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REPORT TO THE NATIONAL WILDFIRE COORDINATING GROUP

What Is the Appropriate RAWS Network?

PMS 1003 **August 2012**

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Forward

In 2009, the NWCG Executive Board requested the Fire Environment Committee (FENC) to develop guidance for managing the interagency Remote Automated Weather Station (RAWS) network. In support of this work, the FENC commissioned an analysis of the RAWS network by the Desert Research Institute, Program for Climate, Ecosystem and Fire Applications. The findings of the analysis were reported to the FENC in April 2011.

The final guidance was approved by the NWCG Executive Board for interagency use in August 2012. The analysis report, published herein as PMS 1003, *Report to the NWCG: What Is the Appropriate RAWS Network?*, is part of the approved collection of weather station network guidance.

Program for Climate, Ecosystem and Fire Applications

What is the Appropriate RAWS Network?

Final Project Report

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Division of Atmospheric Sciences

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What is the Appropriate RAWS Network?

by

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Foreword

This report, for the National Wildfire Coordinating Group (NWCG) Fire Environment Committee, provides requested analyses on the RAWS network that can be used to make informed local and national programmatic decisions and recommendations. Because this study was commissioned by NWCG, the report is fire centric; however, the uses of RAWS information extends beyond fire weather, and this should be a consideration for any decisions about a single station or the network as a whole. This report addresses the question: what is the appropriate RAWS network? For further information regarding this report or the project described, please contact either:

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Executive Summary

The Remote Automated Weather Station (RAWS) network currently totals approximately 2,100 weather-monitoring stations distributed throughout the United States. As of March 2011, 1,732 stations are defined as permanent RAWS with information suitable for a network analysis. The network is interagency in that ownership includes federal and state organizations. The Bureau of Land Management Remote Sensing/Fire Weather Support Unit provides depot maintenance for RAWS. RAWS data are available in the Weather Information Management System (WIMS), and a complete historical archive for each station is maintained at the Western Regional Climate Center (WRCC).

Given the investment in the RAWS program and the extensive usage of RAWS data, it is clear that RAWS is of critical importance to many aspects of fire business (the characterization of fire occurrence in an area, described in terms of total number of fires and acres per year; and number of fires by time, size, cause, fire-day, large fire-day, and multiple fire-day). As stated in the National Wildfire Coordinating Group Fire Environment Working Team (now the Fire Environment Committee (FENC)) October 2007 RAWS/ROMAN Study Report, "The purpose of the RAWS network is to support point and gridded applications of fire weather for fire program analysis, fire danger rating, fire behavior prediction fire weather forecasting, and smoke management." The RAWS/ROMAN study further stated that the size of the RAWS network to achieve this purpose is finite and can be determined by:

- *leveraging other non-RAWS weather observation networks that can contribute to the needs of the fire community and by;*
- *understanding the number and location of RAWS and non-RAWS observations required to support the gridded applications we need.*

This study addresses the two RAWS/ROMAN study statements immediately above. Because of the many different potential applications for RAWS data, the common denominator is to examine RAWS and non-RAWS observations as they affect gridded depictions (or analyses) of fire weather conditions. Two separate analyses were performed. The first was an analysis of the influence of RAWS and selected non-RAWS (National Weather Service (NWS) Automated Surface Observing System (ASOS)) observations on gridded analyses. The second was a quantitative analysis to assess the uniqueness of each RAWS station in terms of a RAWS Uniqueness Index (RUI) developed for this report for this purpose. Finally, the potential for incorporation of data from other networks around the country for fire business is discussed.

This report, for NWCG FENC, provides requested analyses on the RAWS network that can be used to make informed local and national programmatic decisions and recommendations. Because this study was commissioned by NWCG, the report is fire centric; however, the uses of RAWS information extends beyond fire weather, and this should be a consideration for any decisions about a single station or the network as a whole. In particular, there are numerous uses of RAWS data for natural resource management. This report addresses the question: what is the appropriate RAWS

network? The various key aspects of the RAWS network are many including the number of stations, station location, station standards, observation times, elements measured and use of the station information. Given limited resources in supporting and maintaining the network, agency questions have arisen as to how many stations can and should be supported, and to what extent can other data networks be utilized in support of fire business.

Recommendations

It is not the purpose of this study to make specific recommendations regarding any individual RAWS. However, a number of guidance recommendations are offered here that will hopefully assist FENC, NWCG and local units in making decisions about their stations and the network as a whole.

1) If consideration is being given to moving or removing a station, the various station attributes that comprise the RUI should be considered in addition to local knowledge including established documents such as Fire Danger Operating Plans. It is probably best to compare index values within Geographic Area Coordination Centers (GACCs), rather than across the country as a whole. Low index values arise due to one or more quantitative attributes of the station, but low values do not necessarily mean a bad station. It is important to examine all of the input index values comprising the RUI. For example, a high terrain complexity score suggests that the station is measuring across a rapidly changing climate environment due to elevation differences. A high data denial score should be used as an indication that removing a station will have adverse effects on gridded weather and related fields such as fire danger. This may be due to removing the station in the data denial experiment and/or there is a relatively larger horizontal and/or vertical separation to the next station.

2) If there is interest in adding a station, the gap maps shown in Appendices 1-10 based on an Integral Data Influence (IDI) analysis should be used to help assist locating the new site. Zero IDI values on the map show areas of data void (no RAWS representation on the RAWS maps; no RAWS or ASOS representation on the RAWS+ASOS maps); the grid would be improved if areas with low index values had more stations. Utilizing GIS layers, the IDI values can be overlaid on top of other variables such as values at risk, vegetation, agency boundaries, etc. to assist in determining new station locations.

3) Other networks are potentially usable for fire business; however, experience shows that acquisition of historical data and the necessary metadata history is often very difficult. MesoWest provides easy to use output for many other network stations going back to as early as 1997 – this archive increases in more recent years. The Regional Climate Centers such as WRCC also have historical data for some other networks. ASOS is already a major network that is utilized for fire business, especially in the Eastern and Southern GACCs.

ASOS also serves as important input into the Real-Time Mesoscale Analysis and other NWS grids that fire weather meteorologists utilize. Predictive Services could play an important role in performing detailed assessments of these other network data for use in fire weather and fire business activities. However, since this would represent a major paradigm shift in data usage, some guidelines will need to be developed regarding criteria/standards for using other networks, how will those data be assessed and by whom, and processes for implementing the information into fire business. A prominent feature of the RAWS network is its reliability of information and access to the data; these are considerations that will have to be assessed for other potential networks. Another consideration is could a cross-agency effort pay to have other networks be more usable for RAWS purposes. Along these lines, consideration should be given to make RAWS year-round, to better align with other networks that are designed for continuous operation.

4) It is best to think of the RAWS network not in terms of size, but rather agency mission. The network has grown through a need to acquire weather information and add value by determining fire danger, fire behavior, etc. RAWS serves in both capacities of point data and weather grids, and provides unique value by representing geographic areas not generally covered by other networks. Uses of the network and the combination of the metrics provided in this study along with local knowledge should serve as network guides given budgetary constraints. It would be beneficial to address this with a RAWS management plan. Among the various aspects of a management plan, one element should be how to best integrate RAWS into the network of which deployment and maintenance are being covered by cooperators who are able to pay for their stations independent of federal agencies (e.g., state and private, Department of Defense).

5) Future work to support a RAWS management plan would include the investigation and inclusion of specific observing networks (as appropriate via standards, climatological record, etc.) into the grid of observations. Further analysis could be run to show the specific value these additional networks add to the grid. In addition, future work should focus on deriving specific observational data requirements from core RAWS business areas. These data requirements could be used in concert with the grid of observations to define a finite size and distribution of the RAWS network necessary to meet the data requirements. The RAWS management plan should also place emphasis on the various uses of the information, particularly as it supports crosscutting areas such as ecosystem management and long-term ecological studies.

1. Introduction

The Remote Automated Weather Station (RAWS) network currently totals approximately 2,100 weather-monitoring stations distributed throughout the United States. The network operates as a formal interagency collaboration with ownership widely distributed among federal and state partners. The Bureau of Land Management (BLM) Remote Sensing/Fire Weather Support Unit provides depot maintenance for RAWS. Nearly 1,900 stations are cataloged as “Type 4” (National Fire Danger Rating System; NFDRS) RAWS in the Weather Information Management System (WIMS), but nearly 200 of these are portable, test or temporary installations, or lack a proper (National Environmental Satellite Service identification (NESSID; RAWS identification number for use with the GOES satellite). This leaves 1,732 stations that are defined as permanent RAWS as of March 2011. RAWS data are available in WIMS, and a complete historical archive for each station is maintained at the Western Regional Climate Center (WRCC). As stated in the National Wildfire Coordinating Group (NWCG) Fire Environment Working Team (FENWT) October 2007 RAWS/ROMAN (Real-Time Observation, Monitor and Analysis Network) Study Report (hereafter referred to R/R 2007), “The purpose of the RAWS network is to support point and gridded applications of fire weather for fire program analysis, fire danger rating, fire behavior prediction, fire weather forecasting, and smoke management.”

This report, for the NWCG Fire Environment Committee (FENC), provides requested analyses on the RAWS network that can be used to make informed local and national programmatic decisions and recommendations. Because this study was commissioned by NWCG, the report is fire centric; however, the uses of RAWS information extends beyond fire weather, and this should be a consideration for any decisions about a single station or the network as a whole. This report addresses the question: what is the appropriate RAWS network? The various key aspects of the RAWS network are many including the number of stations, station location, station standards, observation times, elements measured and use of the station information. Given limited resources in supporting and maintaining the network, agency questions have arisen as to how many stations can and should be supported, and to what extent can other data networks be utilized in support of fire business.

A network for fire business could (and has for some limited areas in the Eastern and Southern Geographic Area Coordination Centers (GACCs)) extend beyond RAWS. There has been growing interest and demand to develop a nationwide “network of networks” to improve coordination and distribution of weather observations from federal, state and local agencies, academic institutions, commercial firms and the public. A National Academy of Sciences (NAS) committee was tasked to review present observations and make recommendations to develop such a national network on the mesocale (NAS 2009). The NAS report served as the impetus for the Committee for Integrated Observing Systems (CIOS; comprised of many federal agencies including the National Weather Service, U.S. Forest Service, Bureau of Land Management, and National Park Service) to conduct a series of meetings, most recently October 2010 (CIOS 2010). Hence, efforts to address the question “what is the appropriate RAWS network?" inherently assist the RAWS participating agencies to address similar questions.

1a. Purpose of this study

The R/R 2007 report assessed needs/requirements of the fire community for fire weather in order to resolve a RAWS concern (a second concern was directly related to ROMAN): *unplanned growth in the size of the interagency RAWS network while agency budgets are in decline*. The following section is taken directly from the study report, and is very relevant to the purpose of the present study:

> *The original RAWS network was conceived to support the coarse-scale application of fire danger rating. Today, RAWS data are routinely used to support decisions impacting firefighter safety, whether or not to initiate a fuels treatment prescription, air quality, crew readiness, and strategic seasonal and multi-year resource allocations to name a few. Demand for these data happens every day. Last year the ROMAN website received 125 million hits in pursuit of fire weather data. The future use of RAWS data to support gridded, digital data products is already here and growing quickly.*
>
> *The purpose of the RAWS network is to support point and gridded applications of fire weather for fire program analysis, fire danger rating, fire behavior prediction, fire weather forecasting, and smoke management. We believe this purpose is both necessary and appropriate to meet the current and future needs identified by the fire community.*
>
> *The size of the RAWS network to achieve this purpose is finite and can be determined through analysis beyond the resources for this study. This network size should be determined by:*
>
> - *leveraging other non-RAWS weather observation networks that can contribute to the needs of the fire community and by;*
> - *understanding the number and location of RAWS and non-RAWS observations required to support the gridded applications we need.*

The present study addresses the two points immediately above. With so much potential for continued growth of RAWS and related applications, a more tractable and restricted analysis is undertaken. For this analysis, the decision was made to examine RAWS and non-RAWS observations with regard to their influence on gridded depictions (or analyses) of fire weather conditions. The grid concept is discussed in Section 2. The methodology and its application toward the influence of RAWS and selected non-RAWS observations on gridded analyses are described in Section 3. A quantitative analysis of RAWS was undertaken to assess the uniqueness of each station in terms of objective reference measures. This was done by creating a RAWS Uniqueness Index, and is discussed in Section 4. The question of potential usage of other networks around the country was examined and discussed in Section 5. A summary discussion and recommendations are provided in Section 6.

It is not the purpose of the present study to make recommendations regarding the specific removal or addition of RAWS stations. That needs to be done at the local level given the information provided by this analysis along with knowledge of the local environment and agency needs. This report, for FENC, provides requested analyses on the RAWS network that can be used to make informed local and national programmatic decisions and recommendations.

1b. A brief history of RAWS

In 2005, Mitretek was commissioned to perform a review of the basis for the RAWS network (which was provided to BLM in the form of a Powerpoint presentation). In their presentation, they provided a brief summary on the background of RAWS. Published material on early RAWS is nonexistent or not readily accessible; much of what was presented in the Mitretek presentation was based on interviews. The summary that follows is based on Mitretek's synthesis. The earliest considerations of a RAWS network were specific to the newly developed fire danger rating system formed in the 1970s. After some field-testing, stations began to be deployed starting in 1980. A RAWS network plan was developed in the 1980s, which called for a grid approach with 75 mile spacing. BLM did basically implement this grid, but the Forest Service instead implemented their stations relying on local unit managers. These stations (termed Class 1) were to be permanent and not to be moved. If BLM managers thought that an area was inadequately represented, they could add additional stations, though these Class 2 stations were not considered permanent, and could be moved if desired. The original plan also included criteria for determining how many additional stations a local unit could receive. As a point of reference, it is of interest to note that manual fire weather observations date back to the 1920s. The development of the RAWS network also evolved from a desire to automate what was being measured from the manual mid-afternoon observations routinely taken for many years up to that point, and in the 1970s, technology became available to allow for automated weather observations in remote locations.

Figure 1 shows the development of the RAWS network nationally in 5-year increments for the year ending as given. The growth of the RAWS network is quite evident over time, especially with the expansion in the eastern U.S. during the last decade.

Figure 2 shows a histogram of the number of active RAWS for the given year. Generally, the number of stations has been steadily increasing since the mid 1980s. Sizable step jumps are seen in 1985 and 1990, and a more rapid increase during 2001-2004, associated with the National Fire Plan. The last six years shows the lowest rate of increase since RAWS began except for the very early years.

Figure 3 shows a map of RAWS stations colored by period of data record for each station. The red dots represent the most years of data, and the black dots the least. Not surprisingly, stations with the most years of data dominate the West, while the East is mostly comprised of newer stations with 10 years or less of data.

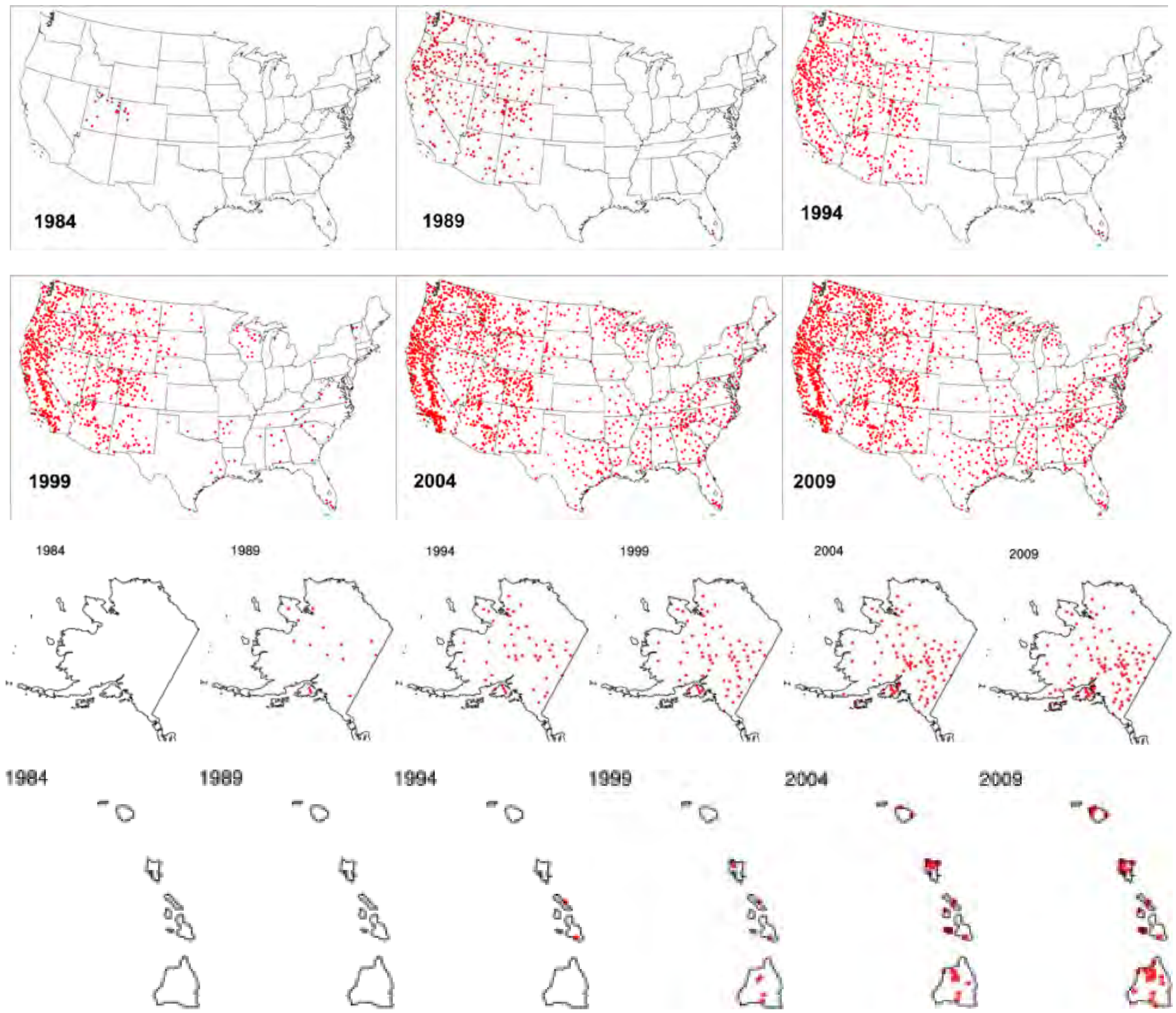

Figure 1. RAWS permanent station locations shown in 5-year increments.

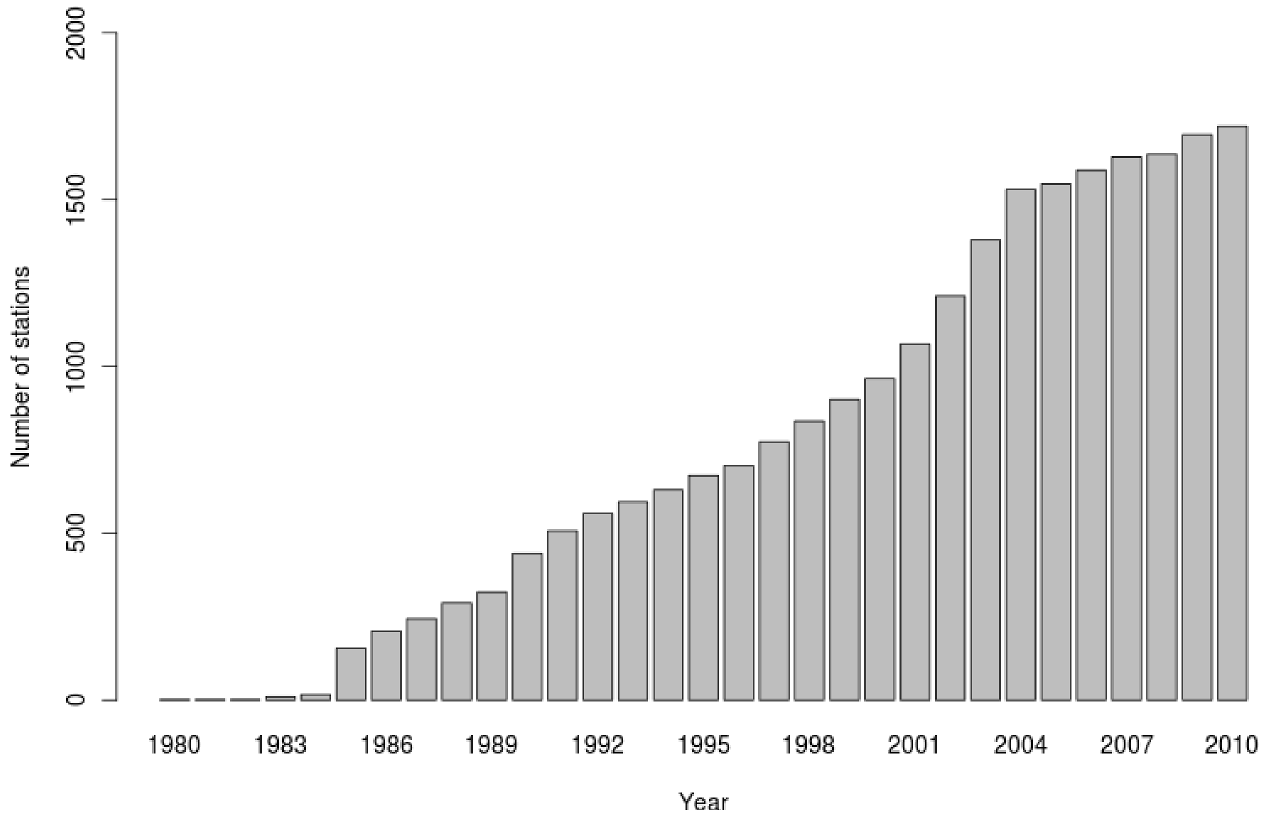

Figure 2. Number of active permanent RAWS stations by year.

Figure 3. Map of permanent RAWS stations colored by number of years with data for each station.

1c. A summary of previous RAWS network analyses

The origin of the RAWS network can be connected back to Gisborne (1937) and Morris (1939). Gisborne noted a lack of guidelines for the determination of the desired characteristics of a fire danger-monitoring network, and suggested that measurements be representative of an area larger than just the observation location (recall that this was also a premise in the development of NFDRS). Morris defined preparedness in terms of readiness for the “worst probable” condition. Two of these concepts remain in place today: 1) the mid-day 1300 local time observation is an approximation of worst case given the timing needed to receive forecasts based on the observation[1], and 2) that fire danger can similarly be represented over large areas of homogeneous vegetation, topography and climate. There remain no guidelines for specifying the properties of a monitoring network, though interagency wildland fire standards and guidelines for station characteristics are well established (NWCG 2009).

The number of formal studies specifically addressing the attributes of a fire weather network is quite limited. Morris (1940) offered the first formal statistical analysis of a fire weather station distribution. The analysis was for ranger districts in Washington and Oregon, and based on variance of wind speed and fuel moisture. The analysis showed for wind speed, as many as four times more stations are needed on mountain tops than at other lower elevation locations; but for fuel moisture, the ratio is close to one.

Knorr (1942) determined that one station per ranger district was adequate in the longleaf pine region of the Southeast based on fuel moisture measurements, though more stations might be needed if wind speed was considered. He did not address the total area that a station would best represent.

Hayes (1944) suggested a noon observation, but appears to be the first to formally highlight the importance of a south slope station. He also did not address observations in the context of degree of areal representativeness.

Tucker (1960) offered a short note on planning the location of fire danger stations. This paper, however, is more oriented toward station siting and exposure than a network station distribution.

Furman (1975) published a General Technical Report on streamlining fire weather station networks. The paper focused on the issue of station duplication, and identifying redundant stations based on fire climate given a need to close one or more stations for economic reasons. Fire climate was defined in terms of the equilibrium moisture content (EMC), and a more sophisticated statistical analysis was performed utilizing principal component analysis. Furman’s definition of the purpose of a fire weather observation network is to monitor what he called the “average worst” fire danger condition, and to monitor the climate representative of the protection area.

[1] This observation time is also an artifact of years of storing only 1300-hour data.

King and Furman (1976) set out to answer the question "What is the necessary station density for a fire danger network?" They used the NFDRS burning index to calculate the spatial mean of fire danger, and then utilized a probability statement based on spatial mean and variance to determine an associated required station density.

Fujioka (1986) developed an objective method for designing a fire weather network by identifying the area to be sampled, the relevant meteorological variables, the target meteorological fields and an interpolation method. In this work, a least-squares criterion with a constrained optimization algorithm was used to determine an optimum network. Simulated rate-of-spread was analyzed in southern California as a test case. The paper also highlighted some other published methodologies for establishing a network for general meteorological purposes.

Brown *et al.* (2001) examined the spatial distribution of RAWS in the Great Basin by correlating meteorological elements of temperature, relative humidity and wind speed, and also applying a geostatistical variogram method to determine optimal station spacing. This study result suggested that RAWS should be no more than 50 miles apart in the Great Basin, but highlighted that elevation should also be factored such that the 50 mile radius applies within each of three elevation bands.

Also in 2001, Terry Marsha at the Northwest Coordination Center applied a statistical procedure to determine RAWS network optimization for the Pacific Northwest GACC. These results were documented as internal office reports. Wind and relative humidity were the primary elements examined. Other GACC meteorologists have conducted local applied studies as well, but these have not been formally documented.

Zachariassen *et al.* (2003) provided a review of the RAWS network from a Forest Service perspective, though it was also intended as an interagency reference. The report describes many aspects of RAWS including an overview of the network, information management systems, agencies involved, data streams and products, operational aspects, uses, data management, projects, and studies and surveys. It also offered findings in assessment form for these thematic areas.

Myrick and Horel (2008) evaluated the influence of RAWS observations on winter temperature and wind analyses in the western U.S. This study demonstrated the considerable positive impact of the RAWS observations on winter weather analyses, where RAWS data considerably augment data from the sparse distribution of other stations in the mountainous regions of the West.

Despite this long history of formal scientific efforts to specify *a priori* the desirable spatial density attributes of a fire weather network, none have ever actually been applied in the establishment of the RAWS network. Other than the early attempt at creating a gridded network, the basis for RAWS station placement has persistently been driven by locally determined needs. Although there may not be anything inherently wrong with this approach, which is based upon fire manager knowledge gained through experience, it does highlight the lack of a RAWS management plan, and easily leads to the question of what should be the ultimate size of the RAWS network. This question is especially relevant if the growth in the size of the interagency RAWS network is outpacing the agencies' financial ability to maintain it, which is a primary concern as stated in R/R 2007.

1d. Uses of RAWS

RAWS began as a fire danger network – an outgrowth of NFDRS that was developed in the 1970s. Today this remains a primary importance of the network, but many other uses have evolved over time. This growth in the diversity of applications is not likely to stop, and in fact appears more poised to accelerate now that sufficient record lengths have accumulated. For example, fire weather data from RAWS is an important component of fire behavior analyses. RAWS observations are critical for Incident Meteorologists during significant fire events, and are used in developing spot forecasts for prescribed burning and wildfire incidents. Over time, many RAWS sites have become invaluable because of their ability to provide information for established long-term climatologies such as for the FSPro decision-support tool; over 400 stations now have 20 or more years of observations.

In 1980, when the first station was installed, it is unlikely that fire managers could have foreseen all of the potential uses of RAWS data, not only within their agencies, but the value that the network now adds externally. For example, a new use that does feed back to the agencies is the ingestion of RAWS data (in addition to thousands of other network station data) into the Real-Time Mesosale Analysis (RTMA) data assimilation system run by the National Centers for Environmental Prediction (NCEP) (Tyndall *et al*. 2010). The grids produced by RTMA provide real-time hourly analyses of temperature, relative humidity, wind and precipitation. This information is disseminated in gridded form and used by National Weather Service (NWS) forecasters and GACC meteorologists. The RTMA effectively serves as observations on a regular grid, driven by point observations including RAWS. This is another reason to state that grids are the future of fire business activities.

Identifying every single use of RAWS is beyond the scope of this study, but it is worthwhile to highlight a number of known uses to show the value of the network from a number of perspectives. Table 1 provides a list of identified uses from 1) the Brown *et al.* (2001) report based on a user survey conducted as part of the project study, 2) by Zachariassen *et al.* (2003) and 3) the R/R 2007 report. This table clearly indicates uses well beyond the three basic applications of fire danger, fire behavior and fire weather. An emerging new interest is climate downscaling (techniques that relate local- and regional-scale climate variables to the larger scale atmosphere, and requires point observations and fine scale grids to accomplish this). Another emerging application is weather information support for smoke management.

2. Gridded Fire Weather as the Common Denominator

Gridded applications are becoming increasingly common to support fire business activities (e.g., FARSITE, Flammap, FSPro tools; and the primary use of these modules in the Wildland Fire Decision Support System; WFDSS), because grids can very effectively depict fire danger, fire behavior and fire weather spatial patterns. Grids are commonly used in NWS forecast operations, and are the basis for numerical model guidance and public forecasts. A weather grid, derived in part from RAWS, provides common information for numerous uses of fire weather information. For example, gridded weather forecasts from the NWS are now used to compute Energy Release Component as part of the Wildland Fire Assessment System (WFAS; http://www.wfas.net/index.php/ndfd-fire-danger-forecasts-fire-potential-danger-91).

Table 1. Selected common uses of RAWS data.

Brown *et al* 2001	Zachariassen *et al* 2003	RAWS/ROMAN study
Predict or estimate fire severity based on historical information	Air quality monitoring	Support decisions impacting firefighter safety
Relate to fire history	Measurement of aerosols	Whether or not to initiate a fuels treatment prescription
Fire investigations	Climatological analyses	Crew readiness
Court cases	Studies of environmental aerodynamics	Strategic seasonal and multi-year resource allocations
Erosion	Ecosystem process modeling	
Historic season ending events	Weather research	
Risk appraisals for wildland fire use	Mesoscale weather forecasting support	
Prescribed burn planning		
Rehabilitation		
Budget analysis		
Fire behavior		
Fire severity funding requests		
Develop programmatic fire management plans		
Ground water and hydrologic assessments		
Summaries to visitors and visitor guides		
Wildlife impacts		
Forest health		
Soils studies		
Vegetation change and response		

A station-based analysis of the RAWS network that tried to account for all uses could be too complex. Accordingly, a method was selected that utilized gridded fire weather conditions as the common denominator for the RAWS network analysis. This choice of methodology was discussed with the FENC fire weather, fire danger and fire behavior subcommittees during an all-hands meeting in Boise, Idaho in December 2009. A grid of 5-km was chosen since it represents the finest scale national forecast grid currently provided by the NWS, and is also the RTMA output scale (the NWS will be shifting operationally to a 2.5 km grid by the end of 2011).

Figure 4 is a schematic of a 5-km grid such as RTMA over an area of mixed complex and flat terrain (as shown by the contours). Meteorology grid cells are typically square, and when referring to a grid size such as 5-km, this means that the grid cell is 5-km by 5-km in size, and covering 25 square km. Data values represent the entire area of the grid cell, not just the center point. It cannot be assumed that a single observation within a grid cell is "truth", as the observations have errors and there could be considerable topographically-induced spatial variability in both instantaneous weather and in long-term climate within the grid cell. One example is how several rain gauges within a grid cell area could easily record different precipitation amounts from a convective storm. Some gauges in this example might receive zero precipitation, though others with substantial amounts. Grids are derived from numerical or statistical modeled analyses. The higher the grid resolution, the more detail will be shown. A simple example is displaying complex topography as a grid – a fine scale grid of 30 meters will obviously reveal much more detail than 1-km. However, depending upon the input, a higher resolution grid does not necessarily mean a more accurate result, even though it may appear that way on a map.

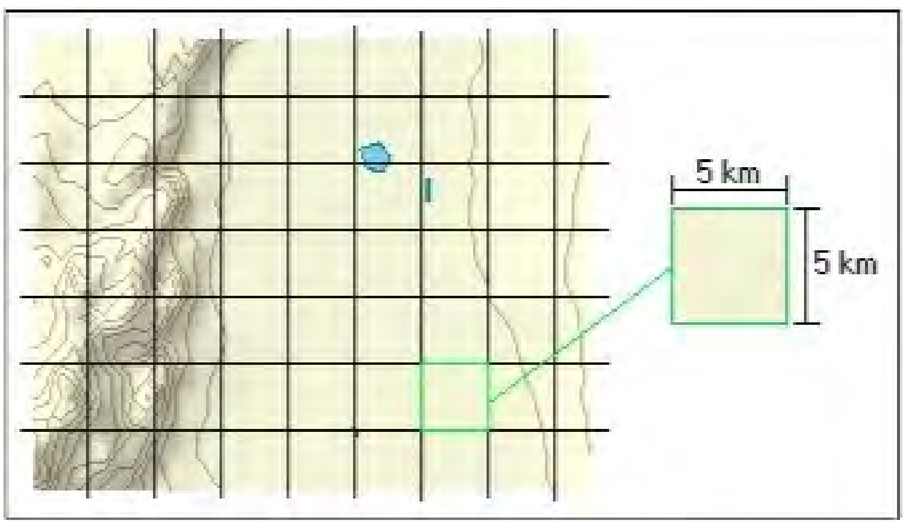

Figure 4. Schematic depiction of a 5-km grid with complex topography.

3. Examining the Influence of RAWS Observations on a Grid

Whether surface observations of temperature, moisture and wind at some stations in the continental U.S. are less critical than others for specifying weather conditions in the vicinity of those stations was examined by (Horel and Dong 2010). Their study is the basis for the grid analysis in this report. The particular analysis approach used was to generate nearly 9,000 variational analyses (estimations of atmospheric conditions) of temperature, relative humidity and wind for midday hours during summer 2008. These analyses were derived from 5-km resolution gridded fields from a 1-hour model forecast and RAWS and NWS (ASOS) observations throughout the continental U.S. The grids help to provide spatial and temporal continuity, but the observations help to define local weather features missed by those grids. These analyses depend on the interplay between station spacing, terrain, the values of the observations and the grids, and assumptions about the observation and grid errors. Figure 5 is an example of a wind speed and direction analysis at the time of the Paradise Fire in northern California. RAWS and NWS observations are shown as well as the analysis wind vectors. Overall, the analysis captures the mesoscale and local wind patterns including strong winds into the Sacramento Valley from the San Francisco Bay region. But there are locations void of weather stations that show strong or weak winds; the only way to verify the model grid is by having stations in these areas. Of course, having stations in observation void areas to begin with would have directly provided input into the grid and improved the modeled results.

The impact of removing RAWS observations on such analyses relative to the impact of removing NWS observations was then examined. That required computing ~600,000 additional analyses in each of which one particular station is removed from the grid. The results suggested that on the order of 100 RAWS within the continental U.S. had nearby ASOS observations such that if the RAWS were removed, the ASOS data could replace the RAWS strictly from a 5-km grid perspective. The remaining approximately 1,600 RAWS showed to be uniquely reporting weather for the grid, and their removal would begin degrade the grid analysis. This study further indicated that although the presence of observational stations within close proximity to one another is relatively common, the sensitivity to removing temperature, relative humidity, or wind observations varies regionally and depends on the complexity of the surrounding terrain and the representativeness of the observations, i.e., the degree to which local observations reflect the conditions over the entire 5km x 5km grid cells. With respect to gridded fire weather modeling, nearly all regions of the country remain undersampled, especially mountainous regions of the western United States.

As a measure of the proximity of stations and influence of local terrain, Figure 6 shows a U.S. map of the Integral Data Influence (IDI) analysis described by Horel and Dong (2010) and constructed from data provided by Dan Tyndall, University of Utah. This particular analysis was completed after publication of the 2010 study, and was done in a more comprehensive and efficient manner for the continental U.S. as a whole (a similar figure by Horel and Dong had to be computed over limited subdomains due to the computing resources available at the time). Larger values of IDI (red colors) indicate locations where NWS and RAWS stations are likely to strongly influence gridded weather analyses (removing stations in these areas would be a detriment to an analysis of weather conditions). That is, brighter colored areas represent locations of good data coverage strictly from the grid perspective; thus, removing stations would begin to degrade a gridded weather analysis. Removing stations from areas of “dense” coverage would begin to change the IDI to lesser values; removal of enough stations in these areas would degrade a gridded fire weather analysis. Removal of stations leads to data gaps. Smaller IDI values (white color) indicate existing data voids considering only the RAWS or RAWS+ASOS networks. Areas of low IDI (blue colors) indicate poor data coverage such that adding stations to these areas would improve a gridded weather analysis, and removing stations in these areas would create data gaps.

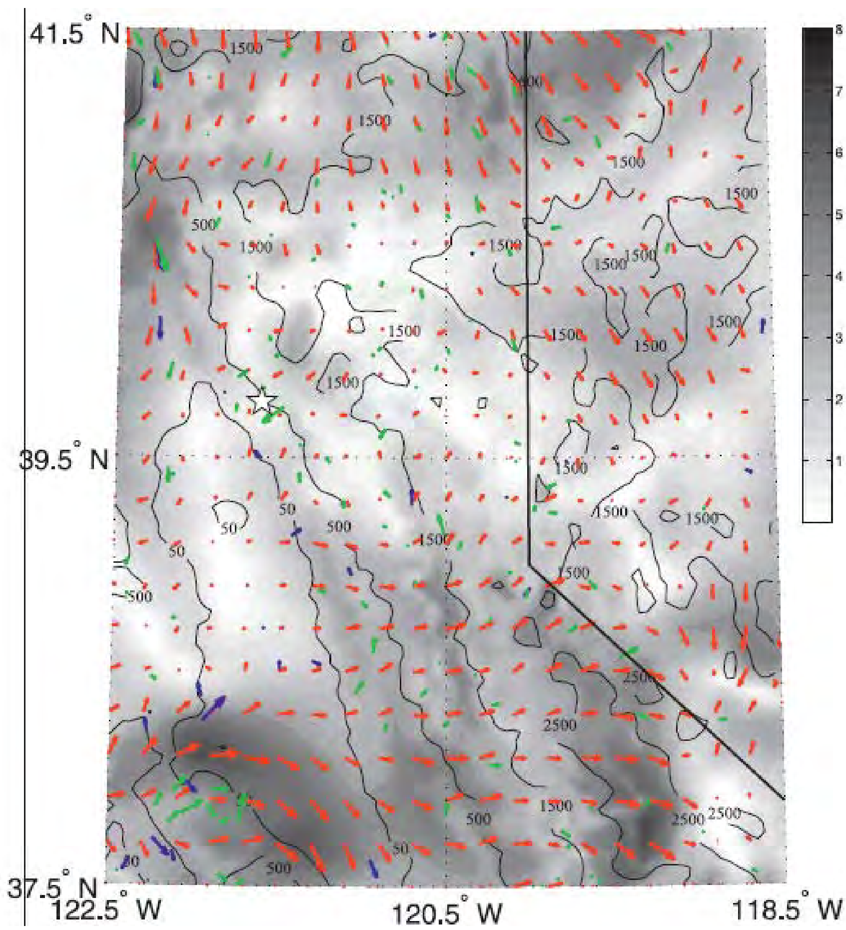

Figure 5. Example illustration of surface wind observations and model grid output for a specific case over northern California during the time (18 UTC 10 July 2008) of the Paradise fire (denoted by the white star). The wind speed (m/s) is shaded and vector winds on the grid are in red at every fourth grid point for pattern clarity. Green (blue) vectors indicate the wind observations from RAWS (NWS stations) and terrain (m) is indicated by contours.

Figure 7 shows RAWS and RAWS plus ASOS IDI values for comparison. Clearly, RAWS alone on the grid indicate large areas of data void, but by including ASOS, many of these areas improve in coverage, and the IDI values increase substantially. It can then be assumed that including even more RAWS or other network stations would improve the results further, hence highlighting the network of networks interest and the potential utilization of other station data for fire business.

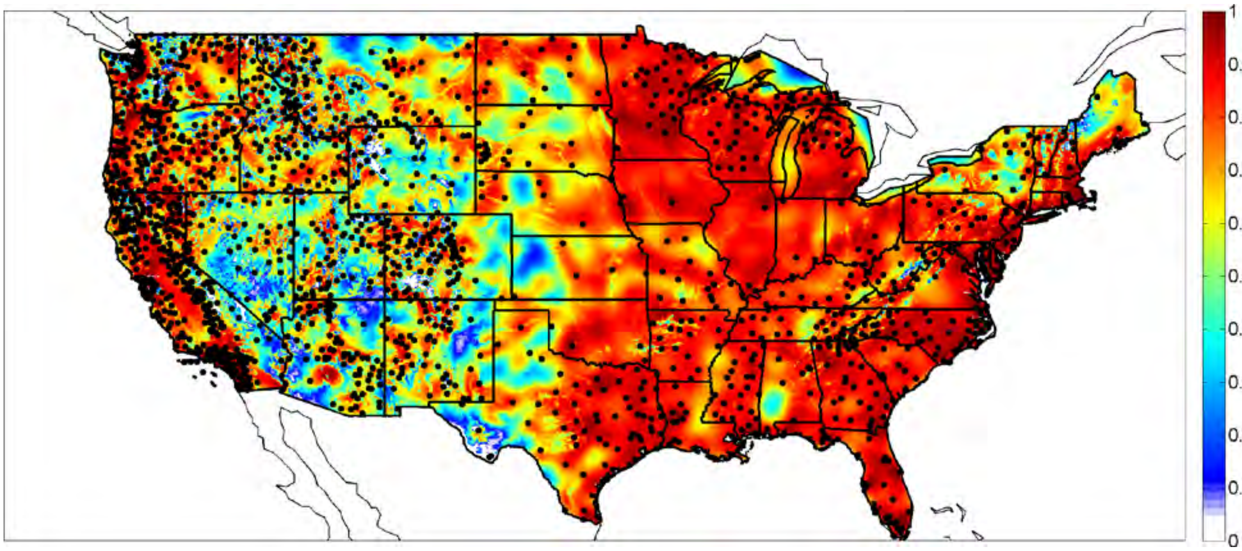

Figure 6. Map of IDI values as described in Horel and Dong (2010) and from data provided by Dan Tyndall. Larger values (red colors) indicate areas where removing stations would be a detriment to the 5-km grid. White areas indicate station data gaps, and blue colors indicate areas where station removal would further increase data gaps. Black dots indicate locations of permanent RAWS.

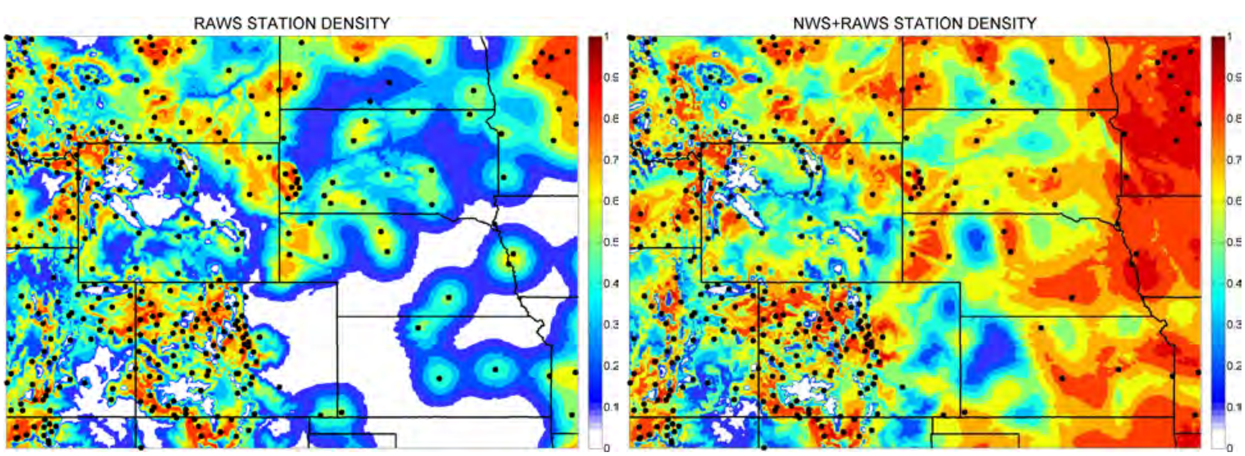

Figure 7. Gap data maps for Rocky Mountain GACC for RAWS only (left map) and RAWS plus ASOS (right map). Interpretation of IDI colored values is the same as in Figure 6.

The IDI analysis is shown by GACC (excluding Alaska) in Appendices 1-10. The IDI analysis was not done for Alaska; for this region, it is recommended referring to the weighted proximity index described in the next section. In short, higher proximity values reflect larger horizontal and/or vertical separations, and thus indicate more uniquely located (without regard to specific siting) stations.

4. RAWS Uniqueness Index

Because of the various potential uses of RAWS, it is difficult to quantitatively place a “value” on each station. For example, how would one derive a quantitative number for the value of a specific RAWS in its usefulness to calculate fire danger? Yet, it is known that most if not all stations are used for a variety of purposes such as those listed in Table 1, and thus are perceived as high value. The data denial analysis in the previous section showed that nearly all RAWS are important for gridded weather, thus they have high value in this regard. More specifically, Horel and Dong (2010) show that the removal of a RAWS has a larger detrimental impact on analyses than the removal of NWS stations (their Table 6). Hence, the ‘‘value’’ of RAWS as examined solely from the standpoint of gridded analysis impact is higher than the “value” of NWS stations. This results from the reduced ability of the grid to be representative of the conditions in the typically remote locations near RAWS where few other network observation stations are likely to be located nearby.

To better objectively assess RAWS, however, a number of attributes related to each station can be quantitatively derived. These attributes, additively combined, form what we refer to as the RAWS Uniqueness Index (RUI), which ranges from 0 to 1. The index, along with the individual attributes, can then be used to assess a station along with what is known locally about the station’s usefulness.

Four attributes, described below, comprise the RUI. Each attribute is converted into an index ranging from 0 to 1.

Maintenance

Station maintenance is extremely important in assuring the quality of observations. Documenting the maintenance is also important as it adds to the station’s metadata record so that any station changes are well understood. A simple maintenance score was defined as the number of times ASCADS was updated during the year indicating a station maintenance action. If at least one change was indicated, which would be expected given normal maintenance, a score of 1 is assigned. It was beyond the scope of this analysis to thoroughly examine each station’s metadata, so this attribute must be considered only a coarse indication of station maintenance. It is assumed that if ASCADS records are updated, then maintenance is occurring and being documented by the station owner. The attribute score is defined as $\Sigma n/N$, where n is equal to 1 if at least one metadata change during the year was found, and 0 otherwise, and summed for the N-years period of record. For example, if a station has been in service for 20 years and showed 20 individual years of metadata changes, then the score is 1; if only 10 individual years of metadata changes, then the score is 0.5. Thus, scores closer to 1 suggest better station maintenance.

Period of Record

The period of record (POR) attribute score is calculated by *n*/30, where *n* is the period of record in years for a specific station, and 30 is the longest period of record for any station through 2009. The POR is based on data stored in the WRCC RAWS hourly data archive, and this may not reflect the complete period. For example, WRCC hourly data for Redding, California begins in 2001, but the NFDRS observations in the National Interagency Fire Management Integrated Database (NIFMID) begins in 1976. Should it be desired to recalculate the RUI for a station known to have a longer period than analyzed in this study, a new index value can simply be calculated by dividing the known *n* years by 30; an index value >1.0 should be set to 1.0.

Data Denial

The denial score is an equally weighted (50% each) sum of two metrics defined by Horel and Dong (2010): weighted proximity and analysis degradation. The weighted proximity is defined as large cliffs. Along the West Coast, climate differs dramatically within just a few miles during the “warm” season. Although the “representativeness footprint” of a station is not truly circular along the coast or in many mountain settings, this simplification was made here for analytical tractability.

The region that a particular RAWS represents for meteorological conditions can be determined by drawing a distance radius around the station to the next nearest RAWS (or other network station). Elevation variance for the radius area is computed for all of the Digital Elevation Model (DEM) data points (90-m DEM for the continental US; 300-m DEM for Alaska; 30-m Hawaii) that fall within the radius. A smaller radius means less area that is being represented. The radius area has greater significance in complex terrain regions with valleys, mountain peaks and steep gradients compared to a flat land where weather change with distance tends to take place more gradually.

The terrain complexity index is calculated by computing the DEM elevation variance within the radius to the next nearest station, and dividing the variance by 1000. This yields an index range from 0 to 1. A zero value means that the radius area is completely flat. The index increases with increasing variance (or terrain variability), such that a value of 1 indicates highly complex or variable terrain in a relative sense compared to flatland.

Figure 8 shows examples of terrain complexity for two RAWS. In Figure 8a, a red radius circle from Oak Creek, California is drawn intersecting the nearest RAWS (not shown). Oak Creek sits near the edge of a valley, representing weather across the valley, very tall mountain peaks (around 14,000 feet), and numerous canyons. The radius line is hidden behind a couple of mountain peaks simply due to the viewing angle. Figure 8b, shows a flat coastal area in North Carolina around the DARE Bomb Range RAWS station. In these areas, land-sea breeze will be more influential on local weather than vertical terrain.

RAWS Uniqueness Index (RUI)

The RUI is the weighted sum of each of the attribution scores. The equation is:

RUI = 0.10xMaintenance + 0.25xPOR + 0.30xDenial + 0.35xTerrainComplexity.

The weights have been subjectively chosen, though they are reasoned with the idea that the RUI is an indicator of station uniqueness. Thus, larger index values indicate stations that are more “unique” than those with smaller index values. For example, if a station were to be removed that had a large RUI, the influence on the grid or a fire application might be substantial if data were not available.

Terrain complexity is given the greatest weight (35%) since it describes the topographic region that the RAWS is representing. This can be critical for any number of reasons related to fire business as well as the grid. The next largest weight (30%) is the denial attribute since it directly describes data influence on the grid. The period of record is given a 25% weight; longer climatologies are more valuable than short ones given decision-support tools such as FSPro, and an overall understanding of the climatology for the area that the station is representing[2]. The smallest weight (10%) is given to maintenance. While this attribute has a relatively small impact on the RUI, it is important to account for how well the station has been maintained. Thus, higher maintenance scores will boost the RUI and vice versa.

Table 2 shows an example subset of the RUI and associated attributes. In this particular example, Burns Canyon, California has a high index value (.636), which is due to all but one of the attributes having a high value. The period of record is long (.633 or 19 years), the nearest RAWS station is a large horizontal distance away, or has a large elevation difference, or both (.925 proximity), and has a large denial score suggesting that removal would substantially affect the grid. The terrain complexity indicates moderate (.498) elevation variability represented by this station. The Burns, Tennessee RAWS provides an example of a smaller RUI value (.258). This is due to a shorter period of record (.233 or 7 years) and minimal terrain complexity (.038; nearly flat); the nearest RAWS is a moderate distance away based on proximity (.473) and the denial index suggests moderate influence on the grid (.487). Recall that proximity is incorporated directly into the denial index, but is shown in the RUI table to provide additional assessment information.

Table 2. Example subset of stations showing quantitative attributes and the RUI.

Station	State	Maintenance	POR	Proximity	Denial	Terrain	RawsIndex	Agency	GACC
BRYSON CANYON	UTAH	1.0	0.767	0.934	0.717	0.250	0.594	BLM	Eastern GB
BUCKEYE	OREGON	1.0	0.833	0.936	0.718	0.223	0.602	USFS	Northwest
BUFFALO CREEK	CALIFORNIA	1.0	0.633	0.881	0.691	0.241	0.550	BLM	Western GB
BURGESS	WYOMING	1.0	0.600	0.924	0.712	0.445	0.619	USFS	Rocky Mountain
BURNS CANYON	CALIFORNIA	0.9	0.633	0.925	0.713	0.498	0.636	BLM	South Ops
BURNS	TENNESSEE	0.4	0.233	0.473	0.487	0.038	0.258	S&PF	Southern
CABINET (TROUT CREEK)	MONTANA	0.9	0.300	0.765	0.632	0.291	0.457	USFS	Northern Rockies
CARR	ARIZONA	0.8	0.367	0.671	0.586	0.181	0.411	USFS	Southwest
CANNIBAL MOUNTAIN	OREGON	1.0	0.833	0.975	0.677	0.128	0.556	USFS	Northwest
COTTONWOOD	ALASKA	0.7	0.633	0.272	0.272	0.105	0.347	FWS	Alaska

Because of the varying complexity of the terrain across the U.S. along with an uneven distribution of RAWS, it is suggested that performing a comparison of RUI values should be done primarily within GACCs rather than across the U.S. as a whole. Comparing the RUI across the country could be misleading from a national perspective because eastern RAWS will generally have smaller values due to lesser terrain complexity than the West. For example, average RUI values for all stations within the eastern and southern areas average .332 and average nearly 0.5 for all of the western (including Alaska) GACCs. This does not imply that an eastern RAWS is less unique than a western one. Access information to the GACC RUI tables is provided in Section 7 – Deliverables.

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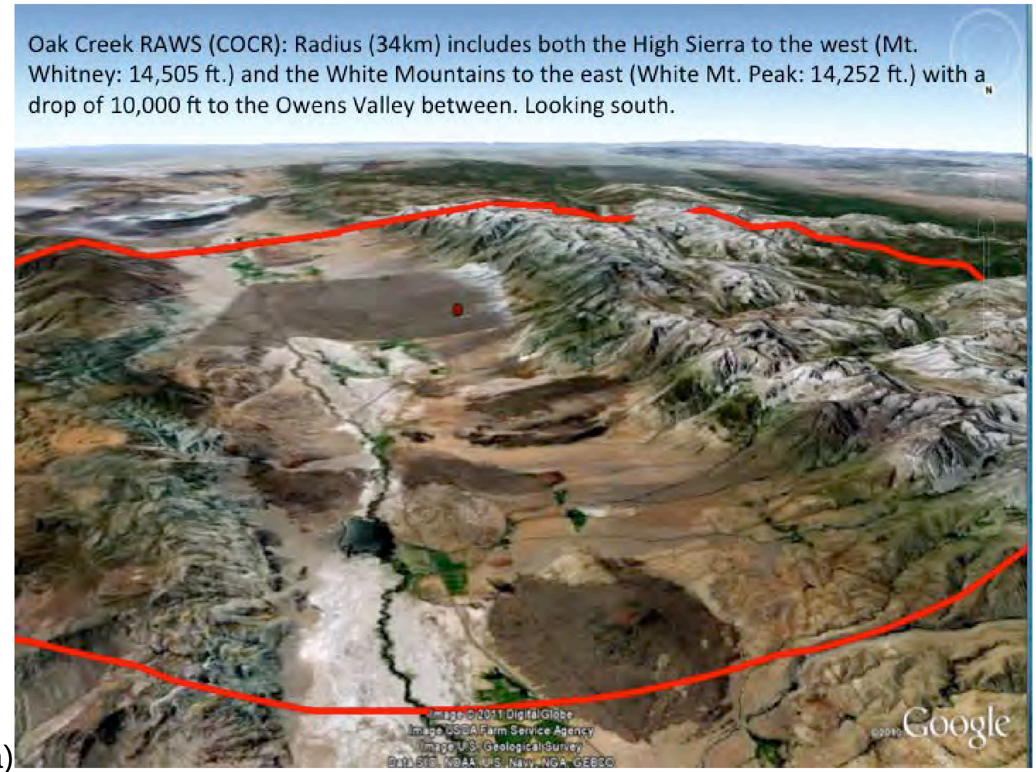
[2] There is a major assumption regarding this weight; that is, RAWS are properly sited, and that the data quality is acceptable from a siting perspective (missing and obvious bad values being dealt with separately). In fact, it is known by Predictive Services meteorologists among others that there are a number of RAWS that are not properly sited, especially due to changes in exposure over time. There is currently no comprehensive summary of RAWS siting problems, so it is difficult to say if and how much of the period of record weight should be reduced due to this issue.



a)

b)

Figure 8. Map perspective of two example RAWS and the terrain features for the area that the station represents; a) Oak Creek, California and b) DARE Bomb Range, North Carolina.

5. Other networks

R/R 2007 stated that the size of the fire weather network should also be determined by leveraging other non-RAWS weather observation networks that can contribute to the needs of the fire community. To some extent, this has already begun. The Florida Division of Forestry has been incorporating two networks into WIMS – the NWS ASOS and the Florida Automated Weather Network (FAWN). Other eastern states have used ASOS either as a fire weather station or as supplemental data to their RAWS (see http://glffc.utah.edu). Nearly all states have weather networks that can potentially be used. Here an overview of networks is provided to supplement RAWS for fire business, with the idea that future work by some entity will provide a more complete analysis and assessment of their usability.

Figure 9 shows a map of RAWS locations (red) and other stations (blue) that are ingested by the NOAA (National Oceanic and Atmospheric Administration) Meteorological Assimilation Data Ingest System (MADIS). MADIS ingests real-time surface (and other) observational weather data from numerous government and non-government data providers, and processes these data for use in products such as the RTMA. RAWS is ingested by MADIS via ROMAN (http://roman.wrh.utah.edu). According to the MADIS web site (http://madis.noaa.gov/madis_sfc.html), there are nearly 34,000 mesonet sites potentially available for data ingest, although roughly 10,000 are considered proprietary and not generally available for release to federal agencies other than the NWS.

Several caveats must be made when considering using other mesonet data. First, the stations need to provide the primary fire weather elements (i.e., temperature, humidity, wind and precipitation). It is desirable that the stations meet NFDRS standards; however, this will unlikely be the case as these networks have been established to meet their own user requirements. Detailed assessment will then be necessary to determine if the data are sufficient for fire business analyses. Predictive Services would be a good group to perform such analyses should opportunity arise. However, using other networks besides ASOS represents a major paradigm shift for the agencies, and some policy or formal approval process may be required to take this step.

If the interest is only to receive real-time hourly observations, then many stations are currently available. In fact, this is what ROMAN does by providing real-time data for networks in addition to RAWS. However, if it is desired to also analyze historical data from these networks, then this can become quite problematic given availability of the data archives. ROMAN and the companion MySQL database associated with MesoWest (http://mesowest.utah.edu) provide access to current and past "provisional" observations from 1997 to the present from the time a station becomes active. If the network extends back earlier than 1997, then the original data source would have to be sought and inserted into the MesoWest database. Such an effort has already taken place for RAWS stations in Minnesota, Wisconsin, and Michigan (see http://glffc.utah.edu).

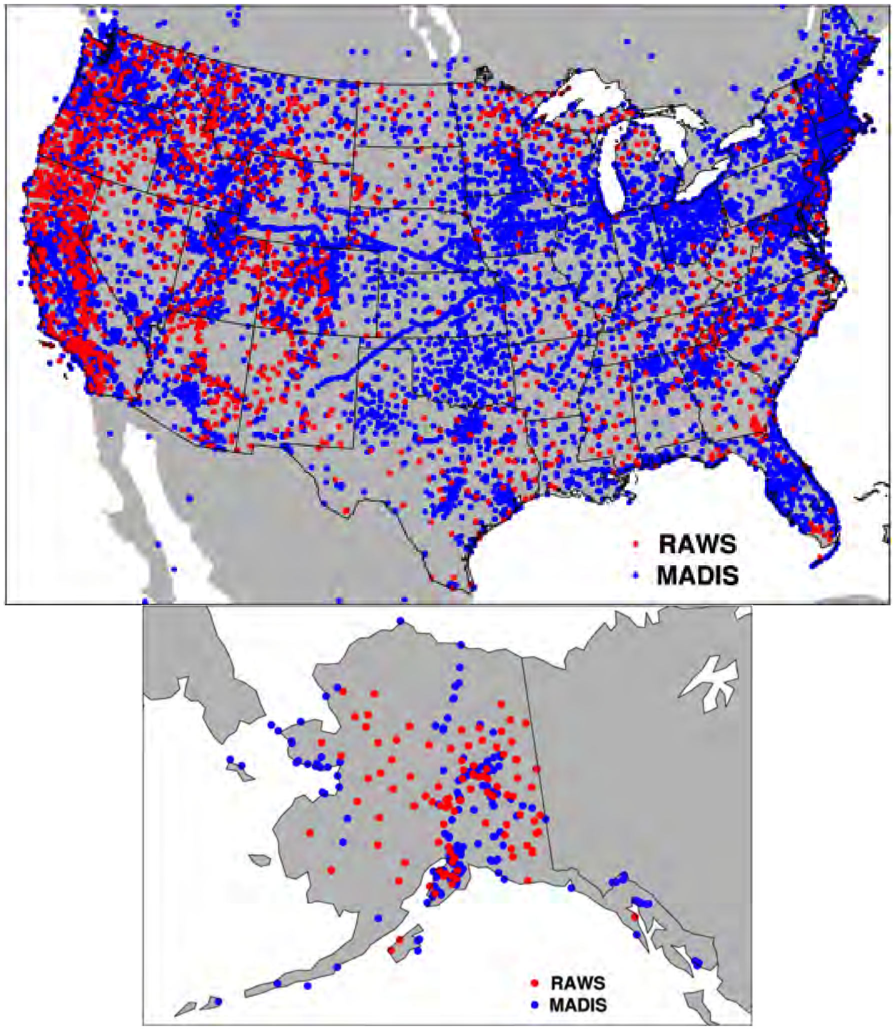


Figure 9. Map of station locations for RAWS (red) and non-RAWS in MADIS (blue).

Table 3 (from Horel and Dong 2010) summarizes critical differences between RAWS and NWS observations. Simply assuming that a NWS observation can supplement RAWS observations or fill a data gap does not take into consideration the additional sensors for soil, fuel moisture and temperature usually available at RAWS sites that are not available at NWS sites. The wind sensor height is another key difference. For ASOS, most sites are at 33 or 26 feet, compared to 20 feet for RAWS.

The website http://madis.noaa.gov/network_info.html provides information links for the various networks that are available via MADIS. MADIS is the prototype "national network of networks". At the present time, there are three MADIS classes based on user accessibility: distribution to all users; distribution restricted to government, research, and education organizations; and distribution to NOAA agencies only. All stations accessible in MesoWest and ROMAN fall in the first category with no restriction on access to that provisional data. The Oklahoma Mesonet is an example of the second category for which a cost recovery or access fee may be charged for government, research, and education organizations. Earth Networks (formerly AWS or most recognized as

Weatherbug) and Weatherflow networks are examples of networks with agreements in place with NOAA only.

Table 3. Differences between NWS and RAWS observations

Characteristic	NWS	RAWS
Location	Often adjacent to airport runways	Preferred in open areas on south facing aspects in mountainous/forested areas
Wind sensor height	10/8 m	6 m
Wind speed averaging interval	2 minute	10 minute
Temperature Aspiration	Yes	No
Routine reporting time	5-10 minutes before the hour[3]	Hourly, but on satellite transmission schedule throughout the hour

It is important to recognize that there is limited coordination of metadata (information necessary to interpret the available observations) on a national basis at the present time. Developing metadata standards and protocols for sharing metadata for all networks were key recommendations of the National Academy of Sciences committee (NAS 2009). The RAWS metadata archive within WIMS is an excellent example of how metadata from a national network can be entered by local experts and then distributed to end-users. ROMAN/MesoWest update metadata continuously, and within five minutes of the first transmission from a portable fire RAWS station, the station data and metadata are accessible, for example. However, the ROMAN/MesoWest team members answer numerous queries from end users and coordinate with RAWS staff to identify and correct inaccurate RAWS metadata (station location errors most frequently). Hence, the information presented here on other local, regional, and national networks is limited and far from complete. WRCC personnel also receive RAWS metadata on a regular basis, and update the Center's archive as warranted.

Access to non-RAWS station retrospective data can be valuable for many fire weather applications. MADIS stores provisional data received in real-time and updates for other networks in netCDF type formatted files as older data are received. Data archival began in 2001, but many stations have been added since that time. Users must request permission to access the MADIS database via ftps or https protocols. MesoWest stores the publicly accessible data available from MADIS and other real-time data streams including RAWS in a MySQL relational database. Data from stations in the western U.S. are available beginning in 1997 with data available nationally since 2002. Users can download data from MesoWest for individual stations using online web tools. Access to quality controlled data directly from data providers may be relevant for analysis of the utility of particular networks; a relatively few network operators provide

[3] ASOS sites can have many special observations during an hour; RAWS has at most 15-minute resolution.

direct web access to their complete archive of data. WRCC (and other Regional Climate Centers) also archive some other network data such as ASOS and special networks within their regions. WRCC maintains the entire RAWS archive including metadata.

Table 4 summarizes selected networks in terms of accessibility to long-term historical archives directly from the data provider, and indicates if the key fire weather elements are observed including air temperature, relative humidity, wind speed and precipitation. Keep in mind that many networks have incomplete and continually evolving metadata. A fee may be charged for the data from some networks. Based on internal attempts at locating historical data for these networks, only eight networks plus ASOS were found to have an archive that is "easy" to access long-term records from. Coastal marine data, though "easy" access, were not examined in this study. Appendix 11 provides a snapshot of all the networks available in MesoWest that are considered publicly accessible by MADIS for which access to the provisional data using web tools is straightforward. Appendix 12 provides a brief summary of other networks including information about web link and historical data accessibility from the web site.

It is well beyond the scope of the present study to examine in detail all of the network data and compare to RAWS. However, sample data were examined in a coarse sense from eight networks (Figure 10) plus four specific ASOS. Knowing that only a few other network stations are collocated with RAWS, the hypothesis was that the general distributions of temperature, humidity, precipitation duration and ERC could be examined to determine if the networks have similar fire weather characteristics. Wind speed was not considered for reasons of sensor height differences and localized effects, and also because the immediate focus was on ERC as the comparison example, which does not require wind speed.

Figure 11 shows a comparison of the Chekika Florida RAWS versus the Homestead Florida ASOS, which is the nearest ASOS station, for May-October 2009. Chekika is located in the Florida Everglades whereas Homestead is near Miami. The upper left plot is ERC-G, and shows that the ASOS tends to have higher ERC values. Temperature, in the upper right panel, is slightly warmer for RAWS, but humidity is higher at Homestead. There is slightly more precipitation duration at Chekika. Because there are differences in the observed weather elements, the ERC-G shows a difference between the two stations. This does not necessarily mean that the ASOS for its location is not a good measure of fire danger, but it does show that the two stations are measuring two distinct environments. This also highlights that the closest station may not necessarily be similarly representative of the other station's environment. This is something to consider for gridded weather even when two or more stations are shown in an area of high IDI values.

Figure 12 shows boxplot distributions of ERC-G for the respective networks versus RAWS by combining the sample stations in each network for the period May-October 2009. While there is general overlap in the distributions, the other networks do not precisely match RAWS. Even though the nearest RAWS was chosen, some of the differences may be due to unique local environments as noted above, rather than other sources such as sensor type, which certainly can cause measurement differences. For several of the comparisons, RAWS has a larger ERC-G spread, and tends to show more outliers (individual circle points). The FAWN network, which is actively being used for NFDRS in Florida, has slightly higher ERC-G values than RAWS. This pattern occurred for five of the eight networks examined.

Table 4. Summary of data elements and access to historical data from other networks.

Coverage	Network	Access	Temp	Wind	RH	Precip
Alabama	A&M Univ	Good	X	X	X	X
Alabama	Auburn U.	Fee	X	X	X	X
Alaska	RWIS	Difficult	X	X	X	
Alaska	Univ	Real-time	X	X	X	X
Arizona	RWIS	Difficult	X	X	X	X
Arizona	AZMET	Easy	X	X	X	X
California	RWIS	Real-Time	X	X	X	
California	China Lake	Difficult	X	X	X	X
Colorado	RWIS	None	X	X	X	X
Florida	FAWN	Easy	X	X	X	X
Georgia	GA EPA	None	Unk	Unk	Unk	Unk
Idaho	NEEL	Good	X	X	X	X
Idaho	RWIS	None	X	X	X	
Great Lakes	GLERL	Good	X	X		
Indiana	PAAWS	?	X	X	X	X
Illinois	RWIS	Difficult	X	X	X	
Indiana	RWIS	Real-Time	X	X	X	
Iowa	RWIS	Real-Time	X	X	X	X
Kansas	RWIS	Real-Time	X	X	X	
Kansas	Mesonet	Good	X	X	X	X
Kentucky	Mesonet	Daily only	X	X	X	X
Kentucky	RWIS	Difficult	X	X	X	
Louisiana	Agr	Good	X	X	X	X
Maryland	RWIS	Easy	X	X	X	
Michigan	MAWN	Easy	X	X	X	X
Minnesota	RWIS	Good	X	X	X	
Mississippi	Mesonet	Difficult	Unk	Unk	Unk	Unk
Missouri	Agr	Easy	X	X	X	X
Missouri	RWIS	None	X	X	X	
Missouri	Air	Difficult		X		
Montana	RWIS	Difficult	X	X	X	
Montana	Air	Good	X	X		
Nebraska	RWIS	None	X	X	X	
Nevada	RWIS	Real-Time	X	X	X	
Nevada	ALERT	Good	X	X	X	X
New Hampshire	RWIS	None	X	X	X	
New Mexico	NMSU	Easy	X	X	X	X
New Mexico	LANL	Real-Time	X		X	X
New York	NEWA	Easy	X		X	X
N. Carolina	Agr	Difficult	X	X	X	X
N. Dakota	NDAWN	Easy	X	X	X	X
N. Dakota	RWIS	None	X	X	X	

Coverage	Network	Access	Temp	Wind	RH	Precip
Ohio	RWIS	Difficult	X	X	X	
Ohio	Agr	Easy	X	X	X	X
Oklahoma	Mesonet	Daily only	X	X	X	X
Oklahoma	RWIS	None	X	X	X	
Pacific NW	NWAC	Real-Time	X	X	X	X
Oregon	RWIS	Real-Time	X	X	X	
Pennsylvania	RWIS	None	X	X	X	
S. Carolina	RWIS	None	X	X	X	
S. Dakota	RWIS	None	X	X	X	
Tennessee	ETOS	None	X	X	X	X
Tennessee	RWIS	None	X	X	X	
Texas	Mesonet	Good	X	X	X	X
Texas	RWIS	None	X	X	X	
Texas	Air	Difficult	X	X		
Utah	RWIS	Difficult	X	X	X	
Utah	Emory County	Good	X	X	X	X
Utah	Army-Deseret	Difficult	X	X	X	
Utah	Army Dugway	None	X	X	X	
Utah	Air	Real-Time	?	X	?	
Virginia	RWIS	None	X	X	X	
Washington	RWIS	Real-Time	X	X	X	
Washington	Hanford	Good	X	X	X	X
Washington	PAWS	Easy	X	X	X	X
W. Virginia	RWIS	None	X	X	X	
Wisconsin	RWIS	Real-Time	X	X	X	
Wisconsin	AWN	Good	X	X	X	X
Wyoming	RWIS	Real-Time	X	X	X	
U.S.	SCAN	Good	X	X	X	X
U.S.	Coastal Marine	Easy	X	X	X	
U.S.	ASOS	Easy	X	X	X	X

There are three locations in which ASOS is nearly collocated with RAWS; these are Redding, California; Ely, Nevada; and Flagstaff, Arizona. Figure 13 shows boxplots of ERC-G for May-October 2010 (note that most recent year is used here compared to all other project analyses done through 2009). At Redding and Flagstaff, ASOS tends to produce slightly higher values than RAWS; Ely ASOS tends to produce slightly lower ERC-G values. For all three cases the differences could be related to sensor types, very localized environments, or that RAWS are effectively hourly averages reporting at the end of the hour ranging anywhere from 00 to 59 minutes after the hour. So an exact match in results is not a reasonable expectation. A true comparison would require different network sensors to be mounted on the same tower and the same observation times. Though there is not perfect result agreement between these two different station types, the general shapes and overlap of the distributions are sufficient to support using ASOS for fire weather purposes as is being done in a few parts of the country. While there are clear sensor differences between the two systems, the wind height could potentially be a larger issue as the two networks have different observation standards.

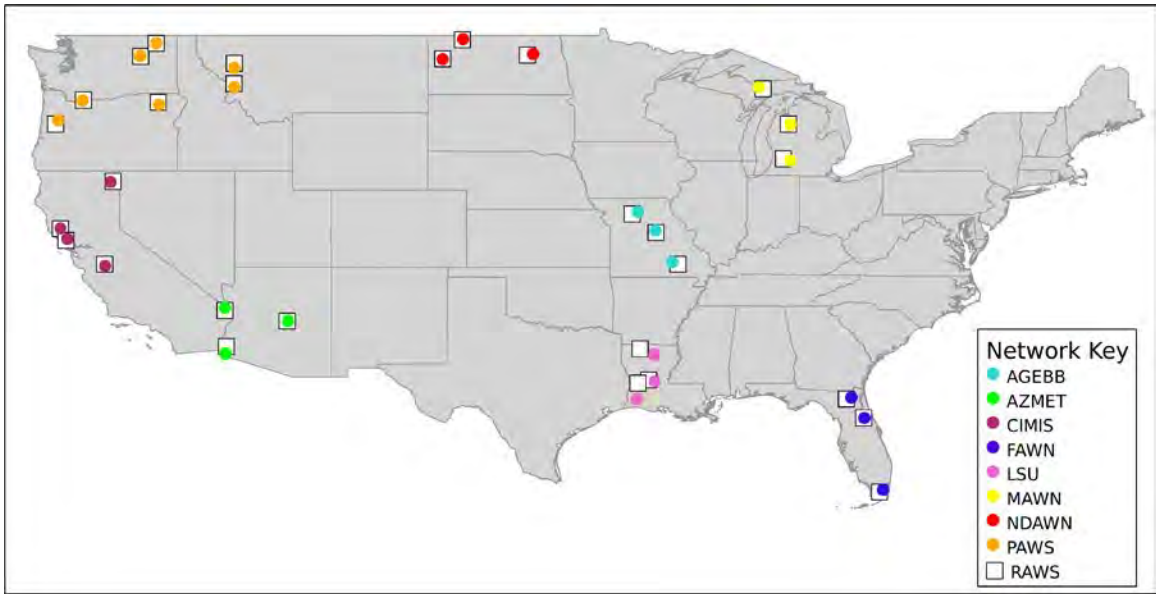


Figure 10. Map showing other network sites that were coarsely compared to RAWS.

To fully assess these other networks for fire business, more detailed analyses are needed. This would be a relevant task for the GACC Predictive Services meteorologists to undertake as they have a good sense of the stations and local environments across their region. As an example, it would be relevant to compare these network data with fire business over a longer period than just a sample season used here. This would help determine if these stations matched outcomes as might be expected. Another approach could be to calculate the Fosberg fire weather index, which combines temperature, humidity and wind speed, and compare with the other networks with RAWS utilizing plots and correlation and bias statistics. The Fosberg index would reduce some of the variability of the individual variables through a single index.

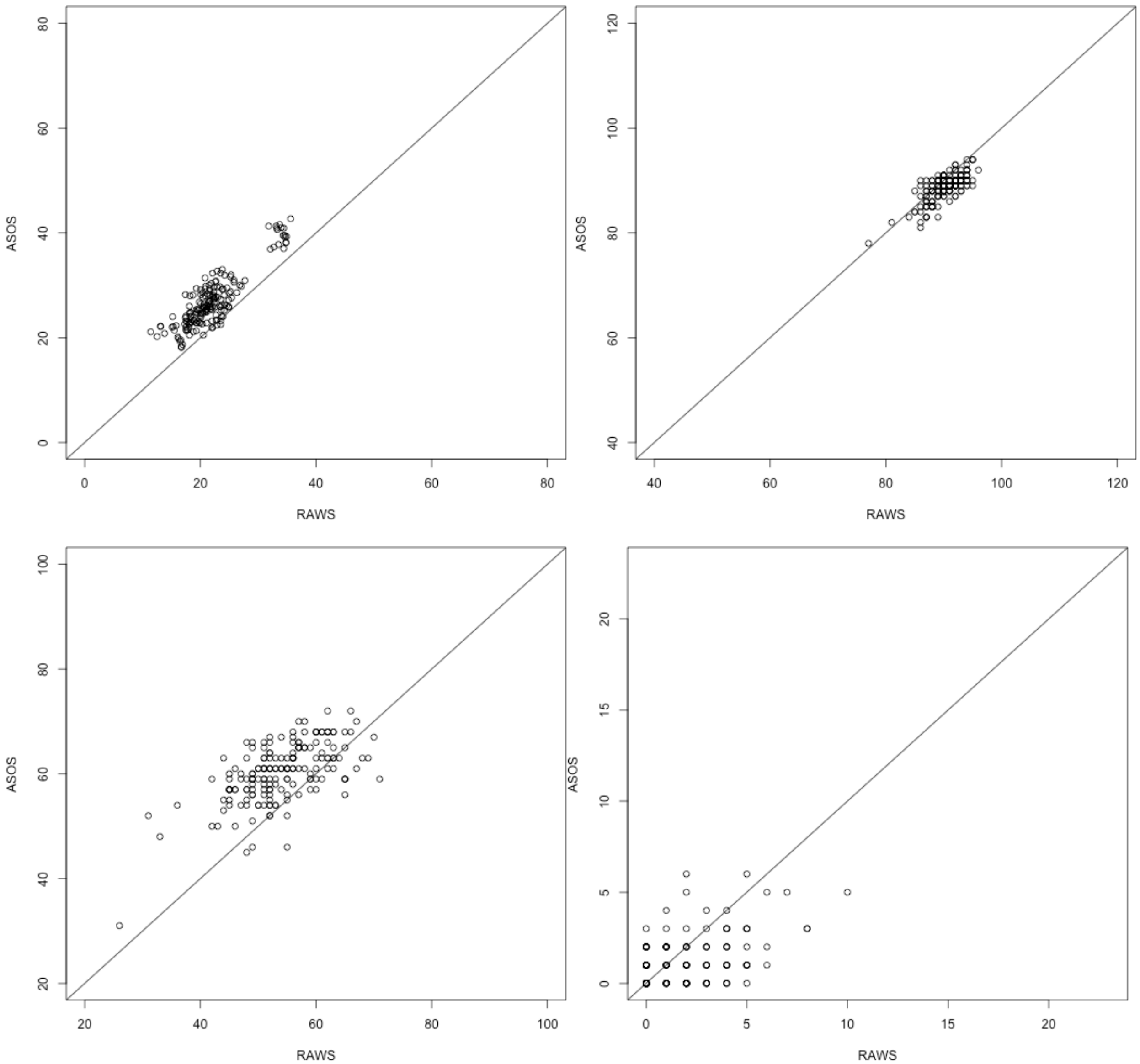
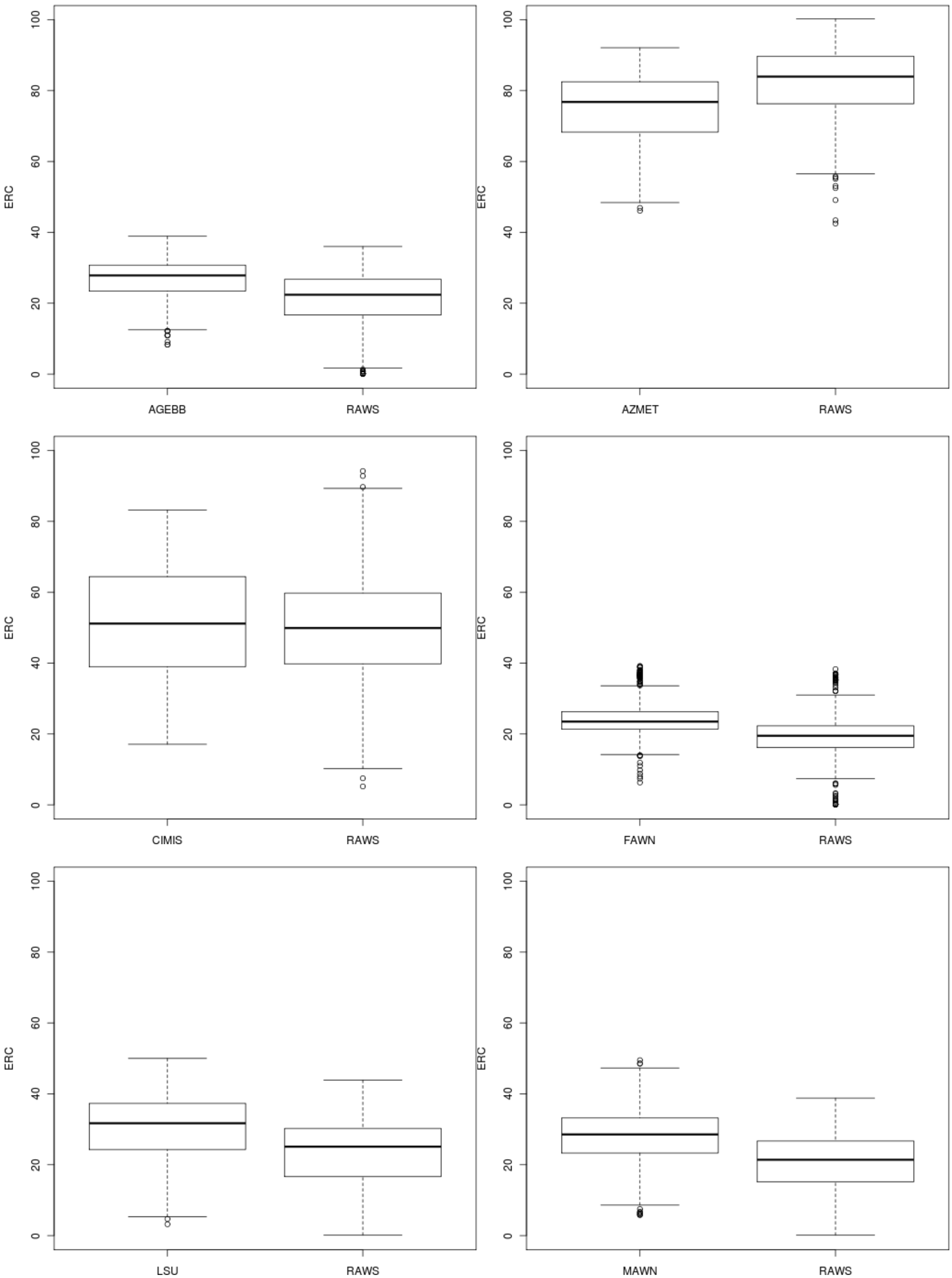


Figure 11. Scatterplots of Chekika Florida RAWS versus the Homestead Florida ASOS for May-October 2009 for ERC-G (upper left), temperature (upper right), humidity (lower left) and precipitation duration (lower right). Observation time is 1300 local time.


ERC
0
20
40
60
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AGEBB
RAWS
AZMET
RAWS
CIMIS
RAWS
FAWN
RAWS
LSU
RAWS
MAWN
RAWS

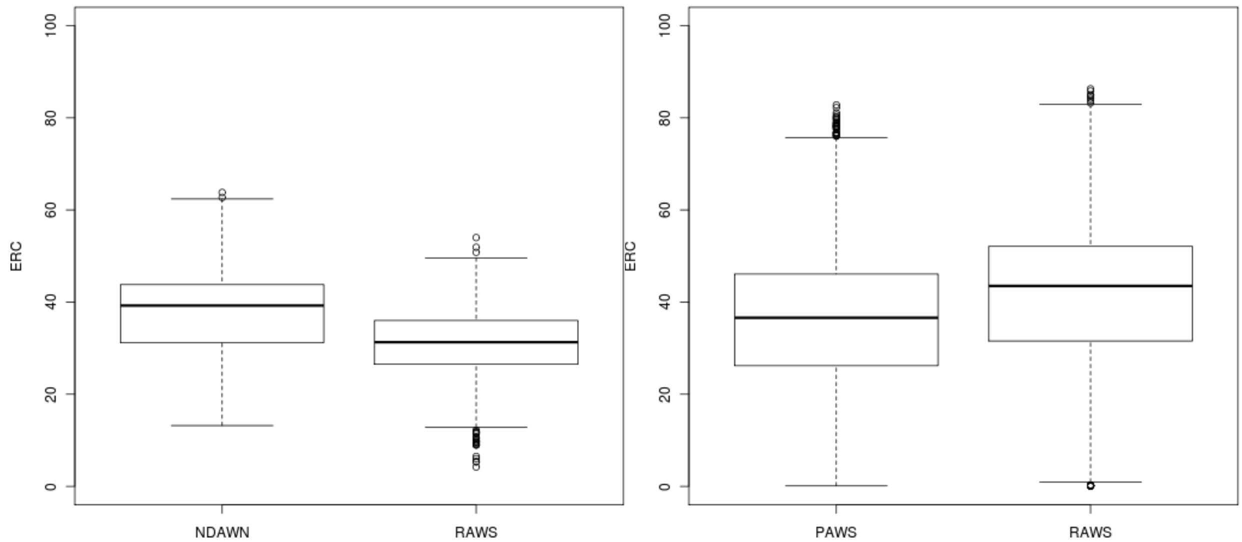

Figure 12. Boxplots of ERC-G distributions combining the sample stations for the respective networks based on May-October 2009 observations.

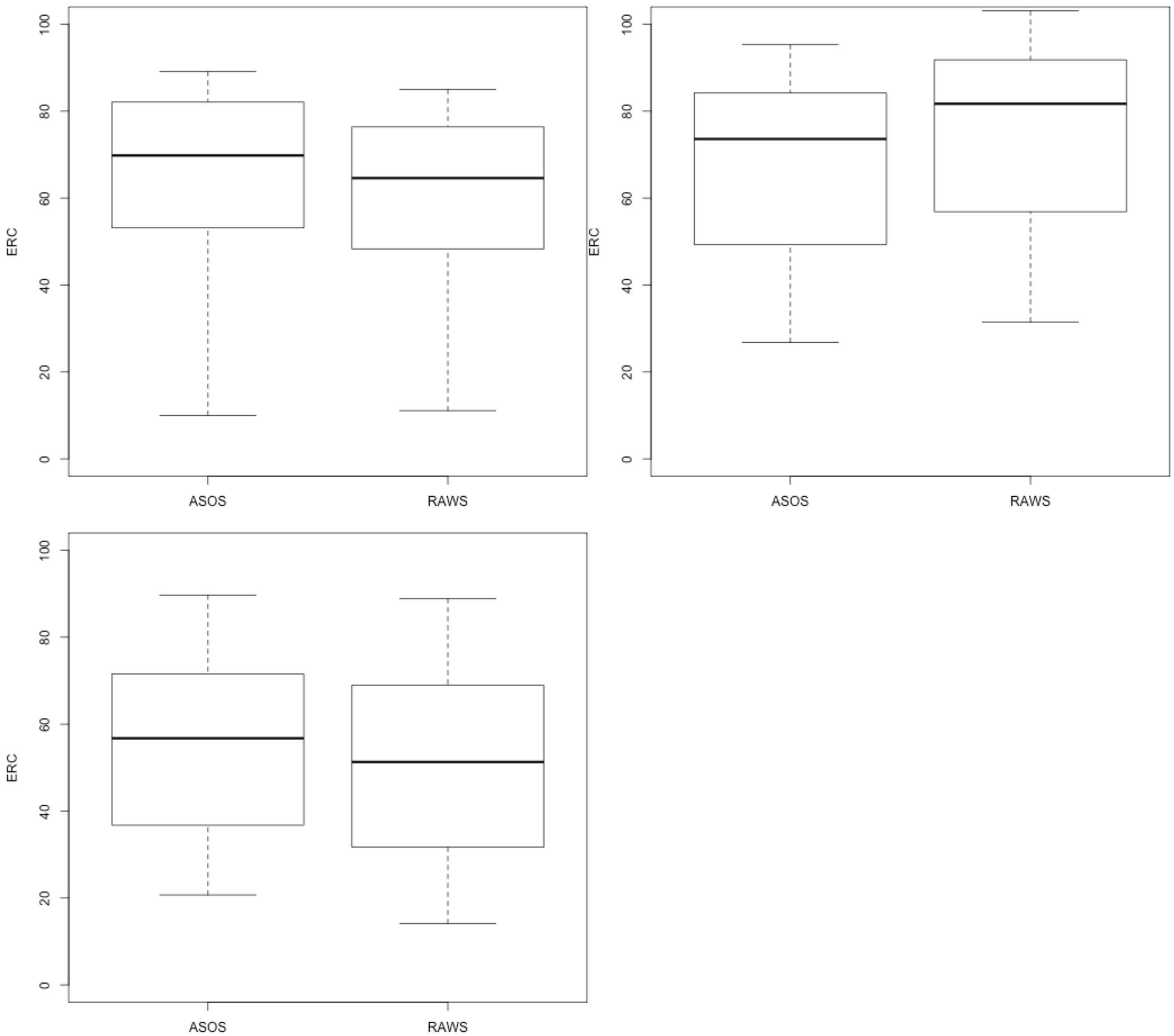

Figure 13. Boxplots showing distributions of ERC-G for Redding, CA (upper left), Ely, NV (upper right) and Flagstaff, AZ (lower right) for May-October 2010.

6. Discussion

This study was undertaken to provide RAWS network information for FENC in making recommendations to NWCG regarding the needs/requirements of the RAWS network. The title of this study, “What is the appropriate RAWS network?”, is to some extent about network size, but also highlights that there are numerous uses of RAWS data. Integrating other networks with RAWS may also yield an appropriate fire weather network. Precisely what constitutes an “appropriate network” depends upon the purpose(s) to which data from the network are applied. For RAWS, the purposes for the measurements have evolved and expanded well beyond the original fire danger use of the 1970s, and will doubtless continue to do so. The immediate primary growth areas are likely to be in climate variability, climate change and ecosystem management.

It is not the objective of this report to state exactly how many RAWS stations there should be, or precisely where they should be located. Both requires local in depth knowledge and agency coordination within a region and nationally via a RAWS management plan. Given resource limitations though, it is understood that the RAWS network (as for any weather/climate network) does have a limit to its capacity. Thus, other networks may provide additional utility if new RAWS cannot be implemented. Even if more RAWS can be introduced, it is likely of value to consider other network data for use in fire business. However, with perhaps the exception of the ASOS network, this represents a new paradigm for fire agencies. Some guidelines will likely need to be developed regarding criteria/standards for other networks, how will those data be assessed and by whom, and processes for implementing the information into fire business. This should also be part of a formal RAWS management plan. But such a plan must also include what happens when other networks fail, or cannot be maintained, etc.

One assumption of this study is that the current metadata for RAWS, especially the latitude and longitude locations, are accurate. However, as Chuck McHugh (personal communication) and others have pointed out, and on the basis of hundreds of site visits by WRCC personnel, there are numerous cases of inaccurate locations, elevations and other station information in the metadata. For most location problems, the error appears to be relatively small, but is larger for some sites. The greatest influence of these errors in this study would be on the data denial experiment, which might lead to an inaccurate conclusion of the impact of removing a station, or suggesting an observation gap. These few cases, however, should not diminish the overall results.

There are other metadata issues as well, which made creating a final RAWS database for examination challenging. These include NESSIDs that get reused, multiple NESSIDs at the same location through the station history, WIMS IDs reused, name changes through the station history, NESSID that changed over time, station removal but still classified as active in WIMS, incorrect station type (e.g., indicated as permanent but actually portable) and changes in latitude/longitude information without explanation. In creating the historical RAWS archive, a significant effort over the past 20 years has been expended by WRCC personnel to address these issues. This largely unsupported[4] and substantial effort remains an ongoing process.

Despite these metadata issues and other known data quality issues (which occur in all observational networks), RAWS should be considered a very good network. In the West, especially, it represents a unique environment that no other network is covering. This alone makes the network invaluable. Many stations now have a period of record of suitable length to describe an area's climate in the vicinity of the station (assuming proper siting). Given a changing and variable climate, this is crucial information to make assessments from. However, it is important that the station has representative quality data, and not just a long period of record.

[4] NWCG does contribute a modest amount of annual funding in support of the WRCC RAWS archive.

Recommendations

It is not the purpose of this study to make specific recommendations regarding any individual RAWS. However, a number of guidance recommendations are offered here that will hopefully assist FENC, NWCG and local units in making decisions about their stations and the network as a whole.

1. If consideration is being given to moving or removing a station, the various station attributes that comprise the RUI should be considered in addition to local knowledge including established documents such as Fire Danger Operating Plans. It is probably best to compare index values within GACCs, rather than across the country as a whole. Low index values arise due to one or more quantitative attributes of the station, but low values do not necessarily mean a bad station. It is important to examine all of the input index values comprising the RUI. For example, a high terrain complexity score suggests that the station is measuring across a rapidly changing climate environment due to elevation differences. A high data denial score should be used as an indication that removing a station will have adverse effects on gridded weather and related fields such as fire danger. This may be due to removing the station in the data denial experiment and/or there is a relatively larger horizontal and/or vertical separation to the next station.

2. If there is interest in adding a station, the gap maps shown in Appendices 1-10 based on an IDI analysis should be used to help assist locating the new site. Zero IDI values on the map show areas of data void (no RAWS representation on the RAWS maps; no RAWS or ASOS representation on the RAWS+ASOS maps); the grid would be improved if areas with low index values had more stations. Utilizing GIS layers, the IDI values can be overlaid on top of other variables such as values at risk, vegetation, agency boundaries, etc. to assist in determining new station locations.

3. Other networks are potentially usable for fire business; however, experience shows that acquisition of historical data and the necessary metadata history is often very difficult. MesoWest provides easy to use output for many other network stations going back to as early as 1997 – this archive increases in more recent years. The Regional Climate Centers such as WRCC also have historical data for some other networks. ASOS is already a major network that is utilized for fire business, especially in the Eastern and Southern GACCs. ASOS also serves as important input into the RTMA and other National Weather Service grids that fire weather meteorologists utilize. Predictive Services could play an important role in performing detailed assessments of these other network data for use in fire weather and fire business activities. However, since this would represent a major paradigm shift in data usage, some guidelines will need to be developed regarding criteria/standards for using other networks, how will those data be assessed and by whom, and

processes for implementing the information into fire business. A prominent feature of the RAWS network is its reliability of information and access to the data; these are considerations that will have to be assessed for other potential networks. Another consideration is could a cross-agency effort pay to have other networks be more usable for RAWS purposes. Along these lines, consideration should be given to make RAWS year-round, to better align with other networks that are designed for continuous operation.

4. It is best to think of the RAWS network not in terms of size, but rather agency mission. The network has grown through a need to acquire weather information and add value by determining fire danger, fire behavior, etc. RAWS serves in both capacities of point data and weather grids, and provides unique value by representing geographic areas not generally covered by other networks. Uses of the network and the combination of the metrics provided in this study along with local knowledge should serve as network guides given budgetary constraints. It would be beneficial to address this with a RAWS management plan. Among the various aspects of a management plan, one element should be how to best integrate RAWS into the network of which deployment and maintenance are being covered by cooperators who are able to pay for their stations independent of federal agencies (e.g., state and private, Department of Defense).

5. Future work to support a RAWS management plan would include the investigation and inclusion of specific observing networks (as appropriate via standards, climatological record, etc.) into the grid of observations. Further analysis could be run to show the specific value these additional networks add to the grid. In addition, future work should focus on deriving specific observational data requirements from core RAWS business areas. These data requirements could be used in concert with the grid of observations to define a finite size and distribution of the RAWS network necessary to meet the data requirements. The RAWS management plan should also place emphasis on the various uses of the information, particularly as it supports crosscutting areas such as ecosystem management and long-term ecological studies.

7. Deliverables

This report serves as the primary project deliverable. However, information produced in conjunction with the project is being made available to the agencies at the web site http://cefa.dri.edu/Cefa_Products/rawsnetwork.php. This information includes Excel files of the RAWS Uniqueness Index by GACC, and the data denial US IDI maps for both RAWS and RAWS+ASOS in GIS format.

8. Acknowledgements

Special thanks are due to numerous individuals for support and contributions to this project and report. Paul Schlobohm, NWCG Equipment & Technology Branch Coordinator, provided substantial thought and direction for the project. The NWCG Fire Environment Committee and sub-committees provided substantial input and feedback into the process and report. Herb Arnold, the BLM Remote Sensing Fire Weather Support Unit Manager, provided valuable insight in the background, history and current aspects of the RAWS network. Jim Ashby and Grant Kelly at the Western Regional Climate Center provided other network information and data, and station maintenance information, respectively. Dr. Beth Hall, Towson University, provided quantitative information on station data quality. Dr. Crystal Kolden, University of Idaho, performed the terrain complexity calculations. Russ Gripp, USFS, provided station listings needed to construct the final analysis set of permanent RAWS. Additional RAWS information was obtained from the WRCC archives. Dan Tyndall, University of Utah, provided the IDI analysis dataset. Nick Nauslar, CEFA-DRI, provided some data checking calculations. Hauss Reinbold, CEFA-DRI, provided some programming support. Andrew Joros, DRI, generated the IDI maps. Robyn Heffernan, National Weather Service, provided some valuable recommendation insight. Dr. Kelly Redmond, WRCC, provided a comprehensive review of the report, offered analysis suggestions, and provided his experience and insight of data networks. The National Park Service funded this project on behalf of the National Wildfire Coordinating Group under the Great Basin Cooperative Ecosystem Studies Unit Task Agreement Number J8R07090009 Cooperative Agreement Number H8R07060001.

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10. List of Acronyms

ASOS – Automated Surface Observing System

BLM - Bureau of Land Management

CIOS - Committee for Integrated Observing Systems

DEM - Digital Elevation Model

EMC - Equilibrium Moisture Content

FAWN - Florida Automated Weather Network

FENC - Fire Environment Committee

FENWT - Fire Environment Working Team

GACC - Geographic Area Coordination Center

IDI - Integral Data Influence

MADIS - Meteorological Assimilation Data Ingest System

NAS - National Academy of Sciences

NCEP - National Centers for Environmental Prediction

NESSID - National Environmental Satellite Service identification

NFDRS - National Fire Danger Rating System

NIFMID - National Interagency Fire Management Integrated Database

NOAA - National Oceanic and Atmospheric Administration

NWCG - National Wildfire Coordinating Group

NWS – National Weather Service

POR – Period of Record

RAWS - Remote Automated Weather Station

ROMAN - Real-Time and Monitor Observation Network

R/R 2007 - RAWS/ROMAN Study Report

RTMA - Real-Time Mesoscale Analysis

RUI – RAWS Uniqueness Index

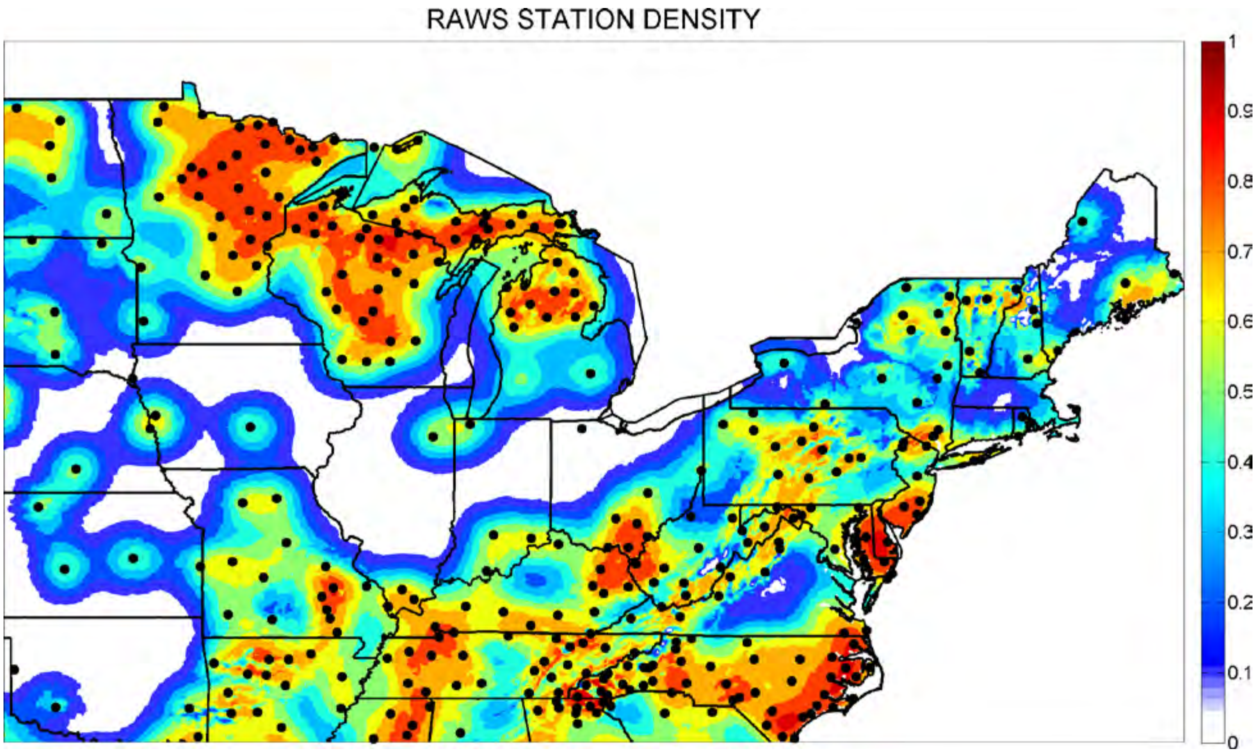
WFAS - Wildland Fire Assessment System

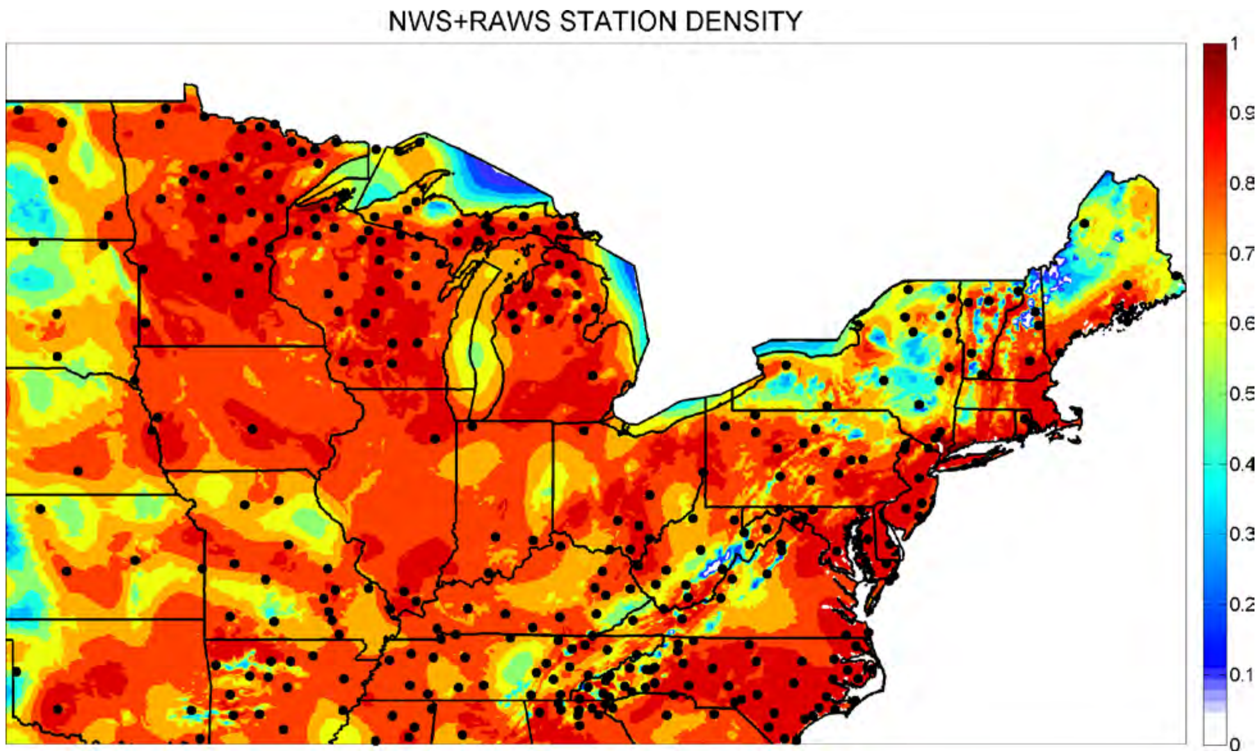
WIMS - Weather Information Management System

WRCC - Western Regional Climate Center

Appendix 1. Data gap maps for the Eastern Area.

The top map shows the IDI values based on RAWS, and the bottom map based on RAWS+ASOS stations. The methods and maps are described in detail in Section 3. Points on the maps are permanent RAWS locations. Stations shown in a white area indicates that they were added after the original IDI analysis.




NWS+RAWS STATION DENSITY
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0.9
0.8
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0.3
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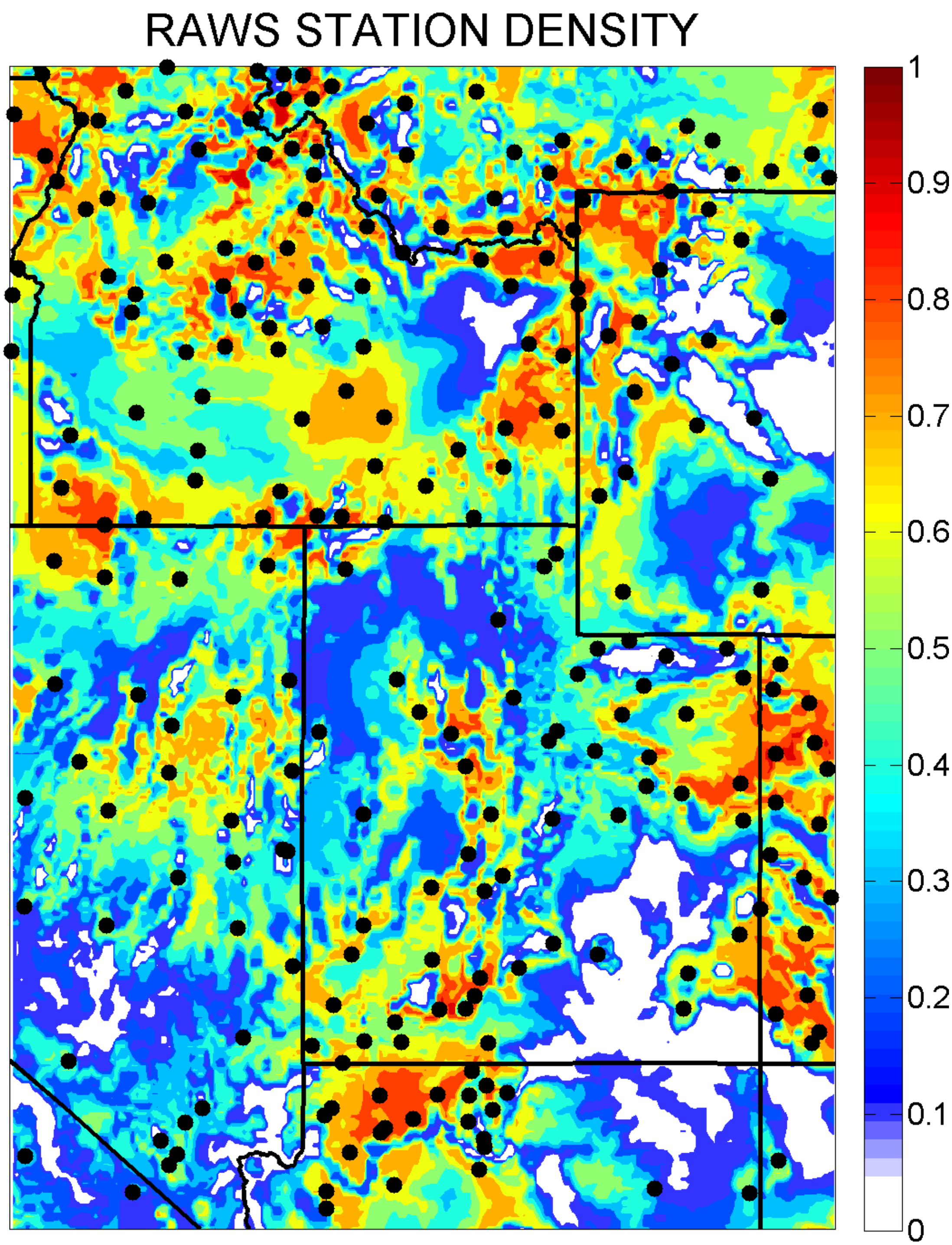
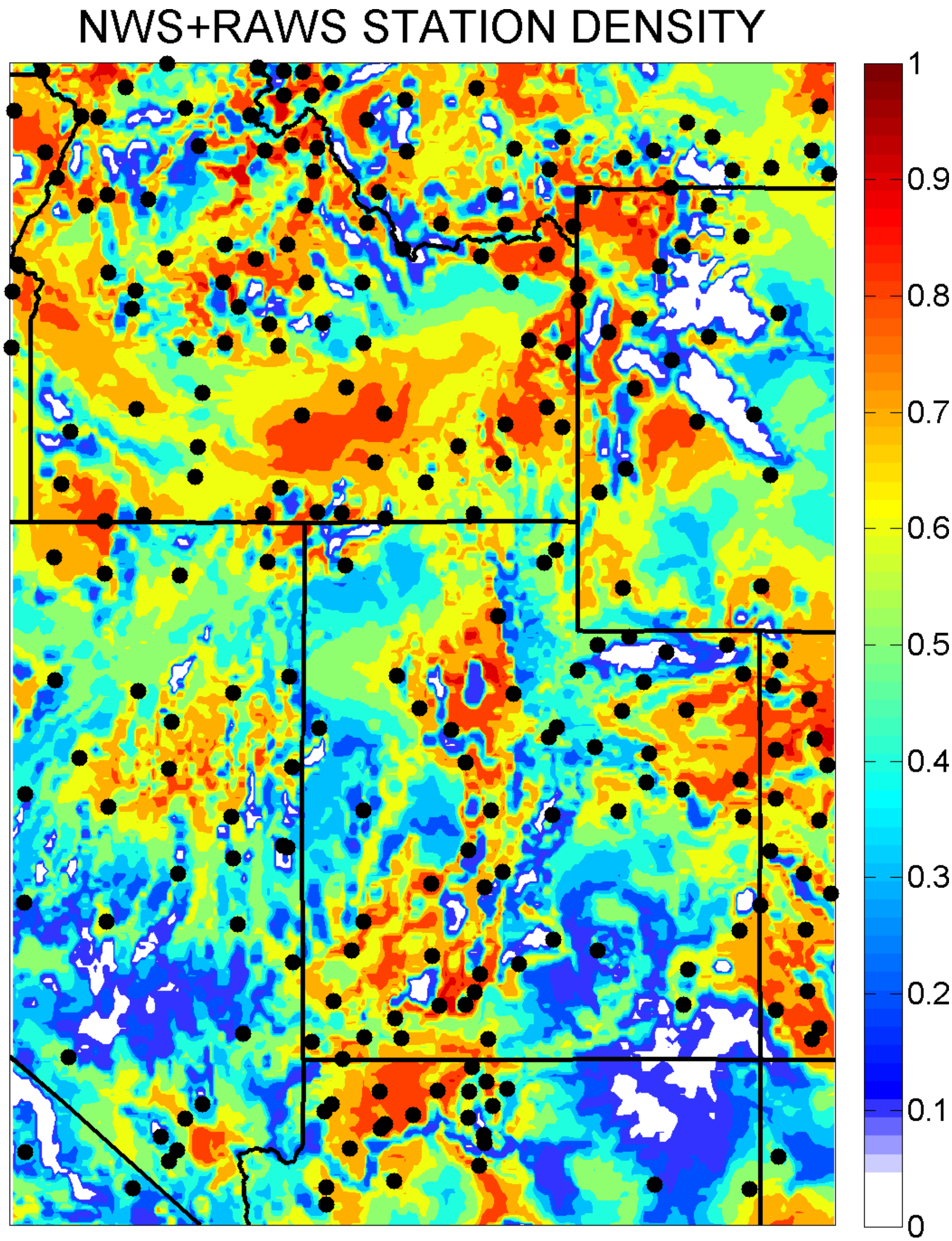
Appendix 2. Data gap maps for the Eastern Great Basin Area.

The top map shows the IDI values based on RAWS, and the bottom map based on RAWS+ASOS stations. The methods and maps are described in detail in Section 3. Points on the maps are permanent RAWS locations. Stations shown in a white area indicates that they were added after the original IDI analysis.




NWS+RAWS STATION DENSITY
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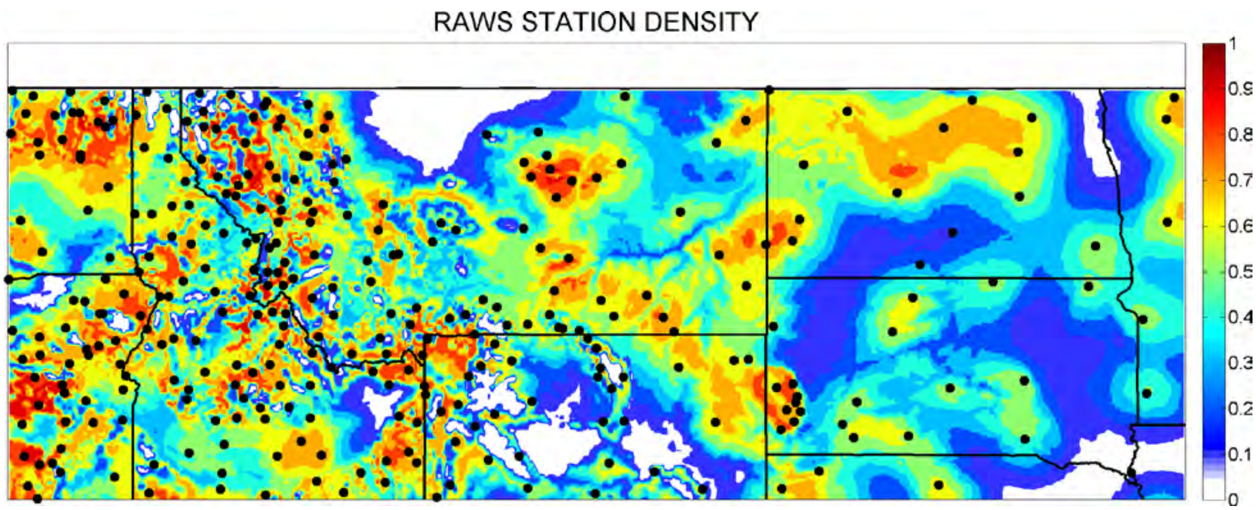
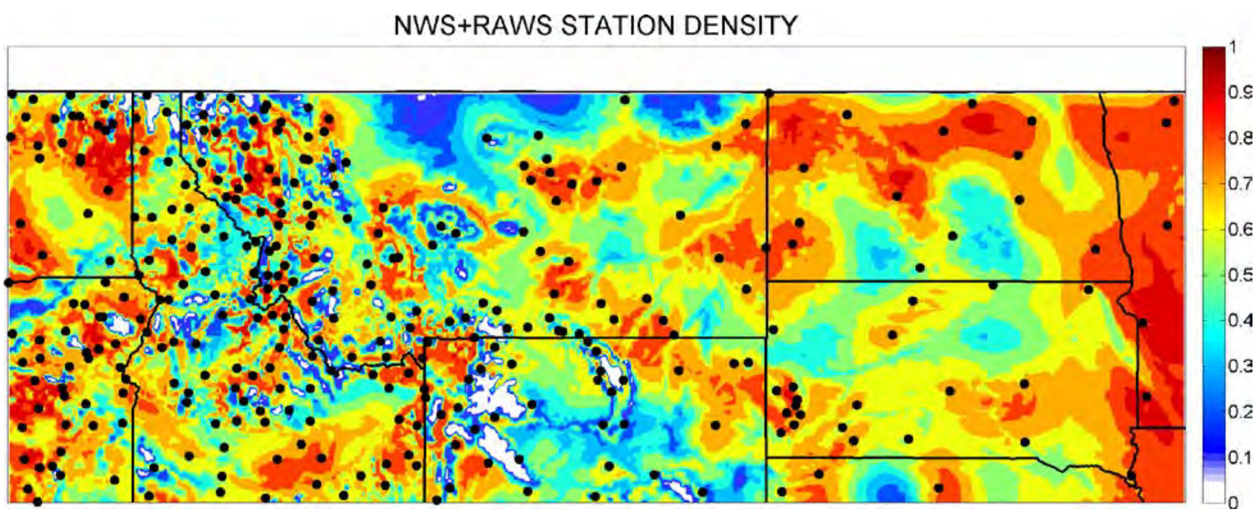
Appendix 3. Data gap maps for the Northern Rockies Area.

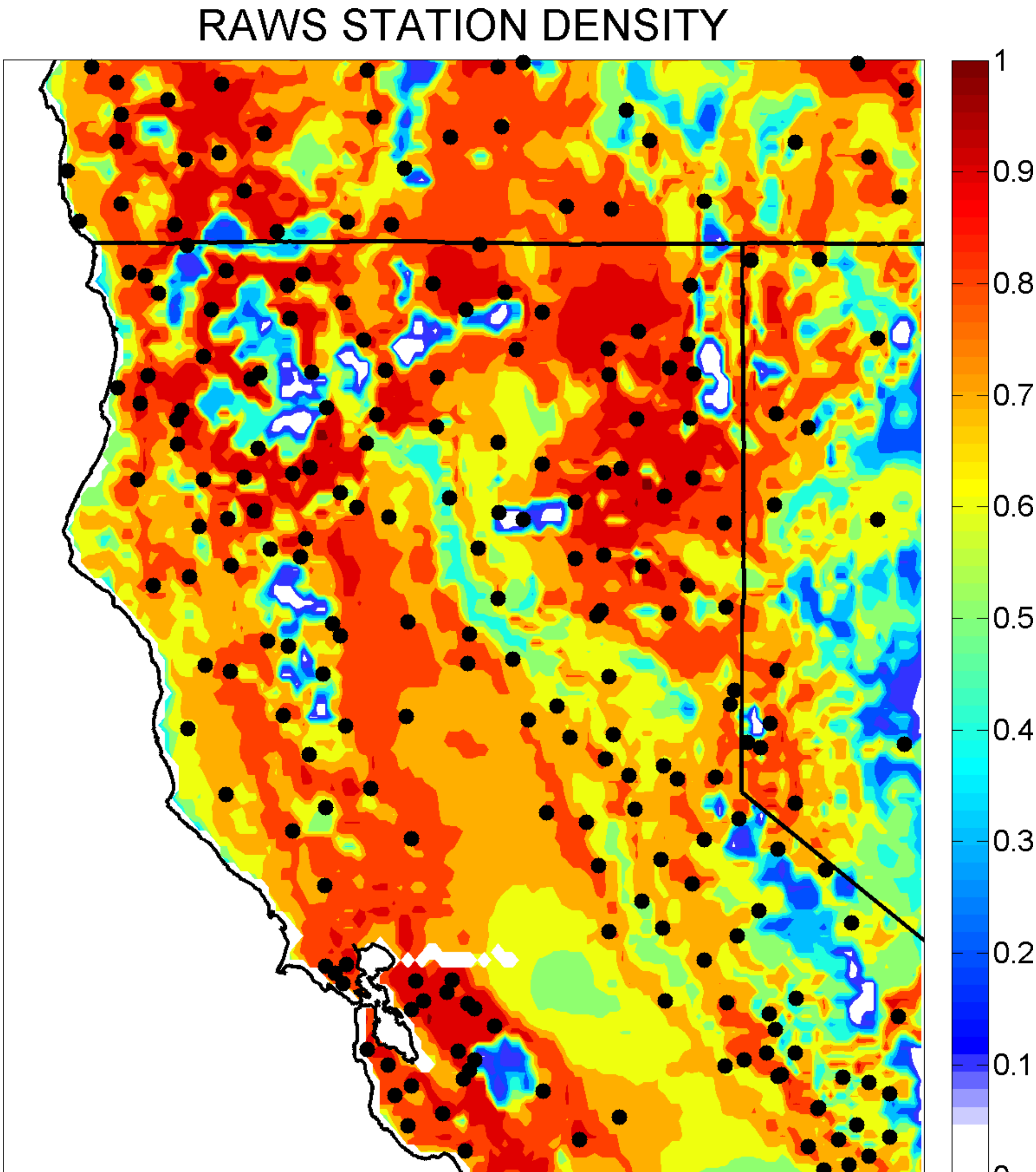
The top map shows the IDI values based on RAWS, and the bottom map based on RAWS+ASOS stations. The methods and maps are described in detail in Section 3. Points on the maps are permanent RAWS locations. Stations shown in a white area indicates that they were added after the original IDI analysis.

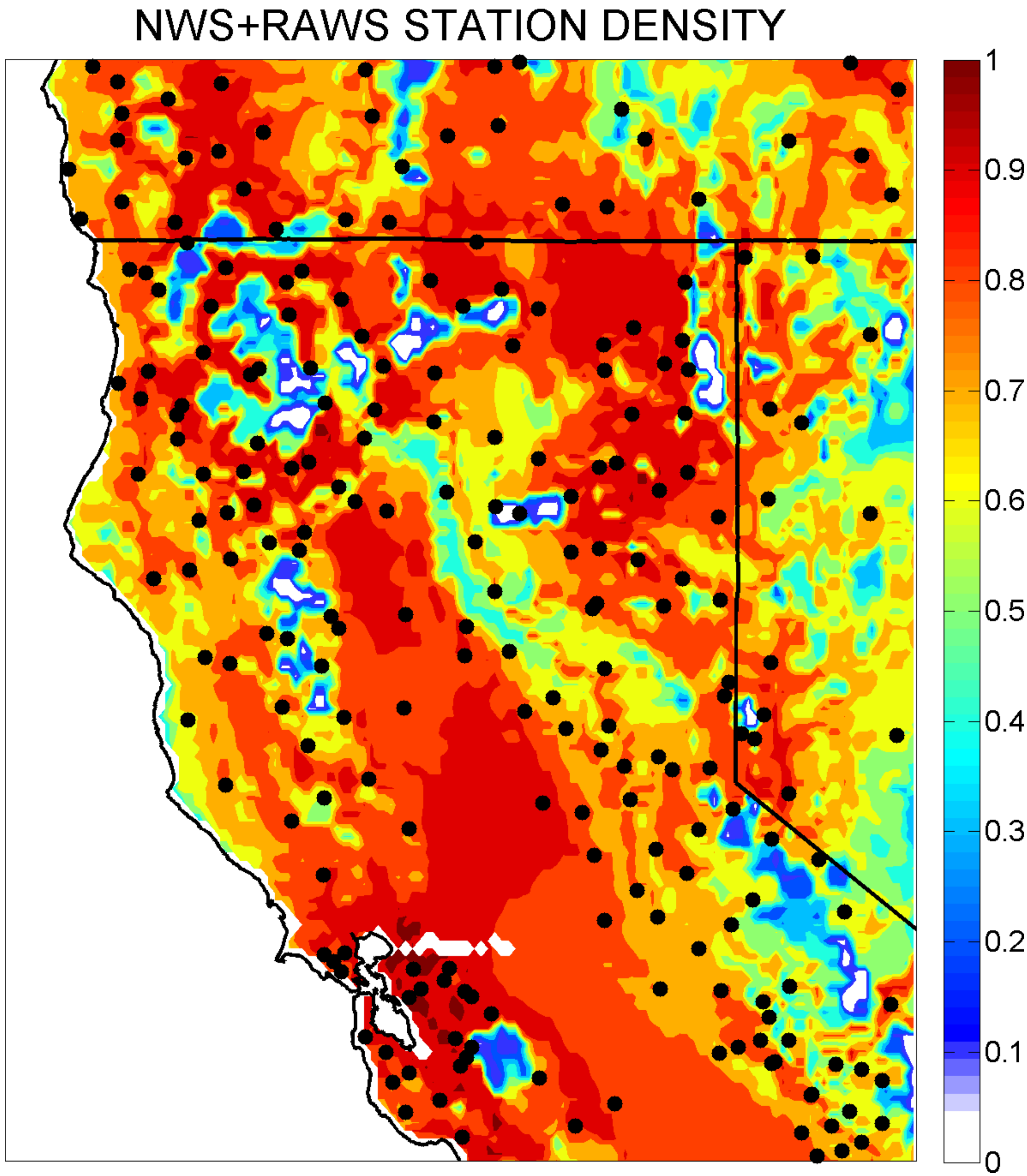




Appendix 4. Data gap maps for the Northern California Area.

The top map shows the IDI values based on RAWS, and the bottom map based on RAWS+ASOS stations. The methods and maps are described in detail in Section 3. Points on the maps are permanent RAWS locations. Stations shown in a white area indicates that they were added to the study after the original IDI analysis.




NWS+RAWS STATION DENSITY
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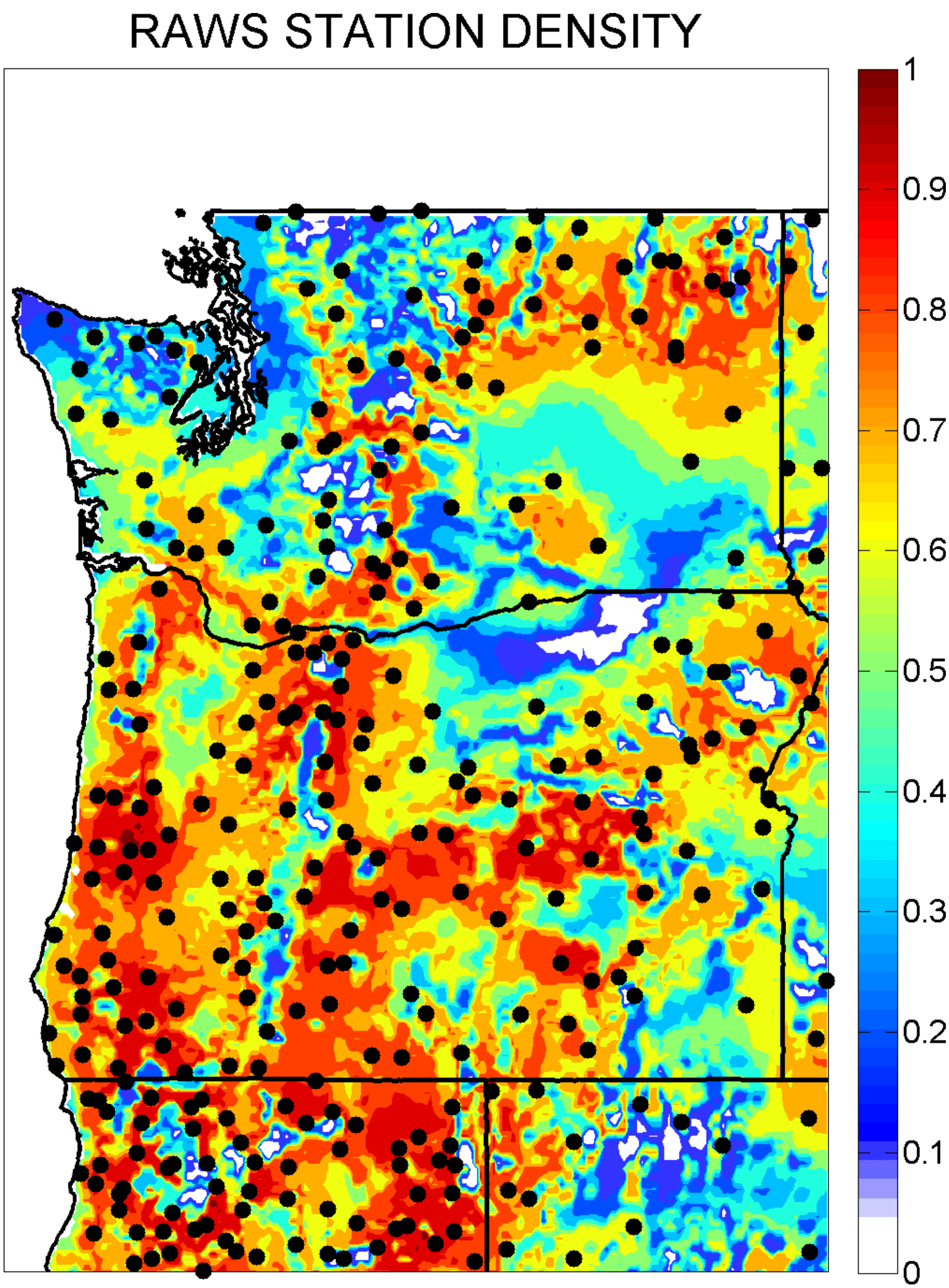
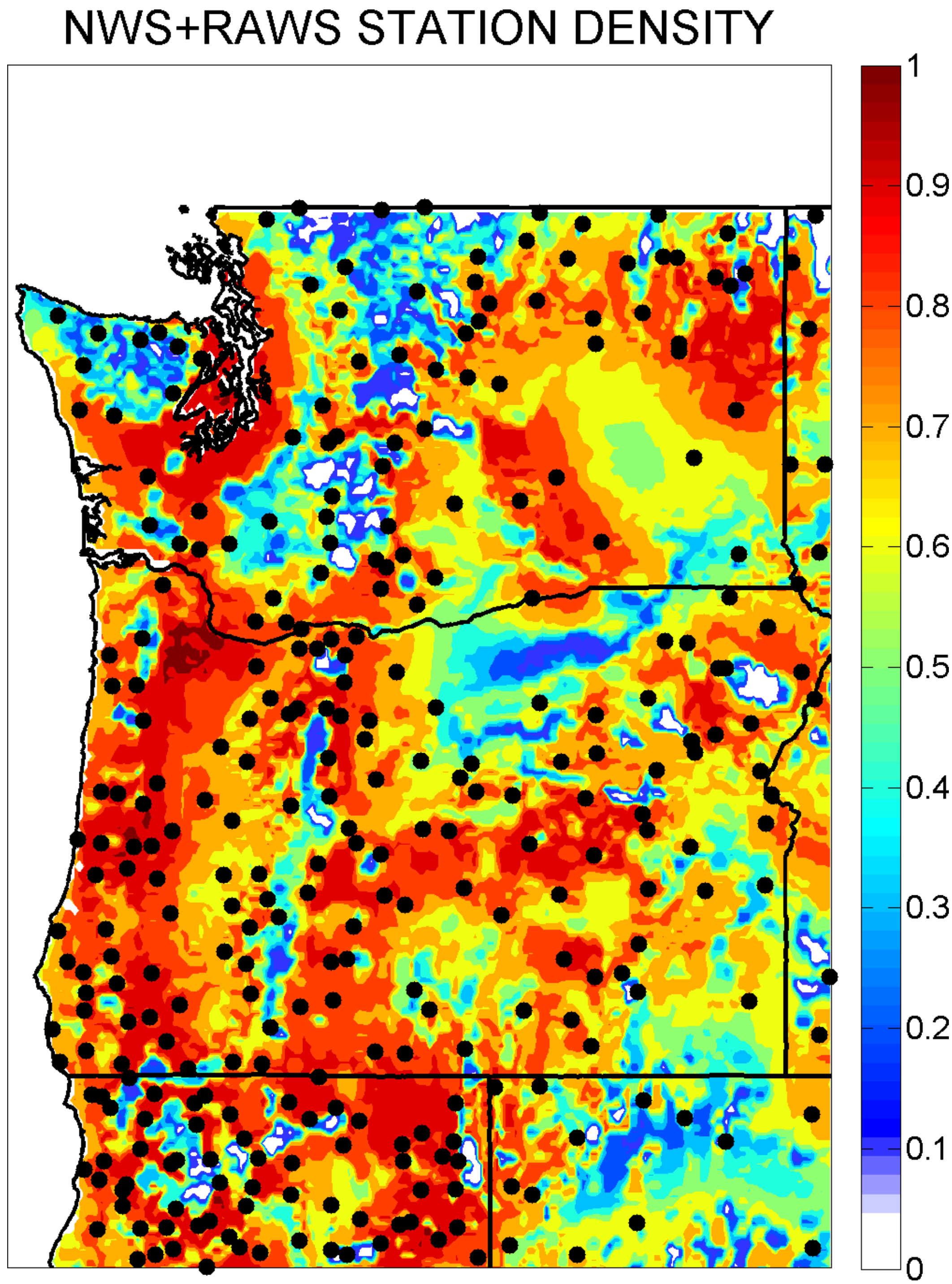
Appendix 5. Data gap maps for the Pacific Northwest Area.

The top map shows the IDI values based on RAWS, and the bottom map based on RAWS+ASOS stations. The methods and maps are described in detail in Section 3. Points on the maps are permanent RAWS locations. Stations shown in a white area indicates that they were added to the study after the original IDI analysis.




NWS+RAWS STATION DENSITY
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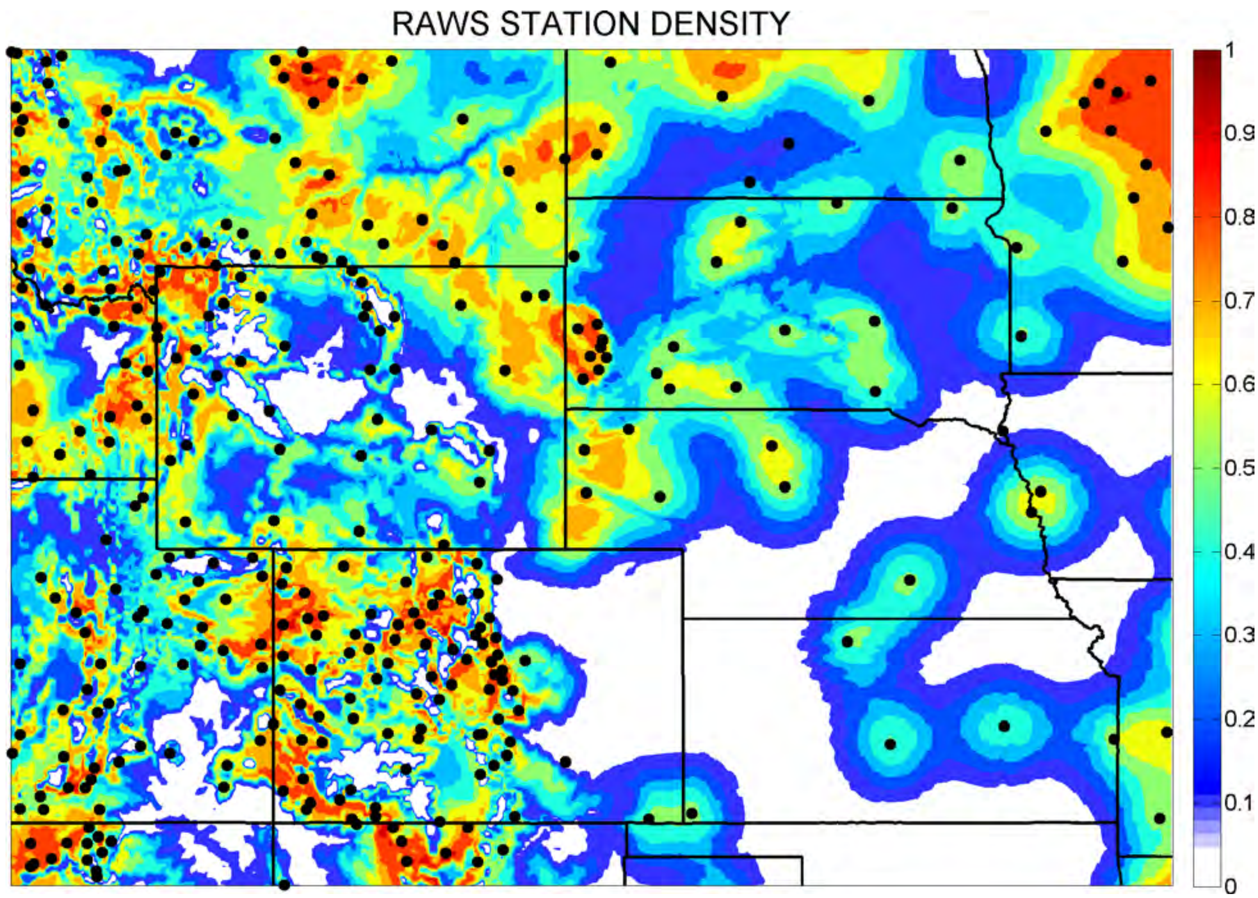
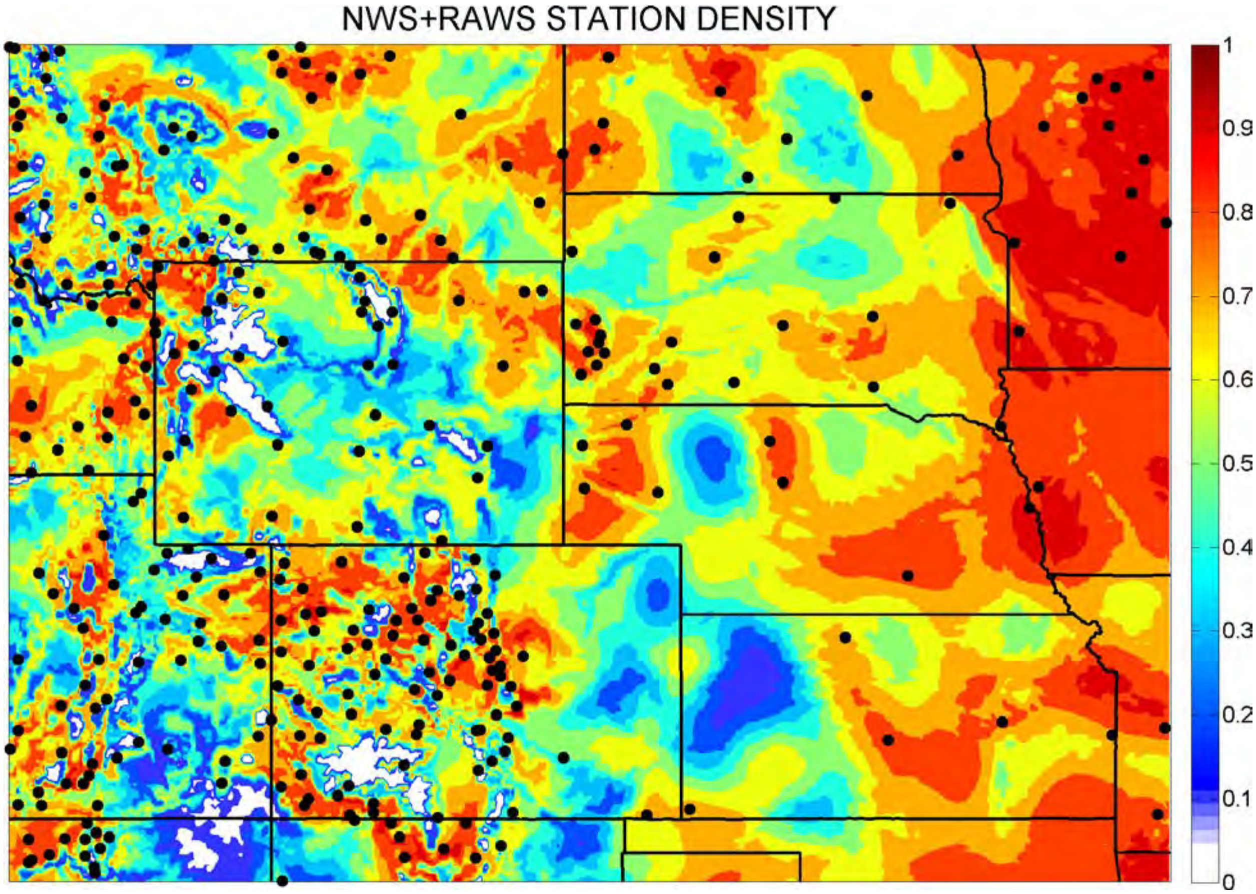
Appendix 6. Data gap maps for the Rocky Mountain Area.

The top map shows the IDI values based on RAWS, and the bottom map based on RAWS+ASOS stations. The methods and maps are described in detail in Section 3. Points on the maps are permanent RAWS locations. Stations shown in a white area indicates that they were added to the study after the original IDI analysis.




NWS+RAWS STATION DENSITY
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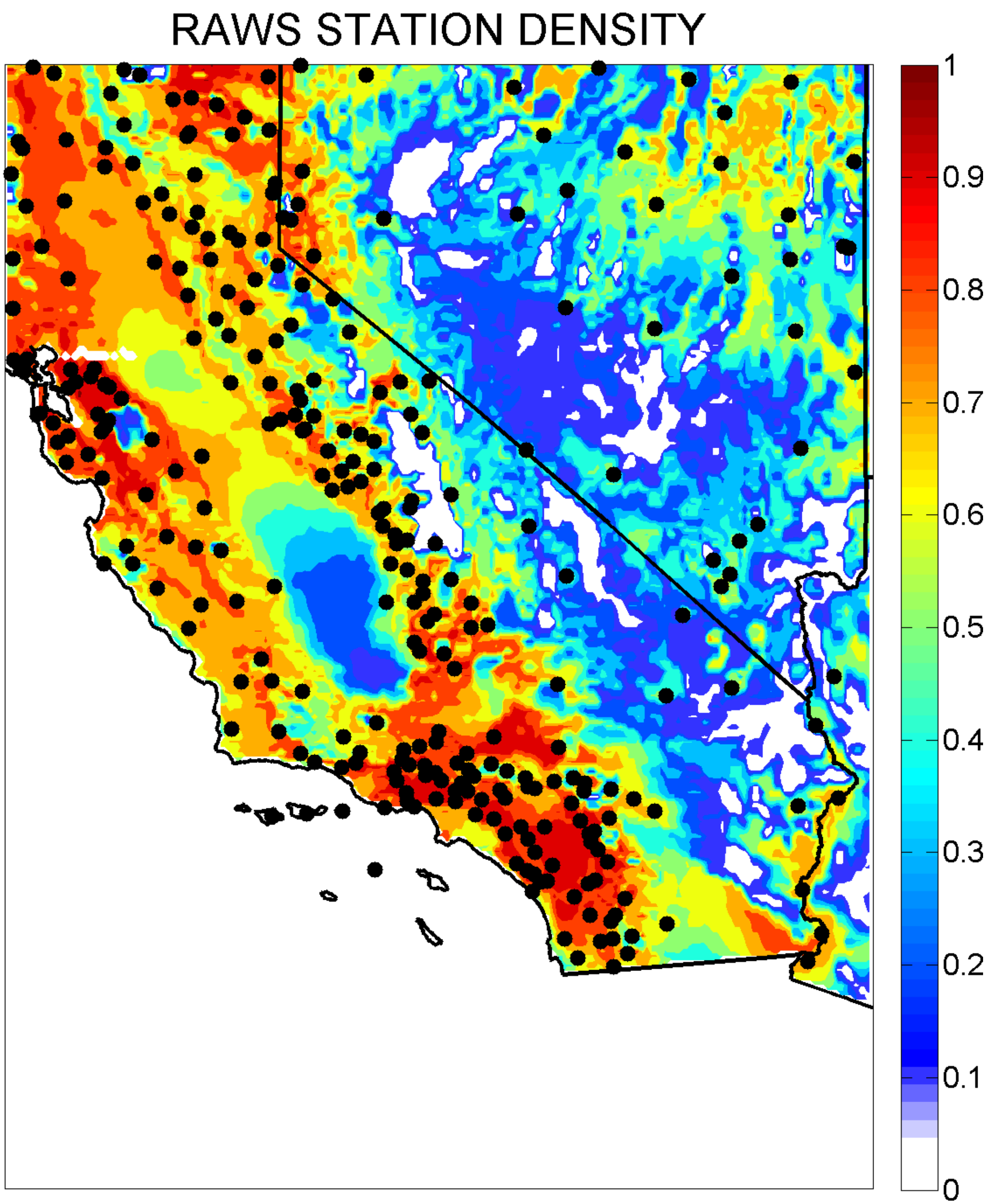
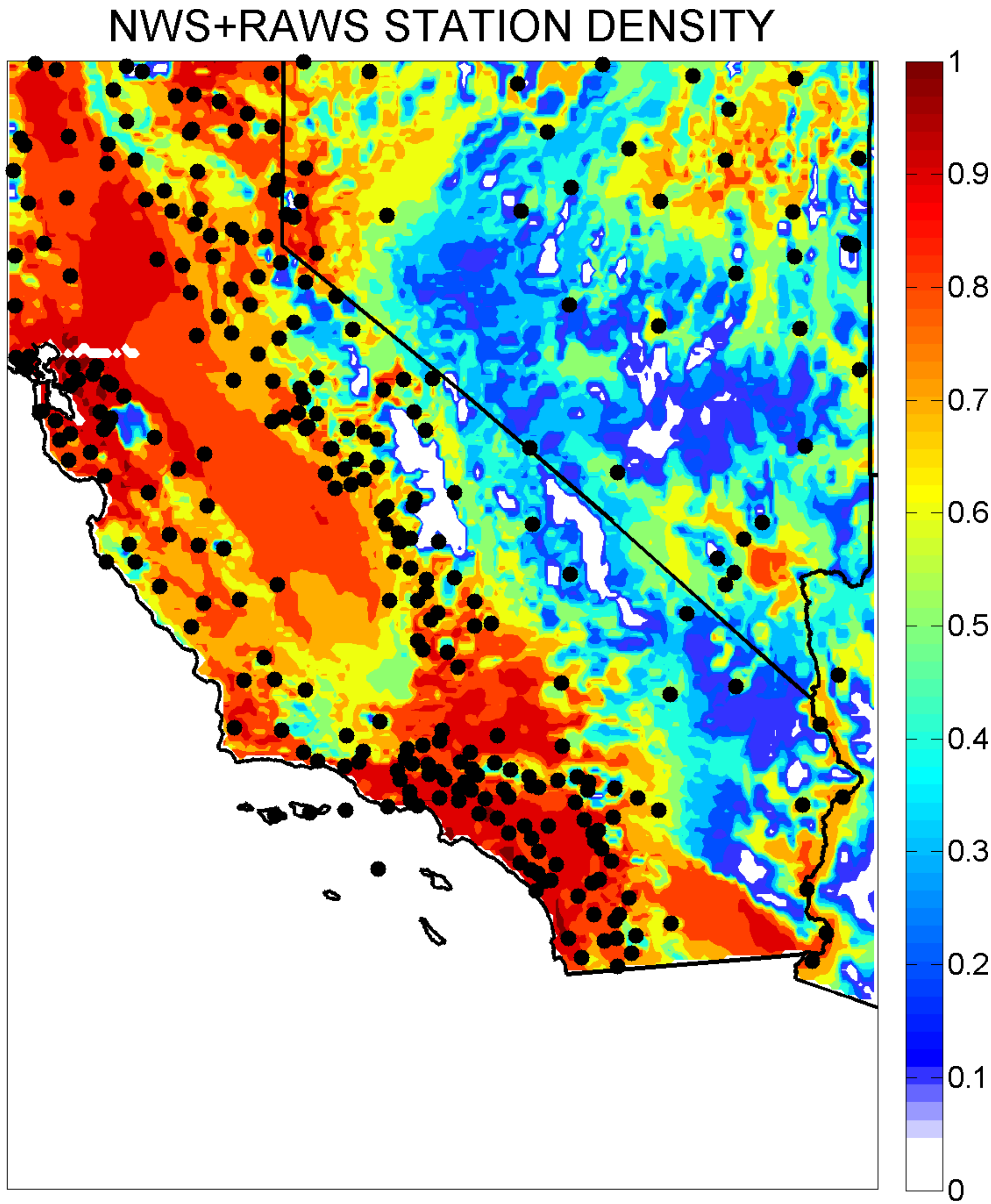
Appendix 7. Data gap maps for the Southern California Area.

The top map shows the IDI values based on RAWS, and the bottom map based on RAWS+ASOS stations. The methods and maps are described in detail in Section 3. Points on the maps are permanent RAWS locations. Stations shown in a white area indicates that they were added to the study after the original IDI analysis.




NWS+RAWS STATION DENSITY
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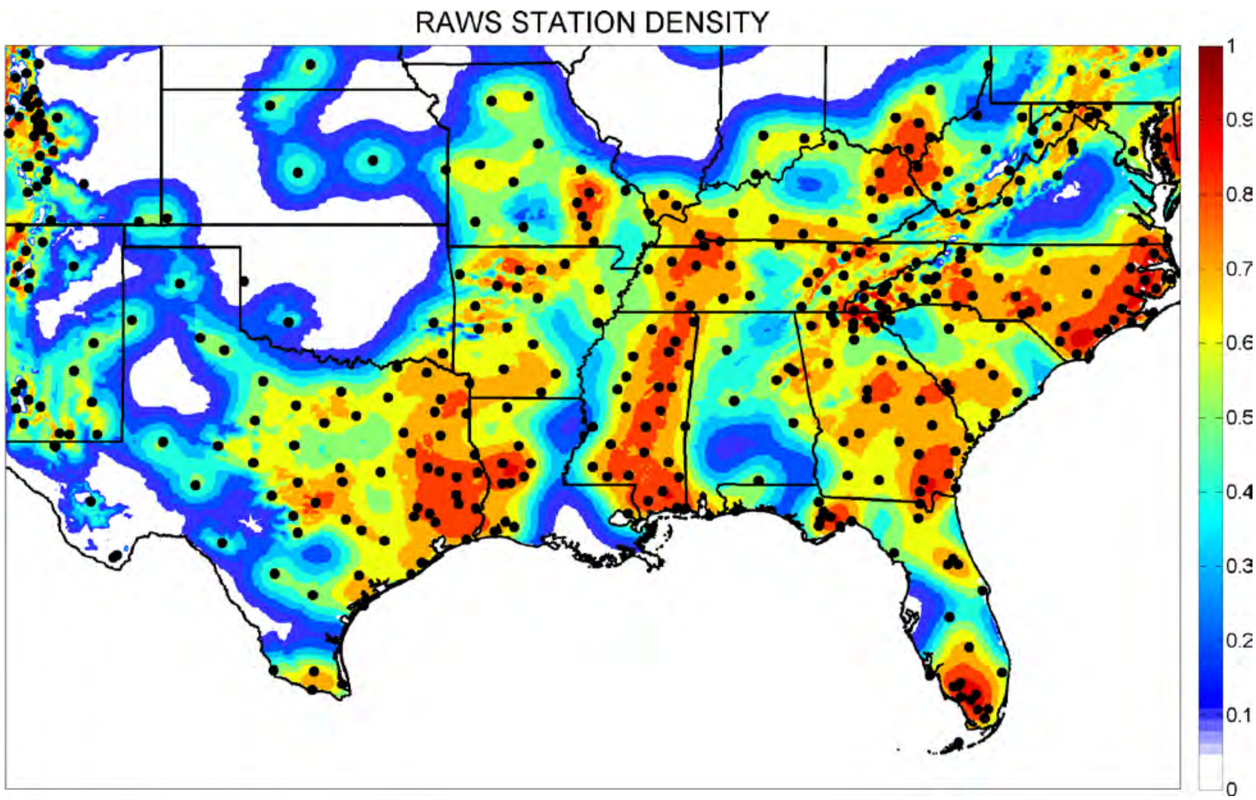
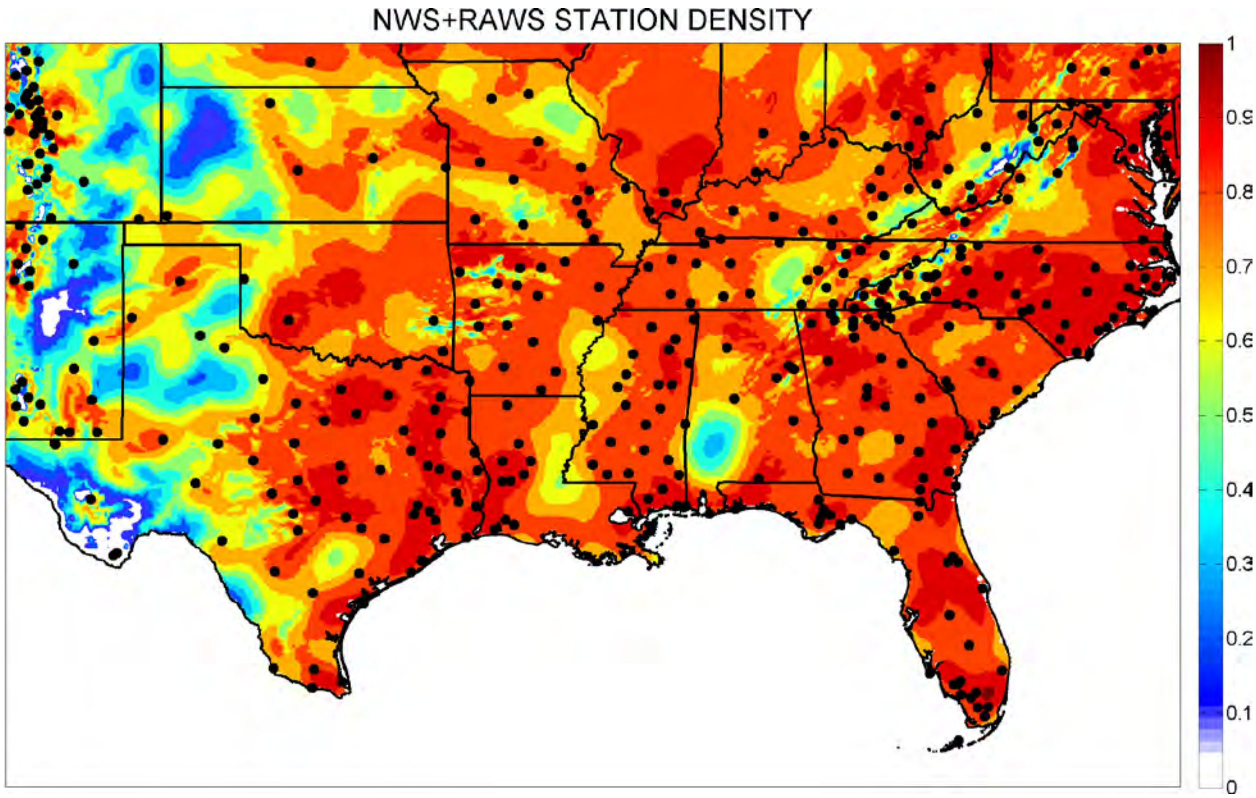
Appendix 8. Data gap maps for the Southern Area.

The top map shows the IDI values based on RAWS, and the bottom map based on RAWS+ASOS stations. The methods and maps are described in detail in Section 3. Points on the maps are permanent RAWS locations. Stations shown in a white area indicates that they were added to the study after the original IDI analysis.




NWS+RAWS STATION DENSITY
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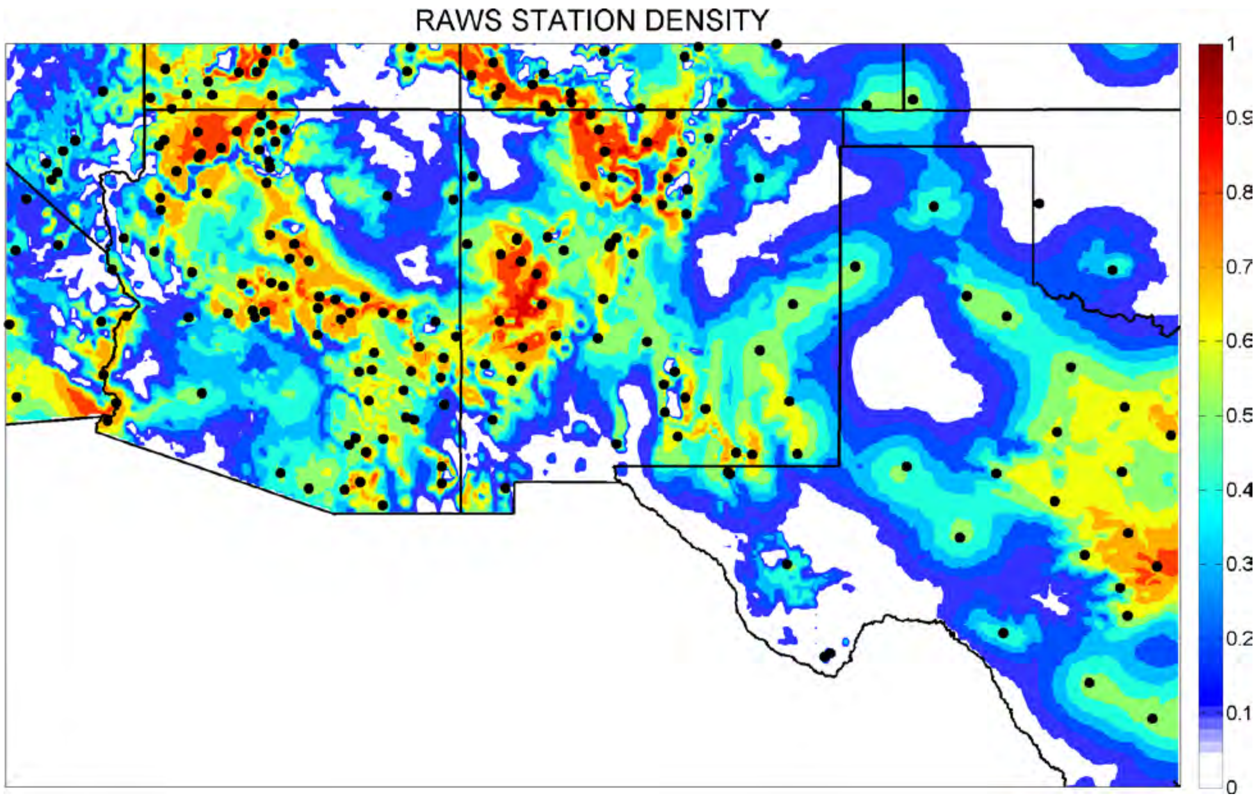
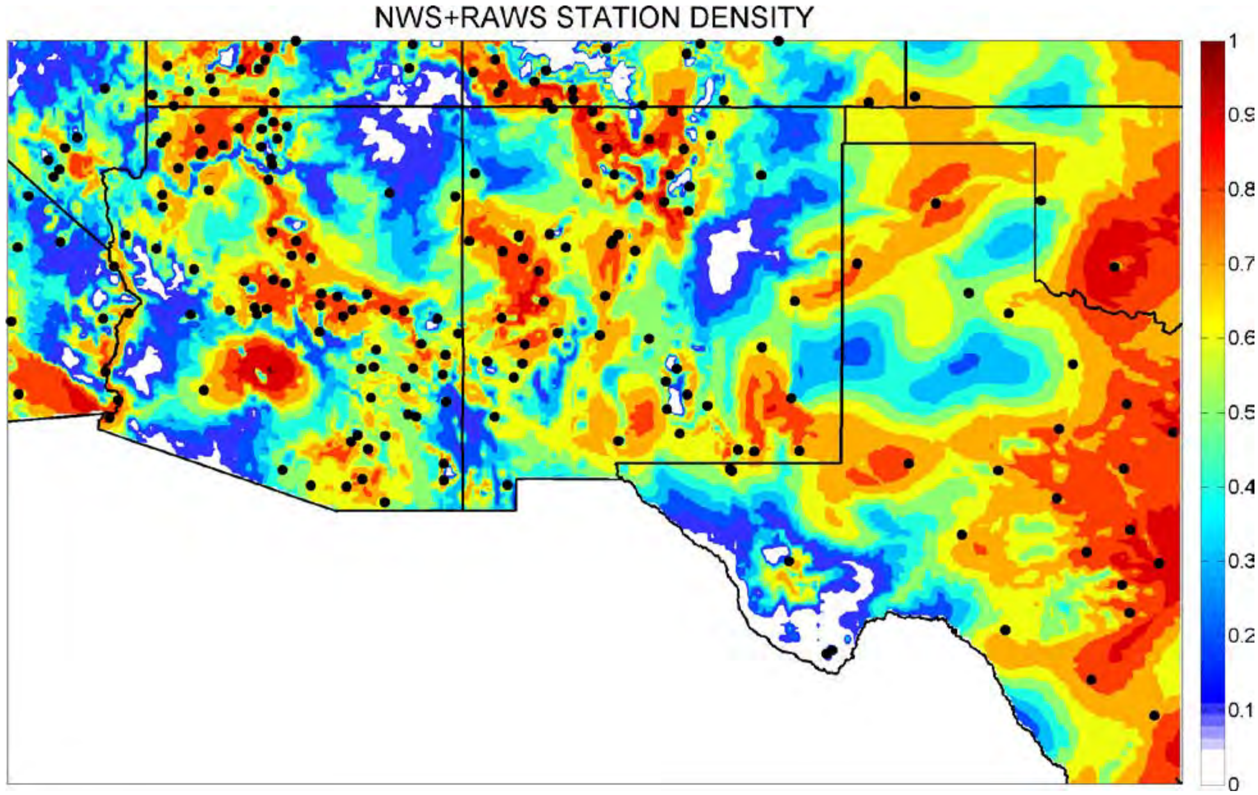
Appendix 9. Data gap maps for the Southwest Area.

The top map shows the IDI values based on RAWS, and the bottom map based on RAWS+ASOS stations. The methods and maps are described in detail in Section 3. Points on the maps are permanent RAWS locations. Stations shown in a white area indicates that they were added to the study after the original IDI analysis.





NWS+RAWS STATION DENSITY
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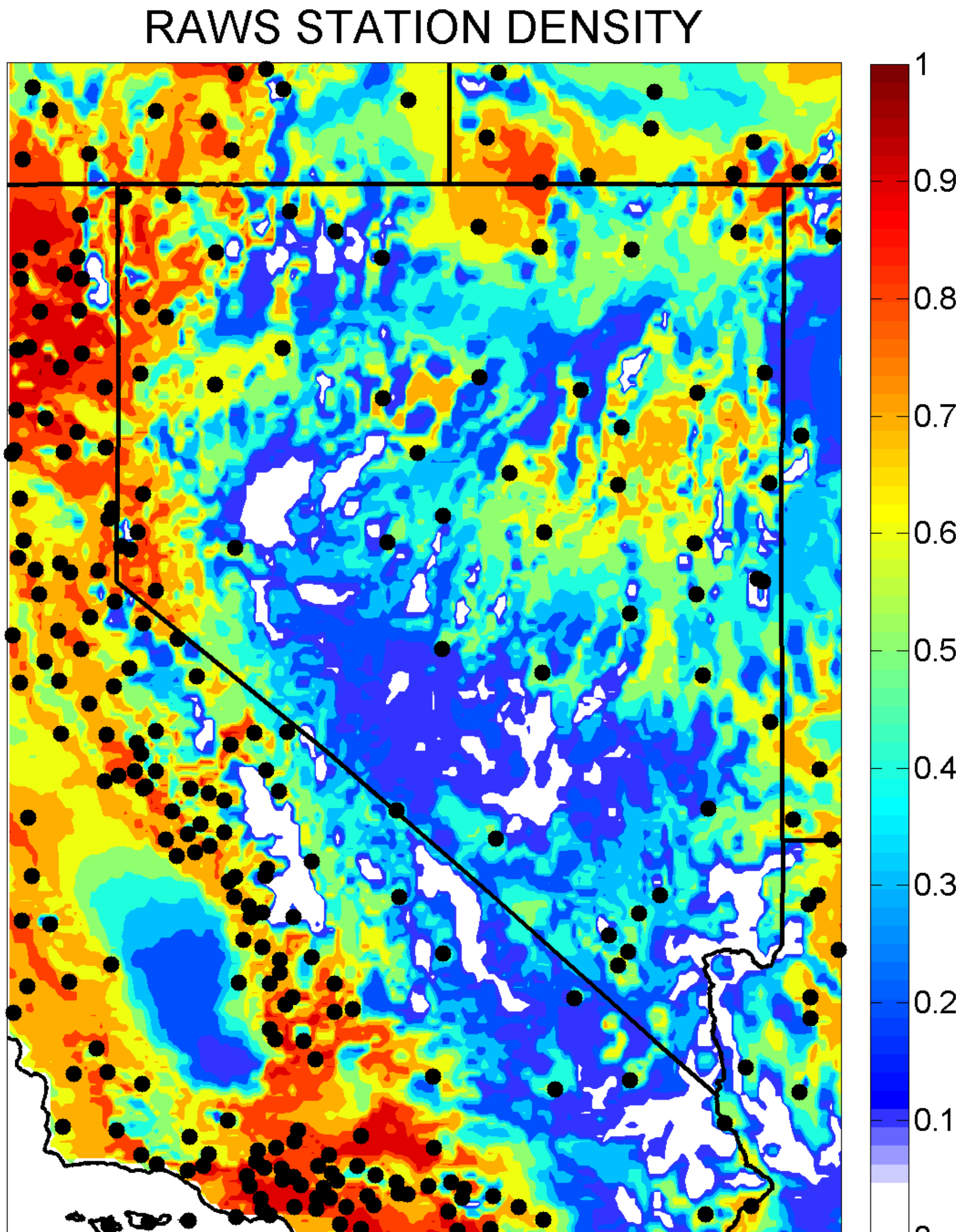
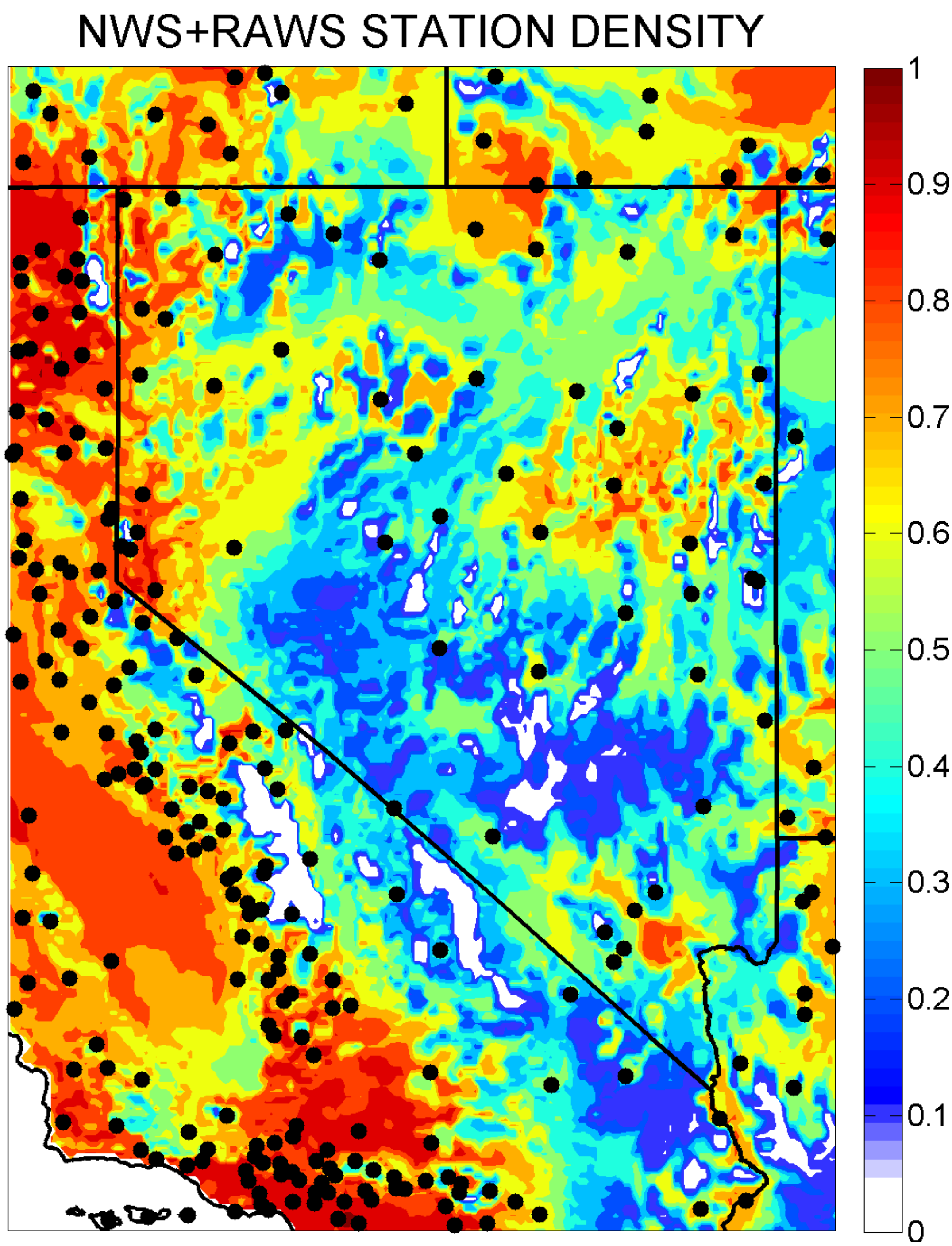
Appendix 10. Data gap maps for the Western Great Basin Area.

The top map shows the IDI values based on RAWS, and the bottom map based on RAWS+ASOS stations. The methods and maps are described in detail in Section 3. Points on the maps are permanent RAWS locations. Stations shown in a white area indicates that they were added to the study after the original IDI analysis.




NWS+RAWS STATION DENSITY
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Appendix 11. Table of weather station networks in MESOWEST.

This table include the network short and full names, the number of active stations as of March 2011, the states represented, and the number stations per weather element.

MNET	Name	Active Stations	States	TEMP	RH	WIND	PRECIP
AFGWFO	Fairbanks Weather Forecast Office	12	AK	12	12	12	10
AGRIMET	U.S. Bureau of Reclamation	90	CA;ID;MT;NV; OR;WA;WY	90	90	77	76
AIRNOW	AIRNow	385	AL;AZ;CA;CT;FL; GA;HI;IA;ID;IL; IN;KS;KY;LA;MA; MD;ME;MI;MO; MS;NC;NE;NJ; NV;NY;OK;PA;RI; TX;UT;VA;VT; WA;WI;WV;WY	385	195	514	44
AKDOT	Alaska Department of Transportation	39	AK	39	39	39	24
APRSWXNET/ CWOP	Automatic Position Reporting System WX NET/Citizen Weather Observer Program	6497	ALL	6497	6465	6490	5690
AQ	Utah Department of Air Quality	19	UT	17	9	19	1
ARL FRD	NOAA Air Resources Laboratory Field Research Division	35	ID	35	35	35	31
ARL SORD	NOAA Air Resources Laboratory Special Operations and Resource Division	30	NV	30	30	30	16
AVALANCHE	Forest Service Avalanche Center	26	ID;UT	26	17	17	9
AZ ALERT	The Flood Control District of Maricopa County	35	AZ	35	35	28	34
AZDOT	Arizona Department of Transportation	17	AZ	17	17	17	

MNET	Name	Active Stations	States	TEMP	RH	WIND	PRECIP
AZMET	The Arizona Meteorological Network	23	AZ	23	23	23	23
BTAVAL	Bridger Teton National Forest Avalanche Center	16	WY	16	9	9	9
BWFO NWS	Boulder WFO National Weather Service	12	CO	12	12	12	3
CA HYDRO	CA HYDRO	77	CA;NV	77	17	14	
CAIC	Colorado Avalanche Information Center	13	CO	13	12	13	1
CALTRANS	California Department of Transportation	17	CA	17	17	17	11
CAMPBELL	Campbell Scientific	4	UT	4	4	4	3
CARB	California Air Resources Board	140	CA	128	84	140	
CBRFC	Colorado Basin River Forecast Center	5	AZ;CO	1			5
CDEC	California Department of Water Resources	5	CA	5	4	2	2
CDOT	Colorado Department of Transportation	78	CO	78	78	78	37
CDPHE	Colorado Department of Public Health and Environment	9	CO	9		9	
CEMP	Community Environmental Monitoring Program	22	CA;NV;UT	22	22	22	22
CIMIS	California Irrigation Management Information System	129	CA	129	129	129	126
CNRFC	California Nevada River Forecast Center	29	CA;NV	29	15	15	28
CPCRC	Columbia Plateau Conservation Research Center	3	OR	3	3	3	3

MNET	Name	Active Stations	States	TEMP	RH	WIND	PRECIP
CRN	Climate Reference Network	95	AL;AR;AZ;CA;CO; FL; GA;IA;ID;IL; IN;KY;LA;ME;MN; MT;NC;NE;NH; NM;NV;NY;OK; OR;PA;RI;SC;SD; TN;TX;UT;VA; WA;WI;WV;WY	95	8	76	85
DCEW	Dry Creek Experimental Watershed	3	ID	3	3	3	3
DEERVLY	Deer Valley Resort	6	UT	6	6	5	2
DEOS	Delaware Environmental Observing System	30	DE	30	30	29	29
DRI	Desert Research Institute	59	CA;CO;NV; OR	59	59	59	38
DUDFCD	Denver Urban Drainage and Flood Control District	24	CO	24	24	24	20
DUGWAY	U.S. Army Dugway Proving Grounds	27	UT	27	27	27	27
EDW	Edwards Air Force Base	14	CA	14	14	14	
FAWN	Florida Automated Weather Network	36	FL	36	36	36	5
FGNet	Utah Fruit Growers Weather Monitoring Network	15	UT	15	15	15	
FGZWFO	Flagstaff Weather Forecast Office	5	AZ	5	5	5	5
GGWWFO	Glasgow Weather Forecast Office	13	MT	13	11	13	7
GNP	Glacier National Park	1	MT	1	1	1	

MNET	Name	Active Stations	States	TEMP	RH	WIND	PRECIP
GPSMET	FSL Ground-Based GPS	88	AK;AL;AR;AZ;CA; CO;FL;GA;IA;KS; KY;LA;MA;MD; ME;MI;MN;MO; MT;MX;ND;NE; NH;NJ;NM;NV; NY;OK;OR;PA; SC;TN;TX;UT; WA;WI;WV;WY	88	88	2	11
GSE	Grand Staircase-Escalante National Monument	8	UT	8	8	8	8
HADS	Hydrometeorological Automated Data System	2433	ALL	731	86	149	2433
HILL	CH2M HILL Hill Air Force Base	1	UT	1	1	1	1
HMMN	Hanford Meteorological Monitoring Network	30	WA	30	4	30	
HNLWFO	Honolulu Weather Forecast Office	21	AS;HI	21		21	20
HNXWFO	Hanford Weather Forecast Office	11	CA	11	10	9	1
HPWREN	High Performance Wireless Research and Education Network	2	CA	2	2	2	2
IADOT	Iowa Department of Transportation	58	IA	58	58	58	28
INDOT	Indiana Department of Transportation	26	IN	26	26	26	5
ITD	Idaho Transportation Department	78	ID	78	78	78	65
KENNECOTT	Kennecott Utah Copper	7	UT	7	1	7	7
KSL	KSL	2	UT	2	2	2	2
KYDOT	Kentucky Transportation Cabinet RWIS	17	KY	17	17	17	17

MNET	Name	Active Stations	States	TEMP	RH	WIND	PRECIP
LANL	Los Alamos National Laboratory	5	NM	5	4	5	4
LAS VEGAS	Clark County Nevada Flood Control District	54	AZ;NV	46	48	50	54
LKNWFO	Elko Weather Forecast Office	2	NV	2	2	2	2
LOXWFO	Los Angeles/Oxnard Weather Forecast Office	26	CA	19	19	18	26
MAMMOTH	Mammoth Mountain Ski Area	5	CA	5	5	4	1
MARITIME	Moored Buoys and CMAN	289	AK;AL;CA;CT;FL; HI;IL;IN;LA;MA; MD;ME;MI;NC; NH; NJ;NY;OH; OR;SC;TX;VA; WA;WI	289	142	288	
MAWN	Michigan Automated Weather Network	60	MI	60	60	59	60
MCSCN	Montana Counties Soil Climate Network	20	MT	20	20	20	20
MDDOT	Maryland Department of Transportation	52	MD	52	52	52	4
ME-CAR-Meso	Caribou Weather Forecast Office	5	ME	5	5	5	5
MEDOT	Maine Department of Transportation	4	ME	4	4	4	
MFRWFO	Medford Weather Forecast Office	1	OR	1			
MISC	Miscellaneous	5	CA;UT;WA	5	5	5	3
MNDOT	Minnesota Department of Transportation	85	MN	84	85	74	85
MSI	Meteorological Solutions Inc.	2	UT	2	2	2	2
MSOWFO	Missoula Weather Forecast Office	10	ID;MT	10	3	6	8

MNET	Name	Active Stations	States	TEMP	RH	WIND	PRECIP
MT DOT	Montana Department of Transportation	61	MT	60	60	61	60
MTRWFO	Monterey Weather Forecast Office	26	CA	2			26
NCAWOS	MADIS Non-Commissioned AWOS	116	AK;AZ;CA;CO;CT; FL;HI;ID;IN;KS; MD;ME;MI;MO; MT;NC;NJ;NV; NY;OH;OK;OR; PA;SD;TX;VT;WA	116	116	116	14
NDDOT	North Dakota Department of Transportation	24	ND	24	24	24	2
NEDOR	Nebraska Department of Roads	48	NE	48	48	48	2
NEMPPA	Northeast Metro Pollution Prevention Alliance	4	CO	4	1	4	
NHDOT	New Hampshire Department of Transportation	15	NH	15	15	15	3
NJNET	New Jersey Weather and Climate Network	40	NJ	40	38	40	39
NOS-NWLON	National Ocean Service Water Level Observation Network	144	AK;AL;CA;CT;FL;GA;HI;IL;LA;MA; MD;ME;MI;MN; MS;NC;NJ;NY; OH;OR;PA;PR;SC; TX;VI;WA;WI	144	12	129	29
NOS-PORTS	National Ocean Service Physical Oceanographic Real-Time System	59	AK;AL;CA;CT;DE; FL;MA;MD;MI; NJ;NY; OR;PA;RI; TX;VA;WA	57	5	59	8
NV DOT	Nevada Department of Transportation	73	NV	73	73	73	73
NWAVAL	Northwest Avalanche Center	31	OR;WA	31	28	20	18

MNET	Name	Active Stations	States	TEMP	RH	WIND	PRECIP
NWS COOP	NWS Modernized Cooperative Observer Program - New England	51	CT;MA;ME;NH; NY;VT	51	51	15	51
NWS/FAA	National Weather Service/Federal Aviation Administration	2038	ALL	2038	2037	2037	1801
ODEQ	Oregon Department of Environmental Quality	14	OR	12	4	14	
ODOT	Oregon Department of Transportation	63	OR	62	63	63	27
OHDOT	Ohio Department of Transportation	164	OH	164	164	164	48
PCMR	Park City Mountain Resort	9	UT	9	8	7	
PDTWFO	Pendleton Weather Forecast Office	30	OR;WA	30	30	30	6
PIHWFO	Pocatello/Idaho Falls Weather Forecast Office	1	ID	1	1	1	1
PQRWFO	Portland Weather Forecast Office	13	OR;WA	2	2	5	13
RAWS	Bureau of Land Management	2073	ALL	2073	2071	2073	2068
SARC	Southern Agricultural Research Center	1	MT	1	1	1	1
SBCAPCD	Santa Barbara County Air Pollution Control District	15	CA	15	6	14	

MNET	Name	Active Stations	States	TEMP	RH	WIND	PRECIP
SCAN	Soil Climate Analysis Network	151	AK;AL;AR;AZ; CA;CO;FL;GA; HI; IA;ID;IL;KS; KY;MD;MN;MO; MS;MT;NC;ND;NE;NH;NM;NV;NY; OH;OK;OR; PA;PR;SC;SD;TN; TX;UT;VA;VT; WA;WI;WY	151	145	151	150
SCHWEITZER	Schweitzer Mountain Resort	2	ID	2		2	
SDGE	San Diego Gas and Electric	88	CA	88	88	88	
SEWWFO	Seattle Weather Forecast Office	6	WA	1	1	6	1
SFWMD	South Florida Water Management District	26	FL	26	26	26	3
SGXWFO	San Diego Weather Forecast Office	69	CA	69	68	69	69
SHASAVAL	Mt. Shasta Avalanche Center	4	CA	4	2	2	2
SNOTEL	Natural Resources Conservation Service	757	AK;AZ;CA;CO; ID;MT;NM;NV; OR;SD;UT;WA; WY	757	71	89	754
SNOWBIRD	Snowbird Ski and Summer Resort	2	UT	2		1	
SNOWNET	Snownet/Local Mesonet	31	ID;UT	30	26	31	22
TOOELE	U.S. Army Deseret Chemical Depot	26	UT	26	26	26	
UPR	Union Pacific Railroad	406	AR;AZ;CA;CO;IA; ID;IL;KS;LA;MN; MO;NE;NM;NV; OK;OR;TX;UT; WA;WI;WY	406		48	
UTAH CLIMATE CENTER	Utah Climate Center	3	UT	3	2	3	
UTAH DOT	Utah Department of Transportation	68	UT	68	68	68	6

MNET	Name	Active Stations	States	TEMP	RH	WIND	PRECIP
VADOT	Virginia Department of Transportation	44	VA	44	44	42	34
VTRANS	Vermont Agency of Transportation	14	VT	14	14	14	
WA DOT	Washington Department of Transportation	97	WA	97	90	96	
WAAQ	Washington State Department of Ecology Air Quality Network	19	WA	18	10	19	1
WIDOT	Wisconsin Department of Transportation	53	WI	53	53	53	
WSMR	U.S. Army White Sands Missile Range	22	NM	22	22	22	22
WTEXAS	West Texas Mesonet	60	NM;TX	60	60	60	5
WY DOT	Wyoming Department of Transportation	64	WY	64	64	64	12
YAKIMA	Bureau of Reclamation Yakima Project	7	WA	7		5	

Appendix 12. Summary of other weather networks.

This list is based on sites checked by WRCC in January 2011. Access refers to a qualitative statement regarding the availability of historical data directly from the provider.

ALABAMA

Alabama Mesonet
http://wx.aamu.edu/ALMNet.php

The Alabama A&M University operates this network of 11 combination meteorological and soil stations (8 in Alabama). The combination stations are included within the USDA/NRCS Soil Climate Analysis Network.

Total stations: 11. Hourly: Yes Height: 10 feet Access: Good

Auburn University Mesonet
http://www.awis.com/mesonet/

Auburn University operates this network of 19 stations at locations throughout the state of Alabama. The network provides hourly observations of air temperature, dew point, wet bulb temperature, relative humidity, precipitation, soil temperature at 4 inches depth, vegetative wetting, solar radiation, wind speed, wind direction, and wind gust.

Total Stations: 19. Hourly: Yes Height: 33 feet Access: Password (fee)

ALASKA

Road Weather Information System (RWIS)
http://www.dot.state.ak.us/iways/roadweather/forms/AreaSelectForm.html

The Alaska Department of Transportation (DOT) operates this network of 40 stations with locations throughout Alaska. The network provides variable temporal resolution observations of air temperature, dew point, relative humidity, wind speed, wind direction, wind gust, and precipitation (only yes/no and sometimes precipitation type).

Total Stations: 40 Hourly: Yes Height: 33 feet Access: Difficult

Seward Peninsula Hydrometeorology Network
http://data.ine.uaf.edu/seward/index.html

The University of Alaska Fairbanks Water and Environmental Research Center operates this network of 8 meteorological stations located on the Seward Peninsula in western Alaska. The parameters measured vary by site but can include hourly observations of wind speed, wind direction, air temperature, relative humidity, net radiation, up/downward long/shortwave radiation, barometric pressure, precipitation, and snow depth.

Total Stations: 8 Hourly: Yes Height 30 feet Access: Real-time only?

ARIZONA

Road Weather Information System (RWIS)

The Arizona Department of Transportation (DOT) operates this network of 7 stations located along I40 in central Arizona. The network provides variable temporal resolution observations of air temperature, relative humidity, dew point, wind speed, wind direction, visibility, and precipitation (yes/no).

Arizona Meteorological Network (AZMET)
http://ag.arizona.edu/azmet/

The Arizona Meteorological Network (AZMET) is part of the Extension Biometeorology Program, which is a service of the University of Arizona Cooperative Extension within the College of Agriculture. The network provides hourly observations of air temperature, relative humidity, vapor pressure deficit, solar radiation, precipitation, soil temperature (2 and 4 inch depths), wind speed, wind direction, wind gust, and reference evapotranspiration. The network consists of 23 stations located throughout the southern half of Arizona.

Total Stations: 23 Hourly: Yes Height: ? Access: Easy

ARKANSAS

None

CALIFORNIA

Road Weather Information System (RWIS)
http://www.dot.ca.gov/dist2/travelmap.htm

The California Department of Transportation (CalTrans) operates this network of 14 stations located in Northern California. The network provides variable temporal resolution observations of air temperature, relative humidity, dew point, wind speed, wind direction, visibility, and precipitation (yes/no). This network is included as part of the University of Utah MesoWest and NOAA/Earth System Research Laboratory (ESRL) Global Systems Division (GSD) MADIS data sets.

Total Stations: 14 Hourly: Yes Height 30 feet Access: Real-time only?

China Lake Weather Station Network

The China Lake Naval Air Weapons Stations (NAWS) operates this network 13 weather stations located around the China Lake NAWS located at the south end of the Owens Valley in central California. Eight of the stations provide 5 minute observations of wind direction, wind speed, wind gust, temperature, relative humidity and station pressure. The other 5 stations provide hourly observations of the same set of parameters as well as precipitation and solar radiation.

Total Stations: 13 Hourly: Yes Height: ? Access: Difficult

COLORADO

Colorado Department of Transportation (DOT) Road Weather Information System (RWIS) Networks

The Colorado DOT operates this network of 109 stations located along roadways throughout the state of Colorado. The network provides 15-min observations of air temperature, dew point, relative humidity, barometric pressure, wind speed, wind direction, wind gust, precipitation type and intensity. Some stations also provided precipitation accumulation and visibility measurements.

Total Stations: 109 Hourly: Yes Height: 33 feet Access: Unavailable

CONNECTICUT

None

DELAWARE

None

FLORIDA

Florida Automated Weather Network (FAWN)
http://fawn.ifas.ufl.edu/

The University of Florida Institute of Food and Agricultural Sciences operates this network of 28 stations located throughout the state of Florida. The network provides 15-minute observations of air temperature (at 2, 6, and 10 ft), relative humidity, wind speed, wind direction, solar radiation, soil temperature (at 10 cm depth), and precipitation. For further

Total Stations: 28 Hourly: Yes Height: 33 feet Access: Easy

GEORGIA

Georgia Forestry Commission Weather Station Network
http://weather.gfc.state.ga.us/climate/climate.aspx

The Georgia Forestry Commission operates this network of 18 stations located throughout the state of Georgia. The network provides hourly observations of air temperature, relative humidity, wind direction, wind speed, and precipitation. (These appear to be RAWS).

Total Stations: 18 Hourly: Yes Height 33 feet? Access: Good

Georgia Ambient Air Monitoring Program
http://www.eol.ucar.edu/projects/hydrometnet/georgia/

The Georgia Department of Natural Resources Environmental Protection Division Air Protection Branch operates this network of ambient air monitoring stations with locations throughout the state of Georgia. At present it is not known how many of these provide any meteorological measurements.

Total Stations: 24? Hourly: Yes Height: ? Access: Good

HAWAII

None

IDAHO

Idaho National Engineering and Environmental Laboratory (INEEL) Network
http://niwc.noaa.inel.gov/Climate.htm

The NOAA/Air Resources Laboratory/Field Research Division operates this network of 31 stations at locations around the Idaho National Engineering and Environmental Laboratory site in southeastern Idaho. The network provides 5-minute observations of air temperature, relative humidity, wind speed, wind direction, solar radiation, precipitation, and barometric pressure.

Total Stations: 31 Hourly: Yes Height 33 feet Access: Good

Idaho Transportation Department (ITD) Road Weather Information System (RWIS) Network http://511.idaho.gov/staticMap.asp?display=nws

The ITD operates this network of 41 stations located along highways throughout the state of Idaho. The network provides 5-minute observations of air temperature, relative humidity, wind speed and wind direction. This network is included as part of the University of Utah MesoWest and NOAA/Earth System Research Laboratory (ESRL) Global Systems Division (GSD) MADIS data sets.

Total Stations: 41 Hourly: Yes Height: 30 feet Access: None thru website

ILLINOIS

Great Lakes Environmental Research Laboratory (GLERL) Real-Time Meteorological Observation Network
http://www.glerl.noaa.gov/metdata/info.html

The GLERL operates this network of 7 stations with locations primarily around southern Lake Michigan (1 in Illinois). The network provides up to 5-minute observations of air temperature, wind speed, and wind direction.

Total Stations: 7-Most in MI Hourly: Yes Height: 12-25 meters Access: Good

Illinois Climate Network (ICN)
http://www.isws.illinois.edu/warm/datatype.asp

The Illinois State Water Survey operates this network of 19 stations at locations throughout the state of Illinois. The network provides hourly observations of air temperature, relative humidity, wind speed, wind direction, solar radiation, evaporation, precipitation, and soil temperature.

Total Stations: 19 Hourly: Yes Height: ? Access: Good

Illinois Roadway Weather Information System (RWIS) Network
http://www.gettingaroundillinois.com/default.aspx?ql=rwis

The Illinois Department of Transportation operates this network of 49 stations located throughout the state of Illinois. The network provides observations of air temperature, relative humidity, wind speed, wind direction, wind gust, and precipitation at an unknown temporal resolution.

Total Stations: 49 Hourly: Yes Height: 33 feet Access: Difficult

INDIANA

Purdue Automated Agricultural Weather Station Network (PAAWS)
http://data.eol.ucar.edu/codiac/dss/id=85.033

Purdue University operates this network of 9 stations at each of its Agricultural Research Centers throughout the state of Indiana. The network provides 30-minute observations of air temperature, wind speed, wind direction, solar radiation, precipitation, and soil temperature at a depth of 4 cm.

Total Stations: 9 Hourly: Yes Height: 10 feet Access: ?

Road Weather Information System (RWIS)
http://netservices.indot.in.gov/rwis/

The Indiana Department of Transportation (DOT) operates this network of 31 stations located throughout Indiana. The network provides variable temporal resolution observations of air temperature, relative humidity, dew point, wind speed, wind direction, visibility, and precipitation (yes/no). For further information visit the Indiana DOT RWIS web page. This data set is included in the NOAA/FSL MADIS data set.

Total Stations: 31 Hourly: Yes Height: 33 feet Access: Current only

IOWA

Iowa Department of Transportation (DOT) Road Weather Information System (RWIS) http://www.dotweatherview.com/

The Iowa DOT operates this network of 50 stations with locations along highways throughout the state of Iowa. The network provides 15-minute observations of air temperature, dew point, wind speed, wind direction, and precipitation. These data are included in the Iowa Environmental Mesonet (IEM) data set developed by Iowa State University. For further information visit the IEM home page or the Iowa DOT Weatherview web page. This data set is included in the NOAA/FSL MADIS data set.

Total Stations: 50 Hourly: Yes Height: 33 feet Access: Real-Time only

KANSAS

Kansas Department of Transportation (DOT) Road Weather Information System (RWIS) Network
http://www.ksdot.org/burcompser/generatedreports/weather.asp#station1

The Kansas DOT operates this network of 44 stations at locations along highways throughout the state of Kansas. The network provides hourly observations of air temperature, relative humidity, wind speed, and wind direction. For further information visit the Kansas DOT RWIS home page or the Surface Systems, Inc Road Weather page. This data set is included in the NOAA/FSL MADIS data set.

Total Stations: 44 Hourly: Yes Height: 33 feet Access: Real-Time only

Kansas Mesonet
http://wdl.agron.ksu.edu/

The Kansas State Climate Office operates this network of 14 stations in southwestern Kansas (formerly operated by the Kansas GWMD #3). The network provides hourly observations of air temperature, relative humidity, wind speed, wind direction, precipitation, solar radiation, and soil temperature.

Total Stations: 14 Hourly: Yes Height: 33 feet Access: Good

KENTUCKY

Kentucky Mesonet
http://www.kymesonet.org/index.html

The Kentucky Climate Center at Western Kentucky University is overseeing the development of this network of environmental monitoring stations throughout Kentucky. For further information visit the Kentucky Mesonet web page.

Total Stations: 40 Hourly: Yes Height: ~30 ft Access: Easy (per day only)

Kentucky Roadway Weather Information System (RWIS)
http://www.kytc.state.ky.us/RWIS/

The Kentucky Transportation Cabinet operates this network of 39 stations with locations throughout the state of Kentucky. The network provides variable (hourly or higher) resolution observations of air temperature, dew point, relative humidity, and wind speed. For further information visit the Kentucky RWIS home page. This network is included in the NOAA/FSL MADIS data set.

Total Stations: 39 Hourly: Yes Height: 33 feet Access: Difficult

LOUISIANA

Louisiana Agriclimatic Information System (LAIS)
http://weather.lsuagcenter.com/Default.aspx

The Louisiana State University AgCenter operates this network of 20 stations with locations throughout the state. The network provides 5-minute observations of air temperature, precipitation, wind speed, wind direction, relative humidity, solar radiation, and soil temperature. For further information visit the LAIS home page. This network is included in the NOAA/FSL MADIS data set.

Total Station: 20 Hourly: Yes Height: ? Access: Good

MAINE

None

MARYLAND

Maryland Department of Transportation (DOT) Road Weather Information System (RWIS) Network
http://www.chart.state.md.us/travInfo/weatherStationData.asp

The Maryland DOT operates this network of 45 stations with locations along highways throughout the state of Maryland. The network provides variable (hourly or higher) resolution observations of air temperature, dew point, relative humidity, and wind speed.

Total Stations: 45 Hourly: Yes Height: 33 feet Access: Excellent

MASSACHUSETTS

Massachusetts Air Monitoring Network

The Massachusetts Department of Environmental Protection Air Program Planning Unit operates this network of 18 stations with locations throughout the state of Massachusetts. The parameters vary by station with 8 providing hourly observations of winds and the other 10 providing air temperature, wind speed, wind direction, solar radiation, relative humidity, and barometric pressure. For further information visit the Air Program Planning Unit page.

Unable to locate met data.

MICHIGAN

Michigan Automated Weather Network (MAWN)
http://www.agweather.geo.msu.edu/mawn/

The Michigan State University and Michigan Agricultural Experiment Station operate this network of 25 stations located throughout the state of Michigan. The network provides hourly observations of air temperature, relative humidity, soil temperature (at 4 inch depth), soil moisture, leaf wetness, wind speed, wind direction, solar radiation, and precipitation. A subset of these parameters is also available every 5 minutes.

Total Stations: 25 Hourly: Yes Height: 6-10 feet Access: Excellent

MINNESOTA

Minnesota Road Weather Information System (RWIS)
http://rwis.dot.state.mn.us/

The Minnesota Department of Transportation (DOT) operates this network of 92 RWIS stations across the state of Minnesota. The network provides variable (hourly or higher) resolution observations of air temperature, dew point, relative humidity, and wind speed. For further information visit the Minnesota DOT RWIS web page. This network is included in the NOAA/FSL MADIS data set.

Total Stations: 92 Hourly: Yes Height: 33 feet Access: Very Good

MISSISSIPPI

Mississippi Mesonet
http://jsumesonet.jsums.edu/index.htm

Jackson State University operates this network. For further information please visit the Mississippi Mesonet web page. This network is included in the NOAA/FSL MADIS data set.

Total Stations: 6 Hourly: Yes Height: 33 feet Access: Difficult

MISSOURI

Commercial Agriculture Weather Station (CAWS) Network
http://agebb.missouri.edu/weather/stations/index.htm

The Commercial Agriculture Program of the University of Missouri Extension operates this network of 21 stations with locations throughout Missouri. The network provides hourly observations of air temperature, relative humidity, wind speed, wind direction, soil temperature (2 cm depth), and solar radiation. For further information visit the network page.

Total Stations: 21 Hourly: Yes Height: 10 feet Access: Excellent

Road Weather Information System (RWIS)

The Missouri Department of Transportation (DOT) and City of St. Peters operate this network of 26 stations located throughout the state of Missouri. The network provides variable temporal resolution observations of air temperature, relative humidity, dew point, wind speed, wind direction, visibility, and precipitation (yes/no). For further information visit the Surface Systems, Inc Road Weather page.

Total Stations: 26 Hourly: Yes Height: 33 feet Access: Unable to locate.

Missouri Air Monitoring Network

http://www.dnr.mo.gov/env/esp/aqm/northmo.htm

The Missouri Department of Natural Resources Environmental Services Program operates this network of 19 stations located throughout the state of Missouri. All stations provide hourly observations of wind speed and wind direction, additionally 16 of the stations provide air temperature, 3 provide solar radiation, and 2 provide relative humidity.

Total Stations: 19 Hourly: Yes Height: 20 feet? Access: Difficult

MONTANA

Montana Department of Transportation (DOT) Road Weather Information System (RWIS) Network

http://rwis.mdt.mt.gov/

The Montana DOT operates this network of 59 stations located along highways throughout the state of Montana. The network provides 5-minute observations of air temperature, relative humidity, wind speed, and wind direction. This network is included within the University of Utah MesoWest and NOAA/FSL MADIS data sets.

Total Stations: 59 Hourly: Yes Height: 33 feet Access: Difficult

Montana Air Monitoring Network

http://www.deq.state.mt.us/energy/renewable/windweb/winddata/index.asp

The Montana Department of Environmental Quality Planning, Prevention, and Assistance Division operates this network of 4 stations located throughout the state of Montana. The network provides hourly observations of air temperature, wind speed, and wind direction.

Total Stations: 5 Hourly: Yes Height: 20 meters Access: Good

NEBRASKA

Road Weather Information System (RWIS)

The Nebraska Department of Roads (DOR) and City of Omaha operate this network of 54 stations located throughout the state of Nebraska. The network provides variable temporal resolution observations of air temperature, relative humidity, dew point, wind speed, wind direction, visibility, and precipitation (yes/no). For further information visit the Surface Systems, Inc Road Weather page. This network is included as part of the University of Utah MesoWest and NOAA/Earth System Research Laboratory (ESRL) Global Systems Division (GSD) MADIS data sets.

Total Stations: 54 Hourly Yes Height: 33 feet Access: None thru NE DOT

NEVADA

Nevada Department of Transportation (DOT) Road Weather Information System (RWIS) Network

The Nevada DOT operates this network of 38 stations with locations along highways in the vicinity of Reno. The network provides 15-minute observations of air temperature, relative humidity, wind speed, and wind direction. This network is included as part of the University of Utah MesoWest and NOAA/Earth System Research Laboratory (ESRL) Global Systems Division (GSD) MADIS data sets. For further information visit the Nevada DOT RWIS home page.

Total Stations: 38 Hourly Yes Height: 33 feet Access: Real-Time only

Clark County ALERT Weather Station Network

http://www.ccrfcd.com/ftrs.htm

The Clark County (Las Vegas area) Regional Flood Control District operates this network of 25 weather stations with locations throughout the county. The network provides observations of air temperature, relative humidity, wind speed, wind direction, and precipitation at varying temporal resolutions.

Total Stations w/wind: 24 Hourly: Yes Height: 10-12 feet Access: Good

NEW HAMPSHIRE

New Hampshire Road Weather Information System (RWIS)

The New Hampshire Department of Transportation operates this network of 12 weather stations located along roadways throughout the state.

Unable to locate data.

NEW JERSEY

New Jersey Weather and Climate Network
http://climate.rutgers.edu/njwxnet/stationmap.php

The Office of the New Jersey State Climatologist collects data from a number of different agencies that operates weather stations throughout the state of New Jersey. These include the National Weather Serivce, the New Jersey Department of Transportation, the New Jersey Turnpike Authority, and the Davidson Lab at Stevens Institute of Technology, among others. Most of the data are of hourly temporal resolution and the paramters vary by network but can include air temperature, dew point, relative humidity, atmospheric pressure, precipitation, wind speed, wind gust, and wind direction.

Includes all stations including RWIS and New Jersey Mesonet. Access OK.

NEW MEXICO

New Mexico State University (NMSU) Climate Network
http://weather.nmsu.edu/cgi-shl/cns/uberpage.pl?selected=3

NMSU operates this network of 16 stations with locations throughout the state of New Mexico. The network provides hourly observations of air temperature, relative humidity, precipitation, wind speed, wind direction, solar radiation, soil temperature, and soil moisture. Further information at: http://weather.nmsu.edu/data/data.htm/.

Stations from numerous NM networks posted. Hourly: Yes Height: Varies
Access: excellent

Los Alamos National Laboratory (LANL) Network
http://www.weather.lanl.gov/

LANL operates this network of 11 stations that operate around LANL in north-central New Mexico. The network includes a 92 m tower with wind and temperature at four levels (also near-surface measurements of temperature, moisture, pressure, precipitation, and surface energy balance terms), a 23 m tower with wind and temperature at two levels (also shortwave radiation), three 46 m towers with wind and temperature at three levels (also near-surface measurements of temperature, moisture, precipitation, and shorwave radiation), and a 36 m tower with wind and temperature at one level (also near-surface measurements of temperature, moisture, pressure, and precipitation). The additional sites provide primarily precipitation. For further information visit the LANL network page and information on the individual sites can be found here.

Total Stations: 11 Hourly: Yes Height: Varies Access: Real-time; Historical data via email

NEW YORK

Northeast Weather Association (NEWA) Network
http://newa.cornell.edu/

The NEWA is affiliated with the New York State Integrated Pest Management Program and operates this network of 46 weather stations primarily in western New York state (43 in New York). The network provides hourly observations of air temperature, relative humidity, soil temperature, leaf wetness, and precipitation. Access to data from this network usually requires a subscription although such fees have been waived in the past (e.g. 2002).

Total Stations: 46 Hourly: Yes Height: Unknown Access: Excellent

NORTH CAROLINA

North Carolina Agricultural Research Service (NCARS) Weather and Climate Network
http://www.nc-climate.ncsu.edu/econet/

The NCARS and North Carolina State Climate Office operate this network of 24 stations located throughout the state of North Carolina. The network provides hourly observations of air temperature, relative humidity, wind speed, wind direction, barometric pressure, solar radiation, photosynthetically active radiation (PAR), precipitation, soil temperature, and soil moisture.

North Carolina Environment and Climate Observing Network (ECONet)
http://www.nc-climate.ncsu.edu/econet/

The North Carolina State Climage Office in cooperation with state and federal agencies oversees this combination of networks with locations throughout the state of North Carolina. Among the networks included in ECONet are the NCARS, ASOS, AWOS, buoy, C-MAN, and SCAN networks described elsewhere. Also included are the North Carolina Department of Air Quality network and the Emergency Management network. For further information visit the ECONet home page.

Total Stations: 35   Hourly: Yes   Height: 33 feet?   Access: Difficult

NORTH DAKOTA

High Plains Regional Climate Center (HPRCC) Automated Weather Data Network (AWDN)
http://ndawn.ndsu.nodak.edu/index.html

The HPRCC oversees and ingests data from various state agricultural networks and makes it available as the AWDN. The AWDN is comprised of 167 stations located primarily in High Plains region (55 in North Dakota). The network provides hourly observations of air temperature, relative humidity, solar radiation, soil temperature, wind speed, wind direction, and precipitation. For further information visit the HPRCC AWDN home page or the North Dakota AWDN home page or the NDAWN page at UND.

Total Stations: 55   Hourly: Yes   Height: 10 feet   Access: Excellent

North Dakota Department of Transportation (DOT) Road Weather Information System (RWIS) Network

The North Dakota DOT operates this network of 14 RWIS locations throughout the state of North Dakota. The network provides hourly observations of air temperature, relative humidity, wind speed, and wind direction. For further information visit the North Dakota DOT RWIS home page or the Surface Systems, Inc Road Weather page.

Total Stations: 14   Hourly: Yes   Height: 33 feet   Access: None

OHIO

Ohio Department of Transportation (DOT) Road and Weather Information System (RWIS)
http://www.buckeyetraffic.org/reporting/RWIS/results.aspx

The Ohio DOT operates this network of 69 weather stations along highways throughout the state of Ohio. The network provides variable (hourly or higher) resolution observations of air temperature, dew point, relative humidity, and wind speed. For further information visit the Ohio DOT RWIS page or the Surface Systems, Inc Road Weather page.

Total Stations: 69 Hourly: Yes Height: 33 feet Access: Difficult

Ohio Agricultural Research and Development Center (OARDC) Network
http://www.oardc.ohio-state.edu/newweather/

The OARDC and Miami University operate this network of 12 stations located throughout the state of Ohio. The network provides hourly observations of air temperature, relative humidity, solar radiation, precipitation, wind speed, wind direction, and soil temperature at 5 and 10 cm depths. For further information visit the OARDC Network home page.

Total Stations: 12 Hourly: Yes Height: 15 meters Access: Excellent

OKLAHOMA

Oklahoma Mesonet
http://www.mesonet.org/

The Oklahoma Climatological Survey operates this network of 116 stations located throughout the state of Oklahoma. The network provides up to 5-minute observations of air temperature, relative humidity, wind speed, wind direction, barometric pressure, precipitation, soil temperature (5, 10, and 30 cm depths), solar radiation, and soil moisture. Some free real-time products are available here. For further information visit the Oklahoma Mesonet home page.

Total Stations: 116 Hourly: Yes Height: 10 meters Access: Excellent (but fee based)

Road Weather Information System (RWIS)

The Oklahoma Department of Transportation (DOT) operates this network of 11 stations located throughout the state of Oklahoma. The network provides variable temporal resolution observations of air temperature, relative humidity, dew point, wind speed, wind direction, visibility, and precipitation (yes/no). For further information visit the Surface Systems, Inc Road Weather page.

Total Stations: 11   Hourly: Yes   Height: 33 feet   Access: Unable to locate

OREGON

Mountain Weather Data Network
http://www.nwac.us/weatherdata/map/

The Northwest Weather and Avalanche Center operates this network of 17 stations located in mountainous areas of Washington and Oregon (4 in Oregon). The network provides hourly observations of air temperature, relative humidity, wind speed, wind direction, precipitation, and snowfall. This network is included within the University of Utah MesoWest and the NOAA/FSL MADIS. For further information visit the Mountain Weather Data Network home page.

Total Stations: 4   Hourly: Yes Height: Unknown   Access: Past 10 days

Oregon Department of Transportation (DOT) Road Weather Information System (RWIS) Network
http://www.tripcheck.com/Pages/RCMap.asp?curRegion=0&mainNav=RoadConditions

The Oregon DOT operates this network of 58 stations located along highways throughout Oregon. The network provides 15-minute observations of air temperature, relative humidity, wind speed, and wind direction. For further information visit the Oregon DOT RWIS page. This network is included as part of the University of Utah MesoWest and NOAA/Earth System Research Laboratory (ESRL) Global Systems Division (GSD) MADIS data sets.

Total Stations: 58   Hourly: Yes   Height: 33 feet   Access; Real-time only

PENNSYLVANIA

Pennsylvania Department of Transportation (DOT) Road Weather Information System (RWIS) Network

The Pennsylvania DOT operates this network of 75 stations with locations along highways throughout the state of Pennsylvania. The network provides variable (hourly or higher) resolution observations of air temperature, dew point, relative humidity, and wind speed. Hourly data from this network is included in the Pennsylvania Hourly Mesonet operated by the Pennsylvania State Climatologist. For further information visit the Pennsylvania DOT RIWS page.

Total Stations: 75   Hourly: Yes   Height: 33 feet   Access: Poor.   Access through PA Hourly Mesonet page does not work nor does the PA DOT RWIS page.

Pennsylvania Air Monitoring Network

The Pennsylvania Department of Environmental Protection Bureau of Air Quality operates this network of 55 stations with locations throughout the state of Pennsylvania. The network provides hourly observations of air temperature, solar radiation, wind speed, and wind direction. Hourly data from this network is included in the Pennsylvania Hourly Mesonet operated by the Pennsylvania State Climatologist. For further information visit the Bureau of Air Quality page.

Total Stations: 55   Hourly: Yes   Height: Unknown: Access: Poor. (See above).

RHODE ISLAND

None

SOUTH CAROLINA

Road Weather Information System (RWIS)

The South Carolina Department of Transportation (DOT) operates this network of 40 stations located throughout South Carolina. The network provides variable temporal resolution observations of air temperature, relative humidity, dew point, wind speed, wind direction, visibility, and precipitation (yes/no).

Total Stations: 40   Hourly: Yes   Height: 33 feet   Access: Unable to locate

SOUTH DAKOTA

South Dakota Department of Transportation (DOT) Road Weather Information System (RWIS) Network

The South Dakota DOT operates this network of 35 RWIS locations throughout the state of South Dakota. The network provides hourly observations of air temperature, relative humidity, wind speed, and wind direction. For further information visit the South Dakota DOT RWIS home page or the Surface Systems, Inc Road Weather page.

Total Stations: 35 Hourly: Yes Height: 33 feet Access: Unable to locate

TENNESSEE

Road Weather Information System (RWIS)

The Tennessee Department of Transportation (DOT) operates this network of 20 stations located along throughout Tennessee. The network provides variable temporal resolution observations of air temperature, relative humidity, dew point, wind speed, wind direction, visibility, and precipitation (yes/no). For further information visit the Surface Systems, Inc Road Weather page.

Total Stations: 20 Hourly: Yes Height: 33 feet Access: Unable to locate

East Tennessee Ozone Study (ETOS) Network

The National Oceanic and Atmospheric Administration (NOAA) Atmospheric Turbulence and Diffusion Division (ATDD) operates this network of 21 meteorological towers throughout eastern Tennessee. The network provides at least hourly observations of air temperature, wind speed, wind direction, relative humidity, and precipitation. For further information visit the ETOS Tower home page.

Total Stations: 21 Hourly: Yes Height: Unknown Access: Unable to locate

TEXAS

West Texas Mesonet
http://www.mesonet.ttu.edu/

Texas Tech University operates this network of 34 stations in the area around Lubbock, Texas. The network provides 5-minute observations of air temperature, wind speed, wind direction, relative humidity, barometric pressure, precipitation, solar radiation, soil temperature (at 5, 10 and 20 cm depths), soil moisture (at 5, 20, 60 and 75 cm depths) and leaf wetness. For further information visit the West Texas Mesonet home page. Meteogram imagery for the West Texas Mesonet is available from the University of Oklahoma.

Total Stations: 34 Hourly: Yes Height: 10 meters Access: Good

Road Weather Information System (RWIS)

The Texas Department of Transportation (DOT) operates this network of 12 stations located throughout the state of Texas. The network provides variable temporal resolution observations of air temperature, relative humidity, dew point, wind speed, wind direction, visibility, and precipitation (yes/no). For further information visit the Surface Systems, Inc Road Weather page.

Total Stations: 12 Hourly: Yes Height: 33 feet Access: Unable to locate

Texas Natural Resources Conservation Commission (TNRCC) Air Monitoring Network
http://www.tceq.state.tx.us/compliance/monitoring/air/monops/historical_data.html

The TNRCC monitors air quality across the state of Texas with this network of 131 stations operated by various local agencies. The network provides hourly observations of a varying set of parameters typically including air temperature, wind speed, and wind direction. For further information visit the TNRCC Air Monitoring page.

Total Stations: 131 Hourly: Yes Height: 10 meters Access: Difficult

UTAH

Utah Department of Transportation (DOT) Road Weather Information System (RWIS) Network

The Utah DOT operates this network of 38 stations located alongside highways throughout the state of Utah. The network provides 15-minute observations of air temperature, relative humidity, wind speed, and wind direction. This network is included as part of the University of Utah MesoWest and the NOAA/FSL MADIS. For further information visit the MesoWest home page or the Surface Systems, Inc Road Weather page.
Total Stations: 38 Hourly: Yes Height: 30 feet Access: Difficult

Emery Water Conservancy District Network

http://orange.ewcd.org/weather/

The Emery Water Conservancy District operates this network of 9 stations with locations around Emery County in east-central Utah. The network provides hourly observations of air temperature, relative humidity, wind speed, wind direction, solar radiation, soil temperature, and precipitation.

Total Stations: 9 Hourly: Yes Height ~30 feet Access: Good

Sevier River Water Users Association Network

http://www.sevierriver.org/weather/

The Sevier River Water Users Association operates this network of 6 stations with locations around Sevier County in central Utah. The network provides hourly observations of air temperature, relative humidity, wind speed, wind direction, solar radiation, soil temperature, and precipitation.

Total Stations: 6 (3 current) Hourly: Yes Height: ~30 ft Access: Good

U.S. Army Deseret Chemical Depot Network

http://www.tcem.org/weather.htm

The US Army operates this network of 26 stations on its site near Tooele, Utah. The network provides 15-minute observations of air temperature, relative humidity, wind speed, wind direction, and barometric pressure.

Total Stations: 26 Hourly: Yes Height: Unknown Access: Unknown (Page not working when checking data)

U.S. Army Dugway Proving Ground Network
http://www.dugway.army.mil/index.php/index/content/id/21

The US Army operates this network of 25 stations on its site in northwestern Utah. The network provides 15-minute observations of air temperature, relative humidity, wind speed, wind direction, solar radiation, and barometric pressure. Data from this network is included in the University of Utah Mesowest and NOAA/GSD MADIS data sets.

Total Stations: 25 Hourly: Yes Height: Unknown Access: Unable to locate

Utah Division of Air Quality Network
http://www.airquality.utah.gov/slc-currentconditions.html

The Utah Division of Air Quality operates this network of 17 stations located throughout the state of Utah (although most are in the north-central portion of the state). The parameters and temporal resolution vary, however all provide at least hourly wind speed and wind direction. Some stations also provide air temperature, relative humidity, and/or other parameters.

Total Stations: 17 Hourly: Yes Height: Unknown Access: Real-Time only

VERMONT

None

VIRGINIA

Road Weather Information System (RWIS)

The Virginia Department of Transportation (DOT), Richmond County, and Suffolk County operate this network of 40 stations located throughout Virginia. The network provides variable temporal resolution observations of air temperature, relative humidity, dew point, wind speed, wind direction, visibility, and precipitation (yes/no).

Total Stations: 40 Hourly: Yes Height: 30 feet Access: None

WASHINGTON

Mountain Weather Data Network
http://www.nwac.us/weatherdata/map/

The Northwest Weather and Avalanche Center operates this network of 18 stations located in mountainous areas of Washington and Oregon. The network provides hourly observations of air temperature, relative humidity, wind speed, wind direction, precipitation, and snowfall. This network is included within the University of Utah MesoWest and the NOAA/FSL MADIS. For further information visit the Mountain Weather Data Network home page.

Total Stations: 18   Hourly: Yes Height: Unknown   Access: Past 10 days

Washington Roadway Weather Information System (RWIS)
http://www.wsdot.wa.gov/traffic/weather/default.aspx?station=2108&id=dt

The Washington Department of Transportation (DOT) operates this network of 65 RWIS stations across the state of Washington. The network provides variable (hourly or higher) resolution observations of air temperature, dew point, relative humidity, and wind speed. For further information visit the Washington DOT RWIS page or the Surface Systems, Inc Road Weather page. This network is included in the University of Utah MesoWest and the NOAA/FSL MADIS data sets.

Total Stations: 65   Hourly: Yes   Hieght: 33 feet   Access: Real-time only

Hanford Meteorological Station (HMS) Network
http://hms.pnl.gov/

The Pacific Northwest National Laboratory operates the Hanford Meteorological Station for the Department of Energy at the Hanford Site in south-central Washington. The network of 30 stations provides 15-minute observations of air temperature, dew point, barometric pressure, wind speed, wind direction, solar radiation, and precipitation. Three of the stations have 60 m towers and one has a 400 m tower with measurements at multiple levels. This network is included within the University of Utah MesoWest and the NOAA/FSL MADIS data sets. For further information visit the HMS home page. This network is included in the University of Utah MesoWest and the NOAA/FSL MADIS data sets.

Total Stations: 30   Hourly: Yes   Height: 10 meters   Access: Good

Pacific Northwest Agricultural Weather Network
http://www.usbr.gov/pn/agrimet/agrimetmap/agrimap.html

The present AgriMet network consists of over 70 agricultural weather stations located throughout the Pacific Northwest (see map). Three stations operated by the NOAA Air Resources Laboratory in Idaho Falls, Idaho provide the weather data required to model evapotranspiration at Aberdeen, Kettle Butte, and Monteview, Idaho. Over 20 stations east of the Continental Divide in Montana are managed by the Bureau of Reclamation Great Plains Region.

Total Stations: 70 Hourly: Yes Height: 6 feet Access: Excellent

Washington Agricultural Weather Network
http://weather.wsu.edu/

AgWeatherNet (AWN) provides access to raw weather data from the Washington State University weather network, along with decision aids. AWN includes 134 weather stations located mostly in the irrigated regions of eastern Washington State but the network has undergone significant expansion in Western Washington and in dry land regions of the state. The AWN network is administered and managed by the AgWeatherNet team located at the WSU Irrigated Agriculture Research and Extension Center in Prosser, WA but is programmatically linked to efforts at other WSU research and extension centers.

Total Stations: 134 Hourly: Yes

WEST VIRGINIA

Road Weather Information System (RWIS)

The West Virginia Department of Transportation (DOT) operates this network of 6 stations located throughout West Virginia. The network provides variable temporal resolution observations of air temperature, relative humidity, dew point, wind speed, wind direction, visibility, and precipitation (yes/no).

Total Stations: 6 Hourly: Yes Height: 33 feet: Access: None

WISCONSIN

Wisconsin Department of Transportation (DOT) Road Weather Information System (RWIS)
http://www.dot.wisconsin.gov/travel/gis/rwis.htm

The Wisconsin DOT operates this network of 62 stations with locations along roadways throughout Wisconsin. The network provides variable (hourly or higher) resolution observations of air temperature, dew point, relative humidity, and wind speed. For further information visit the WIDOT RWIS page. This network is included as part of the University of Utah MesoWest and NOAA/Earth System Research Laboratory (ESRL) Global Systems Division (GSD) MADIS data sets.

Total Stations: 62 Hourly: Yes Height: 33 feet Access: Real-time only

Wisconsin Automated Weather Observation Network (AWON)
http://www.soils.wisc.edu/wimnext/awon/SelectReport.html

The University of Wisconsin Cooperative Extension operates this network of 2 stations with locations in central Wisconsin. The network provides hourly observations of precipitation, solar radiation, air temperature, relative humidity, soil temperature (2, 4, and 20 in depths), wind speed, wind direction, wind gust, and PAR. For further information visit the AWON home page.

Total Stations: 4 Hourly: Yes Height: 10 meters Access: Good

WYOMING

Wyoming Department of Transportation (DOT) Road Weather Information System (RWIS)
http://www.wyoroad.info/highway/roadbuddies.html

The Wyoming DOT operates this network of 27 stations across the state of Wyoming. The network provides hourly observations of up to 15-minute observations of air temperature, dew point, relative humidity, wind speed, wind direction and wind gust. Some stations also provide yes/no precipitation and/or precipitation accumulation. This network is included as part of the University of Utah MesoWest and NOAA/Earth System Research Laboratory (ESRL) Global Systems Division (GSD) MADIS data sets. For further information visit the WYDOT RWIS home page or the State of Wyoming Water Resources Data System WYDOT RWIS archive web page.

Total Stations: 27 Hourly: Yes Height: 33 feet Access: Real-time only

Wyoming Visibility Monitoring Network
http://www.wyvisnet.com/

The Wyoming Department of Environmental Quality operates this network of 3 visibility and air quality monitoring stations throughout the state of Wyoming. Instrumentation varies by site but can include a digital camera, transmissometer, ambient nephelometer, meteorology equipment and air quality monitoring equipment.

Total Stations: 9 Hourly: Yes Height: 10 meter Access: Good

Bridger-Teton National Forest Network
http://www.jhavalanche.org/stations.html

The Bridger-Teton National Forest operates this network of 13 stations on its lands in west-central Wyoming. The network provides 15-minute observations of wind speed, wind direction, precipitation, and snow depth. This network is included within the University of Utah MesoWest and the NOAA/FSL MADIS data sets. For further information visit the Bridger-Teton National Forest Network page at: http://www.jhavalanche.org/.

Total Stations: 13 Hourly: Yes Height: Unknown Access: Fair

Glacier Lakes Ecosystem Experiments Site (GLEES)

The USDA Forest Service Rocky Mountain Research Station operates this research project in the Snowy Range of the Medicine Bow Mountains in southern Wyoming. There are 3 meteorological towers at various locations on the site (6, 18, and 30 heights). Each tower provides 15 min measurements of air temperature, relative humidity, wind speed, wind direction, solar radiation, precipitation, soil temperature (at 0.5 and 20 cm depths) and surface wetness. The 30 m tower is also part of the Ameriflux network. Additionally there are a SNOTEL station, wet and dry deposition stations, and air quality stations on the site. For further information visit the GLEES home page.

Unable to locate data.

NATIONAL NETWORKS

Soil Climate Analysis Network (SCAN)
http://www.wcc.nrcs.usda.gov/scan/

The SCAN is operated by the United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS). The network provides hourly observations of air temperature, relative humidity, wind speed, wind direction, solar radiation, precipitation, barometric pressure, snow water content, snow depth, soil temperature (at 2, 4, 8, 20, and 40 cm depths), and soil moisture (at 2, 4, 8, 20 and 40 cm depths). The 80 SCAN stations are located across the US in primarily agricultural regions.

Total Staions: 80 Hourly: Yes Height: 6-10 feet? Access: Good

Coastal-Marine Automated Network (C-MAN)
http://www.ndbc.noaa.gov/

The National Data Buoy Center (NDBC) operates this network of 55 C-MAN stations with locations along coastlines throughout the US. The network typically provides hourly observations of air temperature, barometric pressure, wind speed, wind direction, and wind gust. Some stations also provide observations of sea water temperature, water level, waves, relative humidity, precipitation, and visibility. For further information visit the NDBC home page.

Total stations: 55 Hourly: Yes Height 10.1 meters Access: Excellent

Union Pacific Railroad Weather Station Network

The Union Pacific Railroad operates this network of 264 weather stations located in the central and western United States. Further information on Union Pacific is available on their home page. This network is included as part of the University of Utah MesoWest and NOAA/Earth System Research Laboratory (ESRL) Global Systems Division (GSD) MADIS data sets.

Total Stations: 264 Hourly: Yes Height: ? Access: Unable to locate