Recent Changes in NWS Upper-Air Observations with Emphasis on Changes from VIZ to Vaisala Radiosondes

BY WILLIAM P. ELLIOTT, REBECCA J. ROSS, AND WILLIAM H. BLACKMORE

Changes from VIZ to Vaisala in U.S. radiosondes resulted in apparent upper-air climate shifts that vary with season, elevation, and region. Other recent U.S. radiosonde changes are documented.

The detection of any climate change, whether due to human activity or natural changes, depends inter alia on the stability of the observing systems. Upper-air climatology is less well known than conditions at the surface but it is as important for understanding climate and its changes. Reliable upper-air radiosonde records begin only after about 1945 but even reconstructing this climate during the last half century is difficult because radiosonde observations have been made with a greater variety of sensors and devices than surface observations. Furthermore, radiosonde data handling techniques have changed substantially over the roughly 5 decades of their routine use. In this note, we examine one particular change in the United States National Weather Service (NWS) upper-air instrumentation in the 1990s: the switch from VIZ to Vaisala radiosondes at some of its upper-air stations at the end of 1995, calling attention to impacts of this change on climate analysis.

This is not the only change in NWS upper-air techniques that has occurred recently, however. In Table 1 we list the systemwide changes in NWS procedures since 1988; this table extends further the list of changes in both radiosondes and data processing that was recorded in Elliott and Gaffen (1991) and extended by Trenberth (1995). Furthermore, in the appendix we list changes since 1988 of the type of radiosonde used at individual stations, and in the locations of NWS stations. In the past, documentation of these changes was often limited to internal NWS reports, which are less accessible. Information on the NWS upper-air program, including the current network, is now available on NWS Web pages and we want to bring this to the attention of interested researchers (see appendix).

There have been several reviews of radiosonde changes and their possible effects on the climate record. Changes in radiosonde instrumentation can be associated with a shift in the mean of the temporal data record at a station, implying there is a systematic bias between the two instrument types. Because such a shift is intertwined with natural variability on many timescales, it can be difficult to identify. Station history information is useful for identifying when artificial biases might arise. On a global scale, Gaffen (1994) discussed temporal inhomogeneity problems

AFFILIATIONS: ELLIOTT (RETIRED) AND ROSS—Air Resources Laboratory, NOAA, Silver Spring, Maryland; BLACKMORE—Office of Operational Systems, National Weather Service, NOAA, Silver Spring, Maryland
CORRESPONDING AUTHOR: William H. Blackmore, NWS HQ, W/OPS22, SSMCII, Room 4324, 1325 East–West Highway, Silver Spring, MD 20902
E-mail: william.blackmore@noaa.gov

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Table 1. Systemwide changes in NWS radiosonde procedures since 1988.	
Date	**Change**
1988	Introduction of VIZ B radiosonde
1989–95	Use of SDD sondes at some stations
1989	Introduction of microcomputer–based recording system*
1993 (Oct)	Gravitational constant in computation of heights changed from 9.8 to 9.80665
1993 (Oct)	Relative humidity < 20% reported and calculated using "1b" coefficients**
1993 (Oct)	Relative humidity reported at T < –40°C instead of "missing"
1996	Vaisala sonde radio transmitters changed from 56H to more reliable 57H
1997 (Jun)	Relative humidity < 20% calculated with "1a" coefficients; introduction of VIZ-B2 radiosonde
1998 (Oct)	Balloons better suited to high-altitude use utilized at Pacific stations
1999 (summer)	Sippican begins manufacturing hygristors in its Mexico plant

*From about 1989 to 1999 there was a MICRO-ART recording system constraint that any temperatures lower than –90.1°C were transmitted as –90.1°C. In 1999 this limit was lowered to –99.9°C.

**For more information see Elliott et al. (1998).

of radiosondes worldwide and Gaffen (1996) compiled known changes in radiosonde instrumentation and reporting practices up to 1993. Elliott and Gaffen (1991) reviewed the radiosonde history of the NWS with an emphasis on moisture data. These studies considered effects of changes in recording and data processing as well as instrument changes.

Two of the major differences among radiosondes are their use, or lack thereof, of temperature corrections for exposure to long- and shortwave radiation, and in the type of sensors used for humidity (see, e.g., McMillin et al. 1992). In particular, the Vaisala instruments use quite different sensors from the VIZ sensors for temperature and humidity, and furthermore, the Vaisala signal processing unit has built-in short- and longwave radiation adjustments. So the Vaisala data transmitted over the global telecommunication system (GTS) are adjusted while the VIZ observations receive no radiation adjustment before transmission.

Luers and Eskridge (1998) compared calculations of the radiation effects, both long- and shortwave, on various types of radiosonde temperature sensors, including the VIZ and Vaisala radiosondes discussed here. They show that the raw observations from both sensors have radiation problems (even after Vaisala's recommended corrections) and they suggest additional adjustments. Chamber tests of humidity elements can be found in Blackmore and Taubvurtzel (1999). Examples of field comparisons of humidity sensors can be found in Schmidlin and Ivanov (1998), who compared relative humidity sensors directly, and Zipser and Johnson (1998) who compared operational results in the Pacific. Both studies found discrepancies between the VIZ and Vaisala relative humidity measurements. Vaisala observations were generally drier than VIZ observations in high humidity conditions, such as in the Tropics (Zipser and Johnson 1998), but were more moist at low humidity (Schmidlin and Ivanov 1998).

Until 1989, the U.S. National Weather Service upper-air radiosonde observations were made entirely with instruments manufactured by VIZ Corporation or its predecessors. Since then, NWS procurement practice requires that there be two vendors whose radiosondes are used in the network to ensure a continuous supply. The lowest bidder supplies about two-thirds of the sondes and the next lowest, one-third of the sondes. Thus, as new bids are requested, the potential exists for changes in sonde characteristics every several years or so. Between 1989 and 1995, NWS used instruments from Space Data Division (SDD) at some stations and, despite them using sensors similar to VIZ, there were some discernable differences (e.g., Wade 1994). These have now been phased out of the NWS network. [See Table A1 in the appendix for the stations and dates since 1988 when SDD as well as other types of sondes were used in the NWS network. The SDD dates differ slightly from those in Elliott et al. (1998) because the latter refers only to the start of humidity problems.] In 1995, NWS introduced the Vaisala RS80-56H radiosondes at 25 stations, and at 35 more stations in 1998. Figure 1 shows the locations of these stations. It is this change of instrumentation at some stations that we examine because the possibility exists for a shift of the monthly means of the reported quantities. Note that the National Centers for Environmental Prediction (NCEP) applies radiation adjustments to the VIZ observations and so the results shown here from analysis of the station records do not apply to the NCEP operational analyses.

DATA. Monthly mean values of temperature (T), dewpoint (T_d), relative humidity (RH), and geopotential height (Z) were extracted from the Monthly Aerological Data Set (MONADS; Sterin and Eskridge 1998) and processed into monthly mean anomaly time series for the period 1991–98. MONADS is a dataset of monthly upper-air statistics derived from radiosonde observations in the Comprehensive Aerological Reference Data Set (CARDS). CARDS data were in turn derived from all available worldwide radiosonde observations and put into a common format after passing through a quality control procedure (Eskridge et al. 1995; Smith 2000). No subsequent corrections for radiation effects on the instrument (e.g., NCEP radiation adjustments) were applied to the data in the CARDS processing procedures.

We examined the records of mean monthly values of temperature (T), dewpoint (T_d), relative humidity (RH), and geopotential height (Z) for effects brought about by the introduction of Vaisala RS80-56H sondes in November or December 1995 at sites previously using VIZ sondes. (We did not examine stations that adopted Vaisala equipment in 1998 because the version of MONADS we used ended in 1998; furthermore, VIZ sondes are now being manufactured by Sippican and there could be difficulty comparing these two nearly simultaneous changes.) Of the 25 stations that adopted Vaisala sondes in 1995, 11 had used SDD sondes or were otherwise unsuitable prior to the change and were omitted from this analysis. Of the remaining 14 stations that changed from VIZ to Vaisala, 3 stations are in the conterminous states, while 6 stations are in Alaska, and 5 stations are in the Pacific. These 14 Vaisala stations were compared to nearby "reference" stations that continued using VIZ, to reduce effects of any overall change in climate during the time period examined. These stations and their associated reference stations are listed in Table 2. Over Alaska and the Pacific, some stations share the same reference station because there were few stations in these areas that used VIZ continuously through this period. Note that the distance between the station and its reference (Table 2) can be (unavoidably) large, especially over the Pacific. A reference station was chosen based on location (near the Vaisala station) and on the correlation of its data with the data of the Vaisala station. Correlations between each Vaisala station and its reference station for 500-hPa T and 700-hPa RH are given in Table 2. These station pairs usually had correlation coefficients of temperature that were greater than 0.6 and often greater than 0.8. There were smaller correlations between RH values, as would be expected.

Time series of the differences between anomalies of each Vaisala station and its reference station were examined at five pressure levels (850, 700, 500, 100, and 50 hPa) for four variables (T, T_d, RH, and Z). Time series were calculated for each observation time (0000 or 1200 UTC) separately. To determine if a shift in the mean is detectable at the time of the instrument change, we used means of the 2-yr periods before and after the change for the comparisons, that is, the 24-month mean of the variable during 1996–97 minus the 24-month mean during 1994–95. This procedure is illustrated in Fig. 2 for 100-hPa temperatures at 0000 UTC at Lihue, Hawaii,

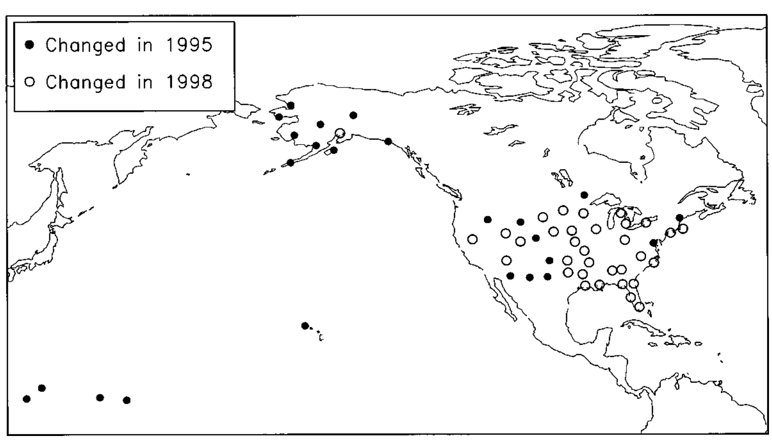

FIG. 1. Locations of radiosonde stations in the U.S. upper-air network that began using the Vaisala radiosonde in 1995 (filled circles) or in 1998 (open circles). Station names are listed in Table 2.

TABLE 2. List of stations that changed to Vaisala radiosondes, the reference stations, distance between a station and its reference station, and the correlations between them for 500-hPa *T* and 700-hPa RH.

Station	WMO no.	Reference station	WMO no.	Distance to reference station (km)	Correlation of 500-hPa *T*	Correlation of 700-hPa RH
Sterling, VA	72403	Pittsburgh, PA	72520	288	0.91	0.52
Denver, CO	72469	North Platte, NE	72562	377	0.86	0.64
Int'l Falls, MN	72747	Green Bay, WI	72645	599	0.85	0.39
King Salmon, AK	70326	Anchorage, AK	70273	455	0.78	0.59
Kodiak, AK	70350	Anchorage, AK	70273	400	0.79	0.34
Kotzebue, AK	70133	Barrow, AK	70026	533	0.85	0.33
Nome, AK	70200	Barrow, AK	70026	832	0.74	0.18
Yakutat, AK	70361	Anchorage, AK	70273	588	0.82	0.59
Cold Bay, AK	70316	St. Paul Island, AK	70308	511	0.85	0.52
Lihue, HI	91165	Hilo, HI	91285	500	0.80	0.68
Koror, Palau WCI	91408	Majuro	91376	733	0.55	0.25
Ponape, ECI	91348	Kwajalein	91366	1054	0.44	0.76
Chuuk, ECI	91334	Majuro	91376	2142	0.55	0.76
Yap, WCI	91413	Majuro	91376	3663	0.49	0.29

which changed to Vaisala instruments at the end of 1995, and at Hilo, Hawaii, which did not. Statistical significance of the difference between the means was assessed with a two-tailed *t* test using a 5% level of significance. In this case an apparent cooling of about 2 K occurred when Vaisala sondes were introduced.

RESULTS. Figure 3 gives the changes of the 100-hPa temperature at 0000 and 1200 UTC. The locations of the reference stations are also shown. The change to Vaisala produced an apparent cooling over the Pacific and over southern Alaska at 0000 UTC (local day) of up to 2.3 K whereas at 1200 UTC (local night) the change produced an apparent warming over Alaska and less apparent cooling over the Pacific. The three stations in the central United States show small changes of either sign at both observation times. At the other pressures the patterns look much the same: 500-hPa temperature differences look similar to 100-hPa changes but are a bit larger, while 500-hPa changes are less than those at 100 hPa but more than at 700 hPa; the 850-hPa changes are quite similar to the 700-hPa changes. We will discuss regional and seasonal differences of the other variables below. The large differences in temperature at high levels are partly because Vaisala adjusts measurements for radiation effects while VIZ does not.

Figures 4–7 summarize the differences for each station at different pressures and for the four variables. The stations have been grouped into an Alaskan group, a Pacific group, and a central U.S. group and the station differences are shown using different symbols according to region. If the differences are significantly different from zero, the symbols are shown to the left of the vertical line denoting the pressure level, otherwise the symbols are to the right of the line.

Figure 4 illustrates the wide variety of apparent temperature changes accompanying the change in instruments. At both times the largest differences are seen at 100 and 50 hPa, as well as the largest spread of difference values. At 0000 UTC, apparent cooling was usually the rule with the strongest effect seen over the Pacific. At 100 and 50 hPa, the apparent cooling was greater than 2 K over the Pacific and was statistically significant at all Pacific stations. At 500 and 700 hPa, the Pacific *T* differences were smaller

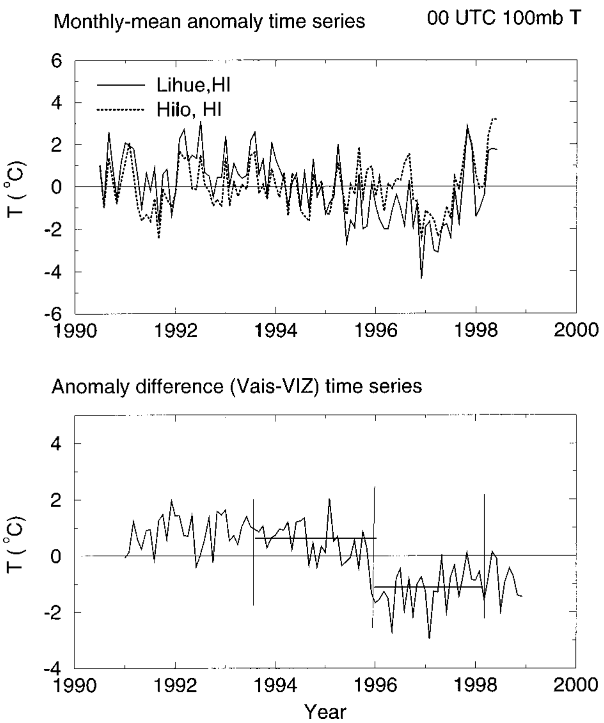

FIG. 2. Example of procedures for identification of a shift in the mean due to the 1995 instrumentation change. (top) The monthly mean anomaly time series of 0000 UTC 100-hPa temperature for Lihue, HI (which changed to Vaisala), and for Hilo, HI (which stayed with VIZ). (bottom) The anomaly difference time series (Lihue–Hilo). The means of the 2-yr periods before and after the change are shown by the horizontal lines. The effect of the instrument change is defined as the difference between the two means. In this case, the change to Vaisala produced an apparent cooling of about 2 K.

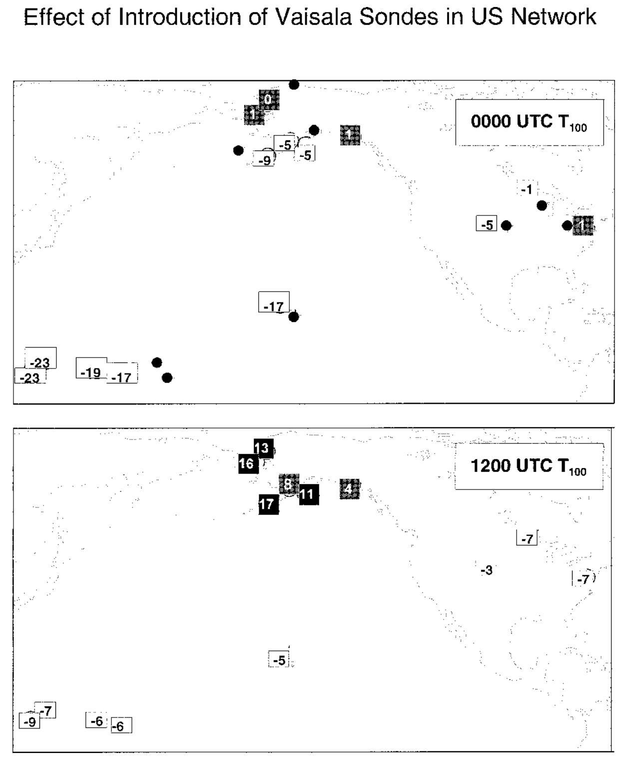

FIG. 3. Changes in the anomaly difference (Vaisala–reference) time series of 100-hPa temperature (values are given in 0.1 K) at (top) 0000 and (bottom) 1200 UTC. Positive changes indicate an apparent warming after the change to Vaisala and are shown with white numbers on black or gray squares. Negative changes (apparent cooling) are shown with black numbers on black- or grey-bordered white squares. Black filled squares (positive changes) or black-bordered squares (negative changes) indicate the change in the mean was statistically significant at the 5% level. Locations of the reference stations are indicated by the black circles.

(about 1 and 0.5 K, respectively) but most were still significant. At 1200 UTC, on the other hand, most Alaska stations showed a significant apparent warming at 100 and 50 hPa, while the Pacific stations showed weak (< 1 K) cooling. The 1200 UTC T differences at levels below 100 hPa were generally not statistically significant and most values were near zero. These differences (at least at high levels) are partly explainable by the lack of a temperature correction for the VIZ measurements.

Differences in Z (Fig. 5) are similar to those of temperature at both times, as would be expected. At 0000 UTC apparent heights could be as much as 120 m lower (80 m higher at 1200 UTC) after the change at 50 hPa. At 500 hPa and below, the Z differences show a scatter of about ±20 m. At 1200 UTC there is a tendency for apparent height differences to be slightly more positive relative to 0000 UTC. There are a few more height differences that are statistically significant than temperature differences.

The differences in RH (Fig. 6) show substantial changes at 100 hPa, both positive and negative. (The humidity variables were not available at 50 hPa.) However, radiosonde reports of humidity with either sensor are unreliable at pressures lower than about 500 hPa because the instrumental responses are poor at cold temperatures and low water vapor. Nevertheless, since values at these levels are reported, the effects of the instrument change need to be considered. At 500 hPa and below, values of RH show little difference between 0000 and 1200 UTC, and range between –8% to +6% with mixed significance. One notably significant difference is at 850 hPa, where Pacific stations show apparent drying of 4%–8% with the introduction of Vaisala instruments. This

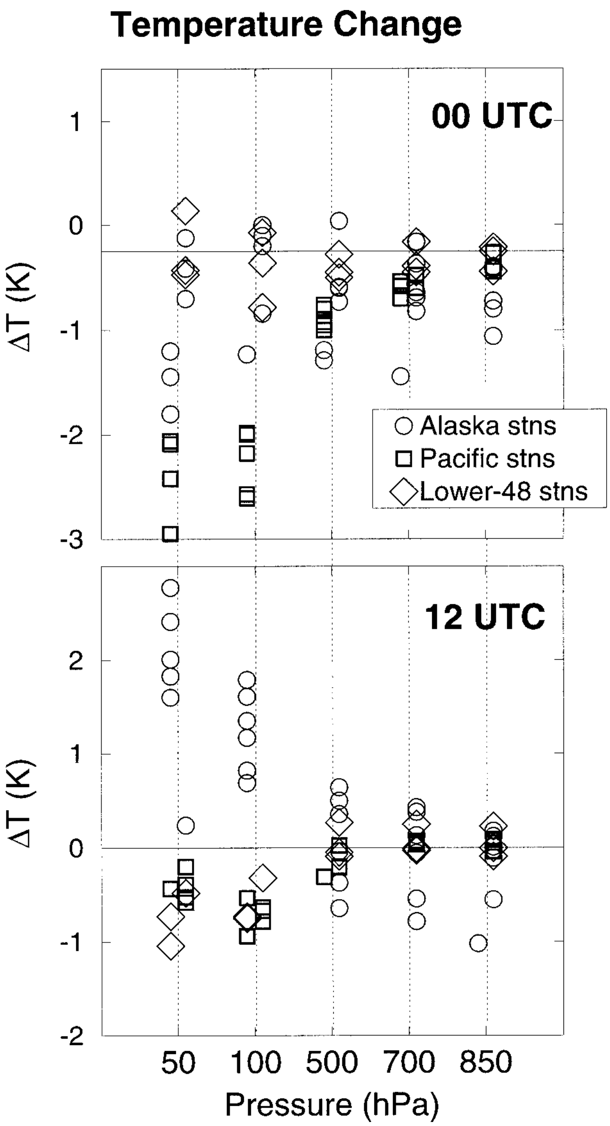

Fig. 4. Changes in (top) 0000 and (bottom) 1200 UTC temperature (Vaisala–reference) at five pressure levels. Stations are divided into three regions and different symbols are used for the stations in each region. There are six Alaska stations, five Pacific stations and three lower 48 (conterminous) stations. Vertical dotted lines separate differences according to statistical significance; differences to the left of the dotted line exceeded the 5% significance level of a t test for difference between two means.

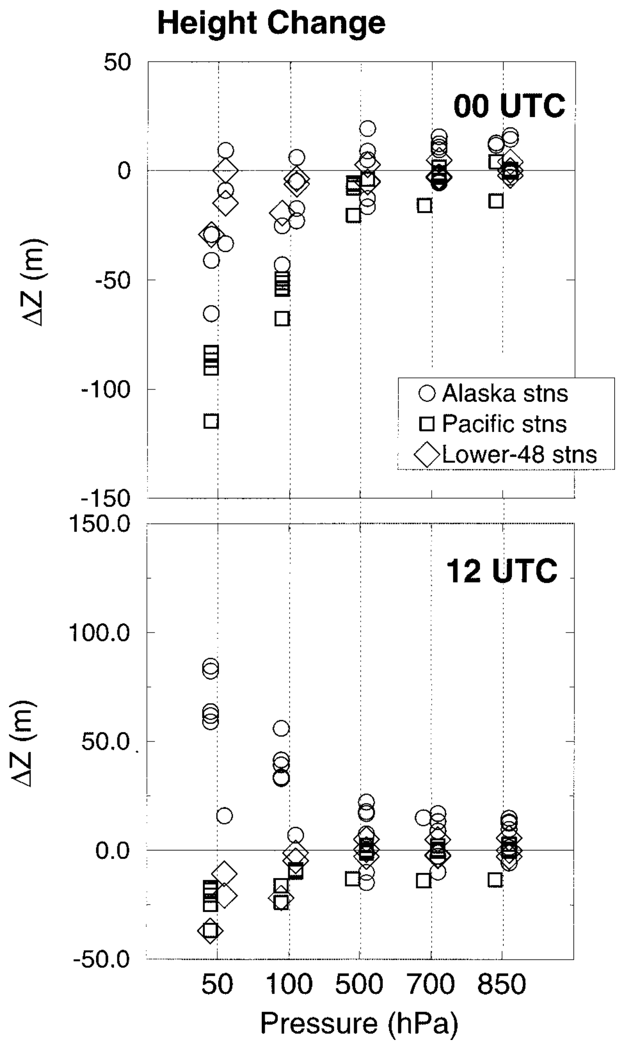

Fig. 5. Same as Fig. 4, but for height changes.

is consistent with the findings of Zipser and Johnson (1998).

Figure 7 shows changes in T_d, which combine features seen in the T and RH differences as might be expected. Most stations show apparent drying when the Vaisala sonde was introduced, especially at 100 hPa, and more so for 0000 UTC than for 1200 UTC. However, like RH, T_d values at 100 hPa are not reliable. The apparent drying at 850 hPa for Pacific stations, seen in RH, is also evident for T_d.

A general point apparent in Figs. 4–7 is that there are distinct regional differences in the response to the instrument change, especially at the lower pressures. Figures 4 and 5 show some regional separations in the 100- and 50-hPa T and Z differences among the stations; the Pacific stations show a larger negative change at 0000 UTC while the Alaska stations show large positive differences at 1200 UTC. Regional variations in the differences of the moisture variables, are most obvious for 100-ha RH at 1200 UTC where most Pacific stations show a significant apparent moistening, while Alaskan and central U.S. stations show drying. Another difference is for Pacific stations at 850 hPa, where drying for Pacific stations is generally only slightly larger than other stations but is statistically significant. The reasons for the regionality

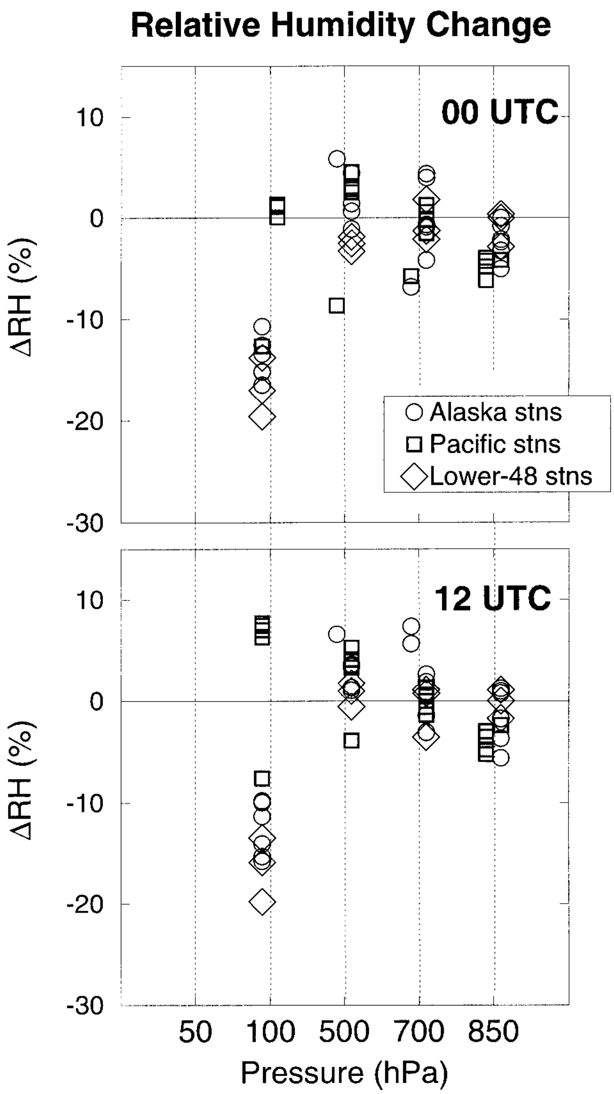

Fig. 6. Same as Fig. 4, but for relative humidity changes.

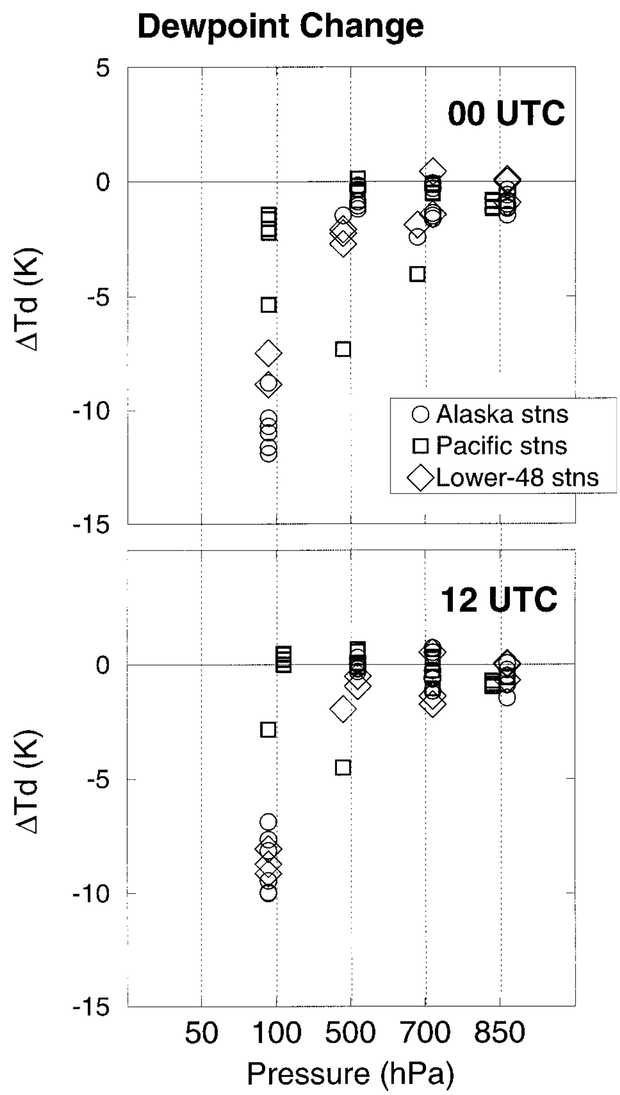

Fig. 7. Same as Fig. 4, but for dewpoint temperature changes.

in the effect of the change are not entirely clear but may reflect the influence of the ambient environmental conditions on the sensor response. For instance, Schmidlin and Ivanov (1998) reported field comparisons between radiosondes where the VIZ-reported RH was higher than that of Vaisala when RH was greater than 60%, but was drier than Vaisala at low RH. VIZ-reported RH was also drier when temperatures were below zero. Although the Pacific drying we report for 850 hPa is consistent with moister VIZ measurements relative to Vaisala at high RH, the difference in sign of the 100-hPa RH results (Pacific moistens, Alaska dries) does not seem to be explainable in this way.

Another general factor is the difference between 0000 and 1200 UTC results. To look more carefully at the day–night temperature differences we averaged the five Pacific stations, and the six Alaskan stations, into two regional groupings and subtracted the 1200 UTC (nighttime) temperature anomalies from the 0000 UTC (daytime) anomalies. Diurnal differences were also computed from a similar regional averaging of the reference stations.

Figure 8 shows the 0000–1200 UTC temperature differences at 100 and 700 hPa for the Alaska stations that changed to Vaisala radiosondes, keeping in mind that Vaisala adjusts the temperatures for radiation while VIZ does not. There is a distinct annual cycle in the day–night differences prior to the change of instruments, especially at 100 hPa. The largest 0000–1200 UTC T differences occur during the summer months, and the smallest during winter. Because Alaska has extended daylight in summer and almost complete darkness in winter, the annual cycle of dif-

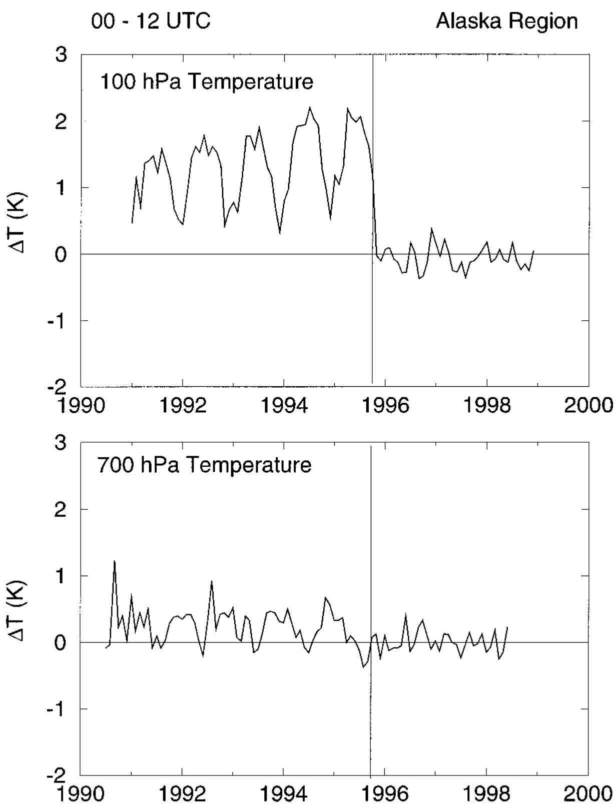

Fig. 8. Regionally averaged 0000 UTC–1200 UTC differences of (top) 100- and (bottom) 700-hPa temperature for the Alaskan region. In this case, no reference time series were used.

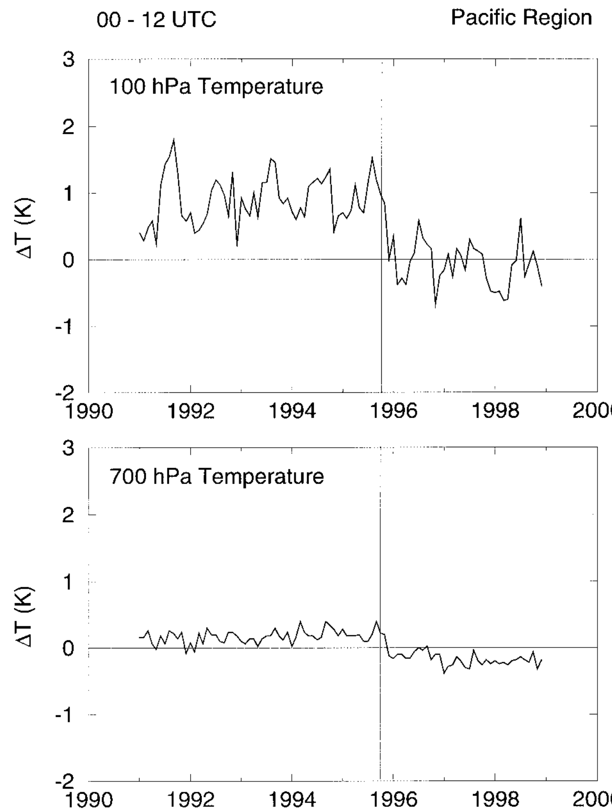

Fig. 9. Same as Fig. 8, but for (top) 100- and (bottom) 700-hPa temperature for the Pacific region.

ferences suggests that solar radiation effects are pronounced for VIZ instruments. This might be expected since observations from VIZ radiosondes are uncorrected for radiation effects and it also suggests that the shortwave radiation effects dominate the longwave effects here.

The annual cycle of differences is virtually gone after the change to Vaisala instruments. The reference stations (not shown) showed no particular break throughout the period, continuing the annual cycle throughout the period of record and demonstrating that the change was not due to natural variations. At 700 hPa (Fig. 8b) the annual cycle in the temporal differences before the change is less prominent than at 100 hPa although there is still a change from warmer daytime conditions with VIZ (i.e., positive 0000–1200 UTC differences) to almost no difference between day and night with Vaisala. The reduced annual cycle at 700 hPa would be expected since radiation effects are most severe at high altitudes (i.e., Luers and Eskridge 1998).

Comparable plots for the Pacific stations (Fig. 9) show, at best, a hint of an annual cycle in the diurnal differences at 100 hPa. Prior to the change, the 0000 UTC temperatures were warmer than those at night at both 100 and 700 hPa. After the change, the 100-hPa anomalies show very little day–night difference (although the differences are noisier than for Alaska, shown in Fig. 8) but at 700 hPa the bias changed from warmer daytime conditions to cooler daytime conditions. This result is unlikely to be radiation-related and differs from the comparable 700-hPa result for Alaska (Fig 8).

The other variables also display day–night differences (not shown). The RH differences are relatively small, generally 1%–2% although they can be as high as 6% drier at night in the Pacific at 100 hPa. The 0000–1200 UTC T_d differences are of the same magnitude and signs as the T differences. Day–night differences for the three conterminous stations (not shown) are within ±0.5 K and show little change after the switch to Vaisala. Since the 0000 and 1200 UTC observation for those stations are both taken when the sun is not so high (e.g., 0600 and 1800 LST at 90°W), it is perhaps not surprising that the impact is small.

Evaluation of seasonal differences is more uncertain since seasonal averages over the 2-yr period before or after the change are based on only 6-monthly values (rather than 24 months for annual averages), but there appears to be little difference between cold season and warm season patterns of temperature differences at each observation time. However, after the change in instruments, dewpoint differences at 700 hPa (not shown) indicate an apparent drying in the warm season but moistening in the cold season in the Pacific and the reverse in Alaska, that is, cold season drying and warm season moistening.

To summarize: at 14 radiosonde stations that changed from VIZ sondes to Vaisala sondes in 1995, substantial differences in mean monthly values of several variables were produced. Differences in monthly values of temperature could reach ±3 K at 50 hPa, ±2 K at 100 hPa, and ±1 K in the lower troposphere. Comparable changes in Z were ±80 m at 50 hPa, ±60 m at 100 hPa, and ±20 m at 850 hPa. Relative humidity changes were about ±5% at 500 hPa and lower. (Suspect values could be as high as −20% at 100 hPa.) Changes in dewpoint were nearly +1 K to −3 K, at 500 hPa and below. (Changes of nearly −12 K were found at 100 hPa.) The magnitude and even the sign of these effects from the time of the instrument change depended on the elevation (pressure), on where the observations were made, on the time of observation, and on the season.

DISCUSSION. Our purpose in this note is to document recent changes in the U.S. NWS upper-air observing network and to quantify the differences in upper-air records when a subset of the station network changed from VIZ to Vaisala radiosondes. These differences between the data records from the two types of radiosondes depend on the height of the observation, the time of day, the region, and the season. Therefore, no single networkwide adjustment will bring the monthly records into alignment. Any adjustment strategy must consider each station's characteristics; geographic location (or at least latitude), seasonality, ambient temperature and humidity, and must vary with altitude. While many of the differences between the two radiosondes may reflect effects of the angle of the sun on the instrument and therefore on the radiation adjustments (or lack thereof), that is not likely to be the sole cause (see Luers and Eskridge 1998). Even at and below 500 hPa, where any radiation corrections are minor, some records show systematic differences. Furthermore, the two sondes use different types of relative humidity sensors which are the likely source of differences in relative humidity.

Many of the changes listed are the results of improvements in sensors or practices that make the observations better or more cost-effective for forecasting purposes. Nevertheless, instrument changes have a deleterious effect on the long-term radiosonde records that are used for detecting climate change. The instrumentation changes resulting from the two-vendor practice as well as other NWS changes such as the moving of some stations in the U.S. network (see appendix) is evidence that homogeneity of the U.S. upper-air climate record is more precarious than ever. The practical reality is that changes will continue in the network and so analysts will have to cope with inhomogeneous records. For instance, NWS is contemplating an entirely new replacement sonde that will incorporate quite different sensors.

These considerations illustrate a wider problem than just the switch from VIZ to Vaisala in the NWS network. There are other sondes besides these two in use around the world. All these instruments may change or new ones may be introduced. The VIZ instrument is now produced by Sippican and while we have not evaluated the effect of this change there may well be differences even though the same sensors are used. Vaisala has a new sonde, the RS90, which could be adopted in the future, not only by the United States but in many other countries. A laudable effort to quantify bias characteristics of operational radiosonde types is the World Meteorological Organization (WMO) Commission for Instruments and Methods of Observations (CIMO) radiosonde intercomparison program (e.g., Schmidlin and Ivanov 1998). Also, there can be changes in data processing that have little to do with sensors, for example, Elliott et al. (1998). All these factors make constructing a worldwide upper-air climatology even more difficult. Detecting climatological changes will be even harder because the apparent changes resulting from instrument differences can be comparable or even larger than anticipated changes in the climate. Some principles for establishing and maintaining climate observation networks that would help the upper-air observation network continue to be useful for climate studies can be found in Karl et al. (1995).

Results from the WMO CIMO radiosonde intercomparison program (e.g., Schmidlin and Ivanov 1998) are a useful guide to differences among instruments but are limited by their lack of an overall standard. For example, the Schmidlin and Ivanov (1998) biases are relative to the Vaisala RS80 radiosonde yet recent studies (e.g., Wang et al. 2002) have shown some biases in the RS80's humidity measurements. One step that would help reduce the problem of ongoing changes in instrumentation would be the development, and use, of a standard upper-air measurement instrument, probably some form of radiosonde, to which all upper-air measurements could be referenced. [Such a standard has been recommended by the National Research Council; NRC (1999).] This device must be as accurate as possible under constraints of cost and deployment. The instrument would have to be one that does not change or, if technological advances make such a change desirable, then careful calibration intercomparisons between the new and older device would need to be carried out. Such a system could be used to reduce the world's upper-air observations to a common reference. The comparisons between instruments and this device would have to encompass many climatological regimes, as the effects on instrument systems are different in different regimes. The device would be valuable for reducing temporal shifts in the mean such as we have shown here and so help produce homogeneous climate records. It would also assist in evaluating other systems for measuring upper-air properties, such as ground- or space-based remote sensing devices.

APPENDIX: RADIOSONDE CHANGES. In Table A1 we list the radiosonde type in use at NWS sites since 1988. The types have been manufactured by VIZ (now Sippican), SDD (a division of Orbital Sciences), and Vaisala. There have been three types of VIZ sondes: designated VIZ B, introduced in 1988; VIZ B2, introduced in 1997; and VIZ Microsonde. Prior to 1988 the VIZ sondes were exclusively used by NWS, and since 1999, VIZ-type sondes have been manufactured by Sippican. Some of the dates are approximate as individual stations may have used available older sondes before switching to new sondes. Information on the current radiosonde network and additional information about the NWS radiosonde program can be found online (www.ua.nws.noaa.gov).

The tables are arranged so that the WMO identifying number is given first, the name of the station is given next and then the subsequent entries give the type of sonde that was in use during which time. If the entry is "n/a," that sonde was not used at the station. The listings are given under the WMO number and the name of the most recent station location (see Table A2).

Table A2 lists the NWS stations that have moved during the period 1988 to 2001. In some cases the move was so close to the old location that the name of the station has not changed, for example, Anchorage, Alaska, while others have required a change of name, for example, West Palm Beach to Miami. In one case, Wake Island, the station closed. The moves have been part of the modernization of the NWS, which led to consolidation of sites at or near NWS forecast offices.

Table A1. Instrumentation changes at NWS upper-air stations during 1988 to 2001.

WMO no.	Name	VIZ B	SDD	Vaisala-RS80	VIZ-B2	Microsonde
70026	Barrow, AK	1 Oct 1988–mid-1998	n/a	n/a	mid-1998–present	n/a
70133	Kotzebue, AK	1 Oct 1988–1 Nov 1995	n/a	1 Nov 1995–present	n/a	n/a
70200	Nome, AK	1 Sep 1988–Jul 1989	n/a	1 Nov 1995–present	n/a	n/a
70219	Bethel, AK	1 Oct 1988–1 Jul 1989	1 Jul 1989–1 Nov 1995	1 Nov 1995–present	n/a	n/a
70231	McGrath, AK	2 Oct 1988–1 Jul 1989 1 Nov 1994–1 Nov 1995	1 Jul 1989–1 Nov 1999	1 Nov 1995–present	n/a	n/a
70261	Fairbanks, AK	4 Oct 1988–1 Mar 1990 1 Nov 1994–1 Nov 1995	1 Mar 1990–1 Nov 1994	1 Nov 1995–present	n/a	n/a
70273	Anchorage, AK	6 Oct 1988–1 Jun 1998	n/a	1 Jun 1998–present	n/a	n/a
70308	Saint Paul Island, AK	4 Oct 1988–mid-1998	n/a	n/a	mid-1998–present	n/a
70316	Cold Bay, AK	6 Oct 1988–1 Dec 1995	n/a	1 Dec 1995–present	n/a	n/a
70326	King Salmon, AK	1 Oct 1988–1 Nov 1995	n/a	1 Nov 1995–present	n/a	n/a
70350	Kodiak, AK	1 Oct 1988–1 Nov 1995	n/a	1 Nov 1995–present	n/a	n/a
70361	Yakutat, AK	1 Oct 1988–1 Nov 1995	n/a	1 Nov 1995–present	n/a	n/a

Table A1. Continued.

WMO no.	Name	VIZ B	SDD	Vaisala-RS80	VIZ-B2	Microsonde
70398	Annette, AK	1 Oct 1988–mid-1998	n/a	n/a	mid-1998–present	n/a
72201	Key West, FL	11 Oct 1988–1 Jun 1997	n/a	n/a	1 June 1997–present	n/a
72202	Miami, FL	21 Jul 1995–1 Jun 1997	n/a	1 Jun 1998–present	1 Jun 1997–1 Jun 1998	n/a
72206	Jacksonville, FL	24 Jan 1995–1 Jun 1997	n/a	1 Jun1998–present	1 Jun 1997–1 Jun 1998	n/a
72208	Charleston, SC	23 Oct 1988–1 Jun 1997	n/a	n/a	1 Jun 1997–1 Dec 1998	1 Dec 1998–present
72210	Tampa Bay, FL	1 Oct 1988–1 Jun 1997	n/a	1 Jun 1998–present	1 Jun 1997–1 Jun 1998	n/a
72214	Tallahassee, FL	12 Jun 1991–1 Jun 1997	n/a	1 Jun 1998–present	1 Jun 1997–1 Jun 1998	n/a
72215	Peachtree City, GA	30 Aug 1994–1 Jun 1997	n/a	1 Jun 1998–present	1 Jun 1997–1 Jun 1998	n/a
72230	Birmingham, AL	23 Aug 1994–1 Jun 1997	n/a	1 Jun 1998–present	1 Jun 1997–1 Jun 1998	n/a
72233	Slidell, LA	25 Jan 1994–1 Jun 1997	n/a	1 Jun 1998–present	1 Jun 1997–1 Jun 1998	n/a
72235	Jackson, MS	1 Sep 1988–1 Jun 1997	n/a	n/a	1 Jun 1997–present	n/a
72240	Lake Charles, LA	19 Oct 1988–1 Jun 1997	n/a	1 Jun 1998–present	1 Jun 1997–1 Jun 1998	n/a
72248	Shreveport, LA	21 Feb 1995–1 Jun 1997	n/a	1 Jun 1998–present	1 Jun 1997–1 Jun 1998	n/a
72249	Fort Worth, TX	11 Jul 1994–1 Jun 1997	n/a	1 Jun 1998–present	1 Jun 1997–1 Jun 1998	n/a
72250	Brownsville, TX	1 Oct 1988–1 Jun 1997	n/a	n/a	1 Jun 1997–present	n/a
72251	Corpus Christi, TX	11 Nov 1989–1 Jun 1997	n/a	n/a	1 Jun 1997–present	n/a
72261	Del Rio, TX	1 Oct 1988–20 Mar 1989 1 Jun 1994–1 Jun 1997	20 Mar 1989–1 Jun 1994	n/a	1 Jun–present	n/a
72265	Midland, TX	14 Oct 1988–1 Mar 1989 1 Nov 1994–1 Nov 1995	1 Mar 1989–1 Nov 1994	1 Nov 1995–present	n/a	n/a
72274	Tucson, AZ	4 Oct 1988–1 Mar 1989	1 Mar 1989–1 Nov 1995	1 Nov 1995–present	n/a	n/a
72293	San Diego, CA	4 Oct 1988–1 Jun 1997	n/a	n/a	1 Jun 1997–present	n/a
72305	Moorhead City, NC	18 Jul 1994–1 Jun 1997	n/a	1 Jun 1998–present	1 Jun 1997–1 Jun 1998	n/a
72317	Greensboro, NC	31 Oct 1988–1 Jun 1997	n/a	1 Jun 1998–present	1 Jun 1997–1 Jun 1998	n/a
72318	Blacksburg, VA	30 Oct 1995–1 Jun 1997	n/a	1 Jun 1998–present	1 Jun 1997–1 Jun 1998	n/a
72327	Nashville, TN	1 Sep 1988–1 Jun 1997	n/a	n/a	1 Jun 1997–present	n/a
72340	Little Rock, AR	1 Sep 1988–1 Jun 1997	n/a	1 Jun 1998–present	1 Jun 1997–1 Jun 1998	n/a
72357	Norman, OK	27 Mar 1989–1 Jun 1997	n/a	1 Jun 1998–present	1 Jun 1997–1 Jun 1998	n/a
72363	Amarillo, TX	1 Oct 1988–1 Mar 1989	1 Mar 1989–1 Nov 1995	1 Nov 1995–present	n/a	n/a
72364	Santa Teresa, NM	n/a	10 Sep 1995–1 Dec 1995	1 Dec1995–present	n/a	n/a
72365	Albuquerque, NM	1 Oct 1988–1 Mar 1989 1 Jun 1994–1 Jun 1997	1 Mar 1989–1 Jun 1994	n/a	1 Jun 1997–present	n/a
72376	Flagstaff, AZ	26 Aug 1995–1 Jun 1997	n/a	1 Jun 1998–present	1 Jun 1997–1 Jun 1998	n/a

Table A1. Continued.

WMO no.	Name	VIZ B	SDD	Vaisala-RS80	VIZ-B2	Microsonde
72387	Desert Rock, NV	4 Oct 1988–1 Jun 1997	n/a	n/a	1 Jun 1997–present	n/a
72402	Wallops Island, VA*	n/a	n/a	n/a	n/a	24 Jul 1996–present
72403	Sterling, VA	1 Sep 1988–1 Nov 1995	n/a	1 Nov 1995–present	n/a	n/a
72426	Wilmington, OH	25 Sep 1995–1 Jun 1997	n/a	1 Jun 1998–present	1 Jun 1997–1 Jun 1998	n/a
72440	Springfield, MO	16 Apr 1995–1 Jun 1997	n/a	1 Jun 1998–present	1 Jun 1997–1 Jun 1998	n/a
72451	Dodge City, KS	13 Oct 1988–1 Jun 1997	n/a	n/a	1 Jun 1997–present	n/a
72456	Topeka, KS	1 Oct 1988–1 Jun 1997	n/a	1 Jun 1998–present	1 Jun 1997–1 Jun 1998	n/a
72469	Denver, CO	1 Oct 1988–1 Nov 1995	n/a	1 Nov 1995–present	n/a	n/a
72476	Grand Junction, CO	19 Oct 1988–1 Jun 1989 1 Jun 1994–1 Jun 1997	1 Jun 1989–1 Jun 1994	1 Jun 1998–present	1 Jun 1997–1 Jun 1998	n/a
72489	Reno, NV	24 Oct 1994–1 Jun 1997	n/a	1 Jun 1998–present	1 Jun 1997–1 Jun 1998	n/a
72493	Oakland, CA	1 Oct 1988–1 Jun 1997	n/a	n/a	1 Jun 1997–present	n/a
72501	Brookhaven, NY	1 Sep 1994–1 Jun 1997	n/a	1 Jun 1998–present	1 Jun 1997–1 Jun 1998	n/a
72518	Albany, NY	1 Sep 1988–20 May 1997	n/a	n/a	n/a	20 May 1997–present
72520	Pittsburgh, PA	1 Oct 1988–1 Jun 1997	n/a	n/a	1 Jun 1997–present	n/a
72528	Buffalo, NY	24 Oct 1988–1 Jun 1997	n/a	1 Jun 1998–present	1 Jun 1997–1 Jun 1998	n/a
72558	Valley, NE	11 May 1994–1 Jun 1997	n/a	1 Jun 1998–present	1 Jun 1997–1 Jun 1998	n/a
72562	North Platte, NE	1 Sep 1988–1 Jun 1997	n/a	1 Jun 1998–present	1 Jun 1997–1 Jun 1998	n/a
72572	Salt Lake City, UT	8 Oct 1988–1 Mar 1990 1 Jun 1994–1 Jun 1997	1 Mar 1990–1 Jun 1994	1 Jun 1998–present	1 Jun 1997–1 Jun 1998	n/a
72582	Elko, NV	3 Aug 1995–1 Jun 1997	n/a	n/a	1 Jun 1997–present	n/a
72597	Medford, OR	6 Oct 1988–1 Jun 1997	n/a	n/a	1 Jun 1997–present	n/a
72632	Whitelake, MI	13 Sep 1994–1 Jun 1997	n/a	1 Jun 1998–present	1 Jun 1997–1 Jun 1998	n/a
72634	Gaylord, MI	24 Apr 1996–1 Jun 1997	n/a	1 Jun1998–present	1 Jun 1997–1 Jun 1998	n/a
72645	Green Bay, WI	1 Sep 1988–1 Jun 1997	n/a	n/a	1 Jun 1997–present	n/a
72649	Chanhassen, MN	22 Mar 1995–1 Jun 1997	n/a	1 Jun 1998–present	1 Jun 1997–1 Jun 1998	n/a
72659	Aberdeen, SD	18 Nov 1994–1 Jun 1997	n/a	1 Jun 1998–present	1 Jun 1997–1 Jun 1998	n/a
72662	Rapid City, SD	8 Nov 1995–1 Jun 1997	n/a	1 Jun 1998–present	1 Jun 1997–1 Jun 1998	n/a
72672	Riverton, WY	25 Aug 1995–11 Nov 1995	n/a	1 Nov 1995–present	n/a	n/a
72681	Boise, ID	15 Oct 1988–1 Apr 1990	1 Apr 1990–1 Nov 1995	1 Nov 1995–present	n/a	n/a
72694	Salem, OR	5 Oct 1988–1 Jun 1997	n/a	n/a	1 Jun 1997–present	n/a
72712	Caribou, ME	20 Oct 1988–1 Jun 1997	n/a	n/a	1 Jun 1997–present	n/a
72747	International Falls, MN	30 Oct 1988–1 Nov 1995	n/a	1 Nov 1995–present	n/a	n/a
72764	Bismarck, ND	1 Oct 1988–1 Jul 1990 1 Jun 1994–1 Jun 1997	1 Jul 1990–1 Jun 1994	n/a	1 Jun 1997–present	n/a

Table A1. Continued.

WMO no.	Name	VIZ B	SDD	Vaisala-RS80	VIZ-B2	Microsonde
72768	Glasgow, MT	1 Sep 1988–1 Jun 1997	n/a	n/a	1 Jun 1997–present	n/a
72776	Great Falls, MT	25 Oct 1988–1 Jun 1997	n/a	n/a	1 Jun 1997–present	n/a
72786	Spokane, WA	4 Oct 1988–1 Jun 1997	n/a	n/a	1 Jun 1997–present	n/a
72797	Quillayute, WA	29 Oct 1988–1 Jun 1997	n/a	n/a	1 Jun 1997–present	n/a
74389	Gray, ME	22 Sep 1994–1 Nov 1995	n/a	1 Nov 1995–present	n/a	n/a
74455	Davenport, IA	14 Feb 1995–1 Jun 1997	n/a	1 Jun 1998–present	1 Jun 1997–1 Jun 1998	n/a
74494	Chatham, MA	1 Nov 1988–Jun 1997	n/a	1 Jun 1998–present	1 Jun 1997–1 Jun 1998	n/a
74560	Lincoln, IL	8 Feb 1995–1 Jun 1997	n/a	1 Jun 1998–present	1 Jun 1997–1 Jun 1998	n/a
78526	San Juan, PR	6 Oct 1988–1 Jun 1997	n/a	n/a	1 Jun 1997–present	n/a
91165	Lihue	16 Oct 1988–1 Nov 1995	n/a	1 Nov 1995–present	n/a	n/a
91212	Guam	1 Oct 1988–1 Nov 1995	n/a	n/a	Sep 1997–present	1 Nov 1995–Sep 1997
91245	Wake	1 Oct 1988–13 May 1997**	n/a	n/a	n/a	n/a
91285	Hilo	15 Oct 1988–mid-1998	n/a	n/a	mid 1998–present	n/a
91334	Chuuk	1 Oct 1988–1 Dec 1995	n/a	1 Dec 1995–present	n/a	n/a
91348	Pohnpei	1 Oct 1988–1 Dec 1995	n/a	1 Dec 1995–present	n/a	n/a
91376	Majuro	1 Oct 1988–mid-1998	n/a	n/a	mid-1998–present	n/a
91408	Korror	1 Oct 1988–1 Dec 1995	n/a	1 Dec 1995–present	n/a	n/a
91413	Yap	1 Oct 1988–1 Dec 1995	n/a	1 Dec 1995–present	n/a	n/a
91765	Pago Pago	4 Nov 1988–1 Dec 1995	n/a	1 Dec 1995–present	n/a	n/a

*Wallops Island, VA, used the Buerkers Locate 403-MHz Loran ground system with VIZ radiosondes before switching over to the Microsonde system.
**Wake Island closed 13 May 1997.

Table A2. NWS upper-air stations that moved during 1988 to 2001 period.

WMO no.	Old location	Lat–long	Elev (m)	Move date	New location	Lat–long	Elev (m)	WMO no.
70273	Anchorage, AK	61°11′N–150°00′W	45	1 Nov 1995	Anchorage, AK	6°09′N–149°59′W	50	70273
72203	W. Palm Beach, FL	26°41′N–80°06′W	7	21 Jul 1995	Miami, FL	25°45′N–80°23′W	4	72202
72213	Waycross, GA	31°15′N–82°24′W	44	24 Jan 1995	Jacksonville, FL	30°29′N–81°42′W	11	72206
72220	Apalachicola, FL	29°44′N–85°02′W	7	12 Jun 1991	Tallahassee, FL	30°24′N–84°22′W	19	72214
72229	Centreville, AL	32°54′N–87°15′W	140	22 Aug 1994	Birmingham, AL	33°11′N–86°47′W	174	72230
72233	New Orleans, LA	30°20′N–89°49′W	3	25 Jan 1994	Slidell, LA	30°20′N–89°49′W	10	72233
72247	Longview, TX	32°23′N–94°43′W	124	21 Feb 1995	Shreveport, LA	32°27′N–93°51′W	85	72248
72255	Victoria, TX	28°51′N–96°55′W	33	11 Nov 1989	Corpus Christi, TX	27°47′N–97°30′W	14	72251
72260	Stephenville, TX	32°13′N–98°11′W	399	11 Jul 1994	Fort Worth, TX	32°50′N–97°18′W	195	72249
72270	El Paso, TX	31°48′N–106°23′W	1193	10 Sep 1995	Santa Teresa, NM	31°52′N–106°42′W	1252	72364

Table A2. Continued.								
WMO no.	Old location	Lat/long (deg/min)	Elev (m)	Move date	New location	Lat/long (deg/min)	Elev (m)	WMO no.
72304	Cape Hatteras, NC	35°16′N–75°33′W	4	18 Jul 1994	Newport, NC	34°47′N–76°53′W	11	72305
72311	Athens, GA	33°57′N–83°19′W	246	29 Aug 1994	Peachtree City, GA	33°21′N–84°34′W	245	72215
72349	Monett, MO	36°53′N–93°54′W	438	19 May 1995	Springfield, MO	37°14′N–93°24′W	391	72440
72353	Oklahoma City, OK	35°24′N–97°36′W	392	27 Mar 1989	Norman, OK	35°14′N–97°28′W	359	72357
72374	Winslow, AZ	35°01′N–110°43′W	1487	26 Aug 1995	Flagstaff, AZ	35°14′N–111°49′W	2179	72376
72403	Sterling, VA	38°59′N–77°28′W	85	23 Sep 2001	Sterling, VA	38°59′N–77°29′W	86	72403
72407	Atlantic City, NJ	39°27′N–74°34′W	22	1 Sep 1994	Brookhaven, NY	40°52′N–72°52′W	21	72501
72425	Huntington, WV	38°22′N–82°33′W	246	9 Nov 1995	Blacksburg, VA	37°12′N–80°25′W	640	72318
72429	Dayton, OH	39°52′N–84°07′W	298	25 Sep 1995	Wilmington, OH	39°25′N–83°49′W	323	72426
72435	Paducah, KY	37°04′N–88°46′W	126	8 Feb 1995	Lincoln, IL	40°09′N–89°20′W	179	74560
72451	Dodge City, KS	37°46′N–99°58′W	790	12 Dec 1996	Dodge City, KS	37°46′N–99°58′W	786	72451
72486	Ely, NV	39°17′N–114°51′W	1908	3 Aug 1995	Elko, NV	40°52′N–115°44′W	1592	72582
72518	Albany, NY	42°45′N–73°48′W	86	20 May 1997	Albany, NY	42°42′N–73°50′W	93	72518
72532	Peoria, IL	40°40′N–89°41′W	200	15 Feb 1995	Davenport, IA	41°37′N–90°35′W	231	74455
72553	Omaha, NE	41°22′N–96°01′W	400	11 May 1994	Valley, NE	41°19′N–96°22′W	351	72558
72576	Lander, WY	42°49′N–108°44′W	1695	25 Aug 1995	Riverton, WY	43°04′N–108°29′W	1698	72672
72583	Winnemucca, NV	40°54′N–117°48′W	1312	25 Oct 1994	Reno, NV	39°34′N–119°47′W	1516	72489
72606	Portland, ME	43°39′N–70°19′W	20	22 Sep 1994	Gray, ME	43°54′N–70°15′W	123	74389
72637	Flint, MI	42°58′N–83°45′W	236	13 Sep 1999	White Lake, MI	42°42′N–83°28′W	330	72632
72654	Huron, SD	44°23′N–98°13′W	392	18 Nov 1994	Aberdeen, SD	45°27′N–98°26′W	398	72659
72655	St. Cloud, MN	45°33′N–94°04′W	315	22 Mar 1995	Chanhassen, MN	44°51′N–93°34′W	290	72649
72662	Rapid City, SD	44°03′N–103°04′W	966	8 Nov 1995	Rapid City, SD	44°04′N–103°13′W	1029	72662
72734	Sault Ste. Marie, MI	46°28′N–84°21′W	221	24 Apr 1996	Gaylord, MI	44°55′N–84°43′W	448	72634
72775	Great Falls, MT	47°29′N–111°22′W	1118	15 Sep 1994	Great Falls, MT	47°28′N–111°23′W	1132	72776
72785	Spokane, WA	47°38′N–117°32′W	720	20 Sep 1995	Spokane, WA	47°41′N–117°38′W	728	72786
91217	Guam	13°33′N–144°50′E	111	10 Apr 2000	Guam	13°29′N–144°48′E	75	91212

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