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Recently, considerable attention has been given to systematic errors occurring in the global radiosonde network. Many operational forecasting centers are involved in global radiosonde network. Many operational forecasting centers are involved in global data monitoring efforts using a short-range forecast from a global forecast model as the comparison tool (Baker 1991, 1992; ECMWF 1988, 1989; Hall 1992; Hollingworth et al. 1986). The WMO International Radiosonde Intercomparison Tests (Nash and Schmidlin 1987) were major efforts that attempted to quantify the differences between the various radiosondes in use worldwide.

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THE DETERMINATION OF RADIOSONDE GEOPOTENTIAL HEIGHT BIASES BY THE NAVY'S GLOBAL DATA ASSIMILATION SYSTEM

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1. INTRODUCTION

Recently, considerable attention has been given to systematic errors occurring in the global radiosonde network. Many operational forecasting centers are involved in global data monitoring efforts using a short-range forecast from a global forecast model as the comparison tool (Baker 1991, 1992; ECMWF 1988, 1989; Hall 1992; Hollingsworth et al. 1986). The WMO International Radiosonde Intercomparison Tests (Nash and Schmidlin 1987) were major efforts that attempted to quantify the differences between the various radiosondes in use worldwide.

The systematic errors may be caused by instrument measurement errors or errors in observing, data processing and reporting practices. A major source of error can be attributed to the effects of both solar (shortwave) and infrared (longwave) radiation on the radiosonde thermistor. The daytime errors are typically dominated by solar radiation, but the infrared radiation component is also important. Nighttime errors are due to infrared radiation only and are dependent upon the infrared environment that the balloon ascends through. The factors that enter into the overall heat balance equation for the radiosonde thermistor include cloud cover, cloud top temperatures, solar zenith angle and surface temperature, as well as the vertical profiles of temperature, aerosols, ozone, water vapor and carbon dioxide (Finger and Schmidlin 1991; McMillin et al. 1988).

The radiation errors vary according to radiosonde instrument and the radiative influences mentioned above, but estimates indicate that the errors increases above 400 hPa with a maximum magnitude of 1 °C to 3 °C (Ahnert 1991; Schmidlin 1991; McMillin et al. 1988).

The errors in the geopotential heights are more significant since the heights are calculated from the temperatures and the errors accumulate with altitude. Because the computed geopotential heights are hydrostatically consistent with the temperatures, standard objective quality control checks are not sensitive to the errors. The geopotential height errors are of particular concern for numerical weather prediction since typically the geopotential heights (not temperatures) are assimilated into the analysis. The magnitudes of the height errors are frequently much larger than the errors attributed to the analysis first guess. Furthermore, the multivariate optimum interpolation analysis assumes that the observations are unbiased, which they clearly are not. Because the sign of the error changes from positive (daytime) to negative (nighttime), use of the uncorrected geopotential heights can lead to inconsistent analyses between 00 and 12 UTC.

Two new radiosonde instrument have recently been introduced into the U. S. upper air radiosonde network to replace the VIZ Manufacturing Company's 'A-sonde' (Bosart 1990; Ahnert 1991). The VIZ 'B-sonde' was implemented starting in September 1988, the Space Data Corporation (SDC) radiosonde was introduced on 1 March 1989. The VIZ 'B-sonde' (VIZB) has error characteristics similar to the VIZ 'A-sonde', but has quite different error characteristics from the SDC radiosonde (Ahnert 1991). The difference in the error characteristics for the two radiosondes currently in use is very striking and of a nontrivial magnitude. Therefore, it is of concern to researchers and operational users alike.

2. BIAS DETECTION TECHNIQUES

Many different procedures have been used to estimate the errors in the radiosonde temperature measurements. Depending upon the technique, the precision, accuracy and/or compatibility is estimated.

Precision is defined to be the degree of reproducibility among several independent measurements of the same instrument type under the same conditions. Ahnert's (1991) tests estimated the precision of the VIZA, VIZB and SDC radiosondes.

Accuracy is determined by the comparison of the radiosonde against another measuring instrument (preferably a measurement standard), but also possibly another instrument type. McMillin et al. (1988) used satellite soundings as a transfer standard to estimate the longwave errors for the VIZA and Väisälä instrument.

Compatibility or comparability is the comparison between different measurements made by radiosondes of different design or manufacture. Intercomparison tests measure the compatibility between two or more different radiosondes by repeated flights of the different instruments mounted on the same platform. The WMO International Radiosonde Intercomparison Tests (Nash and Schmidlin 1987) determined the compatibility between the principal radiosondes in global use at that time. Ahnert (1991) estimated the compatibility between the VIZA and SDC radiosondes.

Schmidlin (1991) used a slightly different approach. The standard VIZ instrument was modified to include three thermistors, each with a different color coating having a different known spectral response. The standard heat transfer equation was solved to determine the thermistor correction.

The main disadvantages with the above techniques are that only a limited number of flights for a limited number of different radiosondes can be made. Thus, it is difficult to quantify the range of the longwave radiative effects as well as the differences between different radiosondes.

Global data assimilation systems have improved to the point that the accuracy of the first-guess (6-hour forecast) is now comparable to that of the radiosonde observations. Hollingsworth et al. (1986) demonstrated the usefulness of a global data assimilation system for monitoring the performance of the global observational network by comparison of the observations with the first-guess. Researchers at the Naval Research Laboratory (NRL) in Monterey, Ca have developed a statistical database to facilitate the monitoring of rawinsonde quality. The differences between the observed geopotential heights and winds and the corresponding NOGAPS (Navy Operational Global Atmospheric Prediction System) first-guess fields interpolated to the observation locations are archived. We began the permanent archive of these statistics starting October 1, 1990. Error estimates were derived from these statistics for the U. S. radiosonde network and the results are presented in the next section.

3. RESULTS

The results discussed in this section are based on the analysis of the observation minus first guess deviations (or observation increments) for the time period of 1 October 1990 to 11 March 1992. Only the observations that pass the objective quality control checks (Baker 1992) and the consistency checks with the first guess (Goerss and Phoebus 1992) are archived. Therefore, the number of observations used to calculate the statistical estimates may not reflect the actual number received. Two months of data, corresponding approximately to April 1991 and September 1991, were lost due to computer problems at NRL and Fleet Numerical Oceanographic Center.

The 100 hPa level was selected for analysis because the solar elevation angles are high enough for the radiation errors to be apparent, there are rarely missing or rejected observations from this level, and it is sufficiently far removed from the top model level of 10 hPa.

The mean of the deviations is referred to here as the bias, but actually refers to the bias relative to the first guess. In data-rich areas, statistics from the multivariate optimum interpolation analysis indicate that the contribution to the bias estimates from the first guess error is small. For example, at 100 hPa, the first guess error is on the order of 20 m.

Fig. 1 shows the average observation minus first guess differences at 100 hPa and 00 UTC for U. S. radiosondes for a 31 day period centered on the summer solstice (21 June 1991). This period was chosen to illustrate the maximum difference between the two radiosonde instruments that occurs during the highest solar elevation angles. The largest biases also occur at this time. The SDC radiosonde stations are marked with a "o" and the VIZ (or VIZB) stations with a "x". In general, the biases increase to the west where the sun is higher in the sky. The biases of the SDC stations are typically 1.5 to 2 times as large (25-35 m) as nearby VIZ stations. Ahnert's (1991) results

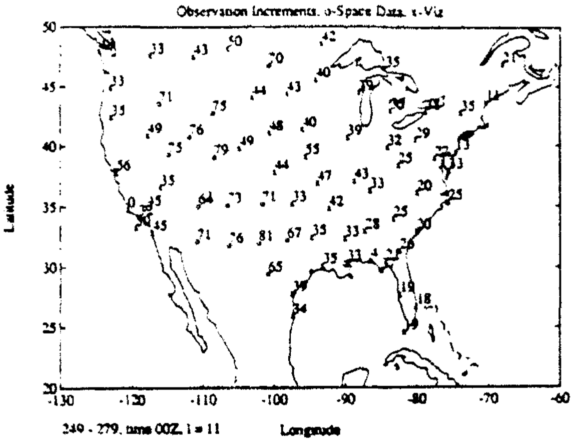

Figure 1: Bias at 100 hPa and 00 UTC for U. S. radiosondes for a 31 day period centered on 21 June 1991. The SDC radiosonde station are marked with a "o", the VIZ stations with a "x".

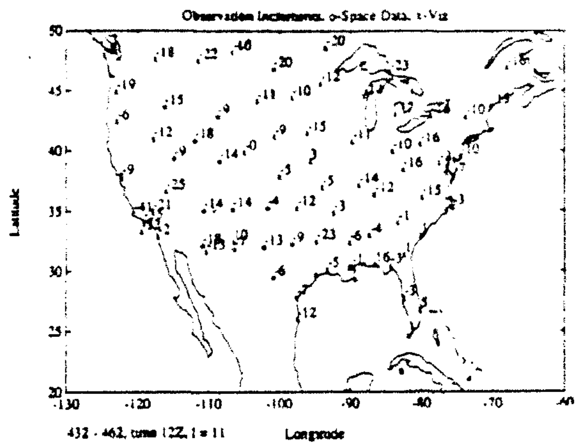

Figure 2: Same as in Fig. 1, but for the 31 day period centered on 21 Dec 1991.

for 100 hPA and solar angles between 0° and 30° indicate a difference between VIZA and SDC of about 32 m. The numbers also compare favorably with Schmidlin's (1991) corrections of 28 m for the VIZ instrument, and Julian's (1991) corrections of 39 m for VIZ and 69 m for SDC.

The corresponding map of the biases at 100 hPa for 12 UTC for the 31 day period centered on the winter solstice (21 December 1991) is shown in Fig. 2. The biases are much smaller and tend to be uniformly negative across the region. The differences between the VIZ and SDC stations are not as pronounced as in Fig. 1.

The distinctive variation of bias as a function of time and solar elevation angle may be seen in Fig. 3 for the SDC station of Bismarck, ND. Also note the consistency between the day-to- day observation increments. There is just one negative observation increment at 00 UTC for positive solar elevation angles, and only a few negative increments for positive solar angles at 12 UTC. The biases are negative for nighttime observations, but rapidly become more positive once the solar elevation angles become greater than about −5°. These negative biases represent the error due to the effects of infrared radiation on the sensor. The standard deviation is roughly the same for daytime and nighttime observations and varies little through the time period.

Fig. 4 shows the same statistics for the VIZ station of Rapid City, SD. The biases show the same characteristic variation with solar elevation

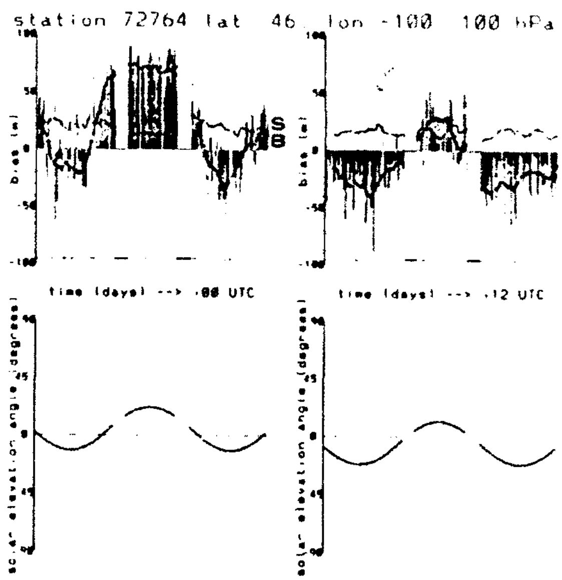

Figure 3: Observation increments, bias, standard deviations and solar elevation angle for the SDC station of Bismarck, ND. The time period runs from 1 October 1990 to 11 March 1992. In top left quadrant, the vertical lines are the 100 hPa observation increments at 00 UTC for each day. The curve labeled with a "B" is the running 30-day centered mean of the increments; the curve labeled with an "S" is the standard deviation. The bottom left quadrant shows the solar elevation angle. The corresponding 12 UTC statistics are displayed in the two right quadrants.

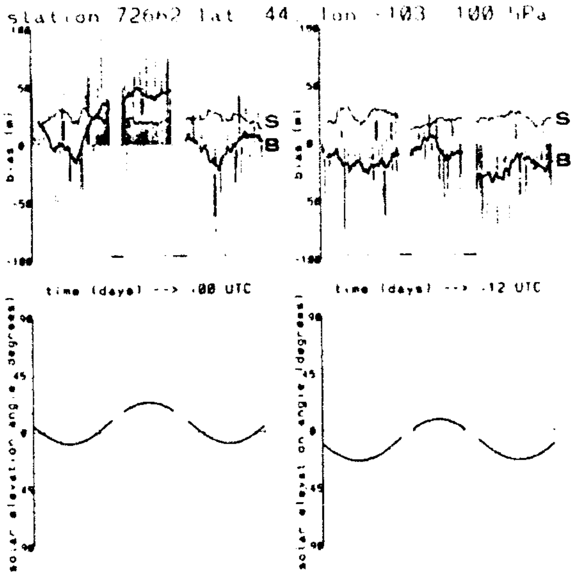

Figure 4: Same as for Fig. 3, but for the VIZ station of Rapid City, SD.

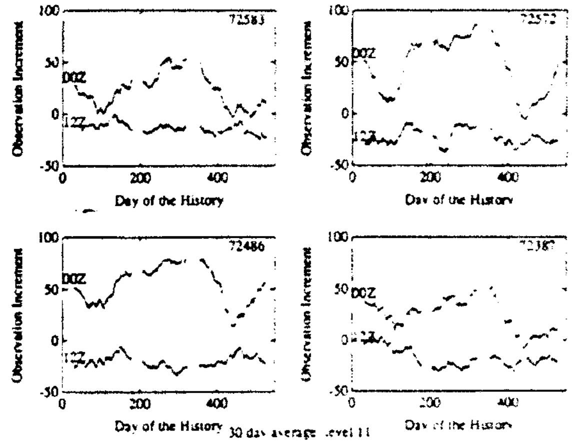

Figure 5: The 20-day running means of the observation increments for 00 UTC and 12 UTC at 100 hPa for the VIZ stations of Mercury, NV (72387) and Winnemucca, NV (72583), and for the SDC stations of Ely, NV (72486) and Salt Lake City, UT (72572)

angle, but the magnitudes of the biases are much less for the VIZ station. The maximum 100 hPa bias for Bismarck (SDC) is around 70 m, while the corresponding maximum bias for Rapid City (VIZ) is about 45 m.

The distinctive differences between the SDC and the VIZ radiosondes are found in the statistics for other U. S. stations as well. For example, Fig. 5 shows the 00 and 12 UTC biases versus time at 100 hPa for four adjacent radiosonde stations. The plotted value is the running average over the previous 30 deviations. The stations using the VIZ instrument are Mercury, NV (72387) and Winnemucca, NV (72583). The other two stations, Ely, NV (72486) and Salt Lake City, UT (72572), use the SDC radiosonde. Once again, the differences between the VIZ and SDC instruments are readily apparent. The magnitude of the biases and the shape of the curves for the VIZ stations are very similar to each other, as are those of the SDC stations. The behavior of the running averages is similar for all four stations at 12 UTC. However, at 00 UTC, the SDC stations show a dramatic increase when the sun angle becomes positive. The VIZ stations show a more gradual increase to a smaller maxima. These increases begin about day 120, corresponding to the end of January. The decrease for all four stations begins at about day 375, or mid-October. In all four cases, the minima are reached at about day 440 or mid-December.

Fig. 6 shows the variation of the bias as a function of height for Bismarck (SDC) for the 31-day period centered on 21 June 1991 corresponding to the maximum solar elevation angles. The daytime biases increase with height and reach a maximum near 10 hPa. The 12 UTC biases switch from negative to positive as the sun angles increase. The standard deviations are similar for both times. Our results indicate a bias of 167 m at 20 hPa, which again compares favorably with a bias estimate of around 160 m derived from Ahnert (1991) and Schmidlin (1991).

The corresponding statistics for Rapid City are shown in Fig. 7. The biases for both times are much less for this VIZ station. The bias of 75 m at 20 hPa compares well with the estimate of 71 m from Schmidlin (1991). The standard deviations are similar to Bismarck. Figs. 8 and 9 show the same statistics for the same two stations for the winter solstice period corresponding to Fig. 2. The biases at both times are negative, but slightly larger for the SDC station. The standard deviation of the VIZ station is slightly larger than for the SDC station.

Some evidence suggests that, depending upon the local longwave radiative environment, the daytime biases begin to decrease again above 30 hPa (Schmidlin 1991). We see a similar trend in our statistics for some U. S. radiosonde sta-

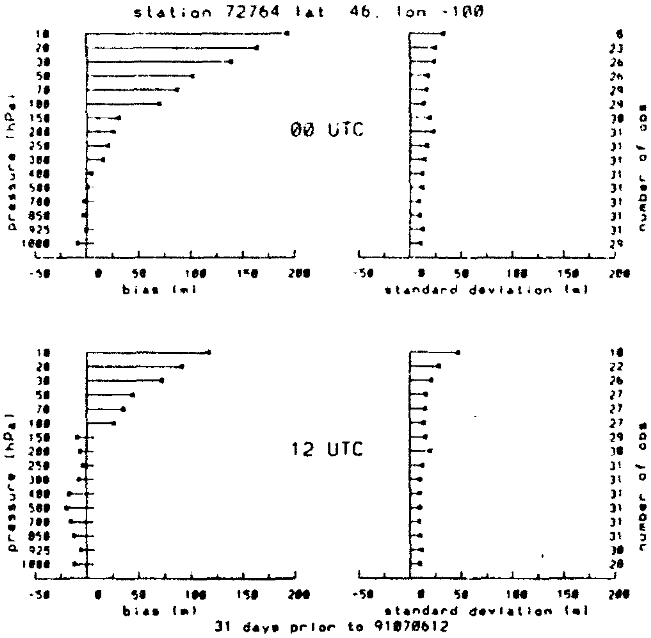

Figure 6: Plot of the 00 UTC bias as a function of height for Bismarck (SDC) computed for the 31 day period centered on 21 June 1991.

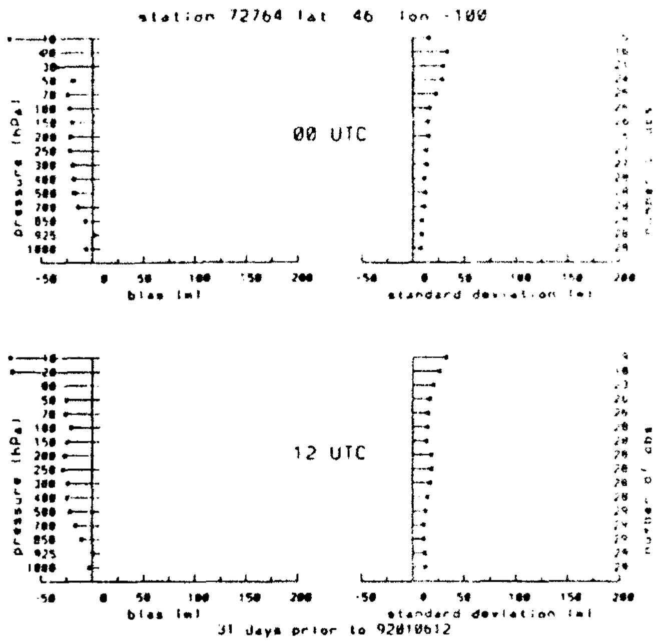

Figure 8: Plot of the 12 UTC bias as a function of height for Bismarck (SDC) computed for the 31 day period centered on 21 December 1991.

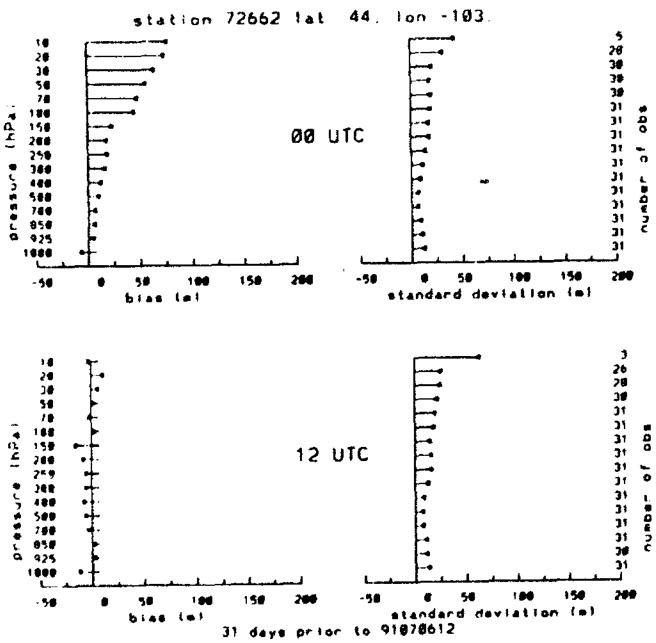

Figure 7: Same as for Fig. 6, but for the VIZ station of Rapid City, SD.

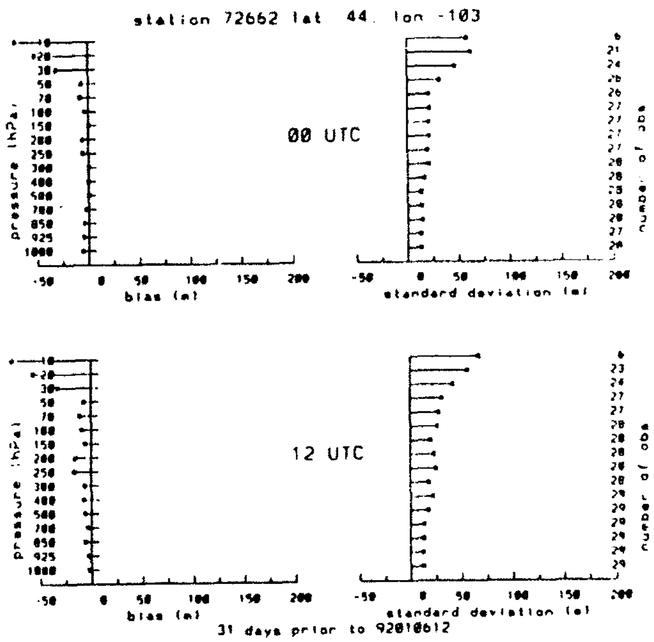

Figure 9: Same as for Fig. 8, but for the VIZ station of Rapid City, SD.

tions. Preliminary results indicate that our statistics may also be capable of estimating the portion of the longwave radiative error that varies over longer time scales (i. e. greater than 20 days) and as a function of location.

4. CONCLUSIONS

The Navy's global data assimilation system has proved to be a useful tool for estimating the radiation errors for the U. S. radiosonde network. The magnitudes and characteristics verify well with the independent results of Schmidlin (1991) and Ahnert (1991). Based on these encouraging results, we plan to soon implement corrections for the biases found for other radiosonde stations globally.

We also anticipate that these techniques will prove useful for estimating the necessary radiation corrections for the reanalysis of historical periods for which the radiosonde type in use at any given station and the proper radiation correction needed (if any) may not be well known.

Finally, although not emphasized here, the statistical database is useful for identifying radiosonde stations with systematic errors other than those due to radiation, or stations with generally poor observation quality.

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