THE DESIGN OF A QUALITY CONTROL ALGORITHM FOR ENVIRONMENTAL SENSOR STATIONS

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1. INTRODUCTION

The use of environmental sensor stations (ESS) to monitor atmospheric and road conditions has flourished in the United States over the past thirty years. At present over 2,500 ESS installations exist nationwide. These ESS provide important information to the surface transportation and surface transportation weather service provider communities in support of roadway maintenance and traveler information. In recent years the quality of the data from ESS has been called into question, particularly those data associated with monitoring pavement conditions. Unfortunately, while effective techniques exist for performing quality control of the atmospheric sensors of the ESS, no effective operational technique exists for quality control of pavement sensor data.

The presentation describes research underway at the UND Surface Transportation Weather Research Center (STWRC) to advance solutions for effective operational quality control techniques of ESS pavement sensor data. The paper provides a compilation of known quality control techniques and extrapolates theoretical best fit techniques for pavement sensors. These methods include but are not limited to techniques involving Bayesian methods, a complex quality control method developed by Gandin, and statistical methods of quality control. The preliminary results of the comparison of these techniques for data collect at a dedicated road weather field research facility are presented. This research facility was established in 2004 by the UND STWRC to support university road weather research. The site includes numerous meteorological instruments as well as sensors for monitoring road and roadway environment conditions. The instrumentation includes temperature, relative humidity and wind probes at 2-, 5-, 10-, and 15-meters, multiple precision precipitation measurement systems, an array of ultra-sonic snow depth sensors, and various pavement and sub-pavement sensors. The pavement sensors perform measurements of temperature, freeze point determination, and condition (dry, wet, etc) of the road surface.

2. DESCRIPTION OF ALGORITHMS

The quality control methods used in this research are operationalized in the form of algorithms that have been coded locally.

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2.1 *National Weather Service (NWS) Meteorological Assimilation Data Ingest System*

The NWS's Meteorological Assimilation Data Ingest System (MADIS) method uses three levels of quality control to test incoming data, with level one being the least sophisticated and level 3 the most sophisticated. The first level is a gross error check to see if the data fall within a Techniques Specification Package (AWIPS TSP 1994) specified set of tolerance limits. There are two types of level 2 checks that evaluate the consistency of the data. The first is a temporal consistency check that compares the data to that of the previous hour. The second is an internal consistency check that enforces reasonable, meteorological relationships among observations measured at a single station. The third level is a spatial check using optimal interpolation. Each observation is checked against observations at nearby stations; if the difference is large, either the observation at this station or at one of the stations nearby is wrong. To determine which is incorrect, the interpolation is redone eliminating one station at a time until the suspect station is found. When the faulty data point is isolated, it receives a flag (GSD ESRL 2005). After all the levels of quality control checks are run, the results are summarized for each station using the symbols found in figure 1.

Preliminary	Z	No quality control performed
Coarse Pass	C	Passed Level 1
Screened	S	Passed Levels 1 & 2
Verified	V	Passed Levels 1, 2, & 3
Erroneous	X	Failed Level 1
Questionable	Q	Passed Level 1, but failed Levels 2 or 3

Figure 1. MADIS Quality Control Flags (reproduced from GSD ESRL 2005)

2.2 *Statistical Method*

Guttman and Quayle (Guttman and Quayle 1989) developed a quality control method for use by the National Climatic Data Center (NCDC). In this method a list of processes is performed sequentially to determine the existence of questionable data. The area encompassing the stations to be considered is divided into arbitrary divisions. Arrays of data are created for each division for which the observation time is the same. The monthly mean for each station is computed and then subtracted from each hourly data value. This results in an array of hourly departures from the monthly mean. The daily means of these departures are then computed. The daily means of departure are then subtracted from each daily departure. This gives a combined measure of each station's daily departure from the monthly and divisional averages. Each value whose corresponding absolute difference exceeds 10°F is preflagged to indicate the need for further scrutiny. This is called the delta test. New daily means and standard deviations are calculated for each day that there exists a station with preflagged data. The new means and standard deviations are calculated without including the flagged data. Each data value that exceeds 3 standard deviations from the daily mean is flagged as 'bad' data. This is called the sigma check (Guttman and Quayle 1989).

2.3 *Bayesian Method*

This method was first proposed by Lorenc and Hammon (Lorenc and Hammon 1988). They proposed that there are two types of errors associated with observations. The first is normal observation error, which they assumed followed a Gaussian distribution. The second is gross error in which case the observation gives no useful information. To begin, various tests are performed on each observation. Lorenc and Hammon used the tests performed in the synoptic data bank program (Atkins 1984). The results of each of these tests are stored as flags. Based on these flags, Lorenc and Hammon determined prior probabilities of gross error in the observations. Each observation was then compared with a background field to determine posterior probabilities. Then Bayes' theorem is applied to determine the probability of the observation being true.

2.4 *Complex Quality Control (CQC)*

This method was developed by Gandin and used at the Hydrometeorological Center in Moscow. This method is similar to the Bayesian method discussed above. However, instead of applying probabilities based on the individual tests, CQC considers the combination of the actual residuals found in each test. The CQC algorithm consists of two parts: the application of the individual tests (known as CQC components), and the decision-making algorithm (DMA). It is the DMA that considers the combination of the residuals to determine if the data should be rejected, corrected or stored. The components of CQC can vary depending on the data, but usually include a horizontal check, a vertical check and a hydrostatic check. The horizontal and vertical checks are a form of optimal interpolation to the station under check from surrounding stations. Thus the horizontal check would be the same as the level 3 check in the MADIS approach described in 2.1 above. "The hydrostatic check has been found to play a crucial role in the CQC of height and temperature at mandatory isobaric surfaces" (Gandin 1988). While the hydrostatic check may be useful in the quality control of atmospheric data, especially of that at various levels, it will be of little or no help in the quality control of pavement sensor data.

2.5 *Kalman Filtering*

"The Kalman filter provides the means for updating estimates of an unknown process by combining observations of that process with a model of the process" (McGinley 2001). In application to surface observations a vector of observations, X, is moved forward in time by a linear matrix operator, F, to calculate the Kalman estimate, $X^{\wedge}$. The associated error covariance, P, is advanced in time by applying the same F and adding cycle-averaged error covariance matrix W. The estimate of X, $X^{\wedge}$, is used as the new datum vector until the arrival of the new set of observations Y. When the new observations arrive, estimates of the error can be made and the error matrix W updated. The Kalman estimates, $X^{\wedge}$, can be used for application in quality control. After determining error thresholds, they can serve as rejection criteria for gross and standard error checks. The can also serve as a short range forecast tool for individual stations (McGinley 2001). In this respect they can be used as an estimate of truth to compare to observations from stations that have no "buddies" nearby. These estimates may also prove useful for estimating truth in temperatures from pavement sensors, where the use of "buddy" sensors may not be effective.

3. PAVEMENT SENSORS

Many significant differences between the quality control of atmospheric data and pavement sensor data exist. One such difference is that in quality control of atmospheric data there are physical relationships that can be used to ensure that the data "agrees" with itself, for example the hydrostatic or geostrophic relationships. Pavement temperature could be compared to temperatures taken at 2-m but the relationship between these two temperatures is complex and often requires the use of a model. If the model could be verified independently of the pavement sensors, then the model could be used to quality control the pavement sensors. The question then becomes how to verify the model. That question is out of the realm of this paper. Another difference is that the atmosphere behaves mostly as a fluid and as such most atmospheric variables are quasi-continuous. This means that an observation taken at one station should be close to an observation taken nearby. The closer the stations are together the closer the observations should be. This allows for the use of spatial, or "buddy" checks. The main variable this paper is concerned with from the pavement sensors is pavement temperature. Pavement does not behave as a fluid. There can be large jumps in temperature over a relatively small distance. A section of pavement that has shade over it can be many degrees cooler than a section that the sun is shining on even though they are right next to each other. This means that comparing the temperatures given by pavement sensors with other nearby pavement sensors may or may not be effective, depending on whether or not they are under the same type of conditions. The existence of these differences means that the quality control methods used for meteorological data may not work as effectively for pavement sensors and if so, a new method would be needed.

4. RESEARCH INVESTIGATIONS

The quality control algorithms described above are being applied to data from the UND STWRC field site and the North Dakota Department of Transportation (NDDOT) ESS network. The locations of ESS in North Dakota as well as the UND STWRC field site are shown in Figure 2. The ability of these algorithms to identify data errors is being compared statistically to determine the most effective method for both the atmospheric data and the pavement sensors. The presentation will provide preliminary results of this statistical analysis. Currently, the NDDOT ESS network has no quality control for pavement sensor data. This research will result in an operational quality control method to be applied to both the atmospheric and pavement temperature data from the NDDOT ESS network and UND STWRC.

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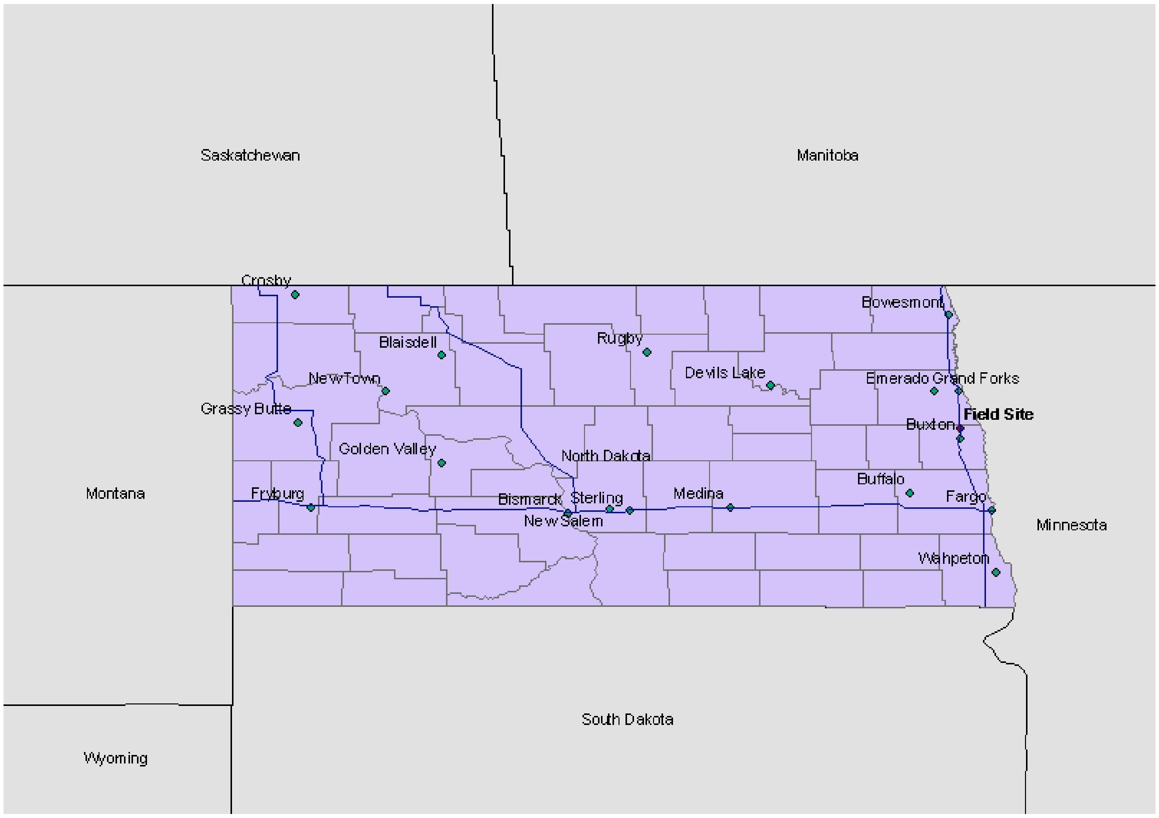

Figure 2. Locations of North Dakota Department of Transportation Environmental Sensor Stations, and University of North Dakota Surface Transportation Weather Research Center field research facility.