

Clarus Quality Checking Algorithm Documentation Report

www.its.dot.gov/index.htm

Final Report — December 21, 2010

FHWA-JPO-11-075



Notice

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof.

Report Documentation Page

Form Approved
OMB No. 0704-0188

The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. **PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.**

1. REPORT DATE (DD MM YYYY) 12 21 2010		2. REPORT TYPE Final		3. DATES COVERED February 2008 – December 2010	
4. TITLE AND SUBTITLE CLARUS QUALITY CHECKING ALGORITHM DOCUMENTATION REPORT				5a. CONTRACT NUMBER DTFH61-08-D-00012	
6. AUTHOR(S) Martha Limber, Sheldon Drobot and Tressa Fowler				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
				5d. PROJECT NUMBER	
				5e. TASK NUMBER 4	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) University Corporation for Atmospheric Research, 3090 Center Green Dr. Boulder, CO 80301				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) United States Department of Transportation Research and Innovative Technology Administration Federal Highway Administration, Office of Operations 1200 New Jersey Ave., SE Washington, DC 20590				10. SPONSORING/MONITOR'S ACRONYM(S) FHWA, HOTO	
				11. SPONSORING/MONITOR'S REPORT NUMBER(S)	
012a. DISTRIBUTION/AVAILABILITY STATEMENT This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.				12b. DISTRIBUTION CODE	
13. SUPPLEMENTARY NOTES Mr. Paul Pisano (COTM)					
14. ABSTRACT (Maximum 200 words) With funding and support from the USDOT RITA IntelliDrive(SM) initiative and direction from the FHWA Road Weather Management Program, NCAR enhanced QCh algorithms that are a part of the current <i>Clarus</i> System. Moreover, NCAR developed new QCh algorithms to extend the capabilities of the current <i>Clarus</i> System. This document highlights the current status of all the QCh algorithms in the <i>Clarus</i> System.					
15. SUBJECT TERMS Clarus, road weather, quality checking					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT None	18. NUMBER OF PAGES 23	19a. NAME OF RESPONSIBLE PERSON Paul Pisano
a. REPORT Unclassified	b. ABSTRACT Unclassified	c. THIS PAGE Unclassified			19b. TELEPHONE NUMBER (202) 366-1301

Preface/ Acknowledgements

This work is sponsored by the U.S. Department of Transportation Road Weather Management Program and the Intelligent Transportation Systems Joint Program Office under contract DTH61-08-D-00012.

Disclaimer Notice

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof. This report does not constitute a standard, specification, or regulation.

The Federal Highway Administration (FHWA) provides high-quality information to serve Government, industry, and the public in a manner that promotes public understanding. Standards and policies are used to ensure and maximize the quality, objectivity, utility, and integrity of its information. FHWA periodically reviews quality issues and adjusts its programs and processes to ensure continuous quality improvement.

The United States Government does not endorse products or manufactures. Trade and manufactures' names appear in the report only because they are considered essential to the objective of the document.

The opinions, findings, and conclusions expressed in this document are those of the authors and not necessarily those of the U.S. Department of Transportation, Federal Highway Administration, or any other sponsor.

Table of Contents

Chapter 1 Introduction and Task Overview	3
Chapter 2 CLARUS Quality Checking Test Algorithms	4
2.1. SENSOR RANGE TEST	4
2.2. CLIMATE RANGE TEST	4
2.3. TIME STEP TEST	5
2.4. LIKE INSTRUMENT TEST	5
2.5. PERSISTENCE TEST	6
2.6. IQR SPATIAL TEST	6
2.7. BARNES SPATIAL TEST	7
2.8. DEWPOINT TEMPERATURE TEST	9
2.9. SEA LEVEL PRESSURE TEST	10
2.10. PRECIPITATION ESTIMATION TEST	11
Chapter 3 References	13
Appendix A, List of Acronyms	14
Appendix B, Metric/English Conversion Factors	15
Appendix C, Precipitation Estimation Procedure	17

List of Figures

Figure 1. Weighting Values by Distance.....	8
---	---

Chapter 1 Introduction and Task Overview

This report satisfies the requirement to document descriptions of the Quality Checking (QChing) tests for the *Clarus* System under Task 4a of TOPR2.

The QChing procedures that have been implemented into the operational *Clarus* System to date include:

- Sensor Range Test
- Climate Range Test
- Time Step Test
- Like Instrument Test
- Persistence Test
- Interquartile Range (IQR) Spatial Test
- Barnes Spatial Test
- Dew-point Temperature Test
- Sea Level Pressure Test

A precipitation estimation test has been designed and is described in section 2.10, but it has not been implemented at the time of this report.

Each individual test is run independently, with the exception of the sensor and spatial tests, and results from one test are not dependent on results of a prior test. In addition, each test is configured to run for a particular set of fields and so not all tests run on all fields.

Chapter 2 *CLARUS* Quality Checking Test Algorithms

2.1. Sensor Range Test

The sensor range test detects sensor readings that fall outside the range of sensor hardware specifications or theoretical limits (i.e., a maximum and minimum value). If a sensor reading does not pass the sensor range test, then no other quality checking tests are performed on that sensor reading.

Each time this quality check is invoked, it is given a single sensor reading. If the sensor reading cannot be obtained, the test returns immediately with an error condition indicating that it failed to run.

The sensor provides the sensor range in the form of a maximum and minimum value. If the sensor value is greater than or equal to the minimum, and less than or equal to the maximum, the sensor reading passes the sensor range quality check. If the sensor reading value is less than the minimum or greater than the maximum, the sensor reading does not pass the sensor range quality check.

2.2. Climate Range Test

The climate range test detects sensor readings that fall outside predetermined climate range values. The climate range data have been drawn from 30 years of National Centers for Environmental Prediction-Department of Energy (NCEP-DOE) Reanalysis 2 data. These reanalysis data are created by running a set of historical observational data through a common model, thus ensuring that the output data are consistent over time. The reanalysis also ensures that data are available in every time period at every grid point. For each weather parameter, the climate range values used in this test were determined by computing monthly minimum and maximum values over a 2.5 degree x 2.5 degree fixed latitude-longitude grid. In the latitude band, this equates to a grid spacing of 172.5 miles. In the longitude band, this varies from 172.5 miles at the equator, to 0 miles at the poles.

Each time this QCh test is invoked, it is given a single sensor reading. The appropriate climate maximum and minimum values used for the test are determined by the month of the sensor reading date and the latitude/longitude region in which the sensor reading location falls. If the sensor reading value is greater than or equal to the climate minimum, and less than or equal to the climate maximum, the sensor reading passes the climate range quality check. If the sensor reading value is less than the climate minimum or greater than the climate maximum, the sensor reading does not pass the sensor climate range quality check.

2.3. Time Step Test

The step test detects sensor readings whose values change by more than a predefined variable-specific or station-specific rate over a thirty minute (past) and five minute (future) configurable period. For example, an air temperature reading from 2:00 p.m. will be compared to the corresponding air temperature sensor readings from the same sensor that was recorded in the time range of 1:30 p.m. to 2:05 p.m.

Each time this test is invoked, it is given a single sensor reading. The system then obtains all of the sensor readings that have been received over the configured time period from the same sensor that are of the same weather parameter type. If either the current sensor reading or the prior sensor readings (a minimum of one is required) cannot be obtained, the test returns immediately with an error condition indicating that it was not able to run.

From the sensor, the system obtains configured positive and negative step threshold rates. If the difference between the current sensor value and the prior sensor value divided by the time difference in seconds ((current – prior) / time difference) falls between the negative step threshold and positive step threshold rates, then the current sensor reading passes the step quality check. If the computed rate falls outside the defined rates, then the current sensor reading does not pass the step quality check. This method assumes that the positive step threshold is specified as a positive value and the negative step threshold is specified as a negative value.

2.4. Like Instrument Test

The like instrument test detects sensor readings whose values differ from the average of all sensor values obtained from the same station with the same weather parameter type by more than a predefined variable-specific threshold. For example, if there were four surface temperatures at the same station, the sensor reading being evaluated would be compared to the average of all of the surface temperatures against the threshold (positive and negative). In reality, few sensors are repeated at a station outside of surface temperature, so this test is not often used.

Each time this test is invoked, it is given a single sensor reading. From the station information associated with the sensor reading, the number of sensors is obtained for the given sensor reading type. If that number is greater than one, it obtains the sensor reading(s) from the other like sensor(s) from the same station that are time-stamped within an hour before the original sensor reading. If additional sensor reading instances cannot be obtained, the test returns immediately with an error condition indicating that it was not able to run.

The like instrument threshold for the current sensor reading type is obtained from the configuration information. If the difference between the average of all sensor reading values plus and minus the threshold (sensor reading \geq average sensor reading – threshold AND sensor reading \leq average sensor reading + threshold) both evaluate to true, then the sensor reading passes the like instrument

test. If either of the comparisons evaluate to false, then the original sensor reading does not pass the like instrument test.

2.5. Persistence Test

The persistence test detects sensor reading whose values remain constant for a predefined variable-specific period of time. For example, if consecutive pressure sensor readings remain unchanged to the precision of the instrument for four hours, the current sensor reading does not pass the persistence test.

Each time this test is invoked, it is given a single sensor reading, which then determines the persistence time period. Consecutive sensor readings from the same sensor and station over that period of time preceding the current observation are then obtained. If the current sensor reading or the prior sensor reading cannot be obtained, the test returns immediately with an error condition indicating that it was unable to run.

If one or more of the consecutive sensor values are different, the current sensor reading passes the persistence quality check. If all of the consecutive sensor values over the given time period are equivalent, the current sensor does not pass the persistence quality check.

2.6. Interquartile Range (IQR) Spatial Test

The IQR spatial test is a method for checking whether a sensor reading is consistent with its neighboring sensor readings. It detects sensor readings that differ by more than a predefined threshold from an expected value within a neighborhood of the target sensor reading.

In general, across large regions, the atmosphere is quite homogeneous spatially. However, there are times and places such as in complex terrain or near frontal systems where close sensor readings are quite different but realistic. As such, the spatial test has some limitations.

A target sensor reading does not pass the IQR test when

$$|Z_e - Z_0| > \max(M * 0.7413 * IQR, \text{minToleranceBound})$$

where

Z_e = Median of neighbors

Z_0 = Target sensor reading

M = Multiplier value: The value is 3 for all fields, except Relative Humidity, which is 2.5

IQR = Interquartile range: The difference between the .25 and .75 percentiles of the neighbors. The coefficient 0.7413 makes the IQR an unbiased estimate of the true standard deviation σ

minToleranceBound = A fixed value set for each field that bounds the minimum acceptable spread between the target sensor value and the estimate.

In order to guarantee adequate spatial variation between neighboring sensors, various tolerance bounds (`minToleranceBound`) are used for different weather parameter fields. These bounds are adjustable, so that they can be tuned further as necessary.

The `minToleranceBound` values for each weather parameter field are as follows:

```
essAirTemperature: 3.5 deg C
essDewpointTemp: 7 deg C
windSensorAvgSpeed: 4.5 m/sec
essAtmosphericPressure: 7.5 mbar
essRelativeHumidity: 15 %
essSurfaceTemperature: 10 deg C
essPavementTemperature: 10 deg C
essSubSurfaceTemperature: 3 deg C
essWetBulbTemp: 7 deg C
```

The IQR test is only effective and thus only run if there are 5 or more Automated Surface Observing Systems (ASOS), Automated Weather Observing Systems (AWOS), and/or Environmental Sensor Station (ESS) neighbors that satisfy all of the following conditions:

- Within a 69 mile radius of the target sensor reading
- Within +/- 350 meters of elevation
- Within 1 hour of the target sensor reading time

Otherwise, the test will not run.

Up to 20 of the nearest sensors to the target sensor reading satisfying the above criteria are chosen to makeup the background field.

2.7. Barnes Spatial Test

Like the IRQ test, the neighboring stations used for spatial comparison are determined by a formula based on configurable tolerance bounds. Unlike the IRQ test, neighboring sensor readings are weighted according to their distance from the original sensor, with the weight decreasing exponentially with the distance from the station. In the *Clarus System*, neighboring values (Z_i) are based on ASOS, AWOS, and ESS *in situ* data. The ASOS program is a joint effort of the National Weather Service (NWS), the Federal Aviation Administration (FAA), and the Department of Defense (DOD). The ASOS systems serve as the nation's primary surface weather observing network. ASOS is designed to support weather forecast activities and aviation operations and, at the same time, support the needs of the meteorological, hydrological, and climatological research communities. The AWOS provides basic aviation weather observations directly to pilots approaching the airport. The majority of the ~170 systems were installed at various non-towered airports (OFCM, 2009).

The neighboring stations used for spatial comparison must fall within a distance set by a configuration parameter. Neighboring observations are weighted according to their distance from the original sensor, with the weight decreasing exponentially with the distance from the station.

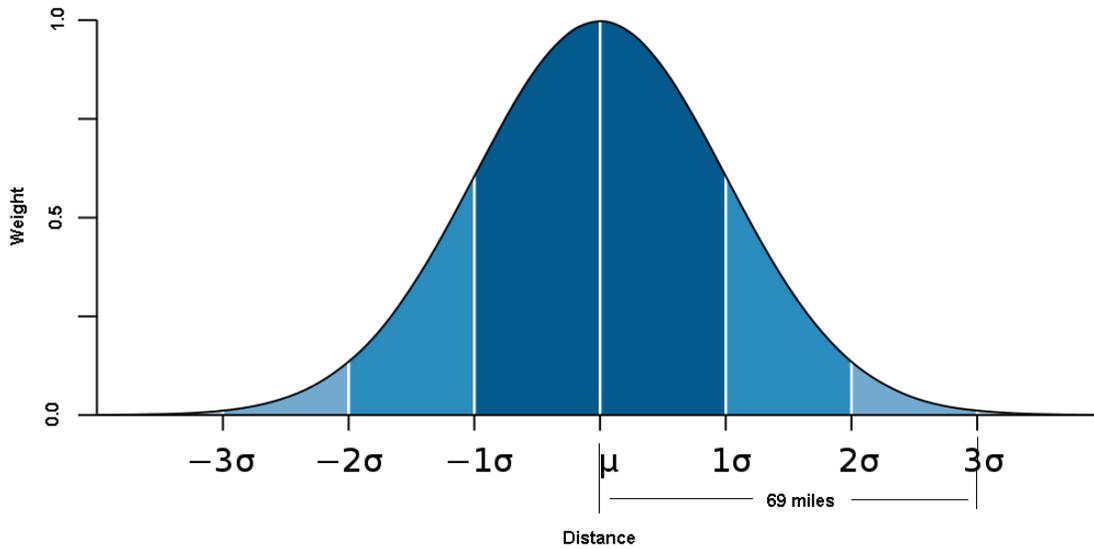


Figure 1 - Weighting Values by Distance

Each time this test is invoked, it is given a single observation. Through the observation instance, it obtains a sensor and a station. If the sensor or station cannot be obtained, the test returns immediately with an error condition indicating that it was unable to run. Then a set of observations to use for the spatial analysis is determined. If there are fewer than two observations of the same type available or if the IQR Spatial Test was able to run, the test returns immediately with an error condition indicating that it was unable to run.

A target observation does not pass the Barnes Spatial Test when the target observation value (Z_0) falls outside of the range defined by the number of configured standard deviations about the weighted mean of the neighboring observations (Z_e).

An observation does not pass the Barnes Spatial Test when:

$$\left| Z_e - Z_0 \right| > \text{SdMin} * \sigma$$

where

Z_0 = Target observation

Z_e = Weighted mean of neighboring observations

Z_i = The i^{th} neighboring observation

SdMin = The configured allowable standard deviations

σ = Estimated standard deviation

and where the weighted mean is computed as follows:

$$Z_e = \left(\sum W(r_i) * Z_i \right) / \left(\sum W(r_i) \right)$$

where

$$W(r_i) = \exp\left(-|Z_i - Z_0|^2 / (2*(r_i/\sigma)^2)\right)$$

The Barnes spatial test only runs when the IQR test does not run and if there are 2 or more ASOS, AWOS and/or ESS neighbors that satisfy all of the following conditions:

- Within the configured radius of the target observation, typically 69 miles
- Within 65 minutes of the target observation time, -60 minutes to +5 minutes to accommodate potential skewed time reporting

Otherwise, the test will not run.

2.8. Dewpoint Temperature Test

Most automated dewpoint temperatures are not sensed directly but derived from other weather parameters. Thus, the dewpoint temperature test detects air temperature and relative humidity sensor readings whose corresponding derived dewpoint temperatures do not pass a Barnes spatial analysis. This test is similar to the Barnes spatial quality check except that it performs the objective analysis on dewpoint temperature sensor readings derived from air temperature and relative humidity sensor readings instead of performing the test directly on the sensor readings themselves.

Each time this test is invoked, it is given a single relative humidity sensor reading. Using sensor and station information, the corresponding most recent (within one hour) air temperature sensor reading is retrieved. If the sensor, station, or corresponding air temperature sensor reading cannot be obtained, the test returns immediately with an error condition indicating that it is unable to run.

At this point, the dewpoint temperature test follows the same method as the Barnes spatial test to obtain the set of sensor readings to use in the spatial analysis, except that it obtains both air temperature and relative humidity for each station. If sensor readings for both air temperature and relative humidity cannot be obtained for a given station, that station is not used in the spatial analysis. If both air temperature and relative humidity sensor readings are not available for at least two stations, the quality check returns immediately with an error condition indicating that it was unable to run.

Once the air temperature and relative humidity sensor readings are obtained, the dewpoint temperature (Td) is calculated for each location using the following formulas.

$$Td = 240.97 * \ln(es/6.1365)/(17.502 - \ln(es/6.1365))$$

Where:

$$es = (RH/100) * 6.1365 * \exp(17.502*T) / (240.97 + T)$$

and:

e_s = saturated water vapor pressure
 T = air temperature in C
 RH = relative humidity

The resulting dewpoint temperature values are then subjected to the objective analysis outlined in the Barnes spatial quality check. If the dewpoint at the original location differs from the estimate by more than three standard deviations ($\sigma > 3$), then the original relative humidity sensor reading does not pass the dewpoint temperature quality check. If the dewpoint at the original location differs from the estimate by three standard deviations or less ($\sigma \leq 3$), then the original relative humidity sensor reading passes the dewpoint temperature quality check.

2.9. Sea Level Pressure Test

The sea level pressure test is a method for checking whether an atmospheric pressure measurement is consistent with its neighboring sensor readings, when both the target pressure sensor reading and its neighbors have been reduced to sea level pressure. It detects reduced pressure sensor readings that differ by more than a predefined threshold from an expected value within a neighborhood of the target sensor reading.

The algorithm is based on the Mesoscale Analysis Prediction System-Sea Level Pressure (MAPS-SLP) reduction algorithm (Benjamin and Miller, 1990). The MAPS-SLP algorithm estimates the surface temperature versus using the sensed surface temperature for the pressure reduction calculation from the 700mb temperature (usually obtained via soundings), which is adjusted by the standard lapse rate to the station elevation.

A formulation of the hydrostatic and hypsometric equation, which relates the change in pressure and the change in temperature, is the following:

$$P_{SL} = P_{STA} * \left(\frac{T_{SL}}{T_{STA}} \right)^{g/R\gamma}$$

where

P_{SL} = the sea level pressure
 P_{STA} = the surface (station) pressure
 T_{STA} (effective temperature) = the temperature assumed to be valid at the surface (station level)
 T_{SL} = the temperature at MSL
 γ = the lapse rate of the temperature
 g = the acceleration due to gravity
 R = the universal gas constant (Benjamin and Miller, 1990).

T_{STA} and T_{SL} are computed by extrapolating downward using the constant lapse rate to the station elevation:

$$T_{SL} = T_{700} + \gamma(z_{700} - 0)$$

$$T_{STA} = T_{700} + \gamma(z_{700} - z_{STA})$$

where

T_{700} = the temperature at the 700 hPa level (Kelvin)

z_{700} = the height of the 700 hPa pressure level in meters above MSL

z_{STA} = the height of the station above MSL in meters.

Data from 700mb observed temperatures from the nearest rawinsonde (balloon) soundings are used when available with a 69-mile radius of the pressure measurement. Reanalysis 30-year 700 mb temperature monthly mean values on a 2.5 x 2.5 degree grid are used as default values when sounding data are not available.

The following constant values are used in the code (U.S. Standard Atmosphere, 1976):

$$g = 9.80665 \text{ m/s}^2$$

$$R = 287.053072047065 \text{ J/(kg- K)}$$

$$\gamma = 6.5^\circ\text{C}/1000\text{m}$$

2.10. Precipitation Estimation Test

The precipitation estimation test utilizes NCEP Stage II and Stage IV data for comparison with ESS precipitation accumulation reports. The NCEP stage II and IV data are real-time, hourly, multi-sensor National Precipitation Analysis (NPA) data developed at the NCEP in cooperation with the Office of Hydrology (Lin and Mitchell, 2005). The Stage II/IV analyses merge radar data with hourly METAR gauge reports and are output onto a 4-km Hydrologic Rainfall Analysis Project (HRAP) grid. The HRAP grid is a National Weather Service (NWS) coordinate system that uses a polar stereographic projection true at 60°N / 105°W. Each hour's analysis is run at 35 minutes past the hour and then run 6 hours and 18 hours later. The first run incorporates precipitation reports from rain gauge sites and the later runs use HADS automated gauge reports transmitted via the GOES Data Collection Platform (DCP). The primary difference between Stage II and Stage IV analyses is that Stage IV Data is manually QC'd at the NWS Regional Forecast Centers (RFCs), so it is generally better than the Stage II data.

The precipitation estimation QCh algorithm compares a target ESS precipitation accumulation report to nearby Stage II or IV grid values. Because there is approximately a one-hour lag in the Stage II/IV availability, recent data measured within the previous hour from neighboring ASOS, AWOS and other ESS stations are also incorporated into the algorithm in order to assess whether the target reports should pass or fail the precipitation QCh test.

The algorithm is designed to check 3, 6, 12, and 24-hour precipitation accumulation values. Only precipitation accumulation reports greater than 1 mm are tested. In addition, only precipitation accumulation reports which have more than 25% of the accumulation period covered by Stage II or Stage IV data are evaluated. If less than 25% of the period is covered, a flag of “not enough data” is returned.

The algorithm is listed in Appendix C, but basically, it assess whether the sensor reading falls within an acceptable threshold of minimum and maximum expected precipitation. The thresholds vary on the sensor reading.

Chapter 3 References

Benjamin, S. G. and P. A. Miller, 1990: An alternative sea level pressure reduction and a statistical comparison of geostrophic wind estimates with observed surface winds. *Mon. Wea. Rev.*, **118**, 2099–2116.

Bluestein, H. B., 1992: *Synoptic–Dynamic Meteorology in Midlatitudes. Vol. I: Principles of Kinematics and Dynamics*. Oxford University Press, 431 pp.

Committee on Extension to the Standard Atmosphere: U.S. Standard Atmosphere, 1976. NOAA, USAF.

Lin, Y., K.E. Mitchell, 2005: The NCEP Stage II/IV precipitation analyses: development and applications. Preprints, *19th Conf. on Hydrology*, San Diego, CA, Amer. Meteor. Soc., P1.2.

McGill, R., L. Tukey and W. Larsen, 1978: Variations of box plots. *Amer. Stat.*, **32**, 12-16.

NCAR, 2010: Validation Report of the Upgraded *Clarus* System. 87 pp.

Office of the Federal Coordinator for Meteorology, 2009: The Federal Plan for Meteorological Services and Supporting Research Fiscal Year 2009. U.S. Department of Commerce/National Oceanic and Atmospheric Administration. 255 pp.

Pauley, P. M., 1998: An Example of Uncertainty in Sea Level Pressure Reduction. *Wea. and Forecasting*, **13**, 833-850.

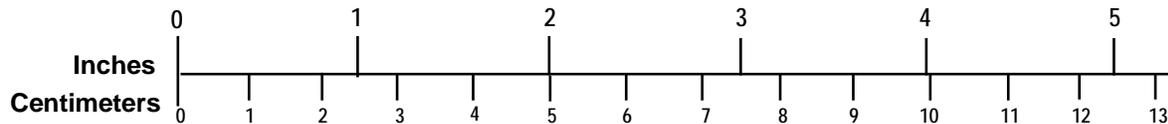
APPENDIX A. List of Acronyms

ASOS	Automated Surface Observing System
AWOS	Automated Weather Observing System
DOD	Department of Defense
DOE	Department of Energy
ESS	Environmental Sensing System
FAA	Federal Aviation Administration
HRAP	Hydrologic Rainfall Analysis Project
IQR	Interquartile Range
MAPS-SLP	Mesoscale Analysis Prediction System - Sea Level Pressure
MHI	Mixon/Hill Inc.
NCAR	National Center for Atmospheric Research
NCEP	National Centers for Environmental Prediction
NOAA	National Oceanic and Atmospheric Administration
NPA	National Precipitation Analysis
NWS	National Weather Service
OFCM	Office of the Federal Coordinator for Meteorology
QCh	Quality Checking
RAL	Research Applications Laboratory
TOPR	Task Order Proposal Request
TOPR2	Task Order Proposal Request No. 2
UCAR	University Corporation for Atmospheric Research

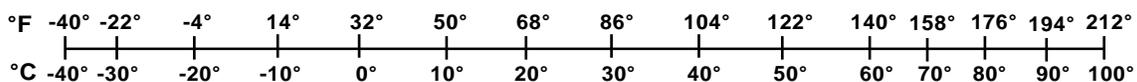
APPENDIX B. Metric/English Conversion Factors

ENGLISH TO METRIC	METRIC TO ENGLISH
<p>LENGTH (APPROXIMATE)</p> <p>1 inch (in) = 2.5 centimeters (cm)</p> <p>1 foot (ft) = 30 centimeters (cm)</p> <p>1 yard (yd) = 0.9 meter (m)</p> <p>1 mile (mi) = 1.6 kilometers (km)</p>	<p>LENGTH (APPROXIMATE)</p> <p>1 millimeter (mm) = 0.04 inch (in)</p> <p>1 centimeter (cm) = 0.4 inch (in)</p> <p>1 meter (m) = 3.3 feet (ft)</p> <p>1 meter (m) = 1.1 yards (yd)</p> <p>1 kilometer (km) = 0.6 mile (mi)</p>
<p>AREA (APPROXIMATE)</p> <p>1 square inch (sq in, in²) = 6.5 square centimeters (cm²)</p> <p>1 square foot (sq ft, ft²) = 0.09 square meter (m²)</p> <p>1 square yard (sq yd, yd²) = 0.8 square meter (m²)</p> <p>1 square mile (sq mi, mi²) = 2.6 square kilometers (km²)</p> <p>1 acre = 0.4 hectare (he) = 4,000 square meters (m²)</p>	<p>AREA (APPROXIMATE)</p> <p>1 square centimeter (cm²) = 0.16 square inch (sq in, in²)</p> <p>1 square meter (m²) = 1.2 square yards (sq yd, yd²)</p> <p>1 square kilometer (km²) = 0.4 square mile (sq mi, mi²)</p> <p>10,000 square meters (m²) = 1 hectare (ha) = 2.5 acres</p>
<p>MASS - WEIGHT (APPROXIMATE)</p> <p>1 ounce (oz) = 28 grams (gm)</p> <p>1 pound (lb) = 0.45 kilogram (kg)</p> <p>1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)</p>	<p>MASS - WEIGHT (APPROXIMATE)</p> <p>1 gram (gm) = 0.036 ounce (oz)</p> <p>1 kilogram (kg) = 2.2 pounds (lb)</p> <p>1 tonne (t) = 1,000 kilograms (kg) = 1.1 short tons</p>
<p>VOLUME (APPROXIMATE)</p> <p>1 teaspoon (tsp) = 5 milliliters (ml)</p> <p>1 tablespoon (tbsp) = 15 milliliters (ml)</p> <p>1 fluid ounce (fl oz) = 30 milliliters (ml)</p> <p>1 cup (c) = 0.24 liter (l)</p> <p>1 pint (pt) = 0.47 liter (l)</p> <p>1 quart (qt) = 0.96 liter (l)</p> <p>1 gallon (gal) = 3.8 liters (l)</p> <p>1 cubic foot (cu ft, ft³) = 0.03 cubic meter (m³)</p> <p>1 cubic yard (cu yd, yd³) = 0.76 cubic meter (m³)</p>	<p>VOLUME (APPROXIMATE)</p> <p>1 milliliter (ml) = 0.03 fluid ounce (fl oz)</p> <p>1 liter (l) = 2.1 pints (pt)</p> <p>1 liter (l) = 1.06 quarts (qt)</p> <p>1 liter (l) = 0.26 gallon (gal)</p> <p>1 cubic meter (m³) = 36 cubic feet (cu ft, ft³)</p> <p>1 cubic meter (m³) = 1.3 cubic yards (cu yd, yd³)</p>
<p>TEMPERATURE (EXACT)</p> <p>$[(x-32)(5/9)] \text{ } ^\circ\text{F} = y \text{ } ^\circ\text{C}$</p>	<p>TEMPERATURE (EXACT)</p> <p>$[(9/5)y + 32] \text{ } ^\circ\text{C} = x \text{ } ^\circ\text{F}$</p>

QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSION



For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures.
Price \$2.50 SD Catalog No. C13 10286

APPENDIX C. Precipitation Estimation Procedure

The precipitation formula is more complicated than the other formulas, and is as follows:

Let

PERIOD = The accumulation period of interest (3, 6, 12, or 24 hours)

ESS_nbrs = The precip accumulation values at all ESS stations within 50 km of the ESS target obs and within 1 hour prior to the ESS target obs time.

ESS_target_value = The ESS precipitation accumulation report value that is evaluated by the algorithm.

METAR_nbrs = The precipitation accumulation values at all ASOS/AWOS stations within 50 km and 0 to PERIOD hours prior to the ESS target obs time. The METAR neighbor value is computed as the sum of all available METAR precipitation accumulation values for the previous PERIOD hours. For example, for a 6 hour accumulation there might be no 6 hour METAR yet available, so the neighbor value might be the sum of a 3-hour METAR and three 1-hour values. If there are no METAR data available for the most recent hour, that hour is omitted. So in this example the 6 hour accumulation would be the sum of a 3-hour and two 1-hour values.

Stage_nbrs = The precip values at all Stage II/IV grid points within the accumulation period and within 10 km of the ESS target obs

All_nbrs = ESS_nbrs union METAR_nbrs union Stage_nbrs

else

if essTargetValue > 1 mm, then

smin = min(All_nbrs)

smax = max(All_nbrs)

tmin = smin - 5

tmax = 2 * smax

if tmax < 8mm,

tmax = 8mm

if tmax > 50 mm,

tmax = smax+25 mm

if tmin < essTargetValue < tmax,

then

PASS

else

NOT PASS

else

essTargetValue is not tested

```
else
  if (3 stage nbrs) <= 10 mm,
    then
      PASS
    else
      NOT PASS
```

U.S. Department of Transportation
ITS Joint Program Office-HOIT
1200 New Jersey Avenue, SE
Washington, DC 20590

Toll-Free "Help Line" 866-367-7487
www.its.dot.gov

FHWA-JPO-11-075