerical parameter adjustable within the request form, so that even when it is not "20-Foot," the level is known for evaluation.
- Store the name of or abbreviation referencing the specific station that should be used for verification as part of the request form. This should include stations from networks not used in this study.
- Evaluate other variables
- Expand the verification time window.

1) SEPARATE NUMERICAL VALUES AND TEXT IN THE SPOT FORECAST

As every WFO coordinates locally with its user community to specify the fields to be included in the spot request, creating a text parser that correctly captures the intention of the forecasts on a national basis is a complex and frustrating endeavor. The parsing algorithms developed here occasionally still fail either by eliminating forecasts from consideration (most often for wind speed) or populating spurious values for verification. Forecasters and end users need to evaluate all forecasts, otherwise the utility of the verification process is undermined. Of course, the factors that make parsing difficult add value for fire and emergency management professionals, contributing layers of detail on timing and variability that help to make critical personnel and containment decisions. This free form information should not be removed from the spot forecasts, nor should all the requests be standardized into a single request form on a national basis. Rather, alternative methods to separate the basic numerical information from the free form information should be straightforward to implement.

2) IMPROVE CONSISTENCY IN THE REQUEST FORM

The adjustments required during this study to capture all the variations to simply define the height of the wind forecasts should be avoided in the future. Initially, it was assumed after inspection of many request and forecast pairs that to parse maximum wind speed from the forecasts required searching for “20 FOOT” or “20 FT.” However, forecast offices changed over time their definitions (e.g., the Salt Lake City WFO in late-2010 switched to “20-FOOT” while others switched to 20FT) or, due to requests from their users, other offices use “EYE LEVEL” (Boise) or “GENERAL” (Marquette). Presumably, in the latter cases, communication with those specific user communities could lead to standardization of what is provided to them. More generally, the level of the wind should be specified in the request form (not input or selectable independently by the forecaster in the spot forecast) so that the values provided in the spot forecast are numerical values supplemented by the height descriptor from the request form.

3) ALLOW USERS TO SPECIFY THE VERIFICATION DATA

The number of forecasts that were not analyzed in this study because of lack of nearby observations was relatively small because observations at often large distances from the spot location were allowed to be used (up to 50 km). Apparent systematic biases when verifying the forecasts relative to the RTMA values (Table 1) suggest that verifying the spot forecasts relative to nearby observations remains the best approach at this time. However, evaluating spot forecasts particularly in complex terrain necessitates allowing users to ascertain which observations to use. This study and the web tools developed for it relied only on NWS/FAA and RAWS observations to take advantage of their established maintenance and siting standards.

The Meteorological Assimilation Data Ingest System (MADIS) and MesoWest currently aggregate observations from over 20,000 other locations from government agencies, commercial firms, and the public, which allow for more widespread areal coverage and increased likelihood of a nearby observation to be closer to the spot location. However, using these other observations introduces greater uncertainty as to maintenance of the sensors, siting, etc. Nevertheless, with further development, the web tools that were developed here could be expanded to include features allowing forecasters and users to see a wider variety of observations against which they could compare their forecast rather than just the closest NWS/FAA or RAWS station.

4) EVALUATE OTHER VARIABLES

As can be seen from Fig. 4, there are many other atmospheric variables and indices that forecast offices include in their spot forecasts. Efforts are currently underway by researchers at the Desert Research Institute to assess and verify upper-air variables (specifically Haines Index, Clearing Index, and Transport Winds) that play a significant role in smoke dispersion. The intention is to use upper-air soundings and model reanalysis data to provide a similarly designed web based system to the one that has been developed for this research. If more WFOs chose to provide their spot forecasts with time series of forecast values at regular intervals (hourly or 3-hourly) rather than simply maxima, minima, or specific conditions expressed generally in local times (e.g., early or late afternoon), then verification of such products would be simpler. The GFE in AWIPS is likely capable of auto-populating such fields.

Evaluating the Discussion section, likely the most important part of the spot forecast to the end user, will be difficult to perform objectively. However, increased efforts should be made to have fire and emergency management personnel take advantage of the web form available to them to provide feedback and critique forecast guidance. At the present time, it is not possible using that form to tie specific comments made by an end user to the guidance for which the feedback relates.

5) EXPAND THE VERIFICATION TIME WINDOW

While this research focused entirely on verification for daytime forecasts that appeared in the first time frame of the forecast, it is not unreasonable that a similar process could provide assessments for the subsequent two periods often present in these forecasts. A more robust parsing system could also easily differentiate between nighttime forecasts, which focus on minimum temperature and maximum relative humidity. Based on our findings concerning the quality of spot forecasts relative to NDFD grids, it would be useful to discern how that skill extends through 24 and 36 hours. Forecasts could also be compared to assess how often and under what conditions offices adjust them in subsequent forecast periods. For example, a forecast issued for a prescribed burn on Monday morning might anticipate a maximum temperature of 24°C for Tuesday (the third forecast period in the spot forecast), a value which is modified in a subsequent forecast to 28°C. Whether that modification improved the forecast or not is useful for understanding the thought process of a forecaster.

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Table 1. Error metrics for prescribed burn and wildfire forecasts issued in the continental United States for maximum temperature, minimum relative humidity, and maximum wind speed during the period 1 April 2009 – 30 November 2013.

	Number of Forecasts (Spot vs. Observation)	**Mean Error (Spot – Observation)**	**Median Absolute Error (Spot vs. Observation)**	**Number of Forecasts (NDFD vs. Observation)**	**Mean Error (NDFD – Observation)**	**Median Absolute Error (NDFD vs. Observation)**	**Number of Forecasts (Spot vs. RTMA)**	**Mean Error (Spot – RTMA)**	**Median Absolute Error (Spot vs. RTMA)**
Prescribed Burn Temperature	44,901	-0.5 ^{o}C	1.3 ^{o}C	42,924	-1.7 ^{o}C	1.7 ^{o}C	39,457	0.4 ^{o}C	1.4 ^{o}C
Prescribed Burn Relative Humidity	44,901	1.5%	5.3%	42,924	6.0%	6.6%	39,457	-3.26%	5.7%
Prescribed Burn Wind Speed	38,017	0.2 m s^{-1}	1.3 m s^{-1}	35,979	0.4 m s^{-1}	1.4 m s^{-1}	33,298	0.2 m s^{-1}	1.1 m s^{-1}
Wildfire Temperature	16,280	-0.4 ^{o}C	1.7 ^{o}C	14,680	-1.5 ^{o}C	2.0 ^{o}C	15,885	0.2 ^{o}C	1.6 ^{o}C
Wildfire Relative Humidity	16,280	0.7%	4.0%	14,680	4.1%	5.1%	15,885	-1.8%	4.2%
Wildfire Wind Speed	8,860	0.7 m s^{-1}	1.5 m s^{-1}	8,075	0.8 m s^{-1}	1.6 m s^{-1}	8,872	0.3 m s^{-1}	1.4 m s^{-1}

Table 2. Marginal distributions for accurate prescribed burn and wildfire spot and NDFD forecasts relative to surface observations during the period 1 April 2009 – 30 November 2013. Thresholds for "accurate" forecasts are 2.5°C, 5% relative humidity, and 2.5 m s^{-1}.

	Number of Forecasts	**Accurate Spot Forecasts**	**Accurate NDFD Forecasts**	**Difference (Spot – NDFD)**
Prescribed Burn Temperature	42,924	75.3%	65.7%	9.6%
Prescribed Burn Relative Humidity	42,924	43.7%	39.0%	4.7%
Prescribed Burn Wind Speed	35,979	76.1%	74.5%	1.6%
Wildfire Temperature	14,680	66.6%	59.1%	7.5%
Wildfire Relative Humidity	14,680	53.3%	49.5%	3.8%
Wildfire Wind Speed	8,075	70.4%	68.8%	1.6%

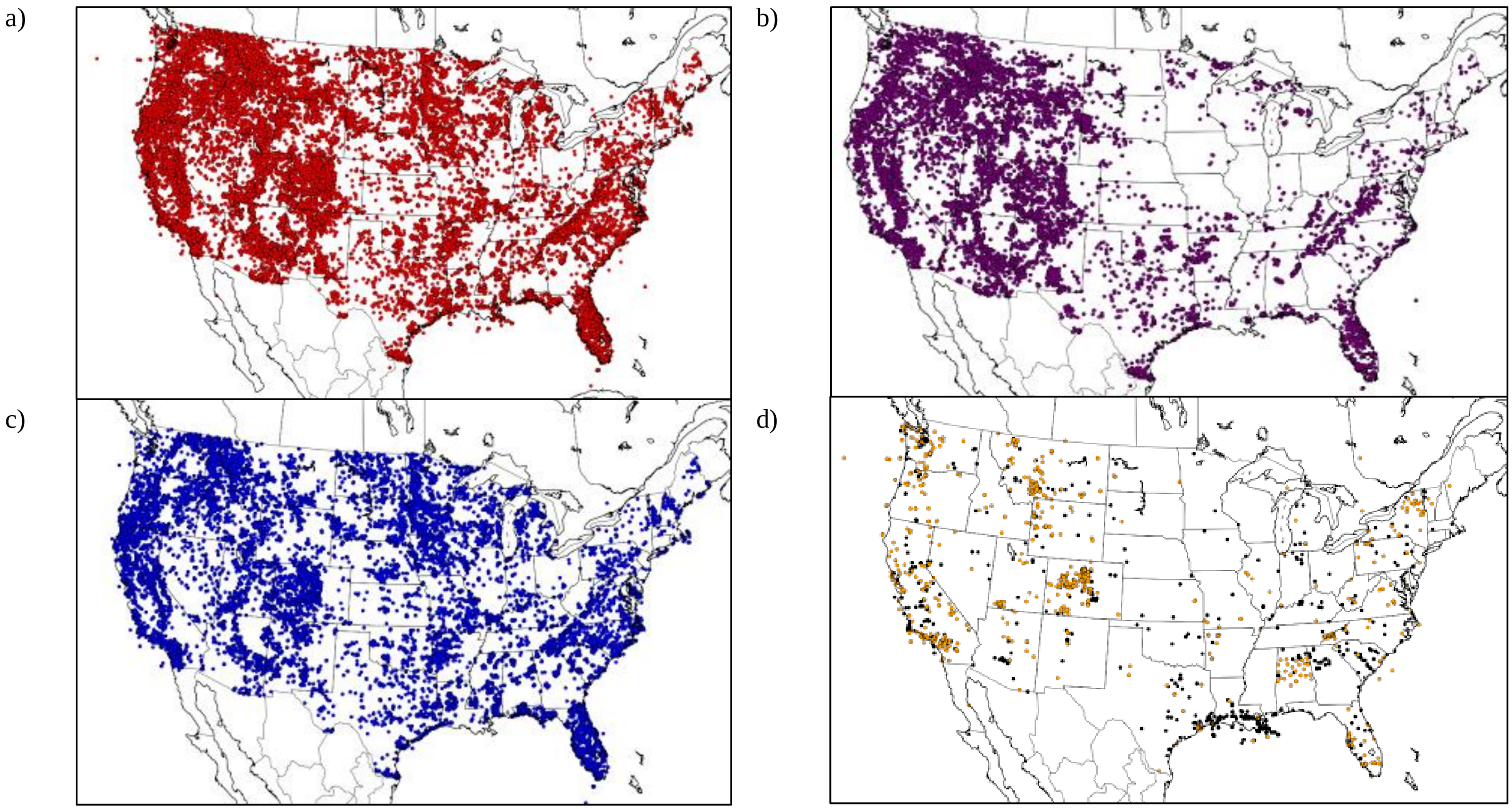


Figure 1. Locations of spot forecasts in the continental United States, April 2009 to November 2013. a) all spot forecasts, b) wildfire spot forecasts, c) prescribed burn spot forecasts, and d) hazardous materials (black) and search and rescue (orange).

SALT LAKE CITY SPOT FORECAST REQUEST

Required Elements in RED (*)

PROJECT NAME

(*)Project Name:

Wildfire HAZMAT

Prescribed Fire SAR

Ignition Time: 0935 Mountain Local Time

Date: 3/25/14

REQUESTING AGENCY

(*)Requesting Agency:

(*)Requesting Official:

(*)Phone Number: Ext.

FAX Number:

Contact Person:

REASON FOR SPOT FORECAST REQUEST

(*)Must choose either Wildfire or one of the Non-Wildfire reasons

Wildfire

Non-Wildfire

Under the Interagency Agreement for Meteorological Services (USFS, BLM, NPS, USFWS, BIA).

State, tribal or local fire agency working in coordination with a federal participant in the Interagency Agreement for Meteorological Services.

Essential to public safety, e.g. due to the proximity of population centers or critical infrastructure.

For NWS Spot forecast policy, see section 4.0 in NWS Instruction 10-401 at http://www.nws.noaa.gov/directives/010/010.htm

LOCATION

(*)Lat:

(*)Lon:

7.5' Quad:

Legal (T/R): UT

*Enter Lat/Lon (WGS84/NAD83 preferred), Legal(T/R) also acceptable.

(*)Elevation: Top Bottom

Drainage:

(*)Aspect:

Size: (Acres)

FUEL

Type:

Sheltering

Full

Partial

Unsheltered

OBSERVATIONS

Place	Elev	Time	Wind	Temp	Wetbulb	RH	Dewpt.	Sky/Weather

PRIMARY FORECAST ELEMENTS

TDA TNT TMR (Today, Tonight, Tomorrow)

LAL

Haines Index

Clearing Index

Sky/Weather

Temperature

Humidity

Wind - 20 Foot

REMARKS

Submit Request | Cancel Request | Clear Form

Figure 2. The online spot forecast request form for Salt Lake City (SLC) WFO.

```
BMBB91 KSLC 202121
STQSLC

A SPOT FORECAST REQUEST HAS JUST BEEN RECEIVED FOR A WILDFIRE
NAMED "Patch Springs"

           PRIORITY:  IMMEDIATE
               DATE:  8/20/13
               TIME:  1521
       PROJECT NAME:  Patch Springs
       PROJECT TYPE:  WILDFIRE
  REQUESTING AGENCY:  USFS
REQUESTING OFFICIAL:  Chris Church
     REQUEST REASON:  WILDFIRE
                FAX:
    EMERGENCY PHONE:  (800) 592-9907
           LOCATION:
              STATE:  UT
               DLAT:   40.3413
               DLON:   112.6699
           EXPOSURE:  s
          FUEL TYPE:  Grass,Brush,Timber
        SHELTERING:   PARTIAL
   BOTTOM ELEVATION:  5312
      TOP ELEVATION:  8400
       SIZE (ACRES):  31000

WEATHER CONDITIONS AT PROJECT OR FROM NEARBY STATIONS
Cedar Mountain RAWS ELEV=4650 TIME=1455 WIND=NE11 Gto19 T=86 TW= RH=28 TD= mostly
cloudy
 ELEV= TIME= WIND= T= TW= RH= TD=
 ELEV= TIME= WIND= T= TW= RH= TD=
 ELEV= TIME= WIND= T= TW= RH= TD=

...REMARKS...
Please include tomorrow night, LAL and CWR in all forecasts.

Thanks, new team taking fire tomorrow. Thanks for all the help the
last 3 days. Really appreciated the phone callsand the spots  Chris.

...WEATHER PARAMETERS REQUESTED...
             LAL: 0,0,1
    HAINES INDEX: 0,0,1
  CLEARING INDEX: 0,0,1
     SKY/WEATHER: 0,0,1
     TEMPERATURE: 0,0,1
        HUMIDITY: 0,0,1
  WIND - 20 FOOT: 0,0,1

SITE:  SLC
```

Figure 3. Example request form for Patch Springs Wildfire, 20 August 2013.

```
FNUS75 KSLC 202145
FWSSLC

SPOT FORECAST FOR PATCH SPRINGS
NATIONAL WEATHER SERVICE SALT LAKE CITY UT
323 PM MDT TUE AUG 20 2013

.DISCUSSION...SHOWERS AND THUNDERSTORMS WILL CONTINUE ACROSS
NORTHERN UTAH INTO THE OVERNIGHT HOURS. THERE IS THE POTENTIAL FOR
THESE STORMS TO IMPACT THE PATCH SPRINGS FIRE. THESE STORMS ARE
WET...AND WILL BE ACCOMPANIED BY MODERATE TO HEAVY RAIN. EVEN IF A
STORM DOES NOT DIRECTLY IMPACT THE FIRE...GUSTY AND ERRATIC WINDS
FROM STORMS IN THE VICINITY MAY AFFECT THE FIRE. THE POTENTIAL FOR
THUNDERSTORMS TO DEVELOP DECREASES TOMORROW THROUGH FRIDAY AS
MOISTURE DECREASES ACROSS THE AREA. WINDS WILL INCREASE FROM THE
SOUTH ON FRIDAY.

.REST OF TODAY...
  LAL.................3.
  HAINES INDEX........3 ..VERY LOW.
  CLEARING INDEX......1000+.
  SKY/WEATHER.........PARTLY CLOUDY (65-75 PERCENT CLOUD COVER).
                      SCATTERED SHOWERS AND THUNDERSTORMS.
  MAX TEMPERATURE.....87-91.
  MIN HUMIDITY........22-24 PERCENT.
  WINDS - 20-FOOT.....UPSLOPE/UPVALLEY 6 TO 11 MPH. GUSTY AND
                      ERRATIC IN THE VICINITY OF THUNDERSTORMS.

.TONIGHT...
  LAL.................3.
  HAINES INDEX........3 ..VERY LOW.
  SKY/WEATHER.........MOSTLY CLOUDY (75-85 PERCENT CLOUD COVER).
                      SCATTERED SHOWERS AND THUNDERSTORMS.
  MIN TEMPERATURE.....65-67.
  MAX HUMIDITY........52-54 PERCENT.
  WINDS - 20-FOOT.....DOWNSLOPE/DOWNVALLEY 5 TO 9 MPH.

.OUTLOOK FOR WEDNESDAY...
  LAL.................2.
  HAINES INDEX........3 ..VERY LOW.
  CLEARING INDEX......1000+.
  SKY/WEATHER.........PARTLY CLOUDY (40-50 PERCENT CLOUD COVER). A
                      SLIGHT CHANCE OF SHOWERS AND THUNDERSTORMS.
  MAX TEMPERATURE.....92-94.
  MIN HUMIDITY........19-21 PERCENT.
  WINDS - 20-FOOT.....UPSLOPE/UPVALLEY 6 TO 11 MPH.

.WEDNESDAY NIGHT...
  LAL.................4 UNTIL MIDNIGHT...THEN 3.
  HAINES INDEX........3 ..VERY LOW.
  SKY/WEATHER.........MOSTLY CLOUDY (75-85 PERCENT CLOUD COVER).
  MIN TEMPERATURE.....69-72.
  MAX HUMIDITY........40-45 PERCENT.
  WINDS - 20-FOOT.....DOWNSLOPE/DOWNVALLEY 5 TO 9 MPH.



FORECASTER...HOSENFELD
REQUESTED BY...CHRIS CHURCH
REASON FOR REQUEST...WILDFIRE
.TAG 20130820.PATCH.01/SLC

$$
```

Figure 4. Example spot forecast from Patch Springs Wildfire, 20 August 2013.

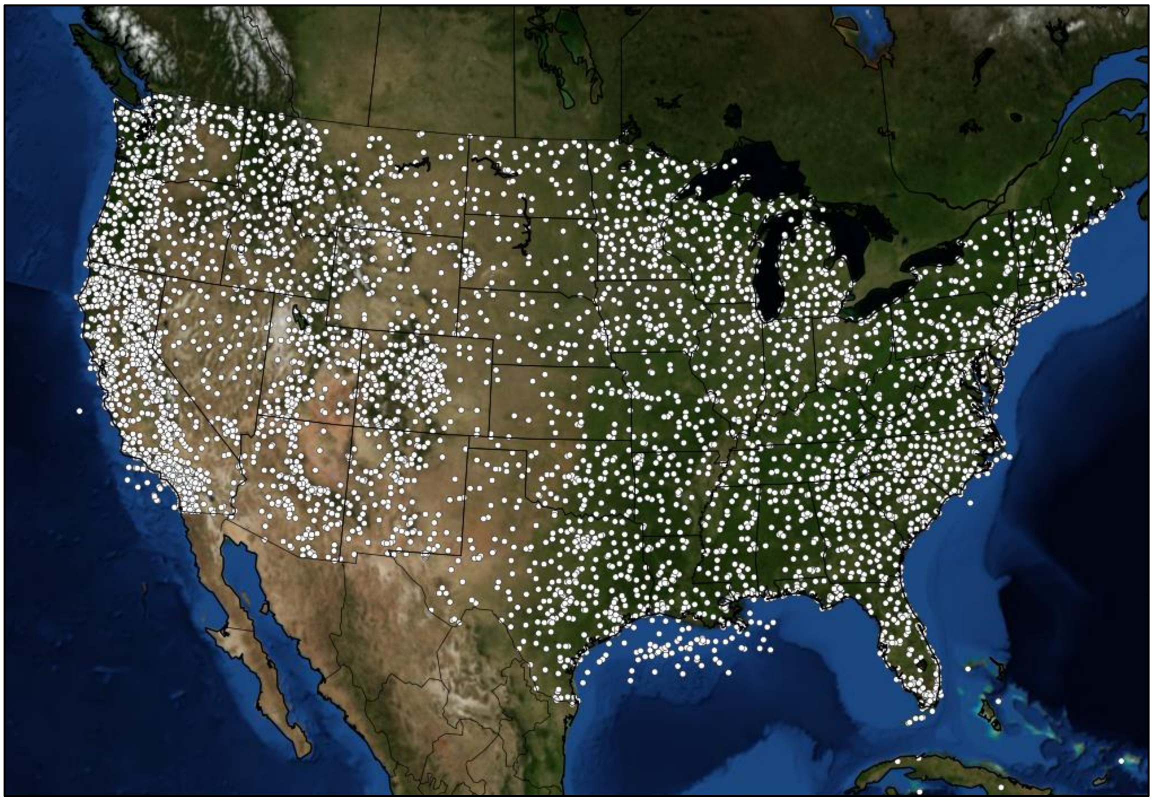


Figure 5. Locations of NWS/FAA and RAWS stations in MesoWest.

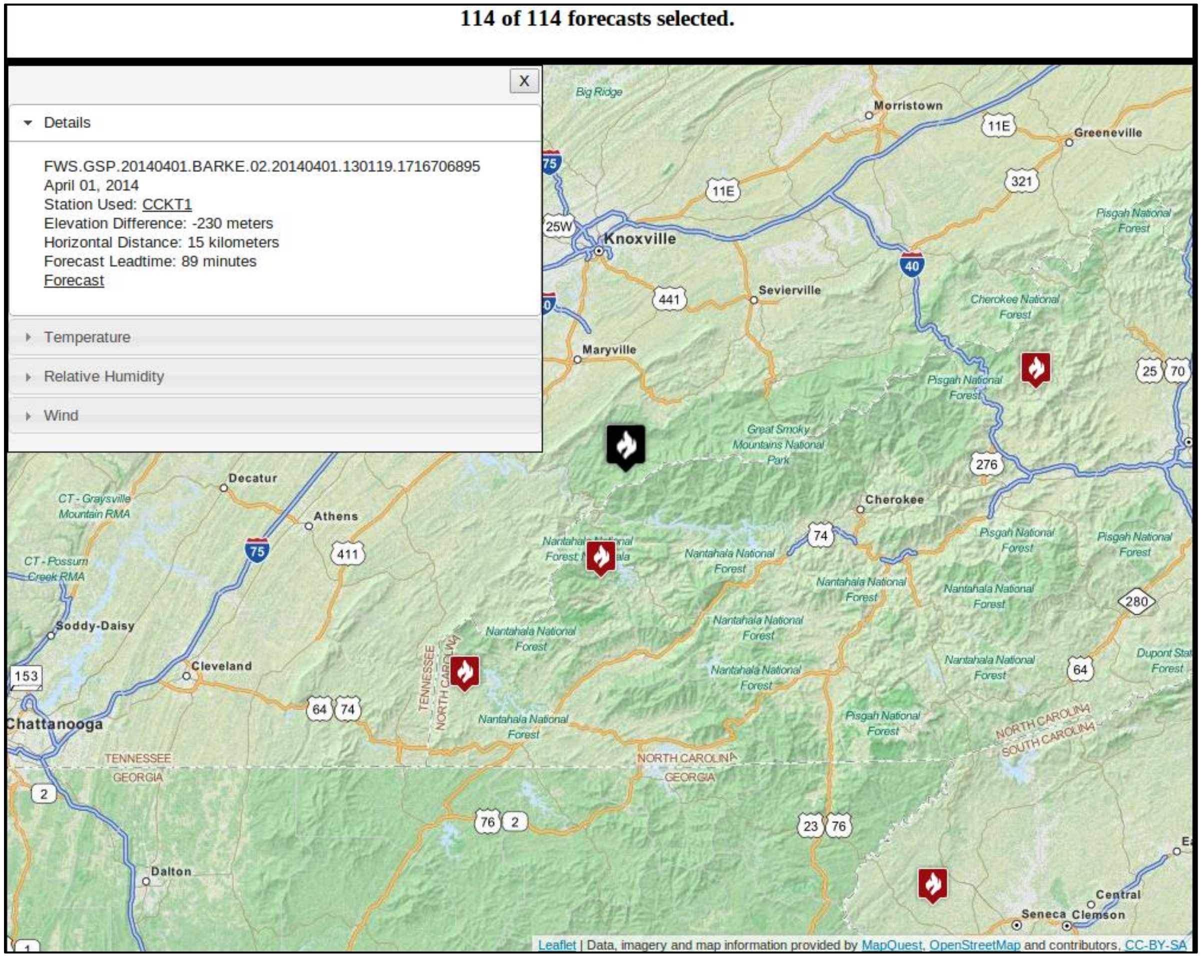


Figure 6. Illustration of the map section of the web tools available at http://meso1.chpc.utah.edu/jfsp/. Shown are markers for prescribed burn spot forecasts issued in the southern Appalachian Mountains on 1 April 2014. Upon clicking a marker, a box appears containing information about the spot forecast and the verification values, in this case for the Barker II Prescribed Burn. This box also contains links to the MesoWest page for the verifying station and to the spot forecast itself.

a)

b)

c)

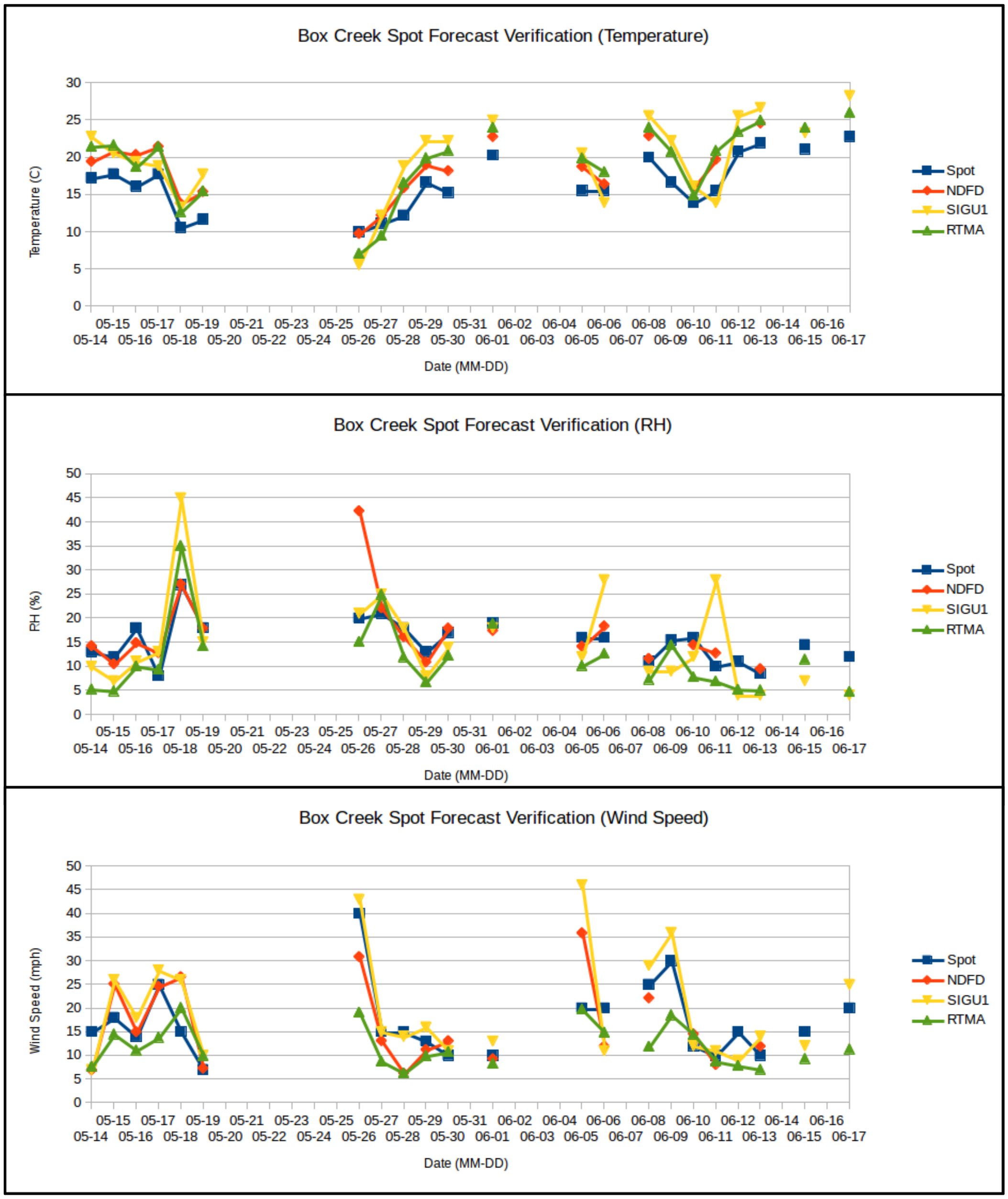


Figure 7. Forecasts and verifying data during the Box Creek prescribed burn and subsequent wildfire. Data are for a) maximum temperature (^{o}C), b) minimum relative humidity (%), and c) maximum wind speed (m s^{-1}).

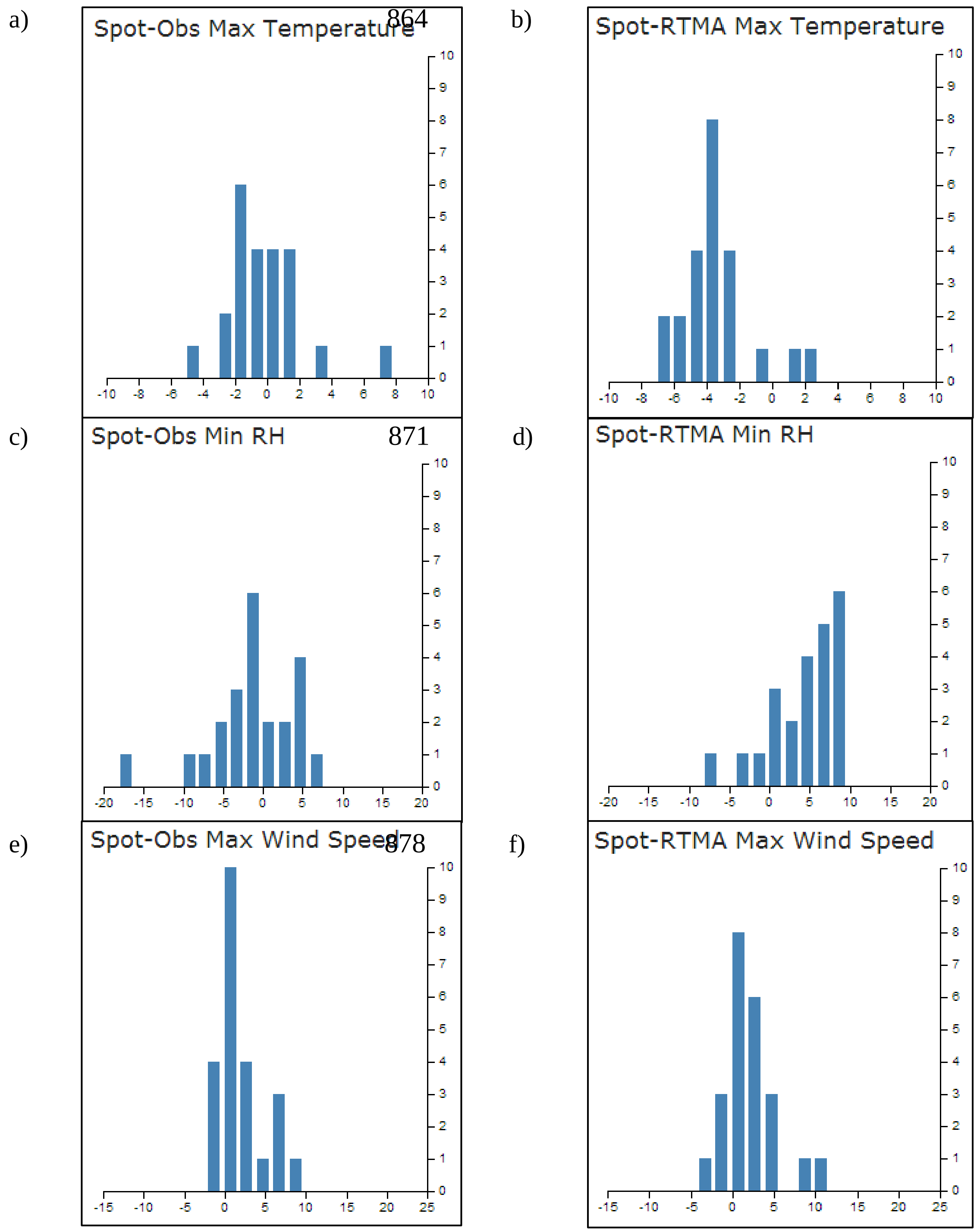
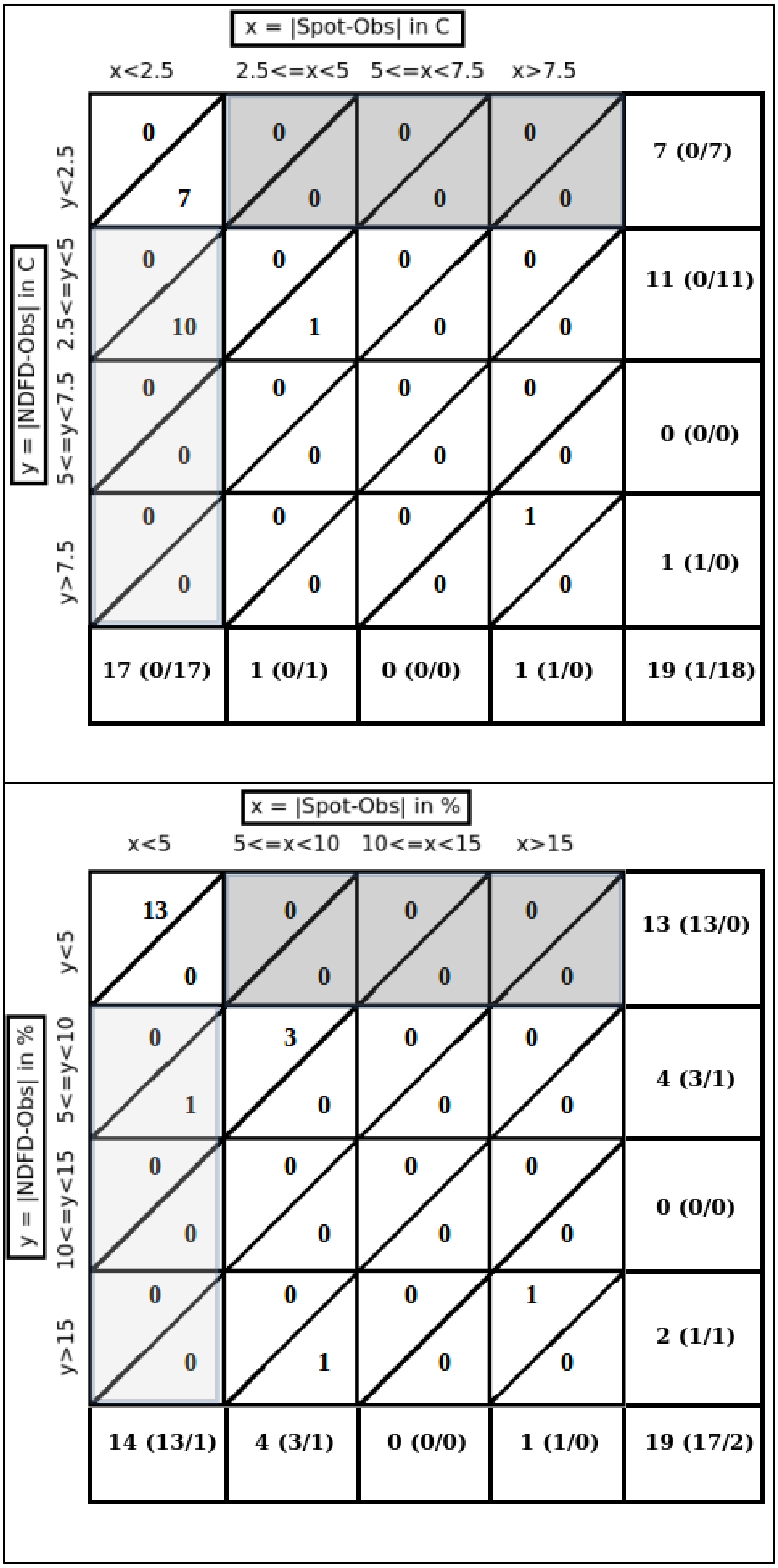


Figure 8. Histograms of differences between Box Creek spot forecasts and observations at TT084. Histograms are for a) maximum temperature (°C), c) minimum relative humidity, and e) maximum wind speed (m s^{-1}); b) as in a) except verified against the RTMA, d) as in c) except verified against the RTMA, and f) as in e) except verified against the RTMA.

a)

b)


x = |Spot-Obs| in C
x<2.5
2.5<=x<5
5<=x<7.5
x>7.5
y = |NDFD-Obs| in C
y<2.5
2.5<=y<5
5<=y<7.5
y>7.5
7 (0/7)
11 (0/11)
0 (0/0)
1 (1/0)
17 (0/17)
1 (0/1)
0 (0/0)
1 (1/0)
19 (1/18)
x = |Spot-Obs| in %
x<5
5<=x<10
10<=x<15
x>15
y = |NDFD-Obs| in %
y<5
5<=y<10
10<=y<15
y>15
13 (13/0)
4 (3/1)
0 (0/0)
2 (1/1)
14 (13/1)
4 (3/1)
0 (0/0)
1 (1/0)
19 (17/2)

c)

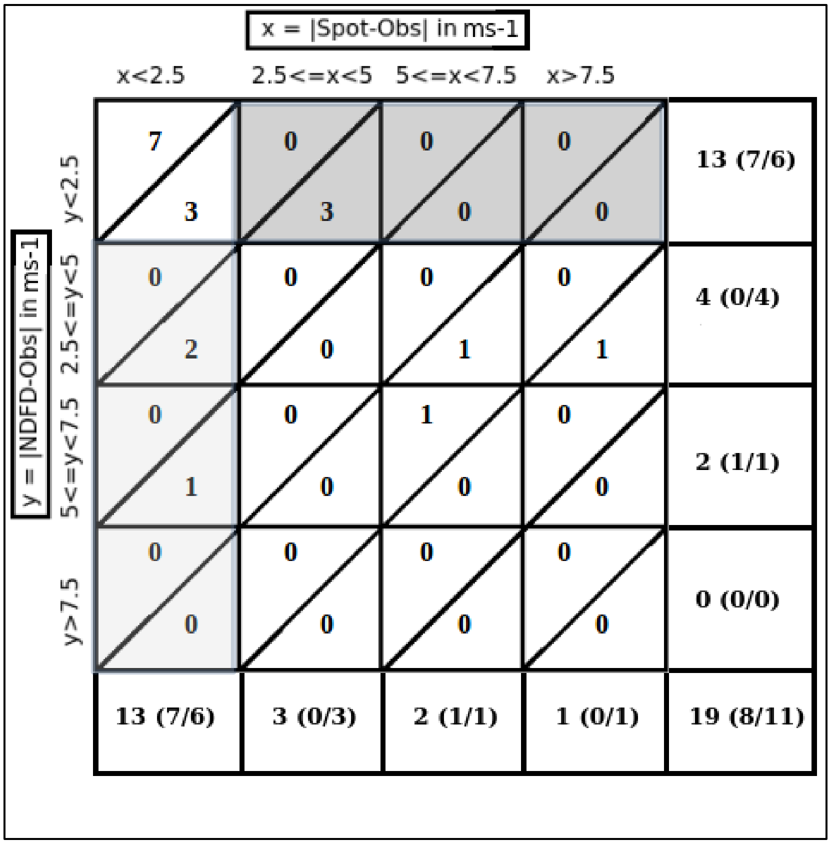


Figure 9. Count of the number of cases for absolute differences between spot forecasts and observations (columns) and NDFD forecasts and observations (rows) for the Box Creek case for: a) maximum temperature (°C), b) minimum relative humidity (%), and c) maximum wind speed (m s^{-1}). Marginal counts for the spot (NDFD) errors are shown in the bottom column (right row). Values above (below) the diagonal lines in each bin indicate spot forecasts that are within (greater than) specified ranges of the NDFD forecast values. These ranges are 1°C, 5%, and 1 m s^{-1} of the NDFD forecast for temperature, relative humidity, and wind speed, respectively. Each marginal count is also separated into values differentiating between spot forecasts within (outside) the specified ranges of the NDFD values. Light (dark) shading denotes the cases where forecasters provided accurate (inaccurate) forecasts when the NDFD forecasts were inaccurate (accurate).

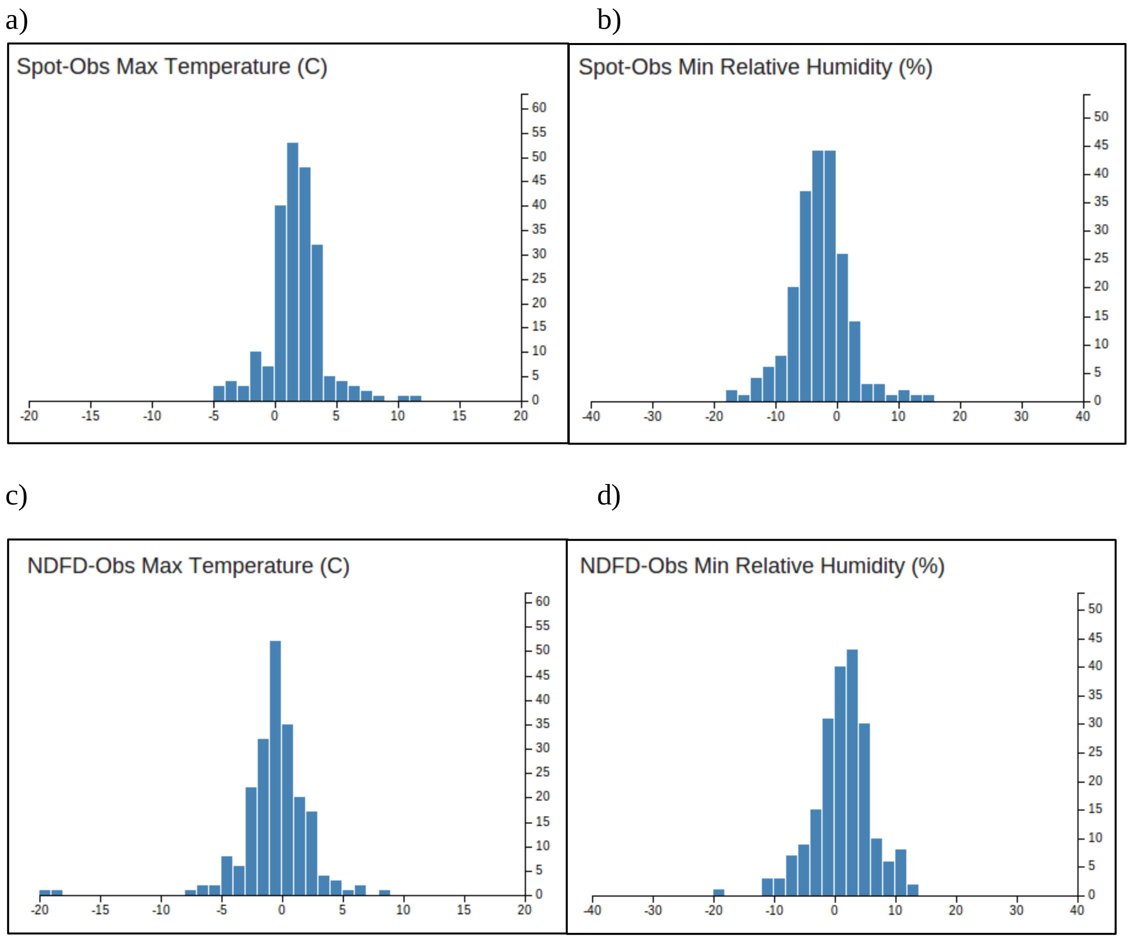
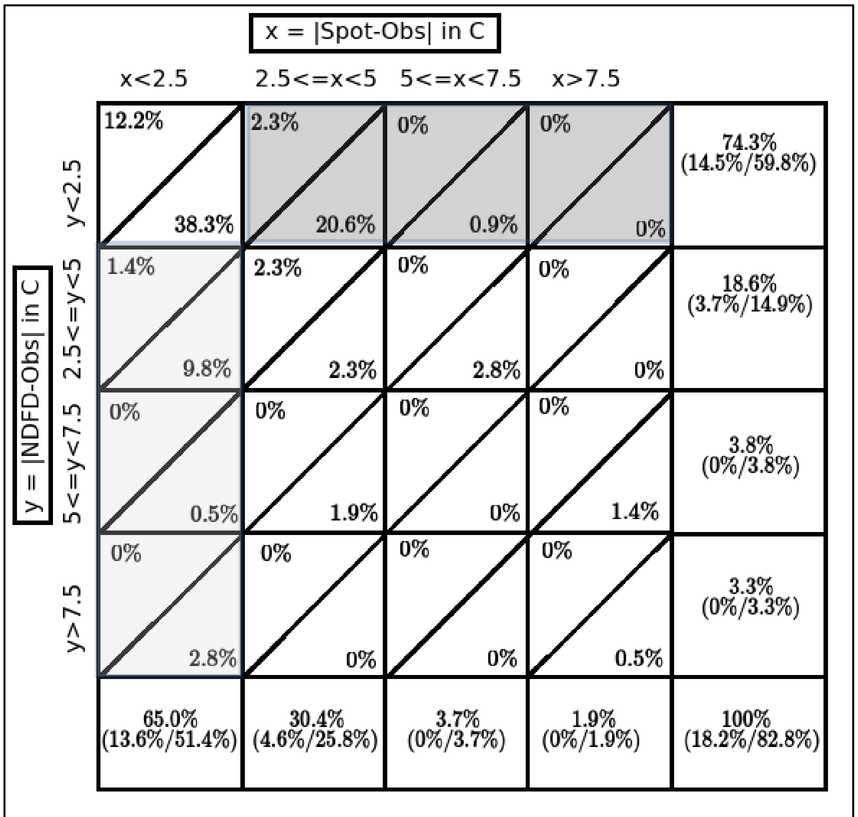
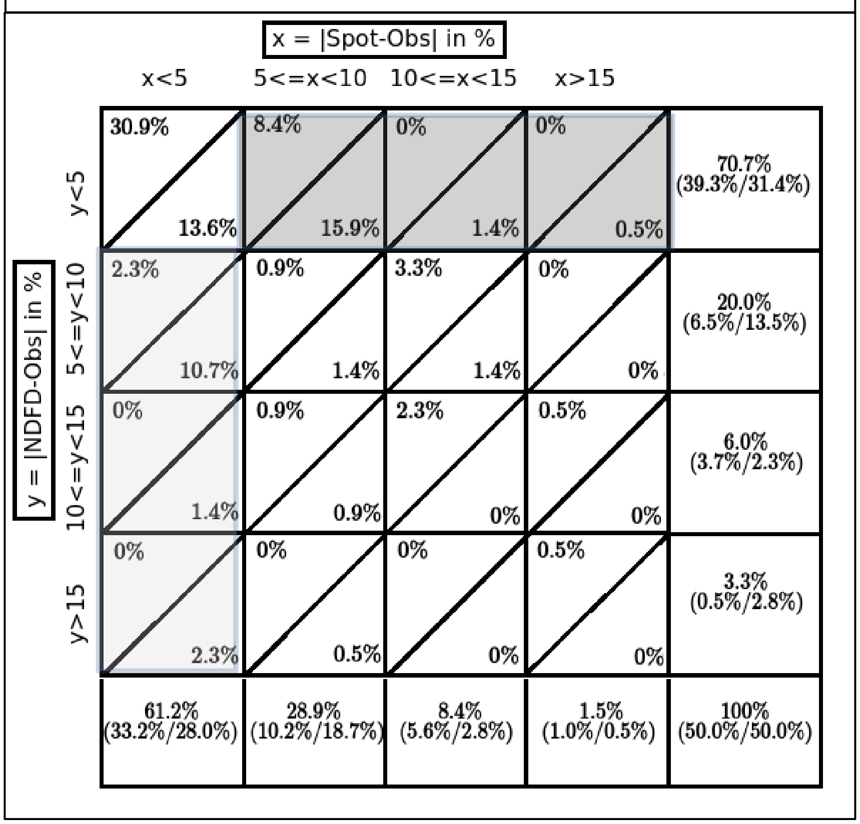


Figure 10. Histograms of errors for prescribed burn spot forecasts for the Tucson CWA for: a) maximum temperature (^{o}C), b) minimum relative humidity (%). c) As in a) except for NDFD forecasts. d) As in b) except for NDFD forecasts.

a)


x = |Spot-Obs| in C
x<2.5
2.5<=x<5
5<=x<7.5
x>7.5
y = |NDFD-Obs| in C
y<2.5
2.5<=y<5
5<=y<7.5
y>7.5
12.2%
38.3%
2.3%
20.6%
0%
0.9%
0%
0%
74.3%
(14.5%/59.8%)
1.4%
9.8%
2.3%
2.3%
0%
2.8%
0%
0%
18.6%
(3.7%/14.9%)
0%
0.5%
0%
1.9%
0%
0%
0%
1.4%
3.8%
(0%/3.8%)
0%
2.8%
0%
0%
0%
0%
0%
0.5%
3.3%
(0%/3.3%)
65.0%
(13.6%/51.4%)
30.4%
(4.6%/25.8%)
3.7%
(0%/3.7%)
1.9%
(0%/1.9%)
100%
(18.2%/82.8%)

b)


x = |Spot-Obs| in %
x<5
5<=x<10
10<=x<15
x>15
y = |NDFD-Obs| in %
y<5
5<=y<10
10<=y<15
y>15
30.9%
13.6%
8.4%
15.9%
0%
1.4%
0%
0.5%
70.7%
(39.3%/31.4%)
2.3%
10.7%
0.9%
1.4%
3.3%
1.4%
0%
0%
20.0%
(6.5%/13.5%)
0%
1.4%
0.9%
0.9%
2.3%
0%
0.5%
0%
6.0%
(3.7%/2.3%)
0%
2.3%
0%
0.5%
0%
0%
0.5%
0%
3.3%
(0.5%/2.8%)
61.2%
(33.2%/28.0%)
28.9%
(10.2%/18.7%)
8.4%
(5.6%/2.8%)
1.5%
(1.0%/0.5%)
100%
(50.0%/50.0%)

c)

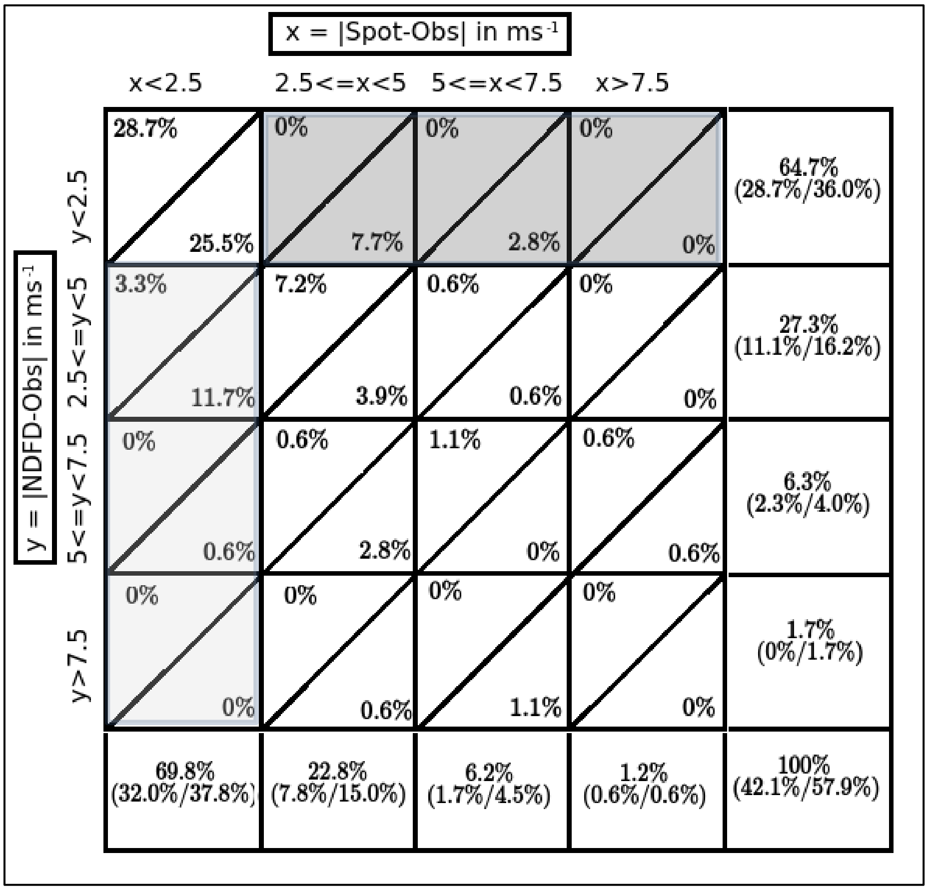


Figure 11. Percentages of the total number of cases for absolute differences between spot forecasts and observations (columns) and NDFD forecasts and observations (rows) for Tucson WFO prescribed burn forecasts for: a) maximum temperature; b) minimum relative humidity; c) maximum wind speed. Marginal percentages for the spot (NDFD) errors are shown in the bottom column (right row). Values above (below) the diagonal lines in each box indicate the percent of the spot forecasts that are within (greater than) specified ranges of the NDFD forecast values. These ranges are 1°C, 5%, and 1 m s^{-1} of the NDFD forecast for temperature, relative humidity, and wind speed, respectively. Each marginal percentage is also separated within the parentheses into values differentiating between spot forecasts within (outside) the specified ranges of the NDFD values. Light (dark) shading denotes the cases where forecasters provided accurate (inaccurate) forecasts when the NDFD forecasts were inaccurate (accurate).

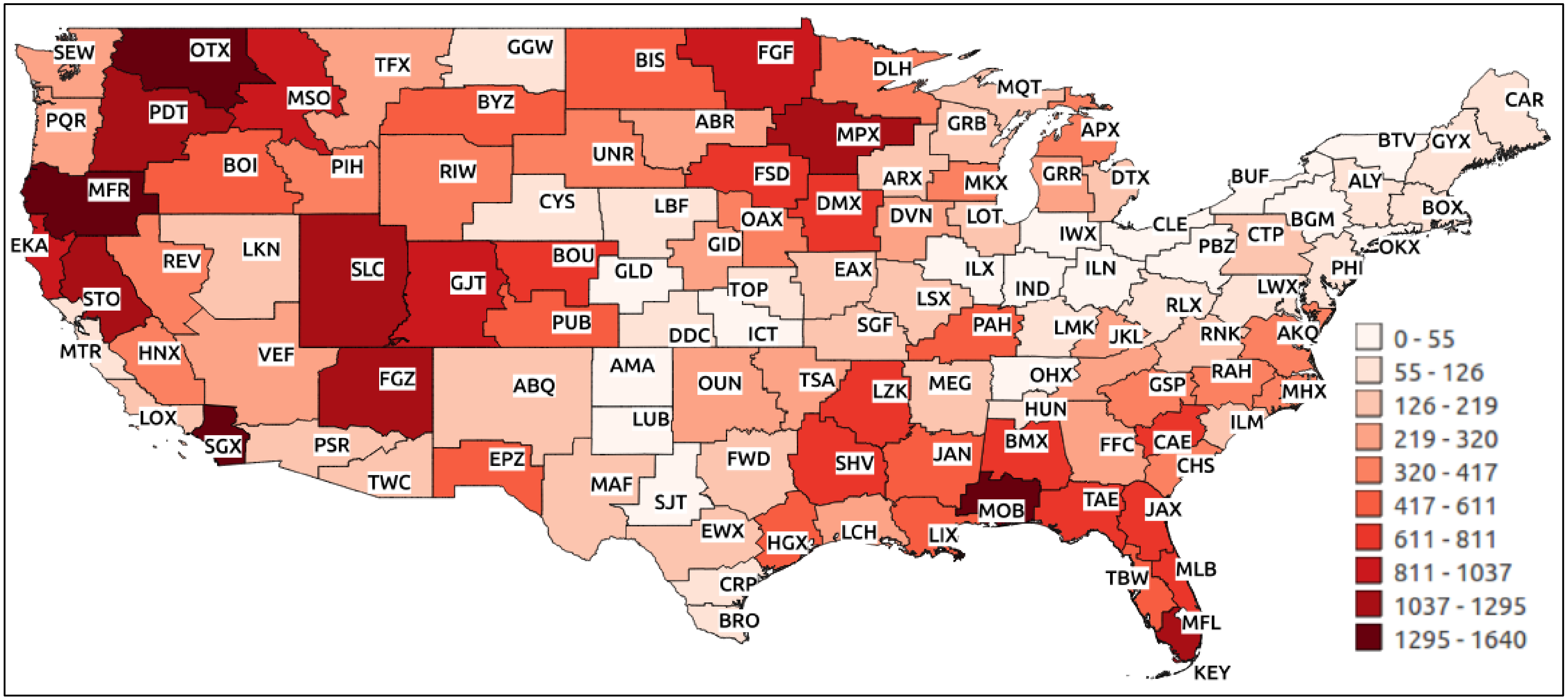
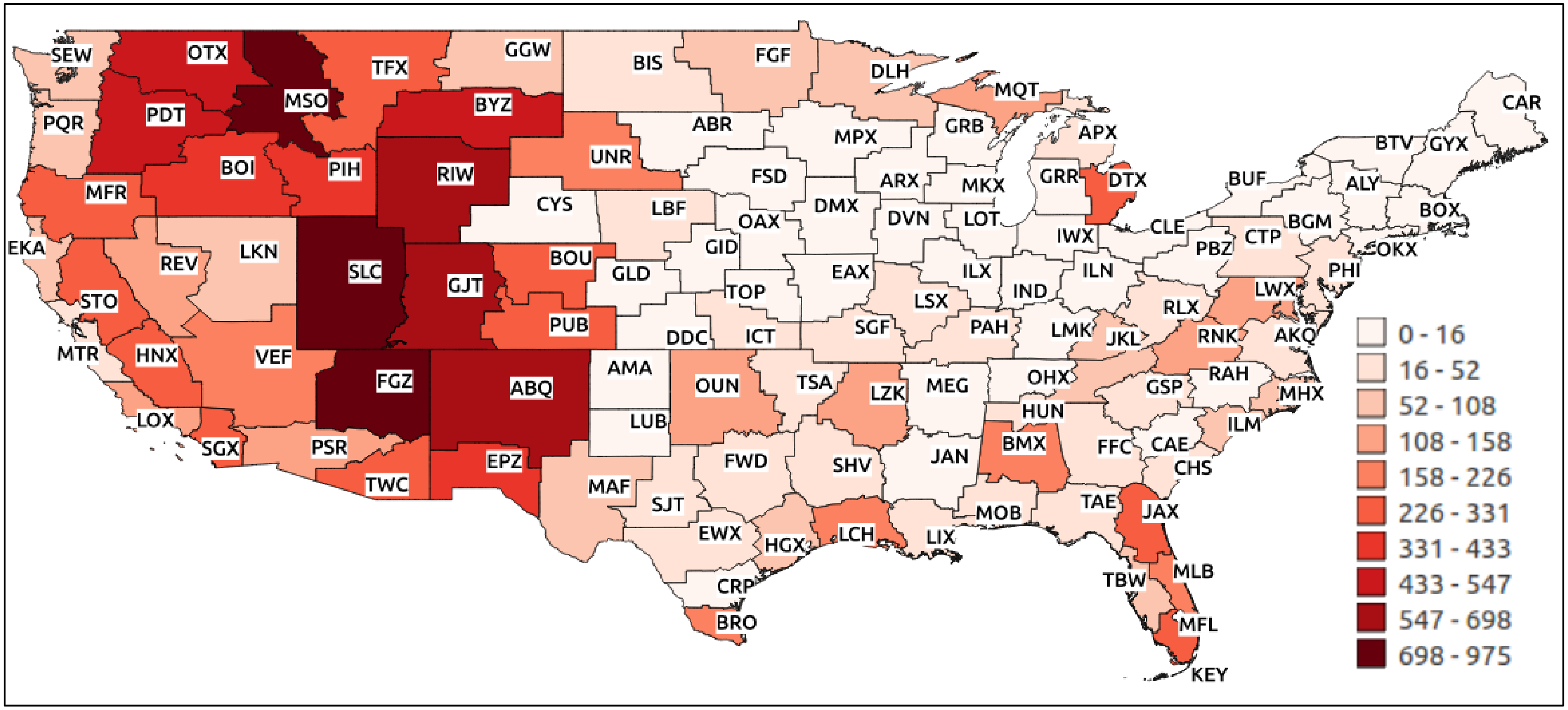


Figure 12. a) Number of prescribed burn spot forecasts analyzed as a function of CWA, April 2009 to November 2013. NWS abbreviation for each WFO is indicated.



b) As in Figure a), but for spot forecasts issued for wildfires.

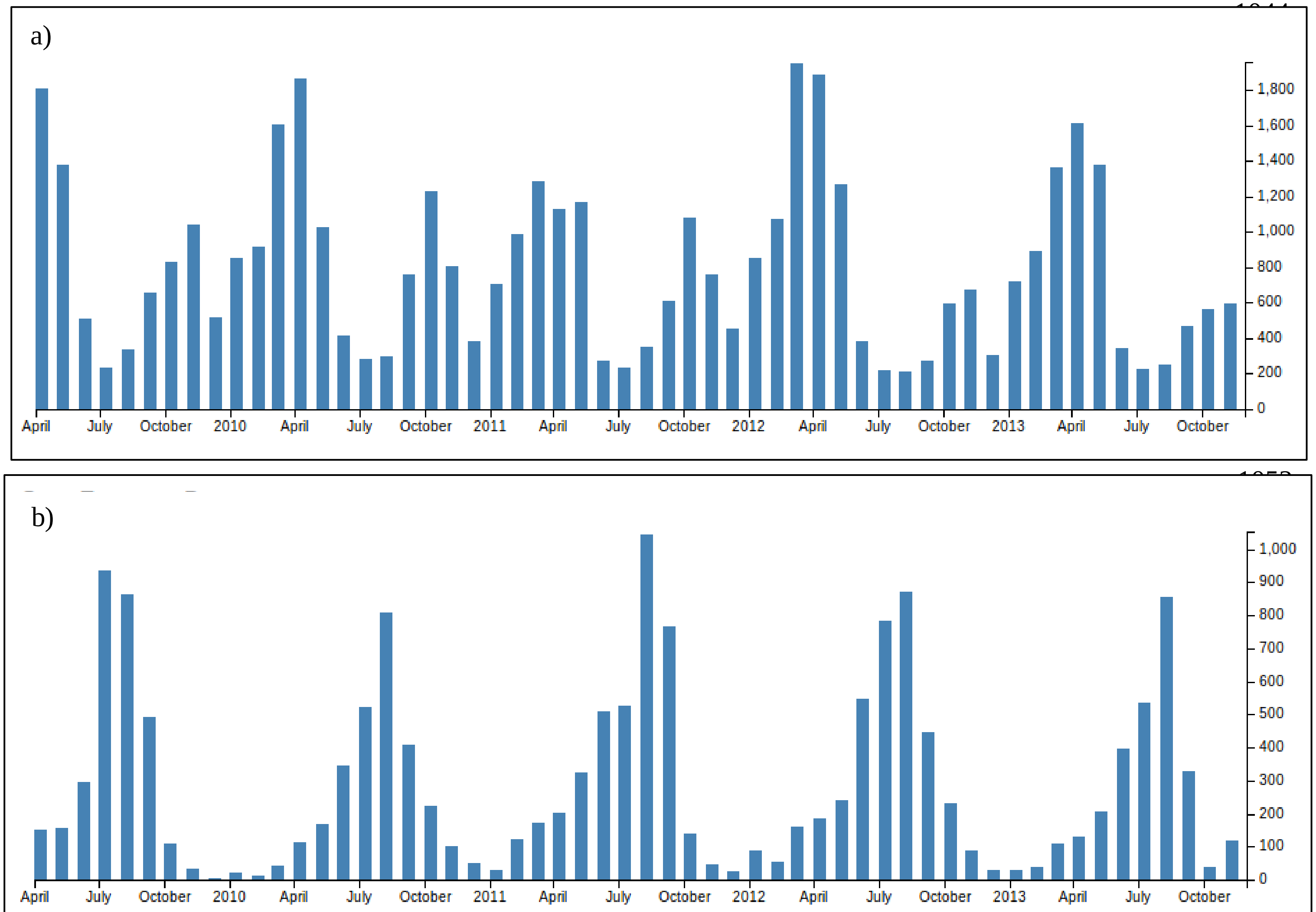


Figure 13. a) Prescribed burn spot forecasts by month, b) as in a), but for wildfire spot forecasts.

a) b)

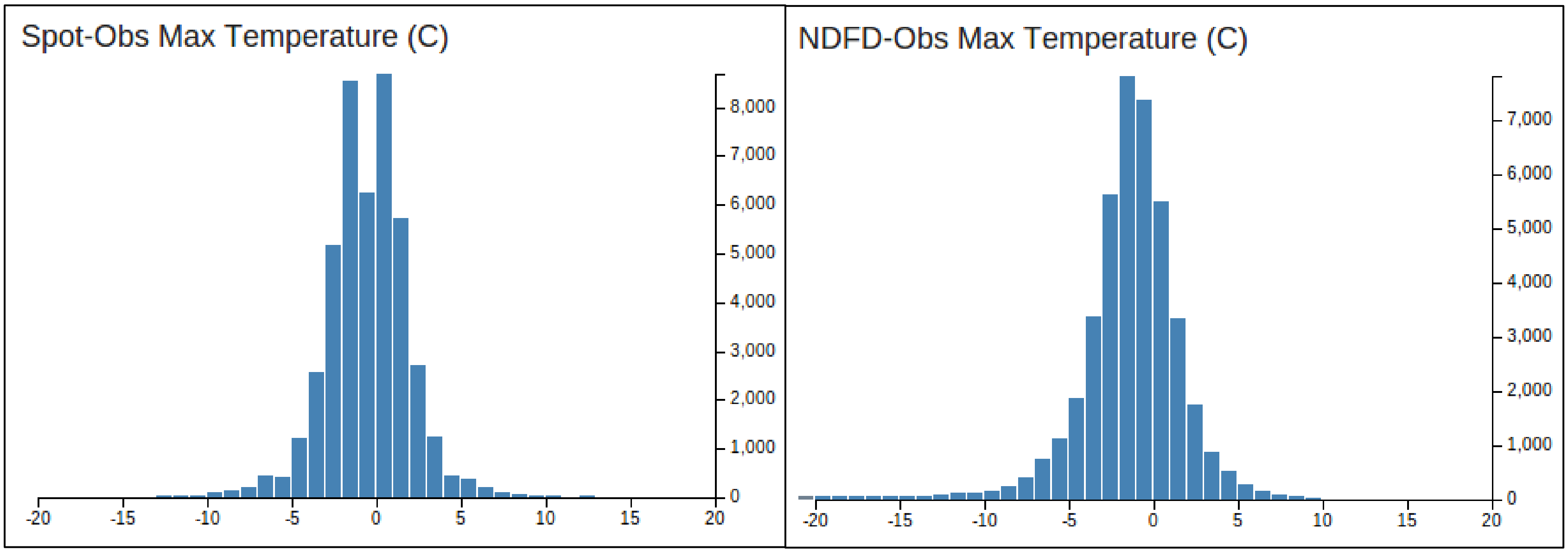
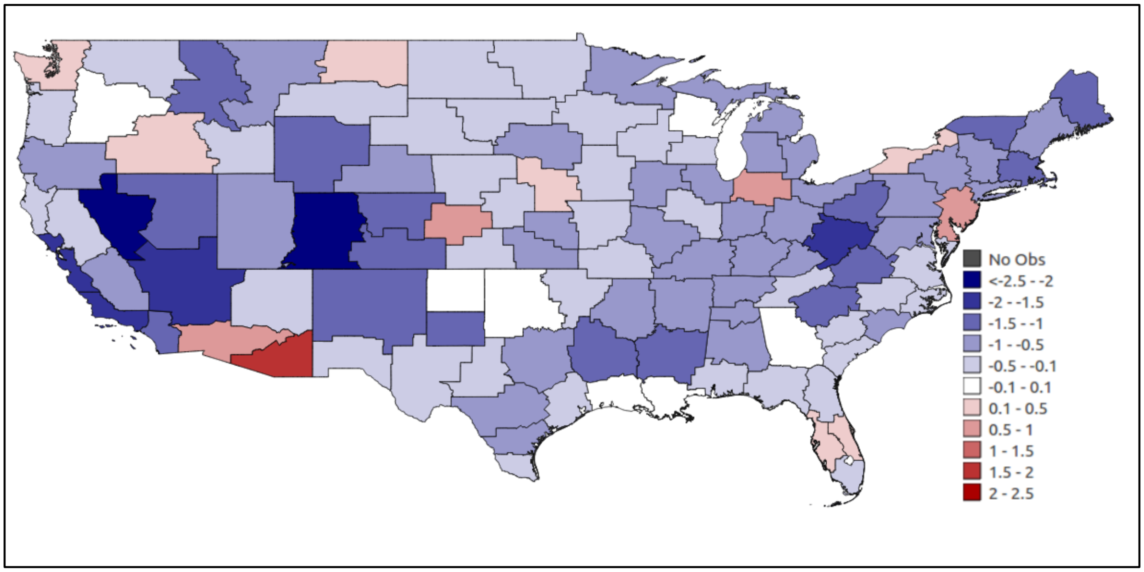


Figure 14. All maximum temperature errors (°C) for prescribed burn forecasts relative to observations for: a) spot forecasts and b) NDFD forecasts.

a)



b)

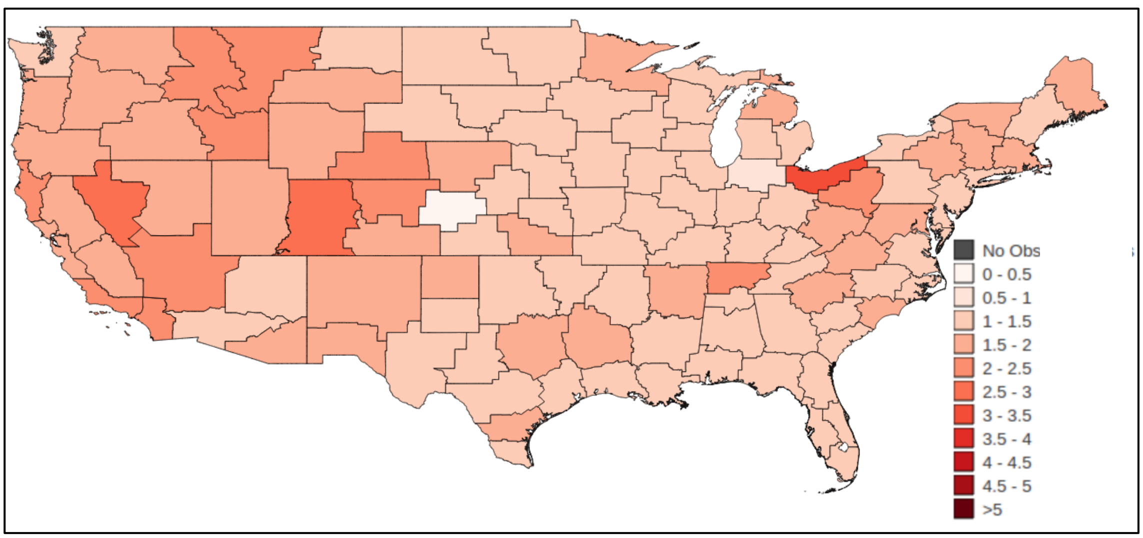


Figure 15. a) Mean error (ME) for prescribed burn spot forecasts for maximum temperature (^{o}C) as a function of CWA. b) As in a) except for median absolute error (MAE).

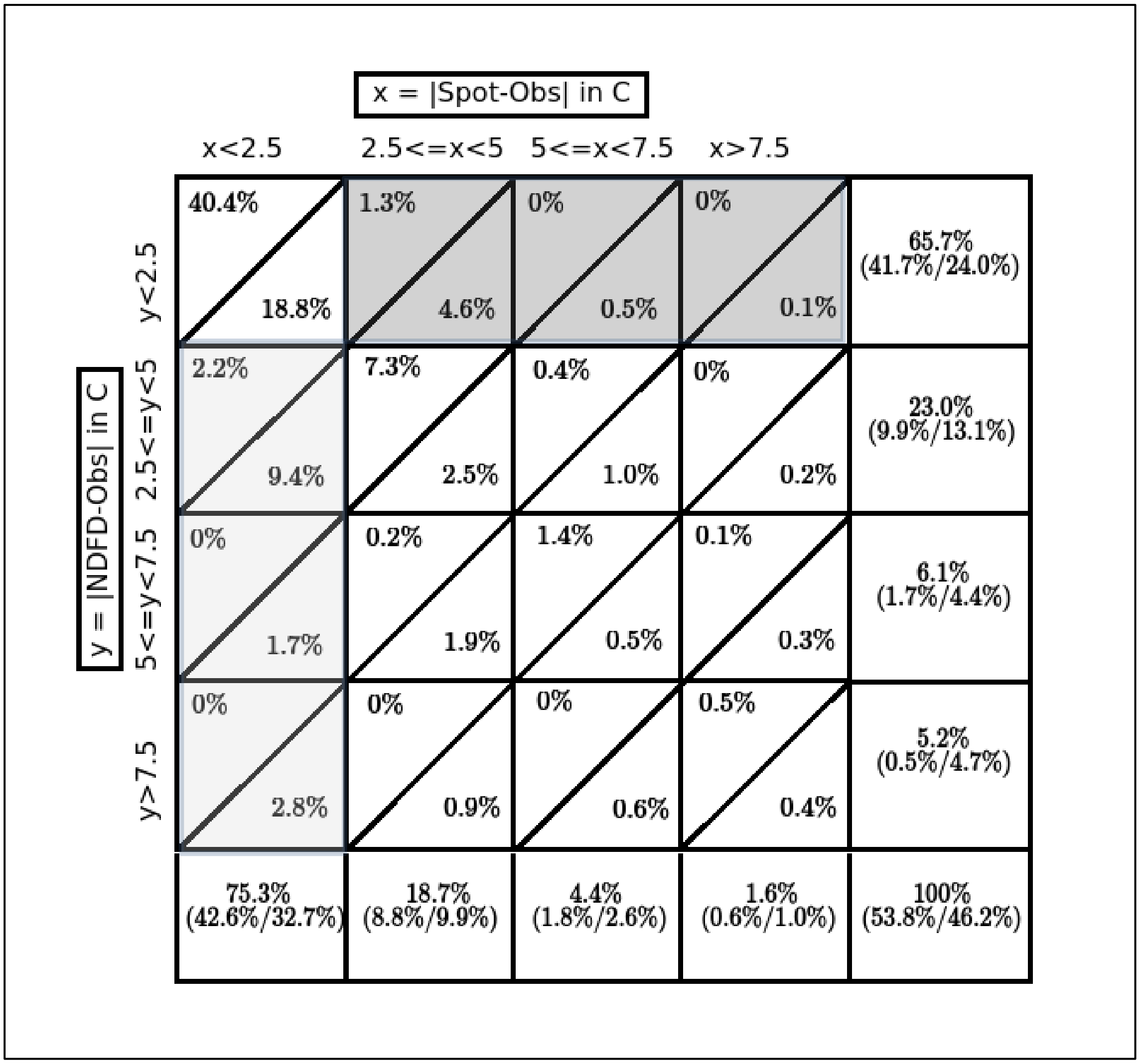


Figure 16. As in Figure 9a, but for forecasts from all CWAs.

a) b)

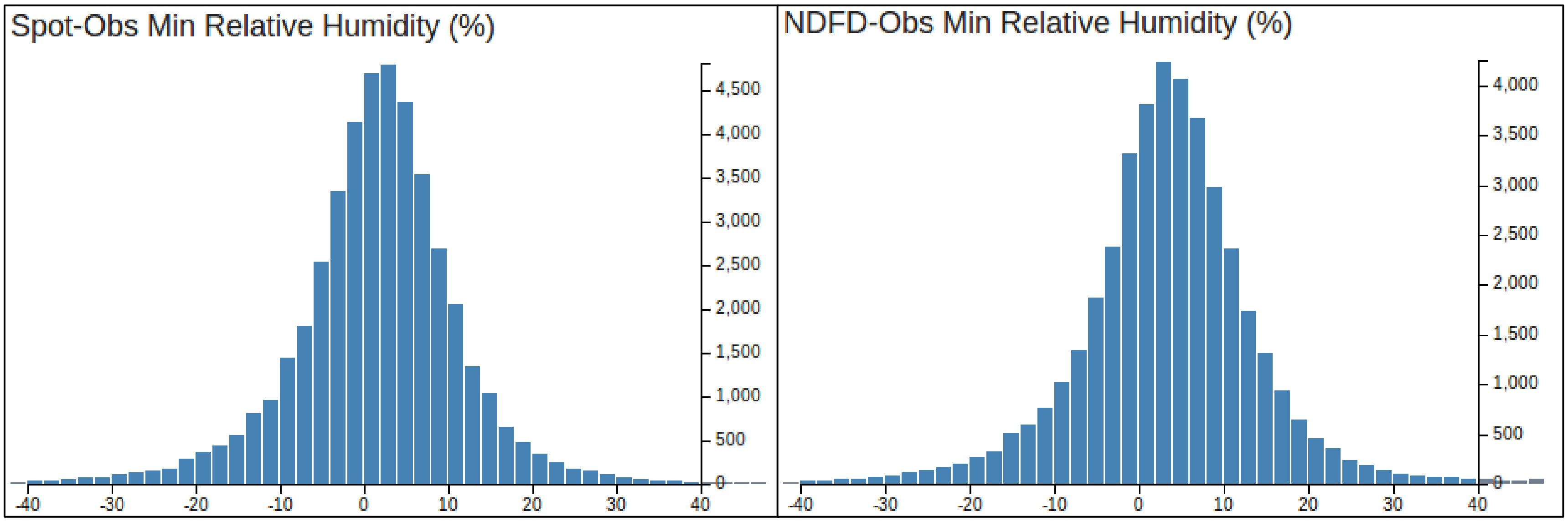
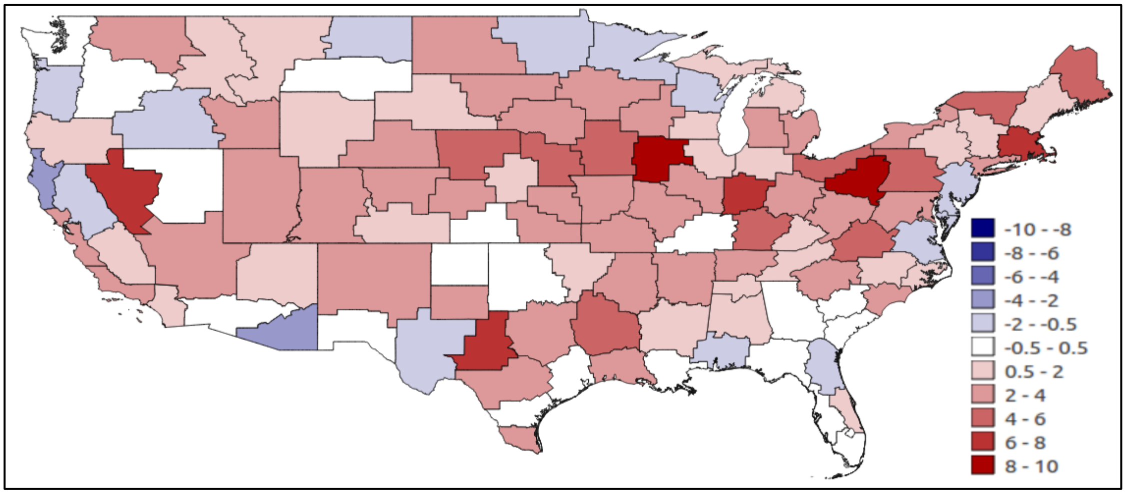


Figure 17. As in Figure 14, but for minimum relative humidity (%).

a)



b)

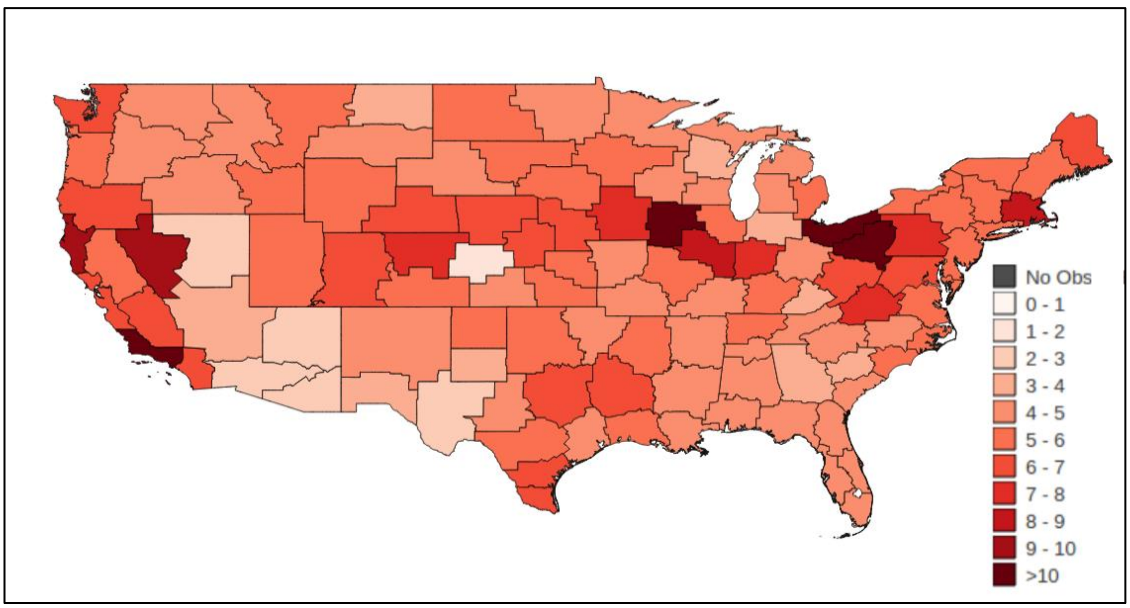


Figure 18. As in Figure 15, but for minimum relative humidity (%).

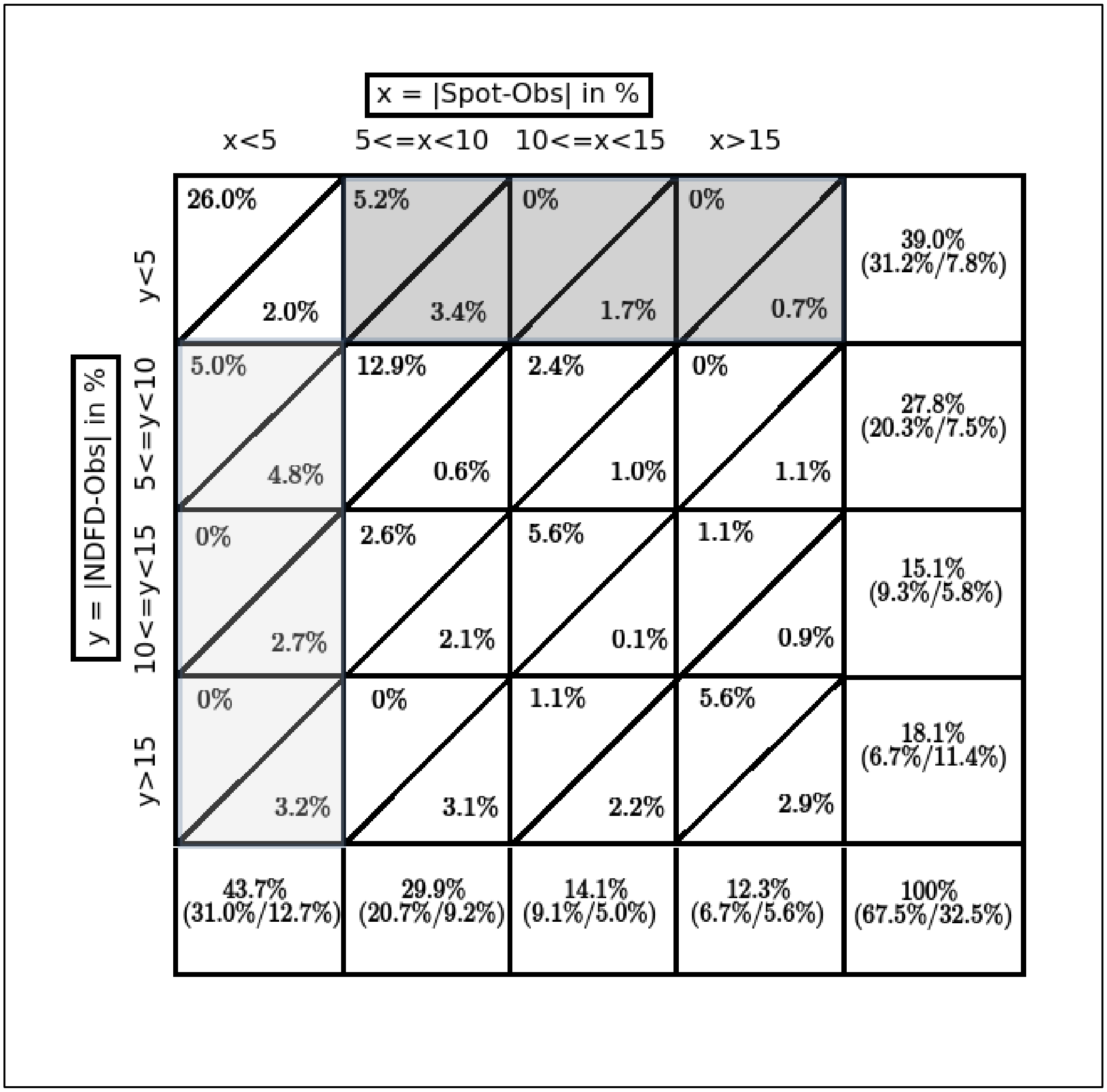


Figure 19. As in Figure 9b, but for minimum relative humidity (%) forecasts from all CWAs.

a) b)

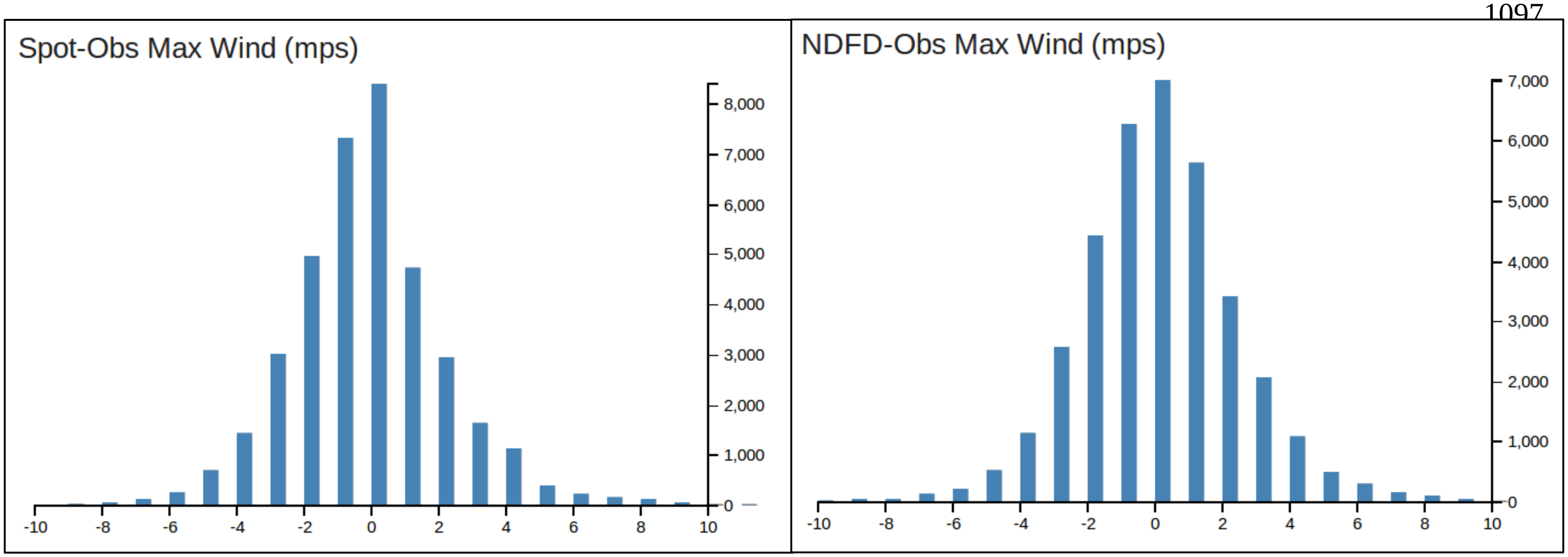
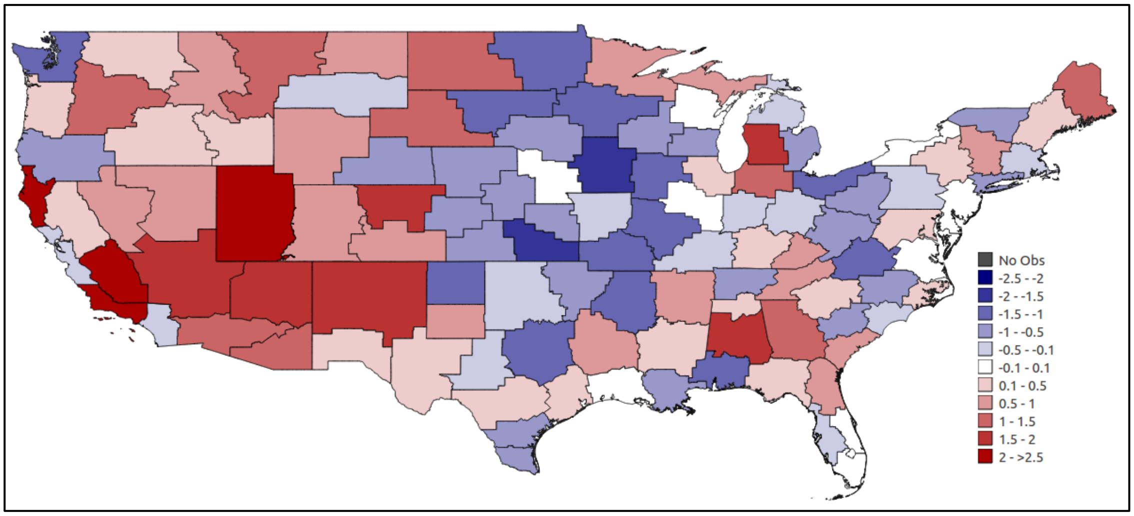


Figure 20. As in Figure 14, but for maximum wind speed (m s^{-1}).

a)



b)

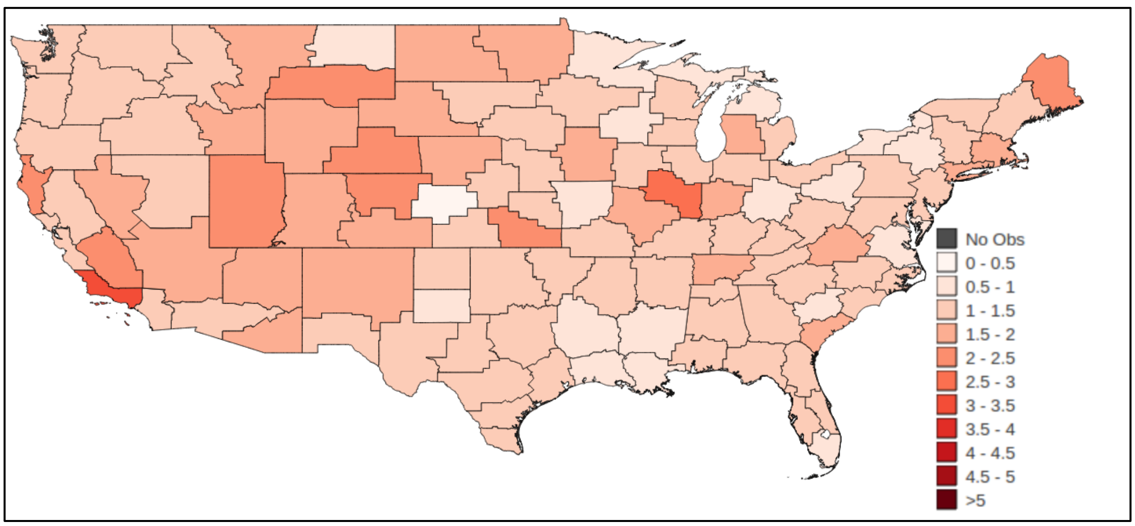


Figure 21. As in Figure 15, but for maximum wind speed (m s^{-1}).

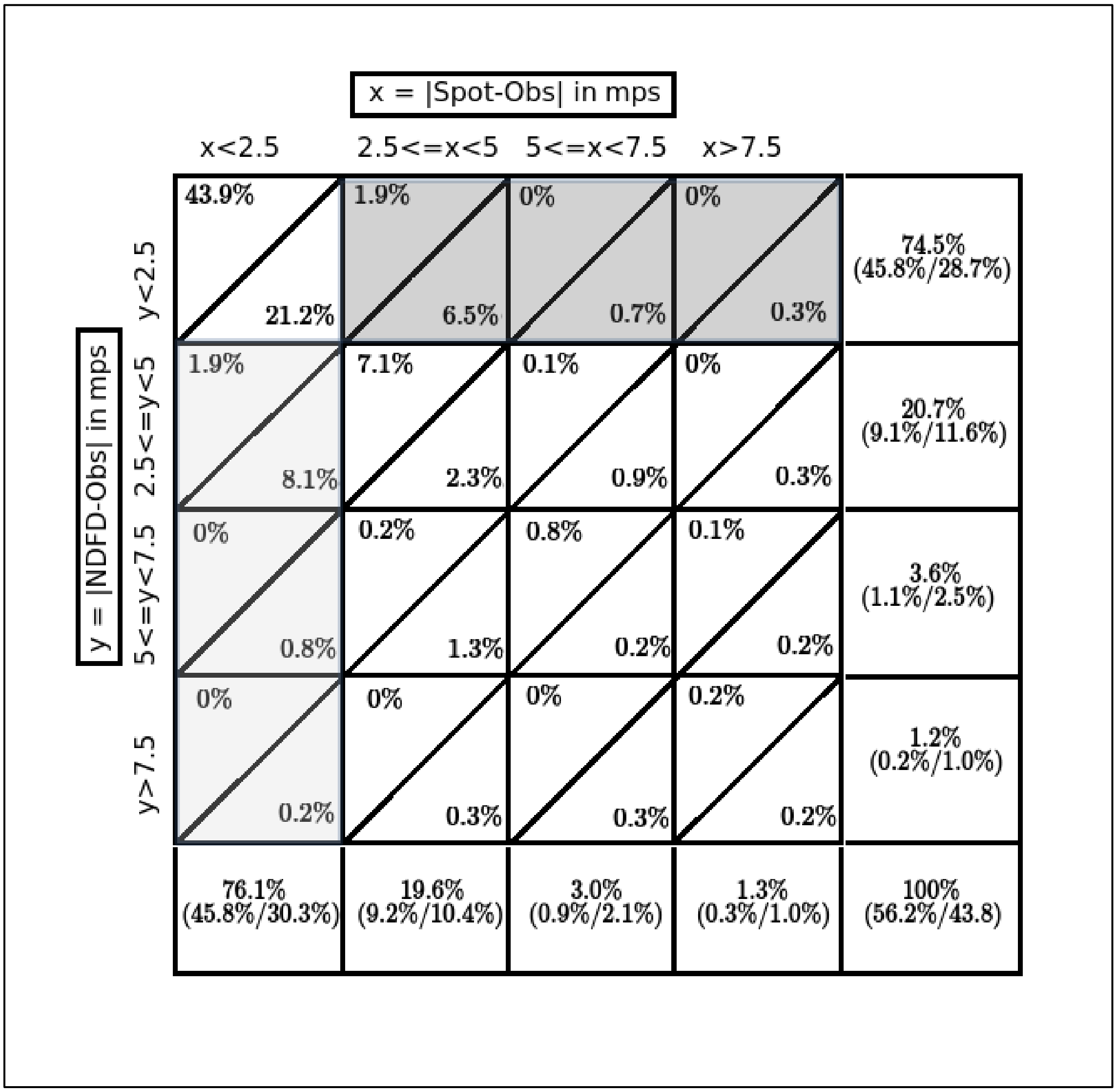


Figure 22. As in Figure 16, but for maximum wind speed (m s^{-1}) forecasts from all CWAs.