1.2 OVERVIEW OF THE UPPER AIR DATA CONTINUITY STUDY: AN INTERCOMPARISON BETWEEN THE NATIONAL WEATHER SERVICE'S LEGACY UPPER AIR SYSTEM AND THE NEW RADIOSONDE REPLACEMENT SYSTEM TO ASSESS TRUE CLIMATIC VARIATION

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1. INTRODUCTION

The National Weather Service's Upper Air Network has provided over 60 years of consistent radiosonde observations from more than 92 sites. Vertical profiles of the atmosphere measuring pressure, temperature, relative humidity, wind speed, and wind direction are critically depended on by several industries including weather forecasting, aviation planning, and climate monitoring. For each industry, especially the climate community, the consistency of these observations is crucial. As the National Weather Service completes a network-wide conversion to a new generation of radiosonde observing systems, it is unknown what the impact will be on upper atmospheric measurements. To characterize this transition, the National Weather Service has established the Upper Air Data Continuity Study to acquire a reliable and thorough dataset that can be used to assess true climate variation.

Data continuity is defined as the compatibility of past, present and future data in a manner from which observational records are free of inhomogeneities resulting from instrument changes, launch and sampling procedure changes, or data processing changes (Peterson and Durre 2002). The Upper Air Data Continuity Study will be useful for understanding the relationship between climate variation and change due to measurement error. The study will determine what component of the total change seen in the climatic data is a result of true climatic variation and what component is related to sensor characteristic changes due to alterations in sensor technology, algorithm change, and new processes and procedures.

Because of this RRS transition and the potential impact on the long-term upper air climate record, NWS directive NDSPD 10-2101 requires a credible data continuity study to be conducted. The requirements for this directive are derived from requests received from day-to-day users, the U.S. climatological services and academia.

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1.1. Testing Locations

The National Weather Service intends to meet these goals through the selection of four NWS locations which possess diverse meteorological and Climatological conditions.

1.1.1. Sterling, Virginia

The Sterling Field Support Center in Sterling, VA provides operational support to National Weather Service Forecast Offices with expertise in sensor and system functions, test and evaluation processes, and NWS observing protocols. A major asset to the Sterling Field Support Center is the meteorological testing equipment available for consensus referencing. The site predominantly experiences a Humid Subtropical Climate with warm summers and atmospheric flow from west to east given its location in the middle latitudes. This provides four well defined seasons, with warm and humid summers and generally mild winters. The coldest period normally occurs in late January when temperatures average 31°F, with the warmest period in late July where temperatures average near 88°F.

Precipitation remains evenly distributed throughout the year with annual precipitation ranges from 25 inches to more than 55 inches. These levels are exceeded during years with many tropical cyclones. Although it varies greatly from season to season, the seasonal snowfall is nearly 24 inches. Snowfalls of 4 inches or more occur only twice each winter on average.

1.1.2. Caribou, Maine

Located nearly 150 miles from the Atlantic coast, Caribou, ME is located within the St. Lawrence Valley and is often under the influence of the Summer Polar Front. It has a Humid Continental Climate that provides for cool summers and long winters.

Abundant rainfall is common in the summer with few dry periods. Autumn weather is characterized by mostly sunny warm days and cool nights.

Seasonal snowfall averages over 100 inches are not unusual during the winter period since temperatures of zero or lower normally occur more than 40 times per year.

1.1.3. Barrigada, Guam

Identified as Tropical Rain Forest, Guam's climate is nearly uniformly warm and humid throughout the year. Afternoon high temperatures are typically in the middle 80s with nighttime temperatures typically from the high 60s or low 70s. Relative humidity varies from 65 to 75 percent in the afternoons to 85 to 100 percent overnight.

Given its location and proximity to the western side of the Northern Plateau, trade winds reach the station after rising abruptly over the cliffs on the island's eastern side. Trade winds which blow from east or northeast are strongest and most constant during the dry season, when wind speeds of 15 to 25 mph are very common. However, a breakdown of the trades occurs during the rainy season which allows for torrential rains over the island. Typhoons can often bring rain and violent winds, as well, with the most frequent occurrence of typhoons in the latter half of the year.

1.1.4. Barrow, Alaska

With the Arctic Ocean to the North, East, and West, and level tundra stretching 200 miles to the south, Barrow can be classified as exhibiting a Polar Tundra climate. Temperatures remain below freezing for the majority of the year, with the daily maxima reaching higher than 32°F on an average of only 109 days during the year. July tends to be the warmest month and during late July to early August, the Arctic Ocean is normally ice-free. Summer ends in September and winter commences once again by November.

At 12:50 p.m. on November 18, the sun dips below the horizon and does not appear again until 11:51 a.m. on January 24. By 01:06 a.m. on May 10, the possible sunshine has increased to 24 hours per day and remains visible until approximately August 2. The terrain of Barrow, AK provides few barriers as protection from the high winds, which in turn assist in lowering the temperatures by radiation and dispersing colder air to lower levels through down slope drainage mechanism.

2. DATA AND METHODOLOGY

2.1. Description of Systems

The Microcomputer Automatic Radiotheodolite (MicroART) system is antiquated and has been in operation in the NWS network since the late 1980s. This system collects and processes upper air data from radiosondes via the ART equipment and an IBM XT computer. An ART Interface Card (ARCTIC) resides within the IBM XT which converts these signals to a digital and numeric form used by the MicroART computer program. Additionally, a user interface is available which allows for data to be displayed and edited during the flight. The MicroART system is only in use by various sites in the Alaska.

The NWS has developed the Radiosonde Replacement System (RRS) to replace the outdated MicroART system. The RRS is comprised of a new RDF tracking antenna referred to as the telemetry receiving system or TRS, 1680 MHz GPS radiosondes, a Signal Processing System (SPS), and a personal computer workstation. In addition to this deployment, a new surface weather observing system is associated with RRS called the Radiosonde Surface Observing Instrumentation System (RSOIS).

A variety of radiosondes are currently flown in the NWS network including the Sippican B2®, Mark IIA®, and the Vaisala RS92-NGP®. The new radiosondes have already had a significant impact on operations due to new technology in sensors for temperature, pressure, and relative humidity measurements. These sensors have differing characteristics, such as higher stability and faster response than current radiosondes fielded.

2.2. Overview of Radiosondes

The two radiosondes which will be used for the Data Continuity Study are the Vaisala RS92-NGP and the LMS B2 1680-MHz. The RS92 instrument uses a digital data transmission scheme modulated at 1680 MHz and consists of a silicon capacitive pressure sensor, a rod type capacitive temperature sensor, and two alternately heated thin film capacitor sensors for relative humidity measurement. A spiral GPS antenna is positioned on top of the radiosonde and receives a GPS position every second then translates into wind speed and direction. Sensor data is telemetered to the ground station at an approximate rate of once every second. The Vaisala frequency setting device must be used to set the frequency of the RS92 radiosonde frequency. In addition to setting the frequency of the radiosonde, it also burns off contaminants which may have collected on the humidity sensors.

The LMS B2 radiosonde is an amplitude modulated 1680 MHz radiosonde with a sensor suite consisting of an aneroid pressure cell, a carbon element humidity sensor, and a ceramic rod resistive temperature sensor. Sensor data are telemetered to the ground station at an approximate rate of once every two seconds. This instrument originates from a long line of radiosondes using the large rod resistive type temperature sensor dating back to the late 1950s.

2.3. Flight Configuration

The DCS flight configuration consists of flying the RS92-NGP and Sippican B2 radiosondes which are tethered to the same balloon via a 6 foot Styrofoam bar stabilized with fiber tape and twine. The bar is 6 feet in length to allow adequate spacing between radiosondes which alleviates tangling during flight. Radiosondes are attached 3 feet below the bar to reduce solar influences. Instruments are positioned at the same height from the bar which enables them to sample the same atmosphere, yielding a more precise data comparison. In order to obtain target ascent rates, a larger balloon than what is currently used in operations is needed to sustain the additional weight during flight.

2.4. Performance of DCS Flights

In order to capture the meteorological and climatic conditions which occur at each station, the test will cover a period of sixty weeks and consist of a minimum of 120 successful dual flights. Successful flights are ones in which both radiosondes report data up to 30 hPa according to the Data Continuity Study Test Plan. Each site has selected a weekday for the dual flights to be performed. Flights are conducted every 7 days at 00 UTC and 12 UTC.

Between May and September 2012, all participating Data Continuity Study sites sequentially began conducting dual flights. This method was primarily determined according to when sites started using the Vaisala radiosonde operationally, and also because of the travel and logistical limitations that had to be addressed when traveling to these remote sites.

2.5. NCDC Archival

In addition to continuing to maintain the usual operational archive, the National Climatic Data Center (NCDC) places both the operational and legacy data from the dual flights into a separate data set. This dataset, along with associated Metadata and documentation, is made available to interested areas of the public through a webpage and FTP directory set up by NCDC.

Flights performed using RWS are archived within the software following each completed flight. However, MicroART flights are only archived at the end of each month. In order for NCDC to accommodate for two datasets from one station without the possibility of overriding, the MicroART was provided a test WBAN ID that is different from the operational header used in RWS.

2.6. Data Analysis Procedures

Prior to performing analysis procedures, data from all DCS locations needed to be compiled to the same location. RWS data was retrieved from an internal data server whereas MicroART data was made available via the FTP site supported by NCDC.

RRS flight data from the remote testing locations was downloaded and reprocessed using the RWS software in order to retrieve the WMO Levels and coded messages from each flight. Store files from the MicroART were reprocessed using the IBM XT to produce similar datasets. Once all flight data had been retrieved, recorded ascension numbers were paired for each dual flight so that data could be used for comparison purposes.

Rawinsonde Observation (RAOB) plots were generated using the coded messages for each flight in order to compare basic meteorological parameters, including tropopause height, freezing level, cloud condensation level (CCL), lifted condensation level (LCL), 1000-500 hPa thickness, 700-500 hPa thickness, and integrated precipitable water (IPW). In addition to comparing the meteorological parameters, external data sources, such as the GPS calculated IPW, were utilized during the evaluation. Although GPS IPW is not viewed as an absolute reference system for this study, it provides additional information on which radiosonde properly represents the relative humidity in the atmosphere. Once differences between all parameters were computed, basic descriptive statistics were calculated. This method of investigation provides a comprehensive overview of how the radiosondes perform in regards to one another.

In addition to the RAOB plot analysis, statistics were compiled for the WMO mandatory levels (TTAA and TTCC) for each flight. Data from the RWS and MicroART were paired for each flight with differences (MicroART minus RWS) being calculated at the pressure levels for geopotential height, temperature, and relative humidity. These differences were then used to generate comprehensive descriptive statistics for each testing location and for all flights.

Since release synchronization could be established at the Sterling Field Support Center, analysis of the higher resolution data was processed on a six second basis in addition to coded messages and level comparisons. Because the data output rate from RWS and MicroART differ (1-second data and 6-second data respectively), sorting was required in order to properly evaluate the high resolution data. To complete these tasks, RWS flight files were filtered through an internal software package capable of converting the dataset. Because corrections are already being applied to the RWS data, the software simply extracts the set interval point, producing an output comparable to that of the MicroART. Data from the MicroART was received in 2 second frames with the 6 second data output being an average over those three values. Although the internal software package does not process RWS data by determining an average as with the MicroART, it does produce a 6-second dataset which can be examined in conjunction with MicroART data. Once all flights were paired, similar descriptive statistics were used to evaluate the higher resolution data as was used with the mandatory levels.

3. DISCUSSION

Approximately 20% of dual flights supporting the Data Continuity Study have been completed by participating sites thus far. This statistic indicates that findings are premature and should be treated only as initial rather than comprehensive results.

3.1. Coded Messages & WMO Levels

In order to aid in the quality control of the flight data, descriptive statistics were run from the coded messages generated from both systems. From these statistics, general trends were observed and compared to those obtained during the higher resolution data analysis. For the temperature, both the mean and standard deviation of the temperature differences remained below 2°C with the majority less than 1°C through the entire atmospheric profile. For relative humidity and geopotential height, larger discrepancies have been noted which can be attributed to greater uncertainty in the sensors used to calculate these meteorological parameters.

Differences for tropopause height, freezing level, CCL, LCL, 1000-500 hPa heights, 700-500 hPa heights, and IPW calculated from the RAOB parameter analysis shows a greater amount of variation when considering the average, standard deviation, and RMSD (root-mean-square-deviation) values. It should be noted that these were compiled with sites independent of one another, unlike statistics using the levels comparison. Overall, sites tend to see the greatest standard deviation in the tropopause height and CCL parameters. Lowest standard deviations for all sites are in relation to the IPW statistics.

3.2. High Resolution Data

For the high resolution data comparison, a random sample of dual flights was chosen for analysis. Flights in this sample surpassed the target pressure of 10 hPa. Pressure, temperature and relative humidity from the two systems were compared to each other by calculating differences of MicroART minus RWS. Geopotential heights between the two systems were also evaluated. Since the RRS is a GPS based system, the Geometric height was compared to the Geopotential height of the MicroART as well.

Initial findings from the selected flights showed pressure differences primarily remaining below 2 hPa. A trend however was noticed where the pressure being reported from the B2 radiosondes was greater than the pressure (both raw and corrected) from the RS92-NGP (Figure 1). Unlike pressure, the temperature data did not show any trending across the raw and corrected parameters. Overall, there were three flights where the B2 radiosonde was predominantly warmer than the RS92-NGP radiosonde and three flights where the RS92-NGP was warmer than the B2. However, when the statistics were generated, the mean value for the B2 minus the RS92-NGP favored the RS92-NGP radiosonde being slightly warmer. When the solar correction is applied to the data values, neither radiosondes are favored to be warmer with a mean difference value of approximately zero (Figure 2).

In regards to the relative humidity, the relative humidity sensors of the B2 radiosondes did not report profiles which properly reflected atmospheric conditions upon reaching the tropopause. This feature was evident on all flights analyzed since the B2 humidity sensor did not dry once this level was exceeded. Prior to the tropopause, average differences ranged between ±10 percent with a slight trend towards the B2 being drier than the RS92-NGP (

Table 1). Height results however did show a trend between the two systems where the MicroART heights were reported lower than those from the RWS (Figure 3). Not only was this true when comparing the Geopotential heights from the different systems to each other, but this was also true when the Geopotential height of the MicroART was compared to the Geometric height of the RWS.

4. CONCLUSION

As the National Weather Service transitions their Upper Air Network to a new generation of radiosonde observing systems, the Data Continuity will assist in obtaining a reliable and thorough dataset that can be used to determine the impact on upper air measurements. The Vaisala RS92-NGP and the Sippican B2 radiosondes which are flown simultaneously will also provide data for climate monitoring and other considerations. The Data Continuity Study is currently underway with less than one quarter of the desired flights completed. Dual flights and data processing procedures are still in their infancy and continue to be developed. As this study and associated analysis continues, processes and procedures are likely to change and become dependent upon findings.

It should be noted that while the Sterling Field Support Center is providing basic analysis in order to conduct quality control of the data, NCDC will provide a more in-depth and comprehensive investigation once the DCS has reached completion based on the availability of resources. By conducting additional data analysis as the study progresses, acceptable errors and theories for comparison will become better understood and accepted. This flexibility will ensure that appropriate analysis techniques are applied in order to retrieve valuable scientific results.

This paper serves as an initial overview to the Data Continuity Study; however, a more comprehensive report is expected to be completed following the conclusion of this study.

5. ACKNOWLEDGMENTS

The NWS wishes to acknowledge ongoing efforts in flight support from participating Data Continuity Study test sites, namely WFO Caribou, ME, WFO Guam, and WSO Barrow, AK. Additional personnel at the Sterling Field Support Center continue to provide invaluable flight and field support for the DCS. Appreciation is also extended to NCDC for their data retrieval and analysis techniques. Finally, the NWS would like to acknowledge field support from regional offices, including Eastern, Pacific, and Alaska Region Headquarters, and technical support from NWS Headquarters. The Data Continuity Study would not be possible without the contributions of these personnel. Opinions expressed in this paper are solely those of the authors, and do not represent an official position or endorsement by the United States Government.

6. REFERENCES

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Peterson, T.C., and I. Durre, 2002: A Climate Continuity Strategy for the Radiosonde Replacement System Transistion, Prepared for the 15 January 2003 Meeting of NOAA's Council on Long-term Climate Monitoring. National Climatic Data Center/NESDIS/NOAA, 73 pp.

7. FIGURES

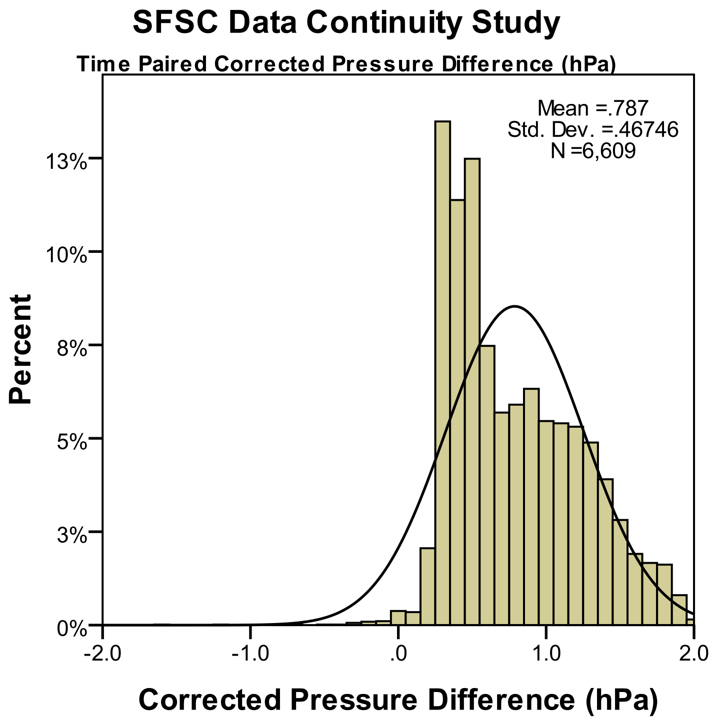

Figure 1 - Pressure Difference Histogram of MicroART Pressure minus RWS Corrected Pressure

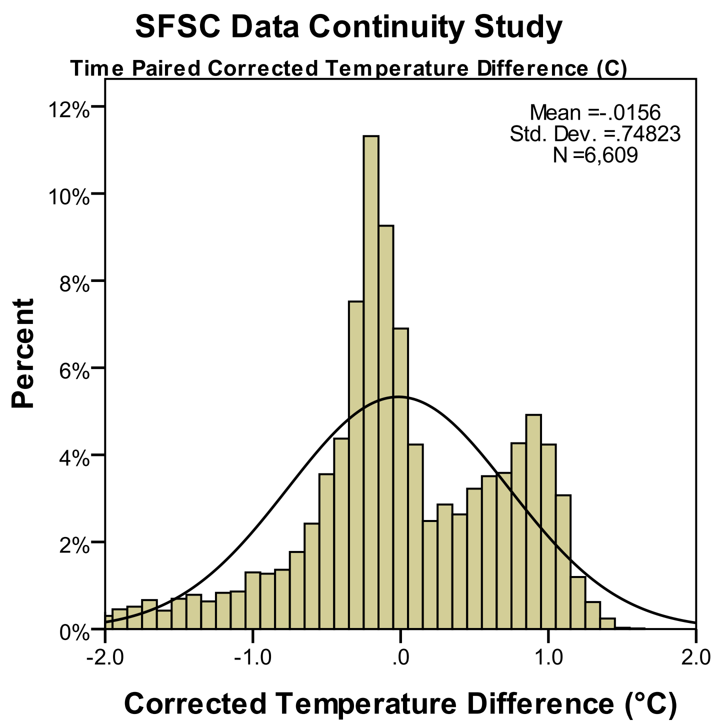

Figure 2 – Temperature Difference Histogram of MicroART Temperature minus RWS Corrected Temperature

Data Continuity Study Time Paired Humidity Difference Statistics						
Pressure Intervals (hPa)	**N**	**Minimum**	**Maximum**	**Mean**	**Std. Deviation**	**RMSD**
19 to 0	963	-0.4	24.2	9.69	8.26	12.74
49 to 20	1119	0.9	27.3	17.92	5.42	18.72
99 to 50	945	16.7	28.6	22.51	3.45	22.78
199 to 100	979	-39.4	27.8	12.70	13.02	18.18
299 to 200	579	-41.1	11.1	-1.58	9.69	9.81
499 to 300	770	-20	13.9	-0.13	6.13	6.13
849 to 500	922	-27.7	16.5	-2.35	5.29	5.79
1070 to 850	332	-13.8	9.7	-1.49	4.66	4.88
ALL	6609	-41.1	28.6	8.99	12.00	14.99
400 to 4	5014	-41.1	28.6	12.43	11.47	16.91
SFC to 400	1595	-27.7	16.5	-1.81	5.38	5.68

Table 1 - Relative Humidity Difference (MicroART minus RWS) Descriptive Statistics

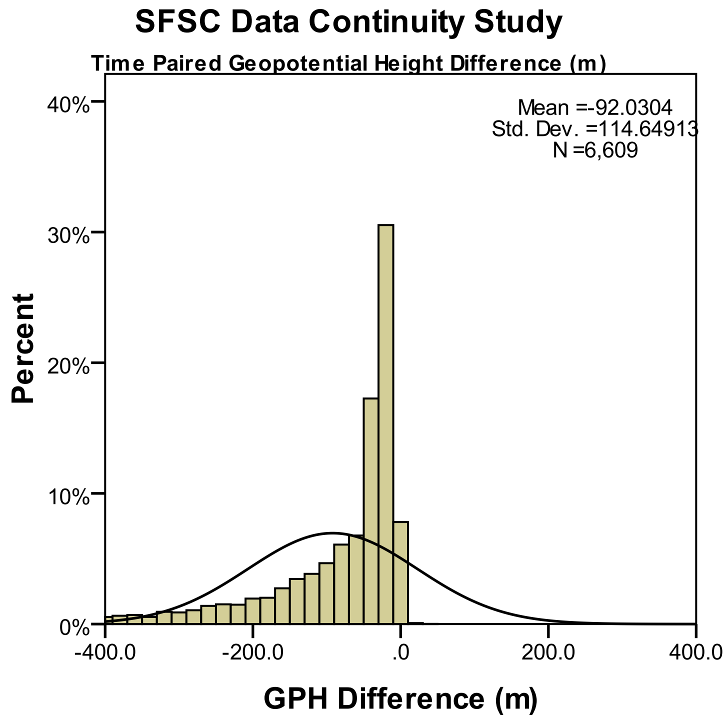

Figure 3 – Geopotential Height Difference Histogram of MicroART GPH minus RWS GPH

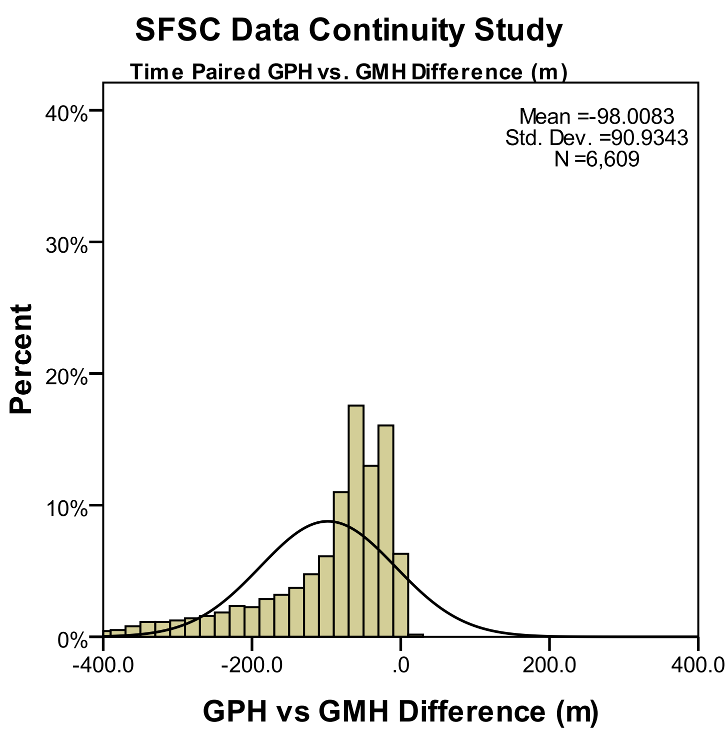

Figure 4 - Height Difference Histogram of MicroART GPH minus RWS GMH