Project Title: An investigation of the differences between Real Time Mesoscale Analysis and observed meteorological conditions at RAWS stations in the northeast United States

Final Report:

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I. Abstract

This project investigates the differences between the gridded meteorological fields produced by the Real Time Mesoscale Analysis (RTMA) and observed meteorological conditions at Remote Automated Weather Stations (RAWS) for two years in the northeastern United States. National Weather Service (NWS) fire weather forecasts are produced using the National Digital Forecast Database (NDFD), which is a gridded analysis of meteorological fields generated by forecasters at NWS forecast offices nationwide. The NDFD is verified by comparing its gridded meteorological fields against the RTMA, which is an advanced modeling and data assimilation system that provides the best-available hourly gridded estimate of surface and near-surface meteorological conditions. However, for fire management activities, which critically depend on fire weather forecasts, RAWS observations are the standard observational data employed for the calculation of fire danger indices, fire behavior analyses, and for observation-based decision support. RAWS fire weather observations are collected from stations that have different siting requirements and standards of measurement than the majority of stations employed to produce the RTMA and to verify and improve the NDFD. Thus, it is necessary for fire weather forecasters and fire managers to understand how RAWS observations differ from the RTMA, and by association the NDFD, in order to make the best possible forecasts and fire management decisions with the available fire weather information.

This statistical comparison between the RTMA and RAWS station data in the northeast United States over a period of two years (August 2008 through July 2010) documents differences between the two sources of meteorological information. Interpretation of the analysis is complicated by uncertainty over when RAWS observations were assimilated into the RTMA. Since the RAWS observations and the RTMA are not fully independent of each other, assessing the ability of the RTMA to capture the temporal and spatial variability of fire weather quantities and determining if systematic differences exist is not straightforward. Nevertheless, we conducted statistical analyses of the differences between RAWS and RTMA data at 237 RAWS stations in the northeast United States. We then performed a series of statistical tests and analyses to determine if systematic geographical, temporal, or topographical differences can be identified. None of these analyses were able to relate differences between RAWS and RTMA to these factors, leading to the conclusion that the major source of differences between the two datasets is local siting characteristics of the RAWS stations. These results indicate that statistical analyses of differences between RAWS stations and National Weather Service data (such as RTMA, NDFD) should be applied on a station-by-station basis and that applications of these results to the RAWS as continuous network are unlikely to yield any improvement in the quality and accuracy of the data for fire applications. The statistical differences between the two data sources are now available in both graphical and text forms at the 237 RAWS stations in northeast Unites States at http://geo.msu.edu/~raws/.

II. Background and Purpose

Fire weather forecasts and the observations used to assess fire danger and to predict possible fire behavior derive from two different sources of meteorological information. Fire weather forecasts are produced from the National Digital Forecast Database (NDFD), which is a gridded analysis of meteorological fields generated by forecasters at National Weather Service (NWS) forecast offices nationwide (Glahn and Ruth 2003). The NDFD is verified by comparing its gridded meteorological fields against the Real Time Mesoscale Analysis (RTMA), which is an advanced modeling and data assimilation system that employs METAR (aviation weather station) and mesonet data to provide the best-available 5-km gridded estimate of surface and near-surface conditions on an hourly basis (Pondeca et al. 2007). The meteorological observations used to assess fire danger from the National Fire Danger Rating System (NFDRS) and to predict possible fire behavior are collected at Remote Automated Weather Stations (RAWS). It is necessary for fire weather forecasters and fire managers to understand whether RAWS observations differ systematically from the RTMA, and by association the NDFD, in order to make the best possible forecasts and fire management decisions with the available fire weather information. This study investigates differences between RTMA and RAWS meteorological data in the northeast United States, which is a densely populated and heavily forested region of the country where numerous prescribed burns and wildfires occur each year. By performing statistical comparisons between the RTMA and RAWS data for multiple years, we document systematic differences between the two sources of meteorological information for the time period of our analysis so these differences can be accounted for when preparing fire weather forecasts and making fire management decisions.

The RTMA system was developed at the National Centers for Environmental Prediction (NCEP) in 2006 to support NWS operational activities and facilitate verification of the NWS NDFD. Via a two-dimensional variational analysis, surface observations, obtained mainly from mesonet and METAR networks, are used to incrementally adjust first guess data to yield a gridded analysis. The Rapid Update Cycle (RUC) model serves as the first guess for the continental United States, downscaled from 13-km to 5-km grid spacing. Following the analysis process, gridded fields of surface pressure, 2-m temperature and dew point, and 10-m wind components are output, as well as estimates of analysis uncertainty. Additionally, the RTMA system consists of the Environmental Modeling Center's (EMC) Stage II National Precipitation Analysis and a cloud analysis product. As with all objective analyses, sources of analysis error include poor first guess fields (due to, for example, insufficient model resolution or inadequate model physics) and inclusion of unrepresentative observations (Manikin and Pondeca 2009). Within regions of complex terrain, analysis errors can also result from differences in the elevation of surface observations and first guess surface fields, as well as observations in valleys unrealistically influencing the analysis in higher terrain (and vice-versa). Lastly, the RTMA is known to deviate considerably from independent observations near atmospheric boundaries, such as cold fronts and dry lines, where slight errors in positioning of boundaries in the first guess field can yield large analysis errors (Manikin and Pondeca 2009).

The NWS employs the RTMA to verify gridded analyses in the NDFD, which is the ultimate source of both routine fire weather forecasts and spot forecasts issued at the request of fire managers nationwide. However, for fire management activities, which critically depend on fire weather forecasts, Remote Automated Weather Stations (RAWS) observations are the standard observational data employed for the calculation of fire danger indices, fire behavior analyses, and for observation-based decision support. It is therefore necessary to understand how RTMA data differ from the RAWS observations employed by the fire management community, so that forecasts of fire danger and fire behavior can be used in the most effective manner possible.

The RAWS network consists of 2,200 interagency stations strategically located throughout the United States. These stations monitor the weather and provide meteorological data that assist land management agencies with a variety of projects such as monitoring air quality, rating fire danger, and providing information for research applications. Fire managers and fire weather forecasters rely on weather data from RAWS to calculate localized fire danger indices and to generate various fire-related forecast products (Zachariassen et al. 2003). RAWS routinely measure air temperature, relative humidity, wind speed, wind direction, and precipitation in addition to fuel stick temperature. Additionally, the capability to measure barometric pressure and solar radiation has been added to many stations, particularly those meeting the new NFDRS standards. To support the operations and decision making required by the various participating agencies, RAWS stations are typically sited in fire-prone remote locations, distant from other surface stations. Myrick and Horel (2008) find that RAWS observations were able to improve the accuracy of objective surface temperature analyses at grid points near RAWS sites by 0.8-1 ^{o}C during the 2003-2004 winter season, with corresponding wind speed analyses enhanced by 1.2-1.4 m s^{-1}. They also assessed the sensitivity of objective analyses generated by the Advanced Regional Prediction System (ARPS) Data Assimilation System (ADAS) to RAWS data, but did not consider sensitivity of the RTMA to RAWS data. The greatest impacts from RAWS observations were found to occur in areas poorly sampled by other observing networks.

RAWS stations have different site selection criteria from those for the METAR and mesonet stations which constitute the majority of stations employed by the RTMA (Benjamin et al. 2007). Thus, validation of the RTMA and NWS fire weather forecasts using RAWS station data must explicitly account for these differences. However, to date there has been no comprehensive analysis of the difference between RAWS observations and RTMA and NWS fire weather forecasts. These differences need to be analyzed and understood in detail before the RTMA-based fire danger and fire behavior forecasts can be interpreted and used in the most effective manner possible.

The purpose of this project is to improve the ability of fire weather forecasters and fire managers to interpret fire weather forecasts and compare them against the RAWS-based decision support tools. Specifically, the project evaluates the ability of the RTMA to capture the temporal and spatial variability of fire weather quantities (surface wind speed and direction, surface humidity, and surface temperature) in the RAWS observations and to determine if systematic differences exist between the RTMA and RAWS station observations at the RAWS station locations.

III. Study Description

1. Study Site

The area selected for this study is the northeastern United States, bounded on the west by the western boundaries of North Dakota, South Dakota, Nebraska, and Kansas, and on the south by the southern boundaries of Kansas, Missouri, Kentucky, and Virginia (Fig. 1). The outline of the selected region thus corresponds to the boundaries of the U.S. Forest Service Northern Research Station jurisdiction, with the addition of the Dakotas, Nebraska, Kansas, Kentucky, and Virginia. The study region consists of a total of 304 RAWS sites, although as will be discussed below, quality control procedures reduce the total number of stations available for analysis to 237.

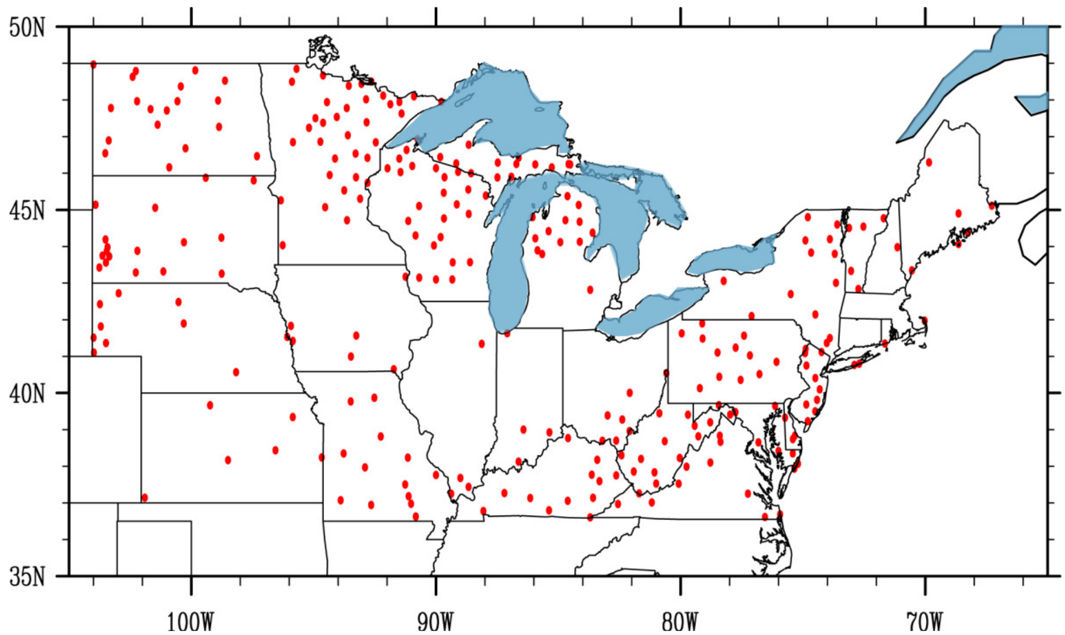


Fig. 1. The domain of the study and the RAWS stations used for comparison.

2. Data acquisition and quality control

The NDFD and RTMA field are archived on their native 5-km resolution grids on the NOAA National Operational Model and Archive Distribution System (NOMADS), accessible from http://nomads.ncdc.noaa.gov/. Data is available for downloading via File Transfer Protocol (FTP) prior to 6 October 2008, and via FTP or Hypertext Transfer Protocol (HTTP) up to the present date.

The Western Regional Climate Center (WRCC) maintains a complete RAWS archive for all stations in the United States. RAWS data for the 304 stations in the study region were obtained and archived locally. Although the WRCC performs quality control of archived RAWS data that flags questionable observations, and regularly scheduled maintenance, calibration, and quick response to sudden or unexpected system failures are performed regularly at RAWS sites (Zachariassen et al. 2003), additional quality control measures were performed prior to our analysis. A gross-range-check algorithm was utilized to eliminate obviously erroneous observations, as was done by Hart et al. (2004) in evaluating mesoscale-model-based Model Output Statistics (MOS) in the Salt Lake Valley of Utah. To limit the number of fire weather variables to a reasonable number, only air temperature, relative humidity, wind speed, and wind direction are examined. The algorithm constrains air temperature to be between -60 and 60 ^{o}C, relative humidity between 0.1 and 100%, wind speed between 0 and 200 m/s, and wind direction between 0^{o} and 360^{o}.

An example of data before and after additional quality control was applied is shown in Fig. 2 for station MSIN.

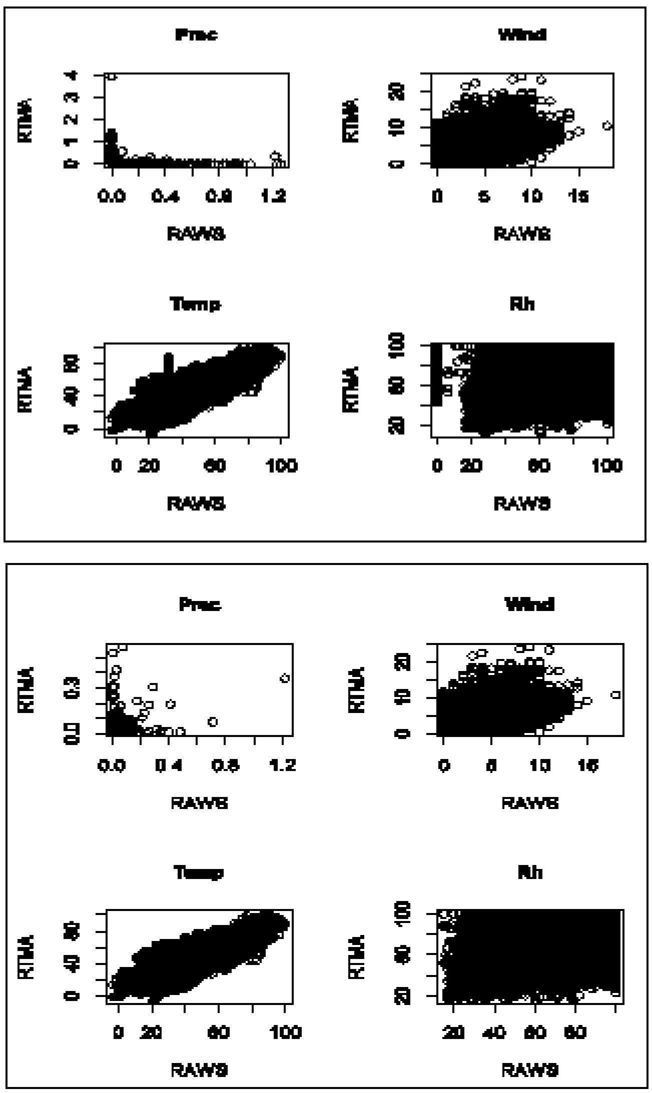


Fig. 2. Scatter plot of data from RAWS and RTMA before (upper panel) and after (bottom panel) additional quality control was applied.

3. Data Analysis

The RTMA data are archived on a 5-km grid while the RAWS stations are scattered across the study region. To compare the two datasets, the RTMA data are first interpolated to each RAWS location via bilinear interpolation, an interpolation method that is widely employed for interpolating gridded meteorological fields to station locations, and is computationally inexpensive compared to higher–order interpolations (e.g., cubic spline). The analyses used two-years of data from August 2008 through July 2010.

At each RAWS location, a number of statistical measures, described below, are computed using hourly data to quantify the differences between the two datasets.

Correlation
Pearson correlation coefficient, r, is calculated

$$r = \frac{\sum_{i=1}^{N} (\phi_i^{RTMA} - \overline{\phi}^{RTMA})(\phi_i^{RAWS} - \overline{\phi}^{RAWS})}{\sqrt{\sum_{i=1}^{N} (\phi_i^{RTMA} - \overline{\phi}^{RTMA})^2}\sqrt{\sum_{i=1}^{N} (\phi_i^{RAWS} - \overline{\phi}^{RAWS})^2}}$$

where N is the number of data points, ϕ^{RTMA} and ϕ^{RAWS} represent meteorological variables (precipitation, temperature, relative humidity, wind speed) for RTMA and RAWS, respectively, and the over bar denotes the mean value. The correlation measures the strength of linear relationship between the two data sources.

<u>Bias</u>

Bias is calculated as $B_i = \phi_i^{RAWS} - \phi_i^{RTMA}$

The mean and standard deviation (SD) of bias is then computed as

$$\overline{B} = \frac{1}{N}\sum_{i=1}^{N} B_i \qquad SD = \sqrt{\frac{1}{N-1}(\sum_{i=1}^{N} B_i - \overline{B})}$$

The mean bias measures the average difference between data points in the two data sources and is useful for identifying systematic differences that can usually be corrected by bias correction algorithms. Standard deviation indicates dispersion from the average and is a measure of random contributions to the difference.

<u>Differences</u>

The absolute differences are measured by taking the absolute value of bias,

$$D_i = |B_i|$$

Similarly, the mean and standard deviation of the absolute differences are computed by

$$\overline{D} = \frac{1}{N}\sum_{i=1}^{N} D_i \qquad SD = \sqrt{\frac{1}{N-1}(\sum_{i=1}^{N} D_i - \overline{D})}$$

<u>Welch's t-test</u>

Assuming that the data from RAWS and RTMA both follow normal distribution with different variances, the Welch's t-test is used to determine whether the means of the normal distribution are the same. The Welch's t-test is a generation of Student's t-test, used for data sets with different population variance which is a reasonable assumption of the two datasets.

To determine whether there is any significant differences in the distribution of the data from the two data sources, *Quantile-Quantile Plot* (*Q-Q Plot*), *Density Plot*, and *Kolmogorov –Smirnov Test* are employed.

Q-Q Plot is a method to compare distributions of two datasets using the empirical cumulative distribution functions (*e.c.f.*) defined as

$$F_N(x) = \frac{1}{N}\sum_{i=1}^{N} I(x_i \le x)$$

where *I(.)* is the indicator function. The *e.c.f.* is very close to the theoretical cumulative distribution function (*CDF*) when N is large which is the case here. For two independent variables *x* and *y*, if they have the same distribution or have a linear relationship, a plot of *x*-quantiles versus *y*-quantiles would be a straight line with a slope of 1.

Density Plot is also used to compare distribution. To estimate the density of the variables from each of the two datasets, the *Kernel Density Estimation*, a method that uses locally weighted averaging distribution, is applied.

$$\hat{f}_h(x) = \frac{1}{N}\sum_{i=1}^{N} K_h(x - x_i) = \frac{1}{Nh}\sum_{i=1}^{N} K(\frac{x - x_i}{h})$$

Assuming Gaussian density for the kernel *K*,

$$\hat{f}_h(x) = \frac{1}{2\pi Nh}\sum_{i=1}^{N} \exp[-\frac{(x - x_i)^2}{2h}]$$

Here, *h* is the bandwidth which is chosen following Silverman's 'rule of thumb'

$$h = \frac{0.94A}{N^{1/5}}$$

where

$A = \min\{\sigma, IQR\}$ with σ being the standard deviation of the data and *IQR* the 25% and 75% interquartile range.

The *Kolmogorov-Smirnov Test* is used to test whether the densities for a variable from the two datasets are the same.

To help identify factors that may influence the differences between the two datasets, the data are further stratified by time including hours of the day, daytime and nighttime, month of the year, and seasons. In this study, daytime and nighttime are subjectively defined as 0800-1900 LST and 2000-0700 LST, respectively and the four seasons are defined as spring (Mar., April., May), summer (June, July, August), autumn (Sept. Oct. Nov.) and winter (Dec. Jan. Feb.). The data are also grouped by geographical factors including latitude and elevation. Once stratified, the statistical measures are then computed for each group and results are compared.

IV. Key Findings

When this project was proposed, the manner in which RAWS observations are assimilated into the RTMA was not documented. It was thought, at the time, that the RAWS represented an independent data source with which to compare the RTMA. However, it has since become clear that RAWS stations have been incorporated into the RTMA for at least one year of the two years employed in this study (John Horel, personal communication). The realization that RAWS observations are incorporated into the RTMA substantially complicates this analysis, particularly because the weighting of each station within the RTMA assimilation routines is unknown, nor is it straightforward to establish precisely when each station was and was not employed in the development of the RTMA. In the following, we summarize the results and major findings from the statistical analyses

a. Overall differences

Fig. 3 shows histograms for the mean bias at the 237 RAWS sites. The results show that the mean bias are consistent at a majority of the sites for all variables examined except temperature. The mean biases are overwhelmingly negative for wind speed and positive for precipitation and relative humidity, which implies that RAWS data are, on average, higher in precipitation and relative humidity and lower in wind speed when compared with RTMA data. For temperature, the mean bias values are almost equally distributed around zero. The mean biases fall most frequently between -1 to -3 mph for wind speed, 2-4% for relative humidity, and ±2°F for temperature.

The large standard deviation values of the mean biases (Fig. 4) indicate that the random factors make a large contribution to the total differences between the variables in the two datasets.

Q-Q plots and density plots revealed no significant difference in the distribution of the variables in the two datasets at majority of the stations.

b. Temporal variability

Various analyses are performed to identify patterns in the differences between the two datasets and factors that may influence the differences.

To determine whether there are any systematic differences between day and night, the data are first separated by daytime and nighttime. Here daytime and nighttime are subjectively defined as 0800-1900 Local Standard Time (LST) and 2000-0700 LST, respectively. Comparison statistics are then calculated for both groups.

Fig. 5 shows box plots for the mean biases for daytime and nighttime. There are clearly some differences between the two regimes especially for temperature and wind speed. For wind speed, the mean biases are negative for both day and night, meaning RAWS winds are, on average, weaker than RTMA winds, and the differences are slightly larger at night than in the day. For temperature, the mean biases are slightly positive during the day and slightly negative at night, implying that the RAWS temperatures are, on average, warmer than RTMA temperature in the day and cooler at night. This diurnal variation of the temperature difference is consistent with what is usually found when comparing gridded analysis with station data with the gridded data usually underestimating diurnal cycle. There are very little differences between day and night for precipitation and relative humidity.

Seasonal dependence of the differences between the RTMA and RAWS variables are examined by grouping the data into spring (March, April., May), summer (June, July, August), autumn (September, October, November) and winter (December, January, February) seasons. As shown in Fig. 6, there are some seasonal variations, but the overall seasonal dependence does not appear to be strong enough to alter the sign of the difference for precipitation, wind, and humidity.

c. Spatial patterns

The possible dependence on geographical locations, such as latitude and elevation, is also examined. Fig. 7 shows the mean difference at each RAWS stations as a function of latitude and longitude for all stations. Similar scatter plots are also made for the standard deviation of the mean difference. The results reveal no evidence of any latitudinal or longitudinal dependence.

To help identify spatial patterns, Fig. 8 plots out the mean and standard deviation of the difference color coded to highlight the stations fall in the top or bottom 25% of the values among all the stations. A careful analysis reveals no evidence of non-random spatial patterns.

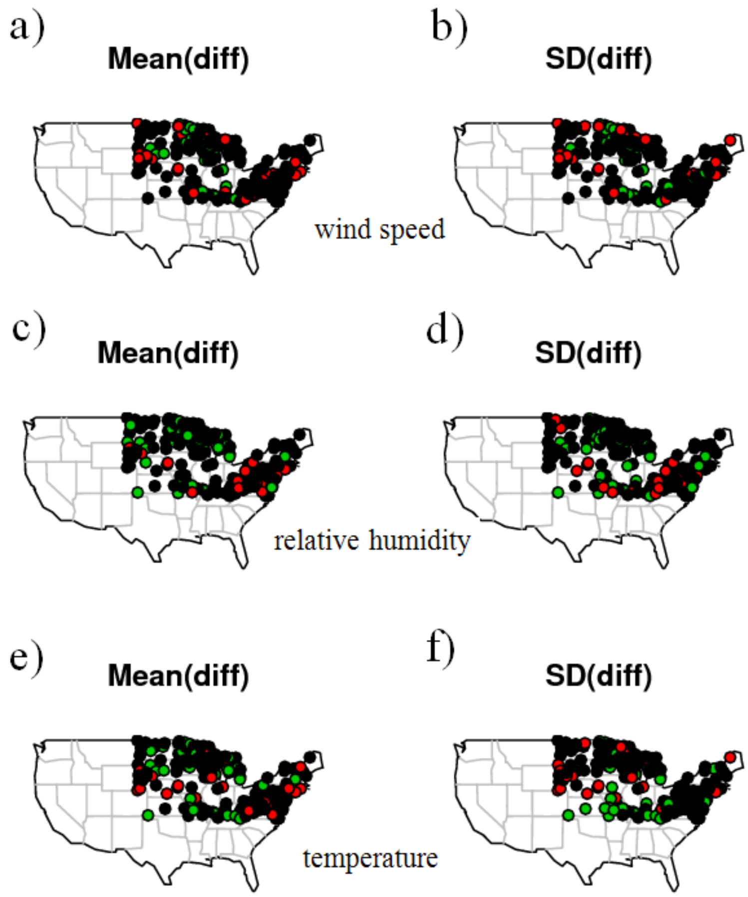


Figure 2. Spatial variability of the distribution of the mean and standard deviation of differences between RTMA and RAWS (RTMA-RAWS) for wind speed (a, b), relative humidity (b, c), and temperature (e, f). Red dots shot the stations with means and standard deviations in the top 25% of the distribution, black dots show stations in the middle 50 % of the distribution, and green dots show stations in the bottom 25% of the distribution.

Stations that exhibited mean differences in the top (bottom) 25% of the distribution for a given variable were more likely to appear in the top (bottom) 25% of the distribution of standard deviation differences as well. However, there was no clear tendency for stations in the top (bottom) 25% for one variable to appear in the top (bottom) 25% for other stations.

The relationship between station elevation and the differences between RAWS data and the RTMA is examined by preparing scatter plots of the means and standard deviations (Fig.9). These scatter plots demonstrate that the correlation between mean or standard deviation of the differences and the station elevation is very weak for all variables. The correlation is slightly negative for relative humidity (Figs. 3c, d) and weakly positive for wind speed and temperature. All of the correlations are too weak to support the hypothesis that a relationship exists between station elevation and differences between RAWS data and the RTMA.

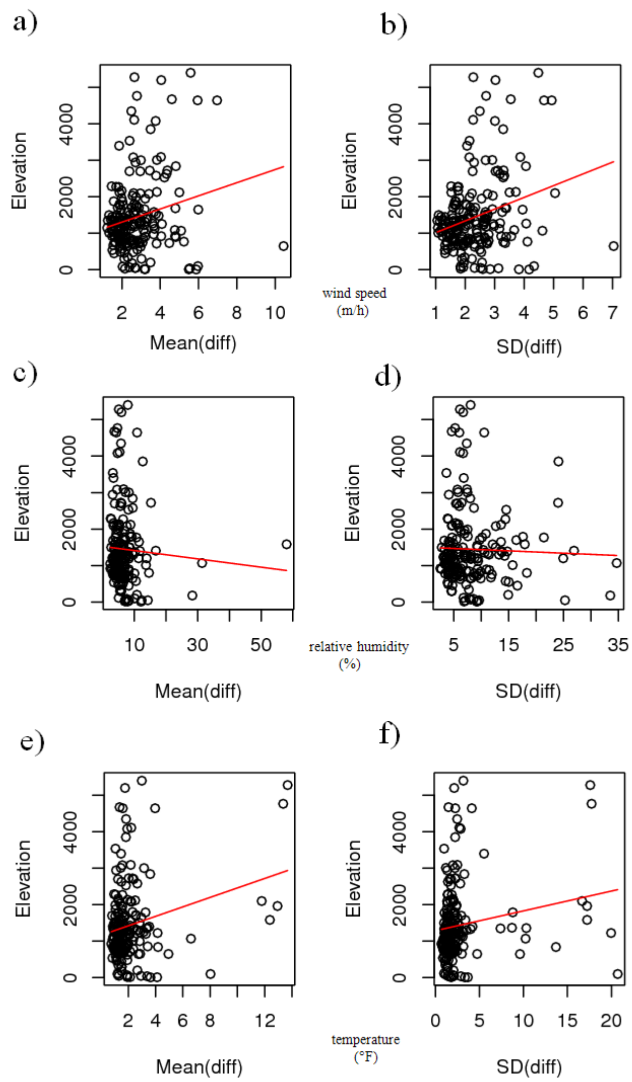


Figure 3. Scatter plot of differences between RTMA and RAWS (RTMA-RAWS) with station elevation (in feet) for wind speed (a, b), relative humidity (b, c), and temperature (e, f). The red lines show the linear fit for the points on the scatter plot.

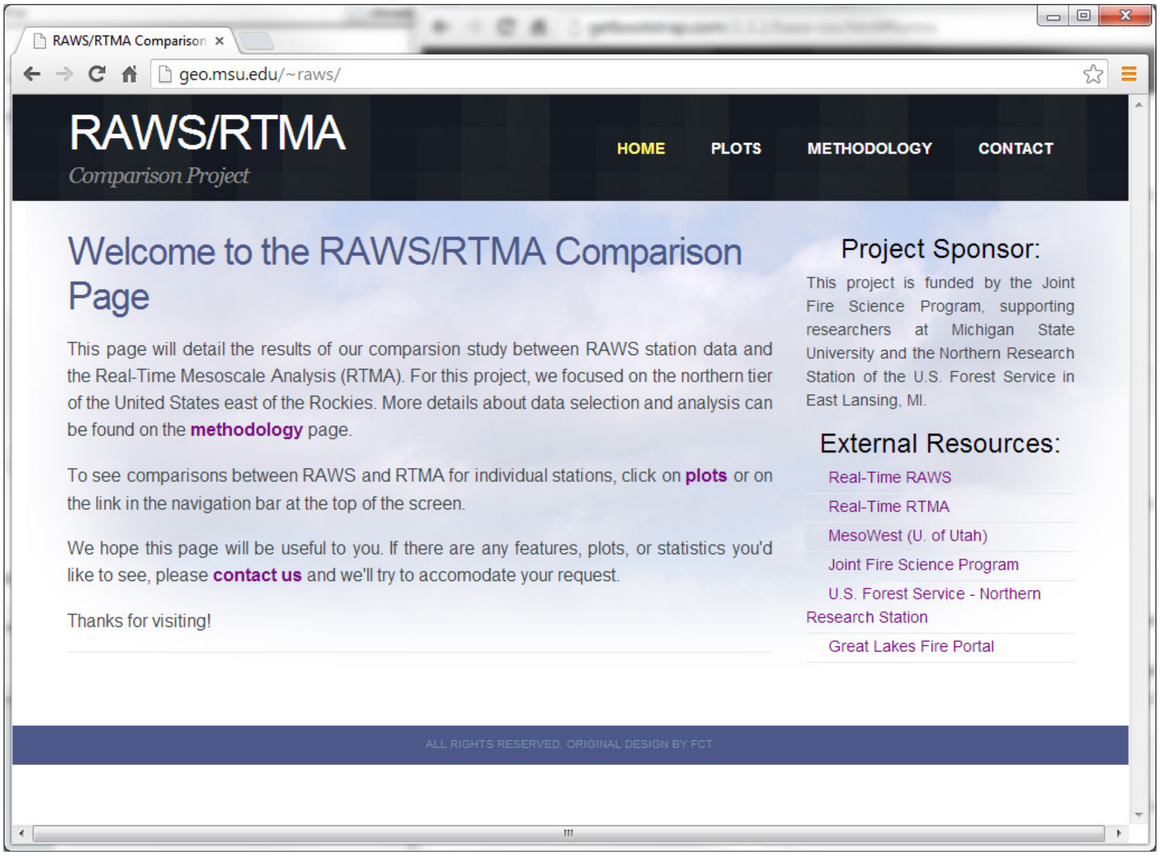
d. Conclusion

The above analyses lead to the conclusion that the primary drivers for differences between RAWS and RTMA data appear to be the details of how the stations are sited. No other analysis revealed a statistically significant or apparent relationship between the datasets for any variable. The analysis was limited by having only two years of data and was further complicated by the late realization that the two datasets are not independent.

V. Deliverables

Deliverable	Delivered	Status
Web site	http://eamcweb4.usfs.msu.edu/mm5-case/RAWSRTMA/index.html	Update as needed
Conferences/ Symposiums/ Workshops	Project description and results presented at: • 9th Symposium on Fire and Forest Meteorology • 4th Fire Behavior and Fuels Conference	Completed
Non-refereed Publications	It was decided that the information on the web page adequately described the application of these statistical analyses.	Completed
Refereed Publications	The realization that the RTMA and RAWS datasets were not independent undermined our ability to develop hypotheses and test conclusions from the analyzed data. As a result, no scientific results that are suitable for peer-reviewed publication were produced by this research.	Not attempted

A web site is developed for dissimilating the results from this study. The web page is designed to allow the users to easily look at some of the key statistics from the RAWS/RTMA data comparison at all stations. The users may simply select a station of their interest from either a dropdown menu or from a map. A pull-down menu will then appear with general information about the station. The user can then select the meteorological variable and the plot type, and the results will appear in a new window. To facilitate viewing and interpreting the results, the stations can be overlaid on different types of background maps including satellite imagery, geopolitical, topography. The users can also zoom in on a site to have a better look at the surroundings of the site. The users may choose to view the results in either graphical or table format. The graphical format includes simple plots such as scatter plots, box plots, and time series plots.


RAWS/RTMA Comparison
geo.msu.edu/~raws/
RAWS/RTMA
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Welcome to the RAWS/RTMA Comparison Page
This page will detail the results of our comparsion study between RAWS station data and the Real-Time Mesoscale Analysis (RTMA). For this project, we focused on the northern tier of the United States east of the Rockies. More details about data selection and analysis can be found on the methodology page.
To see comparisons between RAWS and RTMA for individual stations, click on plots or on the link in the navigation bar at the top of the screen.
We hope this page will be useful to you. If there are any features, plots, or statistics you'd like to see, please contact us and we'll try to accomodate your request.
Thanks for visiting!
Project Sponsor:
This project is funded by the Joint Fire Science Program, supporting researchers at Michigan State University and the Northern Research Station of the U.S. Forest Service in East Lansing, MI.
External Resources:
Real-Time RAWS
Real-Time RTMA
MesoWest (U. of Utah)
Joint Fire Science Program
U.S. Forest Service - Northern Research Station
Great Lakes Fire Portal
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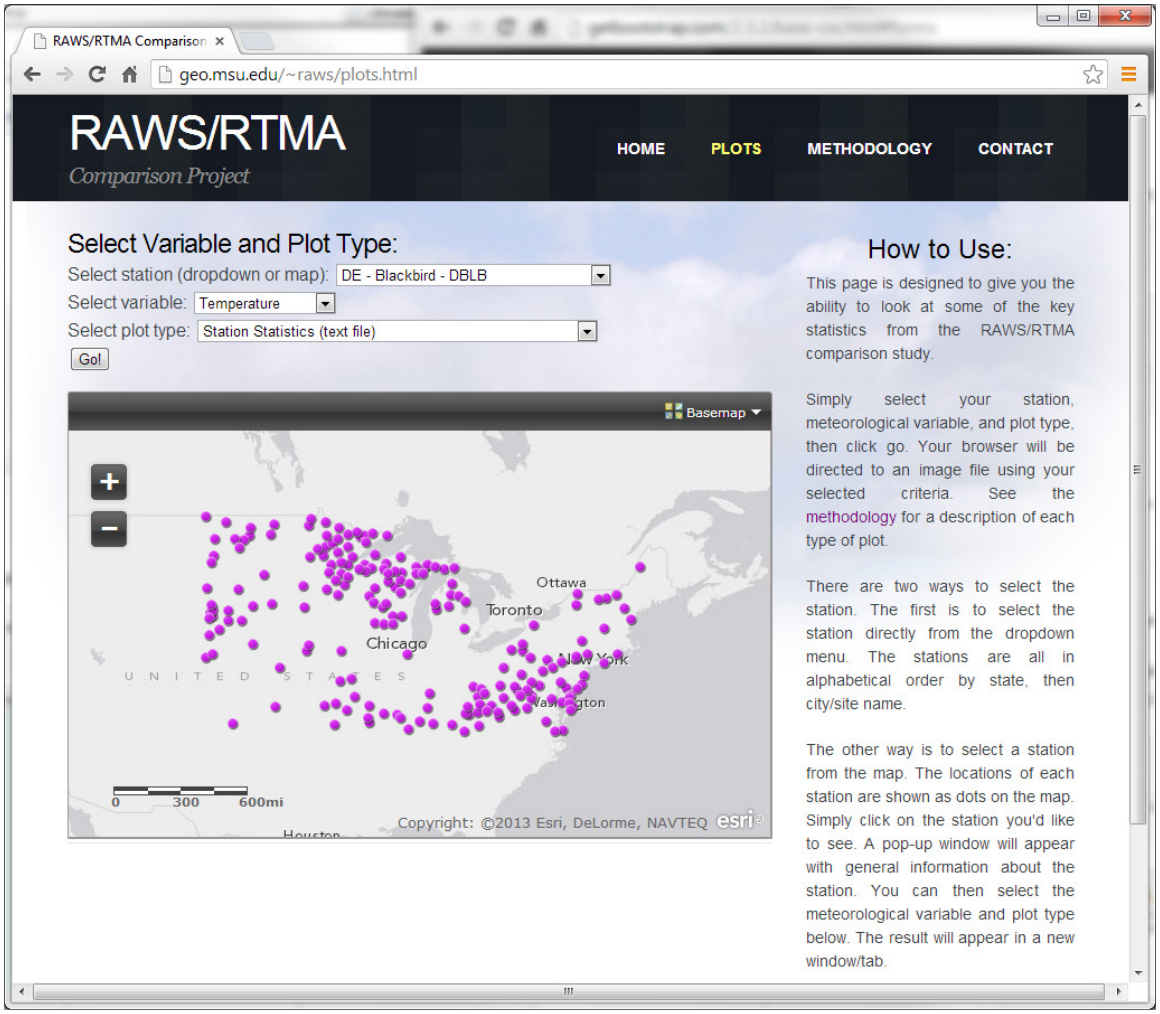
RAWS/RTMA Comparison
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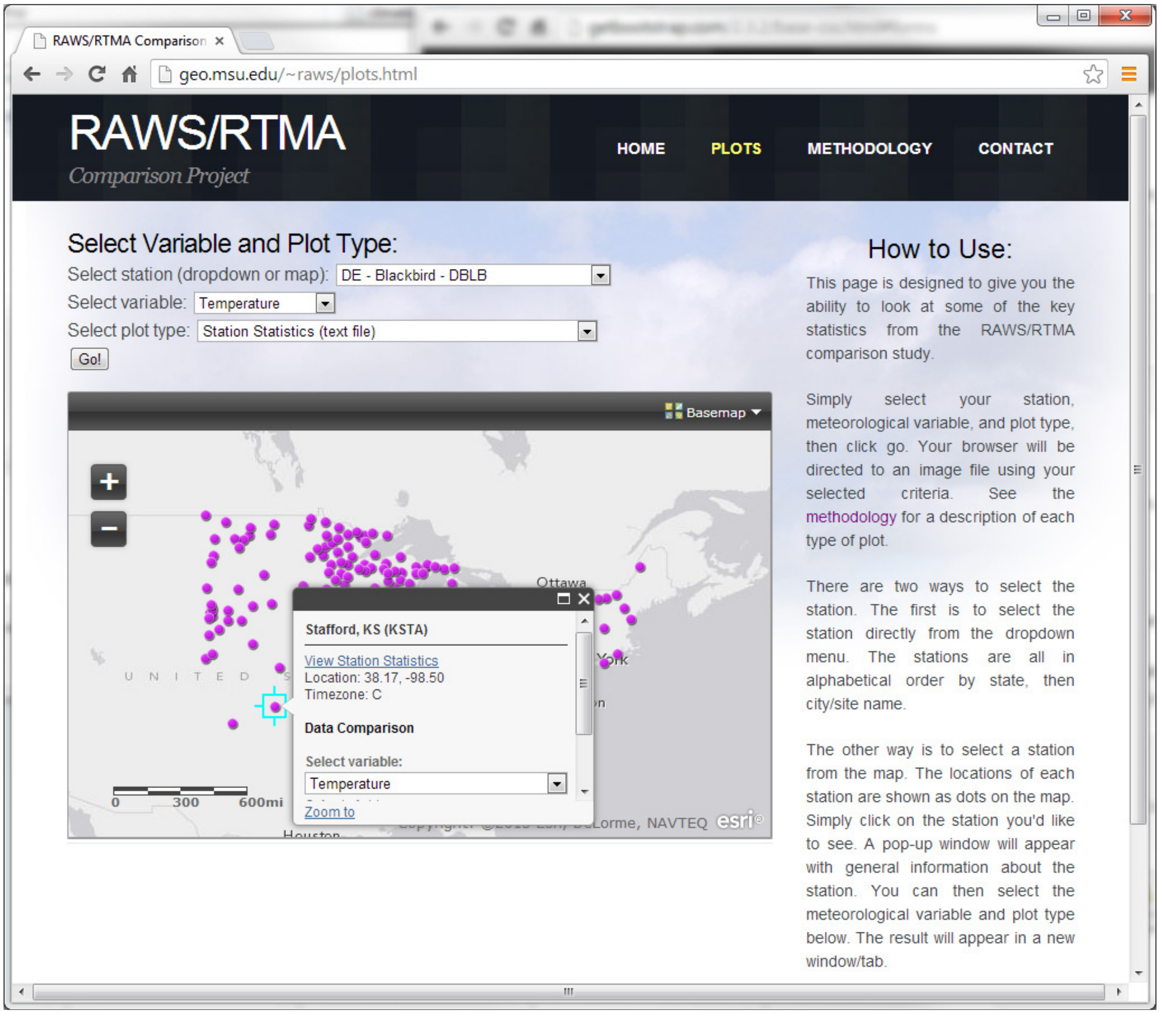
How to Use:
This page is designed to give you the ability to look at some of the key statistics from the RAWS/RTMA comparison study.
Simply select your station, meteorological variable, and plot type, then click go. Your browser will be directed to an image file using your selected criteria. See the methodology for a description of each type of plot.
There are two ways to select the station. The first is to select the station directly from the dropdown menu. The stations are all in alphabetical order by state, then city/site name.
The other way is to select a station from the map. The locations of each station are shown as dots on the map. Simply click on the station you'd like to see. A pop-up window will appear with general information about the station. You can then select the meteorological variable and plot type below. The result will appear in a new window/tab.



VI. Management Implications

As stated earlier, fire weather forecasts and the observations used to determine fire danger derive from two different sources of meteorological information: RAWS and RTMA (NDFD). It is therefore necessary for fire weather forecasters and fire managers to understand whether RAWS observations differ systematically from the RTMA, and by association the NDFD, in order to make the best possible forecasts and fire management decisions with the available fire weather information. This study provides information on the differences between the two data sources at 273 RAWS locations in northeast United States. This information can be used by fire managers in the region to improve the interpretation of NWS fire weather forecasts and clarify their role in fire management decision making.

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