218 THE DEVELOPMENT AND UTILITY OF A DATABASE OF MESONET WIND OBSERVATIONS FOR USE IN THE REAL-TIME MESOSCALE ANALYSIS (RTMA) SYSTEM

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1. INTRODUCTION

The real-time mesoscale analysis (RTMA) system at the National Centers for Environmental Prediction (NCEP), which is part of the Analysis of Record (AOR) project, is designed to provide a realistic, high-resolution (2.5 km) picture of current surface weather (de Pondeca et al. 2007). Its intent is to serve as verification for the gridded National Digital Forecast Database (NDFD) but can also be utilized for situational awareness or the starting point for a nowcast. The analysis is generated using a background field derived from the RUC 1-hour forecast (Benjamin et al. 2007a) as well as current surface observations from a variety of sources, including integrated surface mesonet data. The use of mesonet data presents a unique quality control (QC) challenge for the RTMA. Many mesonet stations are sited in less than ideal environments with obstructions to the near surface wind flow or non-standard anemometer placement (i.e., at heights other than 10 m, Wright 1994). The obstructions and resulting increased surface friction often lead to a low bias in wind speeds recorded from mesonet sites when compared to first or second order weather stations. Surface winds tend to be affected by these siting issues more than temperature or moisture observations (e.g., Benjamin et al. 2007b).

While numerous QC procedures have been examined for use in the RTMA, none have completely dealt with the presence of contaminated data. To avoid the introduction of a low bias, all present mesonet data, except those coming from a predefined list of known well-sited stations, are excluded from the RTMA's analysis. Here, we present a new QC system based on Bayesian statistics and a mySQL database. The database is structured to improve QC for mesonet wind observations in two ways: to increase the number of known well-sited stations for use in the RTMA at all times, and to create a directionally-dependent accept list. The directionally dependent list is designed to identify stations that have obstructions in a particular direction (e.g., a station placed on the side of a building). The RTMA might be able to assimilate wind data from such a station when the wind is blowing from a direction in which the flow around the station was not obstructed and thus unrepresentative.

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Here, sources of interference for a particular station are then identified where possible through the use of aerial (Google Earth) photography.

The system is presented and regionally tested over Florida and southern Georgia. When tested over a one year period (1 August 2008 – 31 July 2009), the number of observations available for use in the RTMA increased by about 18%. The system will be further tested on a nationwide basis and may be expanded for use with other models (i.e., first-guess fields) or with variables other than wind. The database system is designed to be flexible, so that other variables, models or background fields may be used. The thresholds presented here for decision making (i.e., accept vs. reject) purposes are somewhat arbitrary and can easily be tuned.

2. CURRENT RTMA QUALITY CONTROL

The persistent low bias detected in mesonet wind data have presented a continuous QC problem for the RTMA. Many traditional methods of quality control have proved ineffective with dealing with the bias. A buddy-check system such as that used by MADIS (Miller et al. 2005) resulted in many mesonet stations being accepted and known high-quality sites such as METAR sites being rejected because the low bias is so widespread (Benjamin et al. 2007b). MADIS quality control flags have also been applied and were generally found to be unreliable.

Currently, QC for wind observations is accomplished through a series of accept and reject lists (Manikin and Pondeca 2009, Pondeca and Manikin 2009). Originally, all mesonet wind data are rejected from the analysis. Data from a station or network on one of the accept lists are then rescued and assimilated. Stations on a reject list are rejected outright from the analysis. However, most mesonet stations are on neither of these lists due to lack of testing and are thus excluded from the analysis en masse. The accept lists have multiple data sources that include networks with known high siting standards (e.g., METAR, Oklahoma mesonet, South Florida Water Management District). These data are on a provider use list and are rescued. A list of usable stations based on long-term statistics has also been provided by the Environmental Systems Research Lab (ESRL). However, only a limited number of stations are included as not all stations were studied. Local NWS forecast offices also contribute to the station accept and reject lists using their local knowledge and experience. However the vast majority (about 60%) of mesonet stations are not included on any of these lists, and are automatically excluded from the analysis. These stations serve as the focus of this study.

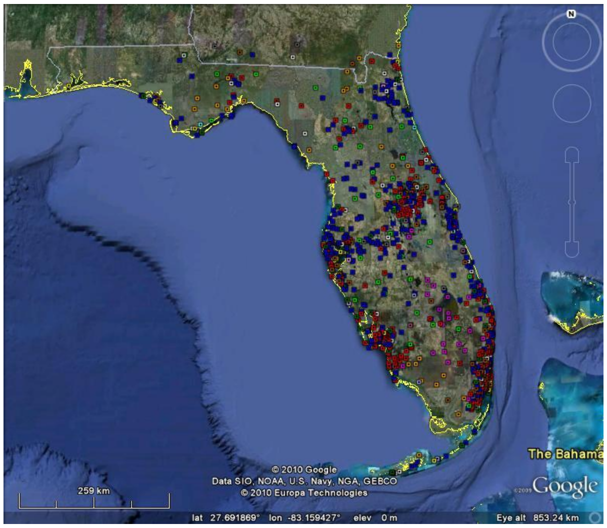

Fig. 1: Florida mesonet stations. Different colors represent different providers/networks.

3. DATASET

The dataset used for this study consists of land-based surface wind observations from all stations in Florida and southern Georgia over a one year period (1 August 2008 – 31 July 2009). For the sake of consistency, stations with multiple observations per hour had only the observation closest to the top of the hour used in this study, the others were discarded. The dataset consists of data from 1,248 stations (Fig. 1) from 17 different networks, with a total of approximately 4 million observations. The corresponding RTMA winds (i.e., the background field obtained from the downscaled RUC, Benjamin et al. 2007a) are also included.

There are important differences between the various networks. Some are simply groups of first and second order weather stations. Some of the mesonet networks are centrally controlled (i.e. have consistent standards for siting, equipment, maintenance and observation frequency that are set and maintained by network administrators), while others are more open source in nature. The latter often consist of weather stations set up by schools and individuals for educational or recreational purposes. While siting standards are provided for these networks, they are not enforced; it is up to the end user to decide the station placement etc. These stations are often considered to be poorly sited due to the presence of obstructions, a constant challenge when dealing with mesonet stations.

The study area was split up into six mesoscale regions, shown in Fig. 2. The regions ensure that weather conditions in one portion of Florida do not affect quality control of stations in other parts of the state. The regions were defined arbitrarily based on constant lines of latitude and longitude; it was desirable to isolate the Florida Keys from the mainland and the panhandle from the peninsula. Stations in a particular region were only compared to other stations in the same region. These regions will be further discussed when describing the quality control tests.

4. DATABASE SETUP

The database consisted of seven tables, and is diagrammed in Fig. 3. These include tables containing observations and background values, station, network, directional bin and quality control flag information. The other two tables contain statistics that are derived from the information in these tables. These statistics are calculated assuming that the RTMA's background field is the 'truth'. The statistics include root mean squared error (both normalized and absolute) for wind speed and direction, mean wind speed and standard deviation, direction standard deviation, wind speed bias, and Pearson correlation coefficient for the wind speed. One of the tables contains daily (00 UTC-00 UTC) statistics (for the available observations) while the other contains statistics based on all observations (i.e., all days and hours) for a given station sorted, based on the observed wind direction, into 45 degree directional bins.

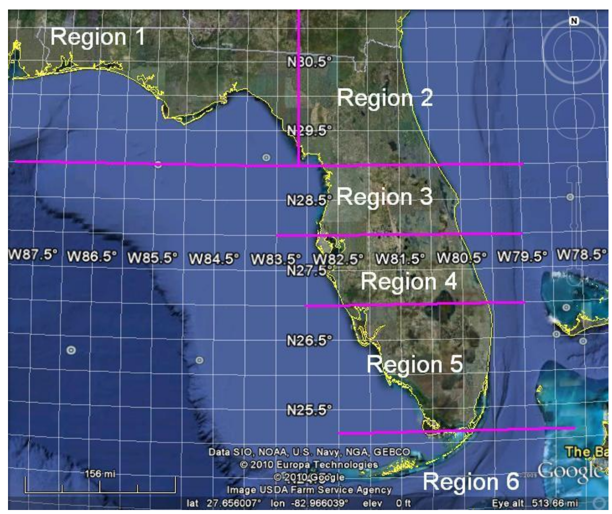

Fig. 2: The six mesoscale regions used in this study.

The database provides a single point of use for all wind data. MySQL in particular is an open source database system that allows for easy organization, storage, and stratification of data. The use of a mySQL database system for QC purposes in the atmospheric sciences is relatively new, but not unprecedented. Benjamin et al (2007b) used such a system to identify acceptable mesonet stations and aircraft for use in the RUC. Some individual mesonet administrators use mySQL or a similar database management system for internal quality control purposes as well (Shafer and Hughes 1996, Shafer et al. 2000, Sonmez 2005).

5. UNIVERSAL ACCEPT LIST ALGORITHM

The universal accept list procedure compares the daily (00UTC-00UTC) innovations (observed - background) of mesonet sites with those of ASOS sites in the same region as defined in Fig. 2. Daily means are used in the formation of this list, individual observations are not considered. The test has two tiers; a diagram/decision tree of the test is presented in Fig. 4. In the first tier of the test (light blue section of Fig. 4), the RMSE for wind speed of every mesonet station is compared to the mean RMSE of all METAR sites in the same region for the same day. These RMSE's are taken from the daily statistics table. If a mesonet station has a daily RMSE lower than the mean RMSE of the regional ASOS sites for at least 50% of the days on which observations were available from that station, the station was considered to have 'passed' tier one of the test.

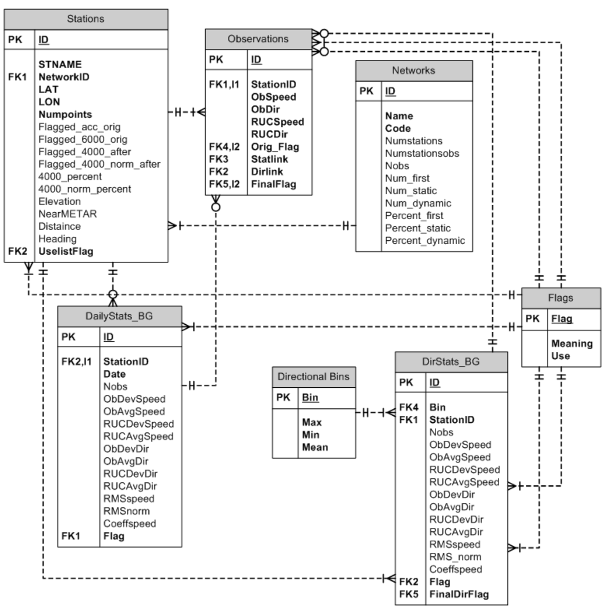

Fig. 3: Entity-relationship diagram showing important tables in the database and their relationships.

The second tier (yellow section, Fig. 4) utilizes a dual hypothesis test to fine-tune the permanent accept list. Two z-tests were conducted to ensure that the difference between the daily mean observed wind speed of the mesonet station in question and the daily mean observed wind speed of the nearest METAR site had an average difference of less than 1.0 ms^{-1}. The nearest METAR site was determined using GIS software (Google Earth). This was done to ensure spatial consistency, i.e., a mesonet station near a METAR site should have an observed wind speed very close to that of the METAR site if the mesonet station is properly sited. A threshold of 1.0 ms^{-1} was chosen arbitrarily. Only days that had a total of 24 observations (i.e. one each hour) for both the mesonet site in question as well as the nearby METAR site were used for the test sample; this was to ensure that observations from all points in the day were represented equally. From these, fifty days were randomly selected for each station. If fewer than fifty days were available, all available days were used instead. A paired difference/correlated data test was developed in accord with the procedures described in Wilks (1995).

Stations that passed both the RMSE test and Z test were included on a universal accept list (green diamond, Fig. 4). Stations that pass the first test only, are not included on the list (see Fig. 4). It was however deemed fruitful to put these rejected stations through a directionally dependent test (brown and dark blue sections, Figs. 4 and 5) described in the following section.

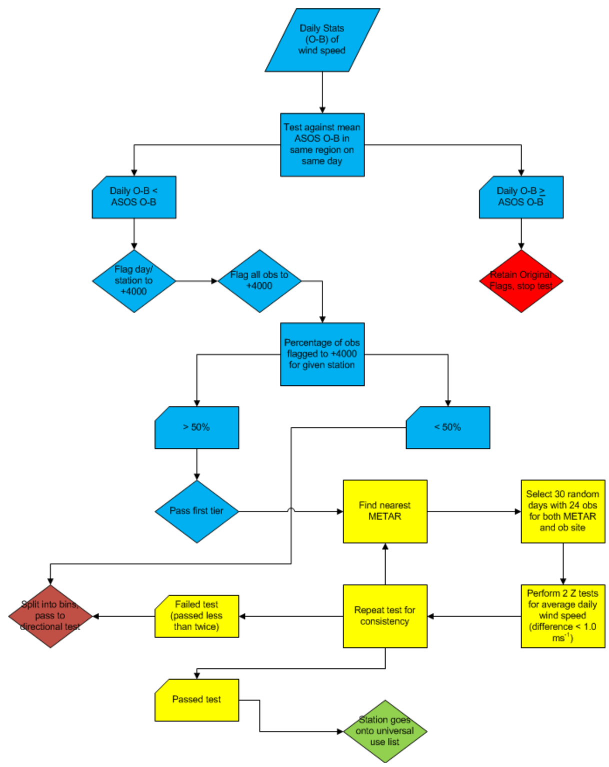

Fig. 4: Decision tree illustrating the universal accept list procedure.

6. DIRECTIONAL ACCEPT LIST ALGORITHM

The directionally dependent accept list test is three-tiered. Stations that were not placed on the universal accept list have their observations split into eight directional bins. Bulk (not daily) statistics were then computed and stored for each station, for each bin. These bin statistics serve as the basis for the directionally-dependent accept list test. A decision tree showing the procedure for the directionally dependent accept list is shown in Fig. 5.

The second and third tiers use a flagging procedure similar to the one used in the previous test. The wind speed RMSEs (both absolute and normalized) were computed for each bin and station. Mesonet sites were compared to ASOS sites in the same region. Those which had an RMSE lower than that of the nearby ASOS stations were flagged (as described in brown sections, Figs. 4 and 5). Two separate flags were maintained, one for normalized RMSE and one for absolute RMSE. Station-bin combinations which had a wind speed RMSE less than the mean wind speed RMSE of ASOS stations for the same bin in the same region were further examined on an individual basis for trends in wind speed as a function of direction in the third tier of the test.

Two z-tests (dark blue section, Fig. 5), applied in a manner similar to the second tier (section 4), were then used as the third tier of the QC test. Given the possibility that a large number of stations might be included as a result, these data were more thoroughly examined before creating a list. Each station-bin pair which was flagged in the second tier test (previous paragraph) was subjected to this more rigorous z-test test. Stations which passed the first tier of the universal list test but not the second were also included despite not being included in the first tier of this test; they were subsequently reorganized into the directional bins. One hundred observations were randomly selected so that the measured wind at the site in question was blowing from a direction within the directional bin in question. These observations were then matched with that of the nearest METAR station at the same time and date and bin. Although observations are sorted by wind direction, the statistical tests are applied only to wind speed. Here, we attempt to remove times for which the winds are light and variable prior to applying the z-test. To accomplish this task, a directional consistency test was performed to confirm that the observed wind direction at the METAR site was within 22.5^{o} of the direction of the observed wind at the site in question. If not, the observation was excluded from the test; this criterion generally resulted in the exclusion of between 30 and 40 of the 100 randomly selected observations, leaving between 60 and 70 (N=30 is widely considered acceptable for purposes of such a z-test).

Fig. 5: Decision tree illustrating the directionally dependent accept list procedure.

Once this stratification was complete, two z-tests were performed on the set of observations. As in section 5, the null hypothesis for the first test was that the average difference (mesonet – METAR) was less than 1.0 ms^{-1}, for the second test this value was changed to greater than or equal to -1.0 ms^{-1}. Stations that pass both z-tests were placed on a list to be used only when the observed wind direction falls within the bin for which the station passed the test. All observations which met these criteria were re-flagged to be included in any retrospective or future analyses; different flags were used to clearly identify why a certain observation was flagged as usable (green diamond, Fig 5).

For a reference to the z-test, the average wind speed difference (mesonet – METAR) was calculated for each bin. This is simply the mean of the difference in wind speed between the two stations at the same time and bin (mesonet – METAR). This includes all observations in the bin in which the difference in wind direction between the two concurrent observations was less than 22.5 degrees, not just the observations randomly selected for the z-tests. For a station that passed the directional z-test, this average difference would likely be between -1.0 and 1.0 ms^{-1}.

7. GENERAL RESULTS

When the resulting use lists were applied to the study dataset, the number of observations found acceptable for use in the RTMA increased by about 18%. The distribution was approximately evenly distributed between observations which were included due to the expanded universal use list and those included due to the directionally dependent accept lists (Fig. 6). 28 additional stations were placed on the universal use list and 148 station bin pairs were placed on the directionally dependent accept list. Most of the stations placed on either list came from one of two mesonets: Weatherflow and the Florida Automated Weather Network (FAWN, Lusher 2009). Stations from the 'open source' mesonets (APRSWXNET, Anything Weather Network, AWS convergence) were generally not added to either list. This generally indicates that the siting standards used in the FAWN and Weatherflow networks were likely consistent with that of the gold standard ASOS.

Most of the stations from the APRS and AWS convergence mesonets that did not pass this quality control test were found to be located in areas that are not flat or open. Nearby obstructions tend to lead to lower wind speeds in these areas. It is worth noting that given the 2.5 km resolution of the RTMA, some of these stations may be appropriate to use (i.e., representative), given these urban areas may exceed the size of the analysis grid box. Some sort of weighting algorithm would likely be necessary to limit the influence of these observations to only areas with similar land use characteristics.

8. STATION EXAMPLES

An example of a station passing the universal accept list test is shown in Fig. 7. This station (MAIF, FAWN network) is sited in an open area near Marianna, FL. It is about 1.5 km from METAR site KMAI. The station is in an open, agricultural environment. MAIF generally recorded wind speeds very near those of KMAI at the same time, and passed the universal accept list test. Because this station was part of the FAWN network, it was subject to strict siting, equipment and maintenance criteria. While this station generally recorded wind speeds similar to those of the nearby METAR site, there was a period (mid-late May 2009) where there appeared to be a significant differences in which the observed winds at both sites were relatively high (close to 6 ms^{-1}, compared to generally between 2 and 4 ms^{-1}, Fig. 8). Current quality control methods such as a real time gross error (background) check would be very helpful in this situation.

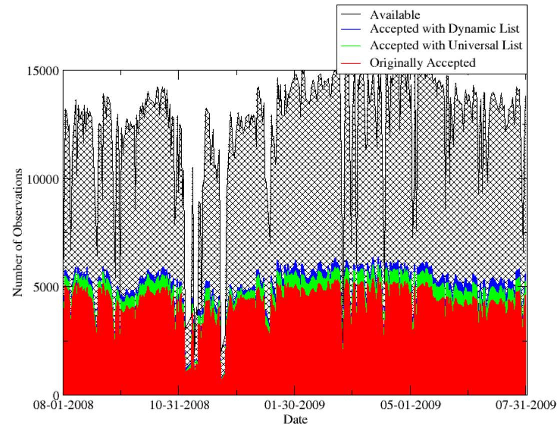

Fig. 6: Number of observations found acceptable by each QC method as a function of date.

Station XBON (Weatherflow network) was placed on the directionally dependent accept list for several adjacent bins. The station is about 17 km from KRSW (Southwest Florida International Airport, Fig. 9). An aerial photograph of the site shows a factory to the west and northwest of the site, along with a small pond. The area east of the site is populated with numerous trees. These trees would likely act as obstructions during periods of easterly flow. Results of the test generally showed that a small (<1.0 ms^{-1}) bias (mesonet – METAR) exists during periods of northwesterly winds, while a much larger bias is evident during periods of southeasterly flow (Fig. 10). Bins which passed the test generally contained few trees while those failing the test were often filled with trees. The factory facility just west of the site appeared to have a negligible effect on observed wind speeds.

Fig. 7: Location of FAWN station MAIF (green) and METAR site KMAI (white)

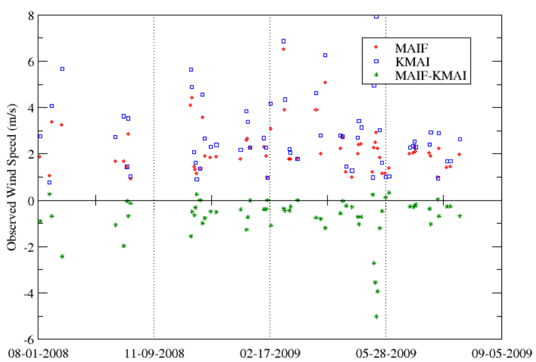

Fig. 8: Average daily wind speeds by date at MAIF (red), KMAI (blue) and the difference between the two (MAIF – KMAI, green).

Fig. 9: Location of Weatherflow mesonet site XBON (green marker/blue circle, center of photograph).

Fig. 10: Image of XBON site with results of test for all eight directional bins. Top line indicates whether average difference in wind speed between METAR and mesonet site is less than 1.0 ms^{-1} (pass if true, fail if false), bottom line indicates whether station-bin combination passed z-test described in section 7.

9. CONCLUSIONS AND FUTURE WORK

The study has allowed for a substantial increase in the number of wind observation sites in Florida found suitable for use in the RTMA, or any other high-resolution analysis or forecast product. The methods used in this study will be expanded and used on a national basis to develop a list of usable and unusable mesonet wind observation sites across the continental United States for use in the RTMA, NAM and GFS models and their respective assimilation systems. As the resolution of these models increase, more data will be needed to account for mesoscale differences in weather conditions that can be verified with mesonet observations.

This study also gives a preliminary procedure as to how to find or infer metadata for mesonet sites where such data is limited or nonexistent. The statistics used in this study along with aerial photography or site visits could be used to identify sources of contamination with mesonet data. This information could then be dealt with in an assimilation system by weighing it, rejecting data from a contaminated station, etc. The database system itself could also be used to identify and quantify mesoscale or even microscale meteorological trends that products such as the RTMA were designed to identify and resolve. Work is underway at NCEP to transition to a mySQL-based archive of surface and upper air data for this purpose. The system will also be used as part of the National Mesonet project (Barth et al. 2010) providing valuable metadata for use in data assimilation.

10. REFERENCES

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