North American Rawinsonde Observations: Problems, Concerns, and a Call to Action

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Abstract

Meteorologists, like most scientists, often use observational data assuming the necessary steps have been taken to ensure that the quality of the data has been properly controlled. Experience developing an archive of upper-air observations from historical and real-time data suggests that some of the steps necessary to assure the basic scientific integrity of these data have not, in fact, been taken. This is especially so in recent years, since the introduction of automation into data observing and processing. Some of the problems and issues related to the observation, collection, and archiving of upper-air data are discussed. The intent of this paper is to stimulate dialogue within the upper-air-data–user community about these issues so that appropriate action can be formulated and implemented.

1. Introduction

It is a fact of human nature that we want to believe someone else is taking care of those things over which we have no direct control, but upon which we depend for the well-being of our enterprises. Thus, it is understandable that meteorologists want to believe the collection and archiving of their datasets are in caring, capable hands, and everything is being done according to well-established and thoroughly documented procedures. Few research meteorologists seem to recognize that much of our data is collected for operational purposes, mostly by the National Weather Service (NWS) and the military. The prevailing attitudes and assumptions within meteorology seem to include a desire to avoid involvement in data acquisition and processing, and that any problems with the archive data reside within the "noise level," wherein there is little or no point in being concerned.

Based on our experience, we find that hopeful assumptions about the quantity and quality of operationally collected data are almost never justifiable. As scientists, we must assume responsibility for both and alert those responsible for implementation of our operational systems to deficiencies when they are discovered. This can be achieved only through an understanding of how our data have been collected, what assumptions may affect their quality, what quality control procedures (if any) have been implemented, and so on. If quantitative validation of theory is at the heart of science, then the quality of the data upon which validations (or refutations) are based is central to the scientific endeavor. Although we concentrate on rawinsonde (radiosonde and rawinsonde are used interchangeably in this report) data in this paper, much of what we are saying applies to other operationally acquired data, like surface observations.

Throughout the years, there have been many changes in instrumentation, data reduction (the method of translating the electrical signal of the radiosonde to actual values of temperature and humidity), reporting and coding practices, frequency and time of observations, location of stations, and data-archiving procedures. For the research meteorologist or climatologist using these data, knowledge of these changes is an important issue that has not received much attention until recently (see Elliott and Gaffen 1991). This may be because, up until the 1980s, there had not been a sufficient record of sounding data available for long-term climate or weather studies. In 1986, the NWS automated the data-reduction function at all their sounding sites. The negative impact of this totally automated system upon the operational data stream is summarized by Schwartz (1990) and is briefly outlined in section 2b. In addition, the late 1980s have seen a proliferation of different ground systems and flight instruments in use within the United States and Canada. The performance variability of these different instruments and systems is another issue, crucial to both the operational forecaster and the researcher, that has seen little attention in the meteorological literature (see, however, Finger and Schmidlin 1991). We have been actively pursuing the creation of a complete radiosonde archive for North America, including updates with operational data. Although most of these historical data reside in the archives at the National Climatic Data Center (NCDC) and the Canadian Atmospheric Environment Service (AES), there is, to our knowledge, no single comprehensive sounding database that contains all operationally collected rawinsonde data over North America, including those from the military. Through efforts to create such an

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archive, we have become aware of many (but probably not all) of the problems that exist within the operational data stream and archive system that are worthy of mention.

In this paper we briefly discuss a few of the real-time and archive rawinsonde data problems that exist today. In no sense is this survey intended to be an exhaustive summary of the entire problem. Rather, by introducing a few of the important issues concerning the observing, reporting and coding, and archiving of upper-air data, we hope to raise the meteorological community's level of awareness that data so long taken for granted are in need of attention and repair. Focusing on problems can give the appearance of being unduly negative; this most definitely is not our intent. Rather, we are calling attention to these issues to open a dialogue within the upper-air-data–user community that we hope will lead to improved data in the future for operational and research meteorologists alike.

2. Real-time data problems

Our presentation of real-time data issues follows no particular sequence; i.e., the order in which these problems appear is in no way indicative of their respective severity or importance. Much of what we have learned has been acquired through day-to-day experience working with real-time data, and through numerous personal conversations with meteorologists in the NWS and NCDC who reprocess these data for the archive.

a. Nonuniformity of equipment

Although the World Meteorological Organization (WMO) has set standards for reporting practices, procedures, and instrumentation accuracy [Federal Meteorological Handbooks (FMHs) 3 and 4; U.S. Department of Commerce et al. 1976, 1981], standards have never been set for the type of balloon, sonde type, ground-tracking equipment, data-reduction hardware and software, or personnel. All these factors can influence data quality and consistency.

Within the last few years, there has been an increase in the number of different sonde types used within the United States. Since 1958, the United States has been flying radiosondes manufactured by VIZ Manufacturing Company. In 1988, the VIZ "A" sonde was phased out in favor of a redesigned sonde known as the VIZ "B" sonde at 83 continental locations. Only United States-operated cooperative sites in Mexico and the Caribbean continue to use the VIZ "A" sonde. Also in 1988, approximately 15 U.S. sites switched to a sonde manufactured by the Space Data Corporation (SDC). Although individual performance characteristics of all three sondes were described recently by Ahnert (1991), direct intercomparison testing between the VIS "B" and SDC sonde has not been performed yet. However, Ahnert's results, showing the precision of the VIZ "A," VIZ "B," and SDC sondes, strongly imply that there are large differences in temperature readings between the SDC and VIZ radiosondes during daylight hours, especially in the stratosphere. In addition, the type of paint used on the SDC humidity-instrument duct was discovered to contribute to differences in moisture measurements between the two sonde types. It is obvious that more intercomparisons need to be made to further quantify the differences between the VIZ "B" and SDC sondes, since these are the primary radiosondes in use in the United States today. Although there has been discussion about the production of a "reference radiosonde" for these types of comparisons (Lally 1991; Finger and Schmidlin 1991), no such instrument exists as of this writing.

The NWS, Canadian, Mexican, Caribbean, and military sites also use different ground systems and software algorithms to reduce their data. Some of these systems are totally automated (e.g., the NWS microcomputer-based Automated Radio Theodolite, or micro-ART system), which carries inherent advantages and disadvantages (Schwartz 1990). Obviously, as the number of hardware and software systems increases with time, data resolution, accuracy, and procedures may vary more widely in space and time than they do now.

b. Effect of automation on data quality

The intent of automation is to standardize procedures, improve data consistency, and cut personnel costs. Certainly, this effort has been at least partially successful. In our opinion, automated procedures have been accompanied by a decrease in the quality control (QC) of data. Too often, obviously erroneous soundings continue to be transmitted over the data network, often undetected by local or national center QC procedures (Schwartz 1989). Overall, it is our observation that upper-air observers are becoming less capable of or less interested in recognizing sounding problems in real time, in comparison to the days when soundings were processed by hand. Automation only appears to demand less of the observer; in fact, observer knowledge is even more important in automated systems than in manual systems. If little or no observer intervention is necessary during data collection and processing, the observer is unlikely to be attentive to the details.

During the summer of 1990, the NWS completed most of the new micro-ART system implementation. The new system, although no doubt an improvement

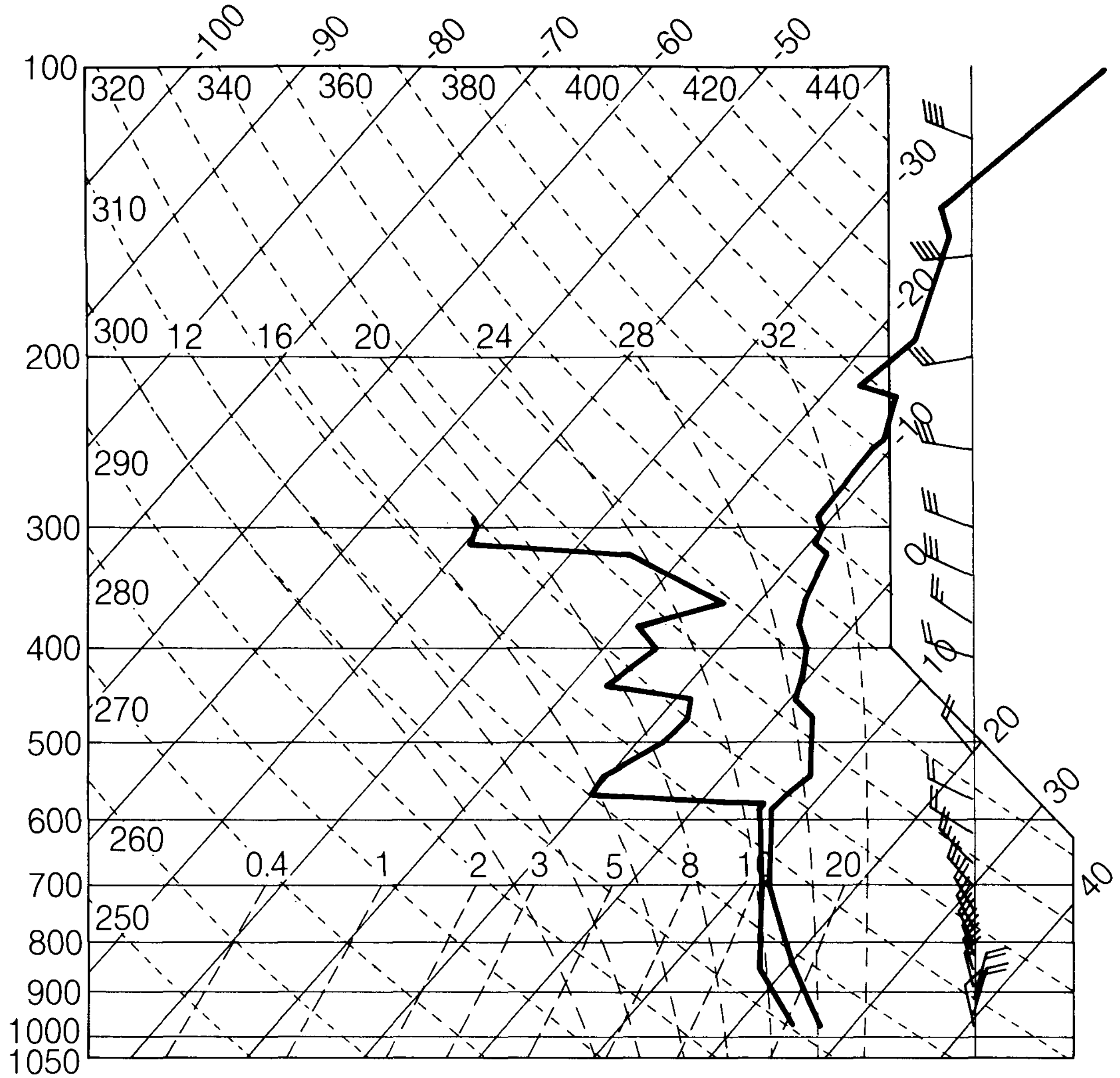

FIG. 1. Erroneous sounding taken at Dayton, Ohio, for 0000 UTC 15 June 1990.

on the original minicomputer-based ART system implemented in 1986, still depends on the observer to perform QC procedures, as we have noted. As a result, some of the problems seen in the operational data may be related to the observers not following new procedures implemented within the new ART system. Irrespective of the causes for the problems we have seen, unusual soundings have been getting into the real-time data stream (and the archive) since the implementation of micro-ART. Figure 1 is an excellent example of a micro-ART sounding that should never have been transmitted operationally. Temperatures (heights) are significantly too warm (high) for any time of the year at this location. Bosart (1990) discusses problems with this sounding in more detail.

c. Nonuniformity of reports transmitted to data centers

In addition to the data from regularly reporting NWS, Canadian, and United States-operated cooperative sites, there are numerous military radiosonde observations taken daily that never get disseminated over global communication networks. These soundings might provide valuable information to forecasters when no other information is available, and to researchers even if not available in real time. Can these soundings be integrated into the real-time data streams or a

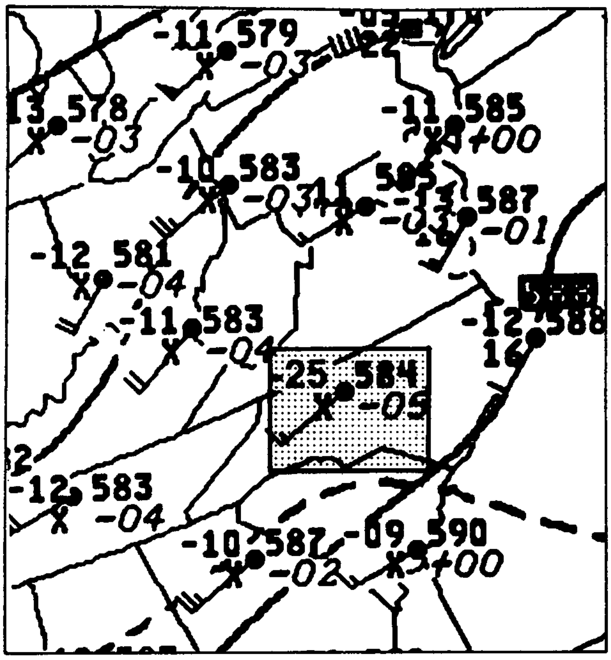

FIG. 2. NMC 500-mb analysis for 0000 UTC 16 November 1990, showing an erroneous temperature at Greensboro, NC (highlighted).

comprehensive archive? Although we know of no obvious reason why not, it appears that most of them never leave the hands of their local users.

We are aware of one problem with including these special-purpose military soundings in the real-time sounding database: many military sites do not follow WMO coding convention for the dissemination of their data. When data are transmitted in non-WMO convention formats, data centers or users who attempt to decode such data often have severe problems handling them, and often good data are rejected because they cannot be decoded. Creation of WMO-coded data from other formats is a simple task, of course, but it does require someone to write conversion programs. Data from Mexico, Canada, the Caribbean, and the military, often coded for transmission by hand, also contain similar coding errors that plague automated decoders.

d. Nonuniformity of quality-control procedures

The micro-ART system often flags data as questionable, but those flagged data frequently are transmitted as received, or changes are made to data without indications that data have been changed. These data are then sent to the NCDC for archive. Those using data decoded by national centers such as NMC need to know what quality control procedures (see, for example, Collins and Gandin 1990) have (and have not) been applied to the raw incoming data. Although these changes or corrections to the data are not transmitted operationally, those using data decoded at national centers should be aware of what has been done to the data. Until recently, NMC's quality control procedures generally have been limited to a comparison of the data to the "first guess" (a short-term forecast from a numerical model of what the sounding should look like). These procedures are usually effective in identifying bad soundings; however, on occasion an erroneous sounding can pass undetected through the NMC QC procedure (Fig. 2). Notice how the −25°C, 500-mb temperature at Greensboro, North Carolina, is too cold in comparison to surrounding observations. A simple hydrostatic testing and correction procedure, which could be applied on-station (e.g., Inman 1968), flags this particular temperature as erroneous.

e. Problematic reporting practices

In the United States, current reporting procedures dictate that relative humidity data are cut off at 20%; that is, whenever the relative humidity falls below 20%, a 30°C dewpoint depression is reported automatically. Wade (1991) indicates that the current hygristor does retain accuracy below 20%, and that this information could be supplied without the current arbitrary cutoff if the transfer equation (relating resistance to relative humidity) is recalibrated for low-end readings. Dewpoint depressions of more than 30°C used to be reported routinely for data up to the early 1970s within the United States, and are still reported in Canada today. The arbitrary cutoff procedure is unnecessary, and it can be argued that it has an adverse effect on forecasting. For example, precision in low-relative-humidity data is an important issue in forecasting and detection of microburst environments common to the southwestern United States (see Krumm 1954) during the warm season.

We have also seen a low bias for relative humidities >96% for U.S. stations, caused by another problem in the VIZ transfer equation (Potts 1980). This problem has been previously discussed by Golden et al. (1986). Prior to 1980, the algorithm that was in use created a high bias in relative humidities >90%; apparently, the 1980 VIZ algorithm (Potts 1980) was implemented to correct this bias and resulted in an overcorrection for humidities in the 96%–100% range. Another correction for relative humidities above 90% was developed by VIZ (see Potts 1983) but, although implemented by the Canadians and discussed by NWS officials (Nordahl 1982), has yet to be implemented by the United States. The effect of this low bias at high relative humidities can be seen in Fig. 3, which is a frequency distribution of relative humidity above 85% at West Palm Beach, Florida, for 731 soundings and all levels (except the surface; the surface point is taken by ground-based equipment) for 1985. Note the sharp drop in the

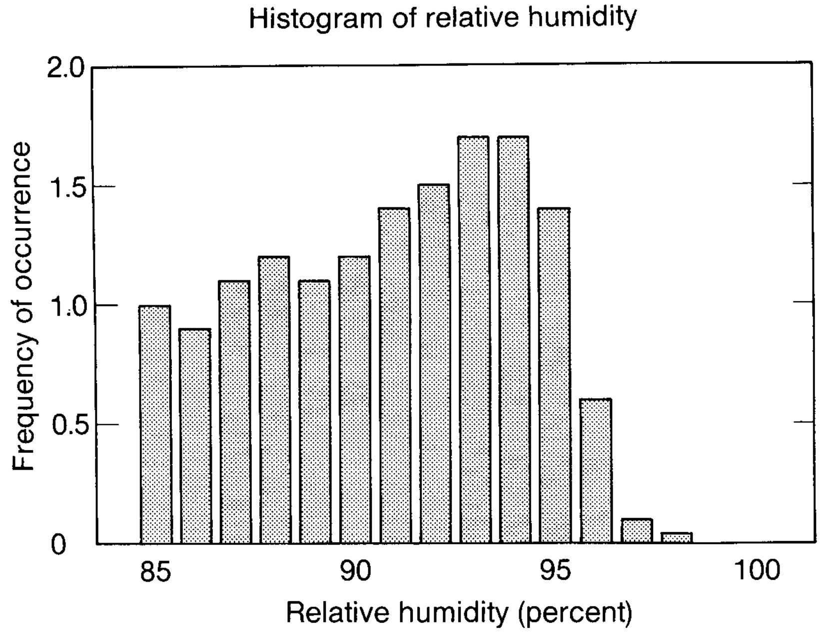

Fig. 3. Relative-humidity (above 85%) frequency histogram for all levels (except the surface) for 731 West Palm Beach, Florida, soundings from 1985.

percentage of total observations of relative humidities above 96%. A similar frequency distribution for Sable Island, Nova Scotia (not shown), does not show the large drop-off in relative humidity occurrences above 96%.

The surface-weather observation and station history data (e.g., latitude, longitude, and elevation) are not currently archived with the upper-air observation. It is common practice that surface conditions from the observation site that takes the hourly weather observations are used, rather than the conditions at the upper-air release site, occasionally leading to unrealistic vertical profiles in the boundary layer of the sounding. (The location of the upper-air and surface observation site are often two different locations.) Note the rapid decrease in relative humidity from the surface to the first point above the surface for the Winslow, Arizona, sounding shown in Fig. 4. Considering that the lower atmosphere is usually well mixed by 0000 UTC, it is probable that this odd profile is a result of an erroneous hourly surface observation from ground-based equipment.

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Wade (personal communication) has noted that sondes that have not been ventilated properly after indoor storage and released into the outdoor environment exhibit an unrealistic rapid decrease in mixing ratio from the surface to the first level above the surface (again, recall that the surface point is taken by ground-based equipment). This is caused by the change in relative humidity from indoors (usually an air-conditioned room; i.e., the indoor air is cooler, with a higher relative humidity than the outdoor air) to outdoors. In addition, Wade's discussion of unrealistic boundary-layer humidity profiles led to SDC's discovery that the paint used in the hygristor duct itself was hygroscopic, which contributes to the problem by retaining the high humidity from the storage room during initial parts of the flight (Fig. 5). Incidentally, the lifted index computed from the profile of Fig. 5 is −11°C, rather heavily influenced by the erroneously high surface-layer mixing ratio.

Within the last few years, we have noted an interesting problem with station elevation and surface pressure from a few of the NWS Central Region upper-air sites. For reasons unknown to us, station pressure is not measured at the location of rawinsonde release at all sites. Rather, at certain places, it is read from a remote altimeter on the runway and corrected for any difference in elevation from the runway to the radiosonde release location. Such was the case at Denver, Colorado, from 1983 to 1988 (Wade and Barnes 1988), where a systematic height error was introduced into the observed data when the site was moved, because of an erroneous algorithm used for the height correction. During the summer of 1990, we noticed that a similar height bias reappeared at Denver, this time of opposite sign. Upon inspection of the problem, we discovered that the NWS Central Region started using the WMO elevation (a runway elevation in most cases) rather than the "elevation for radiosonde purposes" at their sites. This interpretation

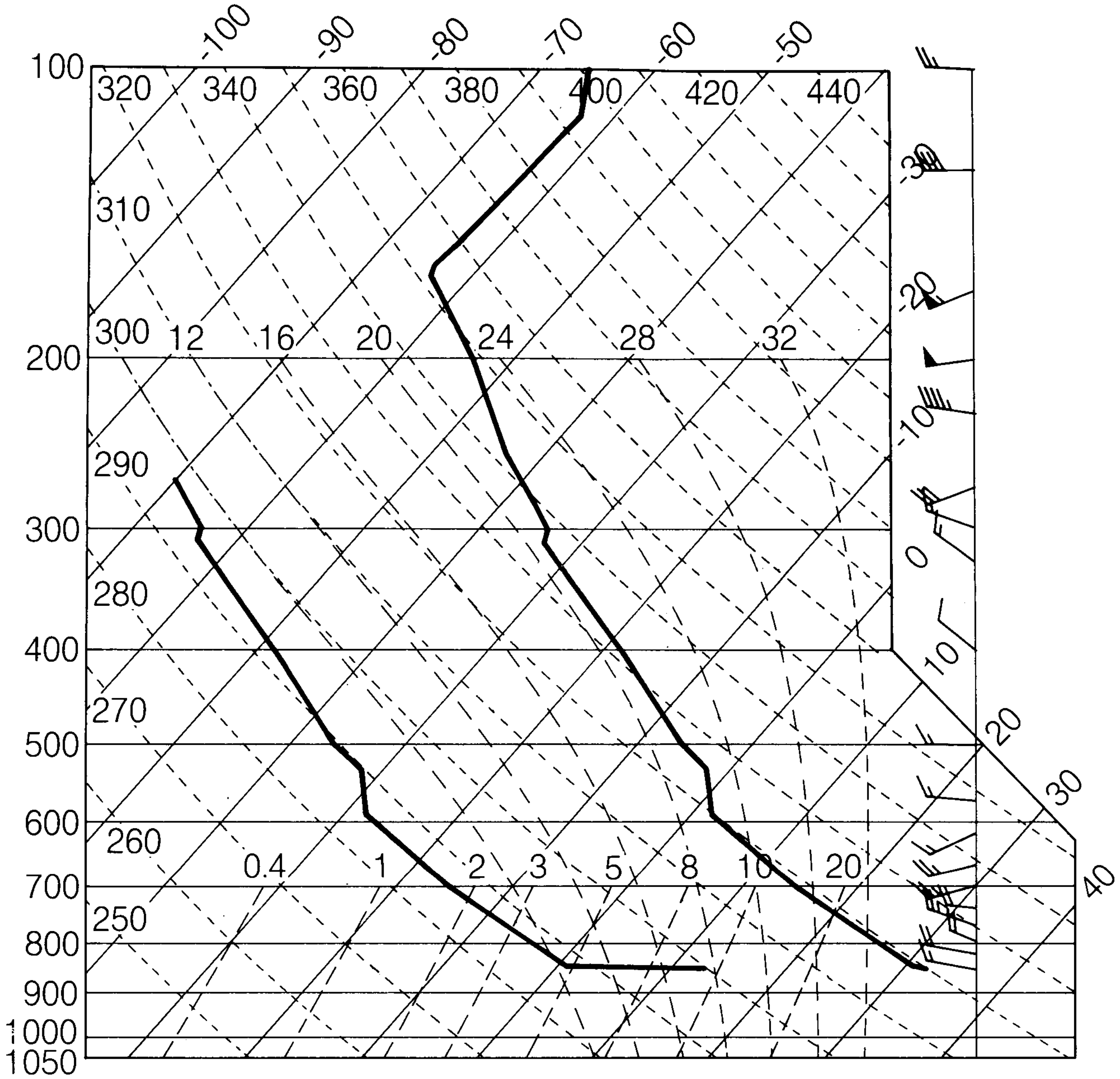

FIG. 4. Sounding taken at Winslow, Arizona, for 0000 UTC 8 June 1990, depicting an erroneous surface level.

of which elevation was to be used for the observation created a 15–30-m positive height anomaly at Denver during the summer of 1990 (e.g., Fig. 6), and likely has created biases elsewhere where runway elevations differ from the elevation of the radiosonde release. It would be logical to assume that NCDC uses the correct elevation in their reworking of the observations for the archive so that only users of these data in real time (e.g., NMC for the numerical models) were affected. This, however, is not invariably true, owing to problems with the station histories (discussed further below).

In Europe, many stations take upper-air observations four times per day, which was the procedure at many sites in the United States until 1957. The advantages of observations more than twice daily are obvious. With an increase in emphasis being placed upon forecasting mesoscale weather disturbances in the modernized NWS of the 1990s, it seems logical that more observations in both time and space are essential. Help from land- (e.g., profilers) and satellite-based remote sensors is still many years away. Moreover, the radiosonde's capability for resolving details of the thermodynamic structure in the vertical has yet to be duplicated by any of the new remote-sensing systems.

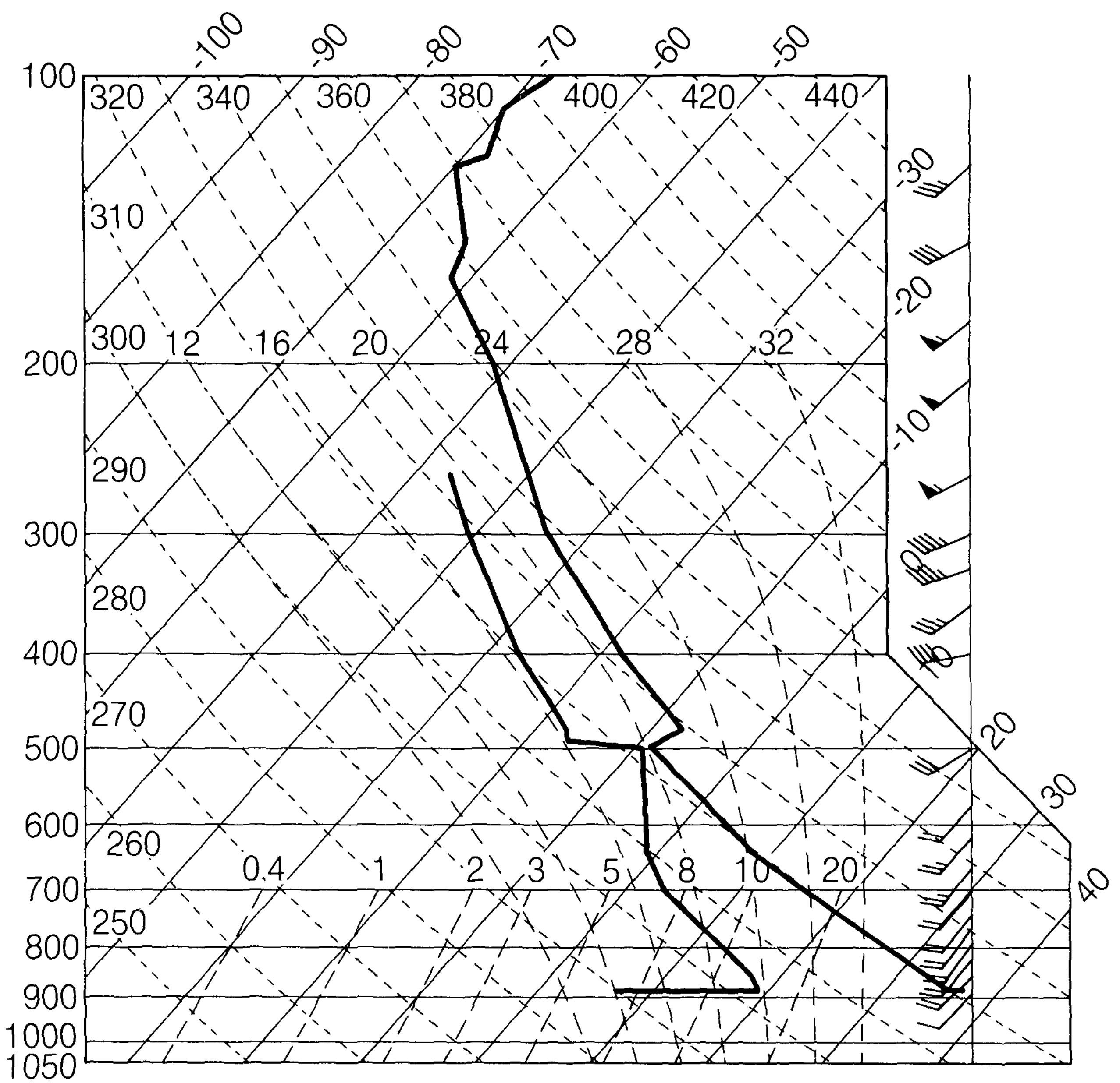

FIG. 5. Sounding taken at Amarillo, Texas, for 0000 UTC 15 June 1990, depicting an erroneous relative humidity boundary-layer profile.

f. Station moves

Within the last few years, the NWS has moved many sounding stations, and plans substantially more moves in the near future as part of its modernization program. This movement of sounding sites obviates the chances for long-term climatological records at many locations. These moves, which are not being done in accordance with any known scientific consideration, also are having a negative impact on operational forecasting by creating data voids and by eliminating an observation depicting terrain-controlled meteorological structure. As an example of the latter, the movement of the sounding site from inland Victoria, Texas, to Gulf Coast Corpus Christi has moved it away from one of the climatologically favored avenues for moisture return off the Gulf of Mexico. Corpus Christi is located such that its moisture profile is heavily influenced by the local maritime environment (e.g., sea-breeze circulation). However, Victoria, approximately 40 miles inland, is more likely to sample the true synoptic-scale return flow of Gulf moisture, which is critical to severe-storm forecasters.

In addition, the NWS has cut funding to the government of Mexico for 0000 UTC soundings and is considering the same for the cooperative stations in the Caribbean. As a result, observations from Mexico (and soon the Caribbean) are limited to once a day, at 1200 UTC. This decision has not been without impact on short-term forecasting over the southern United States. For example, examine the following state forecast discussion, written by an NWS forecaster mentioning how the missing Mexican data has made it more difficult to understand weather systems south of the border and their possible impact within the United States.

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FPUS3 KFTW 260908 COR
NORTH TEXAS FORECAST DISCUSSION...CORRECTED TO EXTEND FFA WEST
NATIONAL WEATHER SERVICE FORT WORTH TX
345 AM CDT THU APR 26 1990
WHAT'S TO SAY. SFC DEW PTS IN UPR 60S TO LWR 70S. EXISTING CNVCTN...
ALBEIT WKNG ATTM...PRODUCED OUTFLOW BNDRIES WHICH WL PLAGUE ERN ZNS
DURG MAX HEATING TIME. STG UPR DIFFLUENCE. AVN APRS BEST IN HNDLG VORT
MAX IN RIO GRANDE VLY. TRACK OF MEX VORT MAX AS INDICATED BY LFM LOOKS
BEST TO US BASED ON H2 TEMP FIELD AND H5 HGT CHGS...BUT HOW ACCURATE
THESE ARE IN MEXICO IS QUESTIONABLE. WE NEED MEX DATA. WL LWR POPS
SHARPLY WRN ZNS TDA SINCE AIRMASS SHD BE WORKED OVR PRETTY GOOD. SHARP
H5 TROF DICTATES KEEPING MENTION OF TSTMS IN FCST THO AND IN VIEW OF
ABV INGREDIENTS...THESE COULD BE SVR. WL KEEP HIGH POPS E TOGETHER WITH
GREATEST CHC OF SVR WX. WL ADJ FFA TO RUN FM CURRENT CNVCTV LN EWD
ACRS RMNDR N TX FOR TDA AND TNGT. MOS TEMPS LOOK TOO LOW...ESPECIALLY
DURG NGTTIME.
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The absence of Mexican data can have a deleterious effect on numerical model simulations whenever key features of a system are in Mexico. For instance, during simulation experiments with a mesoscale model associated with the 10–11 April 1979 Red River tornado outbreak, it was necessary to "enhance" the initial wind fields aloft, owing to a missing Mexican radiosonde, in order to obtain a realistic simulation (Chang et al. 1986). The absence of 0000 UTC Mexican sounding information can influence the short-range forecast, but it is also possible that the absence of information can propagate downstream and contaminate forecasts at longer ranges as well. Moreover, the planned cutback of soundings in the Caribbean could have serious forecast implications during the tropical-storm season. This situation calls to mind a previous discussion about the impact of decommissioning the sounding at "ship PAPA" in the eastern Pacific (see Spagnol et al. 1980), another case where economic considerations overrode the needs of operational forecaster and research scientist alike.

3. Archive data problems

Thus far, we have been concerned with the real-time aspects of the present-day rawinsonde system. However, today's operational data become tomorrow's research data archive. Operational considerations do necessarily drive the decision-making in the NWS, but those decisions can have a large impact on the quality and quantity of the sounding database.

a. The NCDC archive

The NCDC is the repository for all United States, Mexican, and Caribbean nonmilitary radiosonde data. [Note: Although the National Center for Atmospheric Research (NCAR) and other institutions ar-chive radiosonde data, they receive their data from NCDC; i.e., their data is essentially the same as NCDC data.] At NCDC, a set of computer programs reprocess the original station data before the data become part of the archive. It is important for researchers using these data to know some of the details about this processing that distinguish NCDC data from originally transmitted data.

As previously mentioned, it is common U.S. operational practice to report a 30°C dewpoint depression when the relative humidity falls below 20%. In the archive data, these levels appear as 19% relative humidities because NCDC has assigned all relative humidities <20% to 19%. If a computation of dewpoint depression is then performed using the archive humidity data, the user may not always get back the 30°C depression (this is because a 30°C depression at cold temperatures can result in a relative humidity as low as 5%, and these humidities have been set to 19%). A side-by-side comparison of real-time and archive dewpoint profiles often will show 30°C depressions "removed" from the archive data. Therefore, users of archive data should set the dewpoint depression to 30°C whenever they see humidities of 19%.

Archive data contain "generated levels" at even 50- and 25-mb increments (i.e., pseudo-"significant" levels; e.g., 950, 900, 800, 750, 650, 600, 550, 450, and 350 mb always appear in NCDC data). Temperatures and humidities at these generated levels are determined using a logarithmic interpolation in pressure; heights are computed hydrostatically from the temperature profile. In addition, there are more significant levels in the archive (in addition to the generated

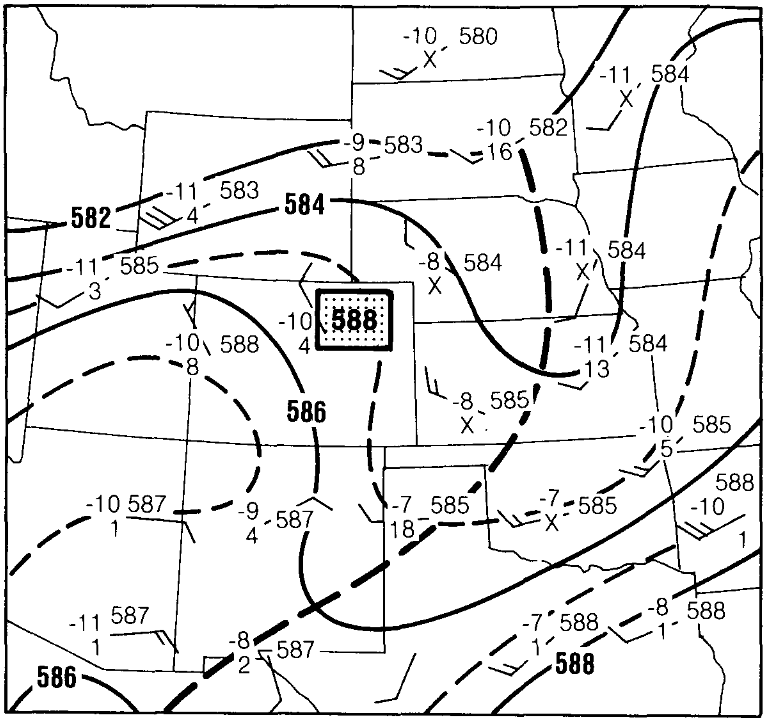

FIG. 6. 500-mb data and subjective-height analysis for 1200 UTC 1 August 1990, depicting erroneous height at Denver, Colorado (highlighted).

levels) than in real-time data because NCDC archives the full resolution sounding in accordance with the FMH-3 (U.S. Department of Commerce et al. 1981). Since the WMO criteria for selection of significant levels is less strict than those outlined in FMH-3, the real-time transmitted data are effectively a subset of the full resolution report archived at NCDC.

Original transmitted data contain winds at WMO defined "regionally fixed and significant wind levels" (U.S. Department of Commerce et al. 1976). NCDC supplies winds that are interpolated from the original 1-min wind data to the thermodynamic mandatory, significant, and generated levels. Often, the result of this interpolation is a smoothed wind profile when compared to the originally transmitted winds (e.g., Fig. 7; see also Stensrud et al. 1990, especially their Fig. 8). A possible undesirable effect of a smoothed wind profile is the underestimation of wind speeds at the core of jet streaks.

Certain pieces of information contained in the "A" part of the original data transmission are not retained in the NCDC archive; maximum wind, tropopause, mean winds, and stability index data are not archived. Nor are the time of rawinsonde release and sonde type retained, although they are included in the "B" part of the transmitted sounding. Station data (latitude, longitude, and elevation) as well as weather at time of release are also not archived as part of the record at NCDC. Although nothing can be done to include this information in old archive data, it is encouraging to note that NCDC plans to archive much of this information in the future.

In the past, decisions concerning how and what radiosonde data are to be archived have not always been made at NCDC with consultation or input from the user community. As a result of this past policy, the decision makers at NCDC have found it difficult to understand what the research community expects from a high-quality archive. It is encouraging to note that this policy apparently is changing as NCDC plans a future archive format.

b. Missing and incomplete data

Before recent technological changes, data for upper air were processed primarily on computer cards. During the 1960s, cards containing significant-level data were lost for some stations. Thus, archived data for those stations during this period consist of mandatory and generated levels only. It is our understanding that these lost data may be available in nondigital form; it will be a massive undertaking to key in the significant-level information if they are not available on a computer-compatible medium.

With the implementation of the mini-ART system in 1986, the number of missing soundings rose sharply.

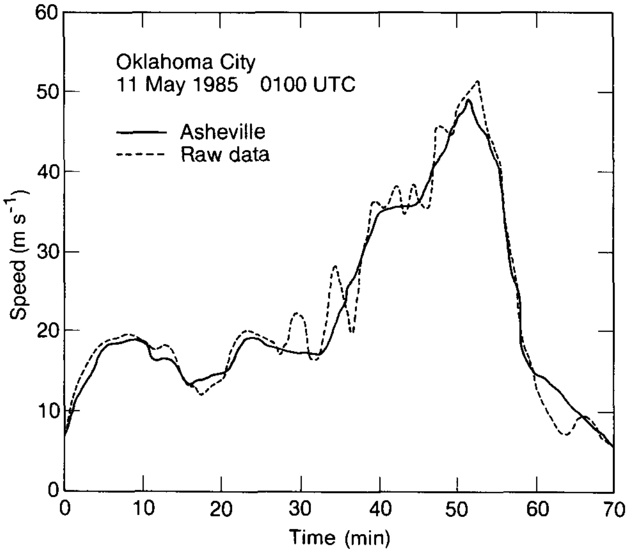

FIG. 7. Comparison of raw and NCDC-processed wind speed versus time at Oklahoma City, Oklahoma, sounding for 11 May 1985.

Many soundings were never taken because of local outages of the electronic equipment (often caused by lightning strikes; see Schwartz 1989 for details). As discussed previously, in 1989 the NWS also started using radiosondes manufactured by SDC. Although not an NCDC problem, the pressure cells with these sondes have been particularly troublesome (Williams, personal communication) for NCDC and have resulted in many incomplete soundings (soundings that terminate at levels below 100 mb) for certain stations in the archive. For example, the archive has many incomplete and questionable rawinsonde data from Amarillo, Texas, during May 1990, and from Grand Junction, Colorado, for most of April 1990.

c. Erroneous data

From 1965 to 1973, because of a bad hygristor duct on VIZ sondes, the humidity data could be in error by as much as 50%. Although this problem has received much attention in the literature (e.g., Friedman 1972; Pratt 1985; Elliot and Gaffen 1991), we are unaware of any correction applied to the archive data. The interpolation scheme that computes winds at significant thermodynamic levels from the 1-min wind data was found to contain errors during the 1970 to 1979 period, and has resulted in questionable winds at certain places; the exact impact of this problem is currently under investigation at this time (Williams, personal communication). Original data records needed to recompute these erroneous winds are not available.

It is interesting to note that there is a problem with Boise, Idaho, archive data for the period from 1948 to 1959. It appears that the computer card decks, upon which the mandatory and significant-level data were originally recorded, had been shuffled before being read onto magnetic tape. As a result, much of the data for this station are unusable. Although one of the authors (BES) recently wrote a computer algorithm that can correct most of these data, we are concerned that similar problems exist elsewhere and simply have not yet been detected.

d. Lack of comprehensive station-history documentation

Informal documentation of station moves, openings, and closings is kept at NWS regional headquarters and NCDC, but it has not been retained in digital form, may not be complete, and is not generally available to the user of radiosonde data. With the exception of a history compiled by the Weather Bureau back in 1962 (U.S. Department of Commerce 1962), there is no formal, up-to-date station history for upper-air soundings. We attempted to create such a comprehensive station history by searching for the original records that indicated changes to active upper-air sites. Much to our dismay, many of these records had been lost or discarded. Nevertheless, from information available from NCDC, NWS regional offices, and the AES, we have compiled a history in digital form. However, because of the lack of authentic information in certain cases, many questions remain in our version of the history. Using rawinsonde data from the past without being sure of station location and elevation is a risky practice, but this describes the current situation for users of the archive.

Instrumentation and ground processing-equipment histories are not readily available, either. Although we have also developed a digital record of equipment history, it is incomplete, at best. Knowing when and where instrumentation has changed is crucial to using the data intelligently. Certainly, those using radiosonde data to infer climate change need to know something about instrument changes in order to separate real signals from instrument bias in long-term meteorological data evaluation, as discussed in Elliott and Gaffen (1991).

e. Accessing data from NCDC

All users of NCDC data, including NWS field employees, are required to cover the cost of retrieving the data from NCDC. For NWS users, if the desired data are on the Automation of Field Operations and Services (AFOS) files, the data can be retrieved for study without further charge. However, AFOS files go back only to 1982, so if data before that time are needed, an ordinary NCDC request must be made. Furthermore, NCDC does not keep a synoptic sort (i.e., ordered by date) of the data, so that if one desires synoptically sorted data, this may need to be done at the user's expense. Ordering data for meteorological case studies is expensive, owing to the processing time it takes NCDC to fill a request, and, in part because of staffing problems, requests may not be filled in a timely manner at NCDC. As a result, forecasters from the NWS engaged in research projects may be denied access to their own data, at least in a practical sense. For the last several years, we have responded to numerous requests to provide data to operational forecasters for their studies because they found it impossible to get data via any of the formal channels.

4. Discussion and recommendations

Elliott and Gaffen (1991) correctly state that "meteorological data, particularly upper-air data, are taken largely for weather forecasting purposes, not to determine climatology." This has not deterred some from using these data for projects such as global warming and detection of climatic change, perhaps because there are no alternatives. Problems with real-time data suggest that some of the observations are of questionable quality for use in weather forecasting, as well. We think it a non sequitur that operational forecast needs can be met with data of lower quality than that required for research.

As evident from much discussion in the literature and in this paper, it is clear that relative humidity measurements from radiosondes still pose major problems. As discussed by Wade (1991), the current sensor has good resolution below 20%. We recommend that the NWS stop its antiquated practice of routinely reporting humidities <20% with 30°C dewpoint depressions. It is clear that the NWS needs to work with the radiosonde manufacturers to refine a transfer equation that relates resistance to relative humidity in order to improve both low- and high-end measurements.

The wide diversity of agencies involved with taking upper-air soundings, each with their own instrumentation and data-reduction software and hardware systems, indicates that coordination leading to standardization is needed in order to have some reasonable consistency among reports. Obviously, intercomparison flights are necessary and a "reference" sonde standard must be developed. In addition, past experience (e.g., micro-ART) suggests that those responsible for the implementation of new sensors, sondes, or ground-based equipment into operations should be more careful in the future to test and validate these systems adequately before they are implemented.

Monitoring of the data stream is needed to ensure adherence to WMO coding practices. We are not aware that any particular agency is responsible for monitoring the coding practices of individual stations so that when violations occur, the station can be notified and the problem corrected. One of the rationalizations given for the drop in support for 0000 UTC Mexican radiosondes has been that these observations historically have contained coding errors, and often have been received too late for use in the numerical prediction models. Rather than cut support for this important product, we recommend trying to solve the problem by improving communications and training, instead of eliminating the problem by removing the data.

It seems clear that quality control of upper-air observations has taken a back seat in the age of automation. Quality control needs top priority, especially because of automation; automation does not remove the need for knowledgeable human intervention any more than an automatic pilot removes the need for a human pilot in an airplane. Automated processing procedures need to be user friendly and understandable by the personnel operating the equipment. Observers need better education and training to recognize what does and does not constitute a good sounding, and clear incentives need to be reinstated for observers to carry out a quality observing program at their station. As currently implemented, system automation has led to a decrease in the incentive for observers to change or delete bad data, even when they have the opportunity to do so.

Lest the reader misunderstand, however, we do believe that technology can help produce more and better-automated quality-control programs on station and at our national data centers. We certainly support continuing development and improvement of automated systems for processing, coding, and transmitting data. The problems lie not with automation, per se, but with its particular implementation at present. Certainly, implementation of CD-ROM and optical-disk technology could alleviate many of the access, expense, and processing problems currently being experienced at NCDC.

Decisions concerning the location, time and frequency of observations, instrumentation type and precision, and what information gets archived have not always been made using scientific reasoning. Rather, budgetary constraints and an obsession to automate at the expense of the human observer seem to dictate what will happen to our observing system. Radiosonde observations are basic to the science of meteorology; the profession surely will suffer if we do not try to uphold high-quality standards for our observations. Meteorology is in danger of becoming a "historical" science, with our best and most complete upper-air data residing in the archives.

At that, there are many problems with the upper-air archive at NCDC. If original station records exist for "lost" data of the 1950s and 1960s, efforts could be made to digitize them for inclusion into the archive. Since documentation of how data are reprocessed is nonexistent, every effort should be made to document old and new computer software that process raw data for the archive. With the advent of highly efficient mass storage technology, the meteorological community should be striving to obtain an archive that contains the highest possible resolution data, with minimal revisions to the original records; smoothing or revision of data should be left to the user and not the archiver of data.

Finally, a concerted effort is necessary to establish a complete and accurate station history, including the type of instrumentation that was in use. This is going to require a commitment from many people and agencies. Once the history has been properly established, archive data may need reprocessing to assure that the correct station elevation and identification are attached to each individual sounding.

For decades, rawinsonde data have been neglected, and the archive reflects that neglect. With the sudden growth of interest in global climate change, it appears that climatologists are looking to the rawinsonde archive for confirmation of their hypotheses. Recently, an attempt to do on a global scale what we have begun for North America has started. The problems we have identified can only be magnified, so the value of a comprehensive world upper-air database hinges on a global commitment to data quality. It well may be that many of the problems with the archive cannot be solved with the means at our collective disposal. While we hope this is not the case, it may turn out that some of the problems with the present archive that we have described are insuperable. However, we do not want to be bemoaning the same problems with our archive ten years from now. If we must make mistakes as we move into an era with a more sophisticated mix of upper-air technologies, at least let them be new mistakes! A carefully considered archival program begun now will result in a quality archive only decades from the present. If we do nothing, then that archive decades hence will be plagued with the same difficulties. We end our discussion with a call to action and a request for commitment. Who will stand up and help assume responsibility for the health of our scientific data? Who is willing to be involved, instead of observing from the sidelines? Who is ready to back up their rhetoric with resources?

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