9. ACCURACY OF WGS 84 COORDINATES

9.1 General

The accuracy of the WGS 84 coordinates of a site is significantly influenced by the method used to determine the coordinates. With the full implementation of WGS 84, the NSWC 9Z-2 to WGS 84 Transformation will no longer be used. Therefore, three basic methods remain for obtaining WGS 84 coordinates. Depending on the data available, the WGS 84 coordinates of a site can be determined:

- Directly in WGS 84 via a satellite point positioning solution using ground-based Doppler satellite tracking data and precise satellite ephemerides (Section 7.2.1). (It is anticipated that current usage of NNSS Satellites will give way to NAVSTAR GPS Satellites and associated tracking data as the latter System nears full operational capability.)

- By a WGS 72-to-WGS 84 Coordinate Transformation (Section 7.2.3).

- By a Local Geodetic System-to-WGS 84 Datum Transformation (Section 7.2.4).

However, the situation is even more complicated since there are several techniques for accomplishing a Local Geodetic System-to-WGS 84 Datum Transformation. In addition, the accuracy of the WGS 84 coordinates of a site is different depending on whether it is a Doppler station or a non-Doppler geodetic network station, or whether the WGS 84 coordinates were determined by a receiver operated in a dynamic or static mode.

9.2 WGS 84 Coordinates Determined via Satellite Point Positioning

The accuracy (one sigma) of a Doppler station's WGS 84 coordinates directly determined in WGS 84 by satellite point positioning utilizing NNSS Satellites, their respective precise ephermerides, and ground-based Doppler satellite tracking data acquired in the static mode is in geodetic latitude, geodetic longitude, and geodetic height:

$$\sigma_{\phi} = \sigma_{\lambda} = \pm 1 \text{ m} \qquad (9\text{-}1)$$

$$\sigma_{H} = \pm 1 \text{ to } \pm 2 \text{ m.} \qquad (9\text{-}2)$$

A similar satellite point positioning capability utilizing NAVSTAR GPS Satellites is currently under development by DMA.

In developing WGS 84, for the 1591 Doppler stations involved, the accuracy (one sigma) of their WGS 84 coordinates determined via the NSWC 9Z-2 to WGS 84 Transformation was assumed to be:

$$\sigma_{\phi} = \sigma_{\lambda} = \pm 2 \text{ m} \qquad (9\text{-}3)$$

$$\sigma_{H} = \pm 2 \text{ to } \pm 3 \text{ m.} \qquad (9\text{-}4)$$

It is these Doppler station WGS 84 coordinates, constituting an integral part of WGS 84, that were used (Chapter 7) to develop Local Geodetic System-to-WGS 84 Datum Transformations.

The WGS 84 coordinate accuracies in the two paragraphs immediately above are absolute accuracies in that they incorporate not only the "observational" or solution error, but the errors associated with placing the origin of the WGS 84 Coordinate System at the earth's center of mass and determining the correct scale for the WGS 84 Coordinate System. The error estimates do not include the uncertainty associated with the attempt to bring the WGS 84 zero meridian into coincidence with the BIH-defined Zero Meridian (1984.0). This inclusion is not necessary since the location of the WGS 84 longitude reference or zero meridian is arbitrary. These absolute accuracy values should not be confused with the sub-meter precision (one sigma):

- Of a Doppler coordinate solution (the "observational" error).

- Of a Doppler coordinate solution which has been repeated independently at the same site.

9.3 WGS 84 Coordinates Determined From the WGS 72-to-WGS 84 Transformation

As seen in Chapter 7, the WGS 72 and WGS 84 geodetic coordinates of a site do not agree due to differences between the WGS 72 and WGS 84 Ellipsoids, coordinate system origins, reference longitudes, and system scales. (Other differences between the two systems are discussed later.) These differences are expressed numerically in Table 7.4 in the form of WGS 72-to-WGS 84 Transformation Formulas. Table 7.5 contains $\Delta\phi$, $\Delta\lambda$, ΔH values obtained from an evaluation of these coordinate conversion formulas along a meridian at five degree intervals of latitude from the north pole to the south pole. Important to the discussion here is the footnote to Table 7.5 which indicates that the recorded $\Delta\phi$, $\Delta\lambda$, ΔH values do not reflect the effect of differences between the WGS 72 and WGS 84 EGMs and Geoids, nor the difference between Local Geodetic System-to-WGS 72 Datum Shifts and Local Geodetic System-to-WGS 84 Datum Shifts. Two WGS 72-to-WGS 84 coordinate conversion situations need to be discussed with respect to the preceding.

First, consider a Doppler station with WGS 72 coordinates known from a satellite point positioning solution, but the related satellite ephemerides and/or station Doppler tracking data, or NSWC 9Z-2 coordinates, are no longer available. The Doppler station may or may not have any known geodetic connection to a local geodetic system (but the station's WGS 72 coordinates must not have been determined from a Local Geodetic System-to-WGS 72 Datum Transformation). In such a situation, the WGS 84 coordinates of the Doppler station would be determined using the WGS 72-to-WGS 84 Transformation Formulas (Table 7.4). These formulas essentially correct the WGS 72 coordinates for the effect of a poorly defined WGS 72 Coordinate System origin, a too small system scale, a longitude reference inconsistent with the WGS 84 (BIH-defined) Zero

Meridian, and the differences between the WGS 72 and WGS 84 Ellipsoids. Since WGS 72 is Doppler-based, by proceeding in this manner from the Doppler station's WGS 72 coordinates, the station's newly derived WGS 84 coordinates should be almost as accurate as WGS 84 coordinates obtained via an NSWC 9Z-2 to WGS 84 Transformation (Table 2.4). (Note the similarity between the formulas listed in Tables 2.4 and 7.4.) The major missing ingredient is the station coordinate improvement possible from use of the WGS 84 EGM as opposed to the WGS 72 EGM. Although the effect on station coordinates of this EGM difference has not yet been established empirically by DMA, the WGS 84 coordinates for such a Doppler station, generated from the station's known WGS 72 coordinates using the WGS 72-to-WGS 84 Transformation Formulas, have the following estimated accuracies (1σ):

$$\sigma_\phi = \sigma_\lambda = \pm 3 \text{ m} \tag{9-5}$$

$$\sigma_H = \pm 3 \text{ to } \pm 4 \text{ m} . \tag{9-6}$$

Next, consider a non-Doppler local geodetic network station with known WGS 72 coordinates, determined using Local Geodetic System-to-WGS 72 Mean Datum Shifts. Since mean rather than localized datum shifts have been used, the station's WGS 72 coordinates may be of poor accuracy. [Due to the paucity of Doppler stations in the 1972 time period, localized datum shifts could only be developed for NAD 27 (CONUS), these in the form of ΔX, ΔY, ΔZ NAD 27-to-WGS 72 Datum Shift Contour Charts.] Therefore, the WGS 84 coordinates of such a site, determined using the WGS 72-to-WGS 84 Transformation (Table 7.4) may also be of poor accuracy, containing the shortcomings of the site's WGS 72 coordinates. Consideration of some coordinate differences provides an idea of the error magnitudes involved.

For the entries in Table 7.5, computed using the WGS 72-to-WGS 84 Transformation Formulas in Table 7.4, the largest differences between WGS 84 and WGS 72 geodetic latitudes and geodetic longitudes are 4.5 and 17.1 meters, respectively, which occur in the equatorial region. The largest geodetic height difference (WGS 84 minus WGS 72) is a negative 4.9 meters which occurs in the south polar area. However, WGS 84 minus WGS 72 coordinate differences are often much larger when the WGS 72 coordinates are determined using Local Geodetic System-to-WGS 72 Mean Datum Shifts. This is readily apparent from [9.1], Figures 26.1 through 26.30, where the WGS 72 coordinates used in forming the coordinate differences (WGS 84 minus WGS 72) for the geographical areas associated with NAD 27 (Alaska), NAD 27 (Canada), NAD 27 (CONUS), SAD 69, ED 50 (Western Europe), OSGB 36, TD, AGD 66, Adindan Datum, and Arc Datum 1950 were determined using Local Geodetic System-to-WGS 72 Mean Datum Shifts developed as part of WGS 72. As an example, contour charts of these WGS 84 minus WGS 72 maximum coordinate differences are provided here for the NAD 27 (CONUS) area, Figures 9.1 through 9.3. [For illustrative purposes, Mean Datum Shifts were used to calculate the WGS 72 coordinates for NAD 27 (CONUS) although, as noted earlier, the more accurate ΔX, ΔY, ΔZ Datum Shift Contour Charts are available for that area.]

The maximum latitude differences, as depicted on these contour charts [9.1], are considerably larger than those appearing in Table 7.5. For example, latitude differences of 0.5 arc second are noted for the SAD 69, OSGB 36, and TD geographical areas, reaching -1.0 and 1.2 arc seconds for the Arc Datum 1950 and NAD 27 (Canada) areas, respectively. In addition, the longitude differences [9.1] are generally larger than the latitude differences. Longitude differences as large as 1.0, 1.2, and 2.6 arc seconds are noted for the SAD 69, ED 50 (Western Europe), and Arc Datum 1950 geographical areas, respectively. These maximum longitude differences are considerably larger than the 0.554 arc second value (Table 7.4), which is the difference between the WGS 72 and WGS 84 reference longitudes (zero meridians). In fact, longitude differences larger than 0.5 arc second occur for all of the above geographical areas except AGD 66, and there, the largest difference equals 0.5 second. Geodetic height differences are also large for some of the geographical areas, reaching 14, 18, and -36 meters, respectively, for the SAD 69, Arc Datum 1950, and TD geographical areas. The maximum geodetic height differences for these areas [9.1] are much larger than any values appearing in Table 7.5. The basic data used in forming these maximum WGS 84 minus WGS 72 coordinate differences is treated briefly in [9.1], Section 26 (Page 26-1).

Therefore, based on the preceding, it can be concluded that the WGS 72-to-WGS 84 Transformation Formulas (Table 7.4) should not be used at a non-Doppler geodetic network station if the station's WGS 72 coordinates were previously determined using the Molodensky Datum Transformation Formulas and Local Geodetic System-to-WGS 72 Mean Datum Shifts. A Local Geodetic System-to-WGS 84 Datum Transformation should be used instead (Section 7.2.4). However, the WGS 72-to-WGS 84 Transformation Formulas (Table 7.4) and WGS 72 coordinates may be used to obtain WGS 84 coordinates for a non-Doppler local geodetic network station if both of the following conditions are met:

- The non-Doppler station is in the immediate vicinity of a Doppler station.

- The WGS 72 coordinates of the non-Doppler station were previously determined using the Molodensky Datum Transformation Formulas and Local Geodetic System-to-WGS 72 Localized Datum Shifts.

For this situation, the WGS 84 coordinates of non-Doppler geodetic network stations determined via Table 7.4 will have the same estimated one-sigma accuracies as expressed by Equations 9-5 and 9-6.

In summary, the preceding indicates that WGS 84 coordinates:

- Determined at a Doppler station using the WGS 72-to-WGS 84 Transformation Formulas (Table 7.4) and that station's WGS 72 coordinates (previously derived from a satellite point positioning solution) have estimated one-sigma accuracies of $\sigma_\phi = \sigma_\lambda = \pm 3$ meters and $\sigma_H = \pm 3$ to ± 4 meters. These accuracy values may change in the future as empirical data related to the effect on station positioning of use of the WGS 84 EGM versus the WGS 72 EGM in satellite point positioning accumulates.

- Determined at non-Doppler geodetic network stations in the immediate vicinity of Doppler stations have estimated one-sigma accuracies of $\sigma_\phi = \sigma_\lambda = \pm 3$ meters and $\sigma_H = \pm 3$ to ± 4 meters if the WGS 84 coordinates were determined using the WGS 72-to-WGS 84 Transformation (Table 7.4), and the station's WGS 72 coordinates used in the conversion were previously determined using the Molodensky Datum Transformation Formulas and Local Geodetic System-to-WGS 72 Localized Datum Shifts.

- Should not be determined at non-Doppler geodetic network stations using the WGS 72-to-WGS 84 Transformation Formulas (Table 7.4) if the station's WGS 72 coodinates were previously determined using the Molodensky Datum Transformation Formulas and Local Geodetic System-to-WGS 72 Mean Datum Shifts. A Local Geodetic System-to-WGS 84 Datum Transformation should be used instead.

9.4 WGS 84 Coordinates Determined From Local Geodetic System-to-WGS 84 Datum Transformations

The WGS 84 coordinates of a non-Doppler local geodetic network station will be less accurate than the WGS 84 coordinates of a Doppler station determined via satellite point positioning (Section 9.2). This is due to the distortions present in local geodetic system networks, the lack (in general) of a sufficient number of properly placed Doppler stations colocated with local geodetic system stations for use in forming the Local Geodetic System-to-WGS 84 Datum Shifts, and the uncertainty introduced by the Local Geodetic System-to-WGS 84 Datum Transformation Formulas themselves.

In converting many local geodetic systems to WGS 84, the WGS 84 coordinates of both Doppler and non-Doppler local geodetic network stations will be determined using a Local Geodetic System-to-WGS 84 Datum Transformation. When such a transformation is used, the WGS 84 coordinates of both Doppler and non-Doppler stations are affected by both a random error and a bias. For the latitude component (ϕ), for example, the random or Gaussian error in the WGS 84 geodetic latitude (or $\Delta\phi$ datum shift) at a non-Doppler station is the same as that for a Doppler (datum conversion) station. This random error, from Equation (9-3), is:

$$\sigma_\phi = \pm 2 \text{ m} \quad .$$

The bias in the latitude component (or $\Delta\phi$ datum shift) at both Doppler and non-Doppler stations is the difference between the true datum shift and the datum shift actually used at the stations.

The probability error space containing the true value when the error source has both a random and a bias component can be expressed mathematically [9.2] [9.3]. The probability density function for ϕ in one dimension, $f(\phi)$, is:

$$f(\phi) = \frac{1}{(2\pi)^{1/2} |\sigma_\phi|} e^{-\frac{1}{2}\left[\frac{(\phi-\delta\phi)^2}{\sigma_\phi^2}\right]} \quad . \tag{9-7}$$

Similar expressions hold for λ and H.

Assuming that the errors in ϕ, λ, and H are uncorrelated, the probability density function in two dimensions is:

$$f(\phi,\lambda) = \frac{1}{2\pi |\sigma_\phi| |\sigma_\lambda|} e^{-\frac{1}{2}\left[\frac{(\phi-\delta\phi)^2}{\sigma_\phi^2} + \frac{(\lambda-\delta\lambda)^2}{\sigma_\lambda^2}\right]} \quad . \tag{9-8}$$

In three dimensions, the probability density function is:

$$f(\phi,\lambda,H) = \frac{1}{(2\pi)^{3/2} |\sigma_\phi| |\sigma_\lambda| |\sigma_H|} e^{-\frac{1}{2}\left[\frac{(\phi-\delta\phi)^2}{\sigma_\phi^2} + \frac{(\lambda-\delta\lambda)^2}{\sigma_\lambda^2} + \frac{(H-\delta H)^2}{\sigma_H^2}\right]} \quad . \tag{9-9}$$

In the above equations, $\delta\phi$, $\delta\lambda$, and δH denote the biases in the WGS 84 geodetic latitude, geodetic longitude, and geodetic height, respectively, at the Doppler and non-Doppler stations.

The one standard deviation probability level may be found from the integrals of the probability density functions, Equations (9-7), (9-8), and (9-9), via numerical integration. In one dimension, utilizing Equation (9-7):

$$P_r(-\sigma_{\ell_\phi} < \phi < \sigma_{\ell_\phi}) = \int_{-\sigma_{\ell_\phi}}^{\sigma_{\ell_\phi}} f(\phi)\, d\phi \tag{9-10}$$

$$P_r(-\sigma_{\ell_\phi} < \phi < \sigma_{\ell_\phi}) = 0.6827 \tag{9-11}$$

where σ_{ℓ_ϕ} is the linear one-sigma error in geodetic latitude. Similar expressions for $f(\lambda)$ and $f(H)$ may be numerically integrated to find σ_{ℓ_λ} and σ_{ℓ_H}, respectively.

The probability density function in two dimensions, Equation (9-8), may be numerically integrated to find the circular one standard deviation probability level:

$$P_r[(\phi^2 + \lambda^2) < \sigma_c^{\,2}] = \int_R\int f(\phi,\lambda)\, d\phi d\lambda \tag{9-12}$$

$$P_r[(\phi^2 + \lambda^2) < \sigma_c^{\,2}] = 0.3935 \tag{9-13}$$

In Equation (9-12), R denotes a circular disc of radius σ_c.

For the three dimensional case, Equation (9-9) may be numerically integrated to find the spherical one standard deviation probability level:

$$P_r[(\phi^2 + \lambda^2 + H^2) < \sigma_s^2] = \iiint_S f(\phi, \lambda, H)\ d\phi d\lambda dH \qquad (9\text{-}14)$$

$$P_r[(\phi^2 + \lambda^2 + H^2) < \sigma_s^2] = 0.1990 \qquad (9\text{-}15)$$

In Equation (9-14), S denotes a sphere of radius σ_S.

Equations (9-10), (9-12), and (9-14) were numerically integrated to obtain values for σ_{ℓ_ϕ}, σ_{ℓ_λ}, σ_{ℓ_H}, σ_C, and σ_S at individual Doppler stations. For the linear case (σ_{ℓ_ϕ}, σ_{ℓ_λ}, σ_{ℓ_H}), the integration was performed numerically using a seven-point Simpson's Rule. For the two and three dimensional cases (σ_C, σ_S), numerical integration was performed using a 64-point and a 512-point 15th degree Gauss Product Formula, respectively [9.4]. The values used in $f(\phi)$, $f(\lambda)$, $f(H)$, $f(\phi,\lambda)$, and $f(\phi,\lambda,H)$ for the random errors in WGS 84 geodetic latitude, geodetic longitude, and geodetic height, $\sigma_\phi = \sigma_\lambda = \pm 2$ m and $\sigma_H = \pm 3$ m, were obtained from Equations (9-3) and (9-4). The values used (in the calculations) for the biases in the WGS 84 geodetic latitude, geodetic longitude, and geodetic height were the residuals $\delta\phi$, $\delta\lambda$, and δH available at each Doppler station (calculation point) from the equations:

$$\delta\phi_i = \Delta\phi_i - \Delta\phi_i(\text{Calculated})$$

$$\delta\lambda_i = \Delta\lambda_i - \Delta\lambda_i(\text{Calculated}) \qquad (9\text{-}16)$$

$$\delta H_i = \Delta H_i - \Delta H_i(\text{Calculated}).$$

In Equations (9-16), the quantities $\Delta\phi_i$, $\Delta\lambda_i$, and ΔH_i are datum shifts known at each Doppler station (calculation point) through the availability of WGS 84 coordinates obtained via the NSWC 9Z-2 to WGS 84 Transformation, Table 2.4. The quantities $\Delta\phi_i$(Calculated), $\Delta\lambda_i$(Calculated), and ΔH_i(Calculated) are values determined at each Doppler station (calculation point) using either the Standard Molodensky Datum

Transformation Formulas with Mean Datum Shifts or Datum Transformation MREs.

Utilizing the approach discussed above, WGS 84 coordinate accuracy calculations were performed for several local geodetic systems assuming the WGS 84 coordinates were determined using the two datum transformation techniques discussed above--the Standard Molodensky Datum Transformation Formulas with Mean Datum Shifts, and Datum Transformation MREs. As previously indicated, unless a sufficient number of Doppler stations has been colocated with local geodetic network sites to ascertain the presence or absence of any significant distortion in the local geodetic network, the accuracy with which WGS 84 coordinates of non-Doppler local network sites can be determined using a Local Geodetic System-to-WGS 84 Datum Transformation cannot be rigorously calculated. However, utilizing the approach discussed above, there is sufficient data available at network Doppler stations to calculate the accuracy of their WGS 84 coordinates as a function of the Local Geodetic System-to-WGS 84 Datum Transformation technique (used to obtain the WGS 84 coordinates).

The individual linear one-sigma accuracy values (σ_{ℓ_ϕ}, σ_{ℓ_λ}, σ_{ℓ_H}) computed at each Doppler station (calculation point) for WGS 84 geodetic latitude, geodetic longitude, and geodetic height were used to prepare contour charts for several local geodetic systems. Such contour charts illustrate how errors in the WGS 84 coordinates of Doppler stations vary throughout the local geodetic network as a function of the datum transformation technique used to calculate the WGS 84 coordinates. Figures 9.4 - 9.6, for example, illustrate how errors in the WGS 84 coordinates of Doppler stations vary throughout NAD 27 (CONUS) when the WGS 84 coordinates are determined using the Standard Molodensky Datum Transformation Formulas with Mean Datum Shifts ($\overline{\Delta X}$, $\overline{\Delta Y}$, $\overline{\Delta Z}$). These and similar contour charts are available in Section 27 of [9.1] for SAD 69, ED 50 (Western Europe), ED 50 (UK/Ireland), ED 50 (UK Only), TD, and AGD 84. Requirements for similar charts for other local geodetic systems should be made known to DMA. (See PREFACE.) From these contour charts, it is apparent that the accuracy of WGS 84 coordinates can degrade considerably when mean datum shifts are used in their determination. This is quite noticeable for WGS 84 geodetic latitudes and longitudes in both the United States (CONUS) and South America [9.1]. Latitude and longitude errors as large as 12 and 10 meters, respectively, are noted in CONUS, with longitude errors reaching 26 meters in South America. Also, errors in latitude and longitude reach 10 and 14 meters, respectively, in Western Europe [9.1].

Similar contour charts, Figures 9.7 - 9.9, illustrate how errors in the WGS 84 coordinates of Doppler stations vary throughout NAD 27 (CONUS) when the WGS 84 coordinates are determined using Datum Transformation MREs. These and similar contour charts are also available in Section 27 of [9.1] for the local geodetic systems identified in the preceding paragraph. Requirements for such MRE-related graphics for other local geodetic systems should also be made known to DMA. (See PREFACE.)

The individual linear, circular, and spherical one-sigma accuracy values (σ_{ℓ_ϕ}, σ_{ℓ_λ}, σ_{ℓ_H}, σ_C, σ_S) computed at each Doppler station (calculation point) for WGS 84 geodetic latitude, geodetic longitude, and geodetic height were also used to calculate linear, circular, and spherical errors (σ_{D_ℓ}, σ_{D_C}, σ_{D_S}) for WGS 84 coordinates for <u>each</u> local geodetic system analyzed. The following equations were used to perform the calculations:

$$\sigma_{D_{\ell_\phi}} = [(\sum_{i=1}^{n} (\sigma^2_{\ell_\phi})_i)/(n-1)]^{1/2}$$

$$\sigma_{D_{\ell_\lambda}} = [(\sum_{i=1}^{n} (\sigma^2_{\ell_\lambda})_i)/(n-1)]^{1/2}$$

$$\sigma_{D_{\ell_H}} = [(\sum_{i=1}^{n} (\sigma^2_{\ell_H})_i)/(n-1)]^{1/2} \qquad (9\text{-}17)$$

$$\sigma_{D_c} = [(\sum_{i=1}^{n} (\sigma_c^2)_i)/(n-1)]^{1/2}$$

$$\sigma_{D_s} = [(\sum_{i=1}^{n} (\sigma_s^2)_i)/(n-1)]^{1/2}$$

where

n = number of Doppler stations (calculation points) utilized in the local geodetic system (n greater than one).

The linear, circular, and spherical errors determined in this manner are listed in Tables 9.1 and 9.2 for WGS 84 coordinates computed at Doppler stations using the Standard Molodensky Datum Transformation Formulas with Mean Datum Shifts, and Datum Transformation MREs, respectively. From these tables and the contour charts discussed earlier, it is apparent that the WGS 84 coordinates of Doppler and non-Doppler stations are more accurate (with minor exceptions) when determined using Local Geodetic System-to-WGS 84 Datum Transformation MREs than Molodensky Datum Transformation Formulas with Mean Datum Shifts. Also, it is noted from a comparison of Table 9.1 and Table 9.2 entries that WGS 84 coordinates exhibiting relatively large errors (Table 9.1) show considerable improvement when based on Datum Transformation MREs (Table 9.2). Compare, for example, the WGS 84 coordinate accuracies for the following datums: Arc 1950, Arc 1960, Carthage, ED 50 (Iran), Indian, Liberia 1964, Luzon, NAD 27 (Canada, Mexico and Central America, Caribbean), Oman, OSGB 36, PSAD 56, and SAD 69. A comparison of Figures 27.1 - 27.21 with Figures 27.22 - 27.42 in [9.1] visually reinforces the findings established statistically via Tables 9.1 and 9.2 -- the superiority of Datum Transformation MREs over Mean Datum Shifts for generating WGS 84 coordinates. The contour charts indicate that Datum Transformation MREs produce WGS 84 coordinates of better accuracy over a much larger geographical extent than do Mean Datum Shifts. For example, compare Figures 9.4, 9.5, and 9.6 with Figures 9.7, 9.8, and 9.9, respectively.

Although the preceding analysis indicates the value of using Datum Transformation MREs to generate WGS 84 coordinates, as opposed to using Mean Datum Shifts, MRE-generated WGS 84 coordinates are not always as accurate as desired. For example, MRE-derived WGS 84 latitudes are of poor quality for the southeastern tip of Texas (Figure 9.7). This poor accuracy is indicative of a problem in that area with either the Doppler station's local geodetic system latitude, or the fitting of the $\Delta\phi$-MRE in that locale. (Although unlikely, the WGS 84 coordinate could be the error source here, and in like situations.) Similarly, MRE-generated longitudes are not as accurate as desired in northern Wisconsin and northwestern Michigan (Figure 9.8). As before, this poor accuracy could be due to a Doppler station local geodetic longitude of poor quality and/or difficulty in the fitting of the $\Delta\lambda$-MRE in that area. A similar situation exists in the Southern Italy and Greece portions of ED 50 where WGS 84 latitudes are of poor accuracy whether generated using Datum Transformation MREs or the Standard Molodensky Datum Transformation Formulas with Mean Datum Shifts. (See Section 27 of Reference 9.1.) Although the poor accuracy for MRE-generated WGS 84 latitudes in the Southern Italy and Greece regions could be due to Doppler station local geodetic latitudes of poor quality and/or difficulty in the fitting of the $\Delta\phi$-MRE in the area, this similarity of accuracy is probably due to an insufficient number of Doppler stations in that region to properly define latitude variations in the ED 50 Network. In areas where local geodetic system latitude variations are known, Datum Transformation MREs are capable of modeling these variations, leading to better accuracy for MRE-generated latitudes than those generated from the use of Mean Datum Shifts. However, since the first known use of the multiple regression equation approach for datum conversion purposes is with WGS 84, it is anticipated that a better practical understanding of the technique and coefficient generation process might also lead to future improvements.

9.5 NAVSTAR GPS-Derived WGS 84 Coordinates

The geodetic basis of NAVSTAR GPS is WGS 84: the WGS 84 coordinate system and associated reference frames (inertial, "instantaneous"), the WGS 84 EGM truncated at n=m=8, and GPS monitor stations directly positioned in WGS 84 (Table 7.3). Since the broadcast ephemerides are based on WGS 84, NAVSTAR GPS receivers automatically give the user's position and velocity in WGS 84 earth-centered, earth-fixed (ECEF) coordinates.

It's important to note that NAVSTAR GPS receivers operated in the navigation (dynamic) mode cannot currently provide WGS 84 coordinates to an accuracy of ±2 meters. Due to current "system" limitations, a dynamic user has the capability to determine rectangular coordinates only to an accuracy of ±10 meters (one sigma, linear) [9.5] [9.6]. Also, results to date [9.7] indicate that a static user, using a GPS receiver in the standard operating mode, can determine his position to no better than ±5 meters (one sigma, linear), without any post-processing of data. The relatively poor quality of GPS-derived positions for static users, at this time, is due to inaccuracies in the GPS satellite ephemerides and the lack of appropriate software for field use.

The possible pessimism generated by the accuracy statements in the preceding paragraph for GPS-derived WGS 84 coordinates needs to be dispelled. For example, GPS-derived WGS 84 coordinates can currently be obtained by a dynamic user to an accuracy of ±2 meters (one sigma) when the receivers are operated in the differential mode [9.8] [9.9]. In addition, the substantial improvements anticipated in NAVSTAR GPS "system" capability, receiver software and storage, and other related areas will lead in the near future to the capability of both fixed and mobile GPS receivers to provide WGS 84 coordinates to an accuracy $\leq \pm 2$ meters (1σ) when operated in the precise positioning service mode.

9.6 Summary/Comments

Tables 9.1 and 9.2 present the one-sigma accuracy of WGS 84 coordinates when such coordinates are determined at Doppler stations using Local Geodetic System-to-WGS 84 Datum Transformations--the Standard Molodensky Datum Transformation Formulas with Mean Datum Shifts and Datum Transformation MREs, respectively. Table 9.2 contains results for the same local geodetic systems that appear in Table 9.1, except for NAD 83. (Datum transformation MREs were not developed for NAD 83 due to its internal consistency and close agreement with WGS 84.) However, the WGS 84 coordinate accuracies provided in Tables 9.1 and 9.2 have limited application since they do not reflect the variable nature of WGS 84 coordinate errors throughout a datum area. This shortcoming is not present in Figures 9.4 through 9.9, and similar figures in Section 27 of [9.1]. These graphics provide detailed information on the variable nature of WGS 84 coordinate accuracy at Doppler stations throughout a local geodetic system (as a function of the datum transformation technique used to obtain the WGS 84 coordinates).

The accuracy values available at Doppler stations from such contour charts may also be valid at non-Doppler sites under certain circumstances. Besides being affected by the datum transformation techniques used, the accuracy of the WGS 84 coordinates of local geodetic system non-Doppler sites is influenced by the site's location within the network (i.e., its proximity to a Doppler station), whether the network has significant distortions, whether enough Doppler stations are available to properly define any existing distortions, and the accuracy with which the Doppler stations are geodetically tied to the local network. Due to the small number of Doppler datum conversion stations available for most local geodetic systems, their often less-than-ideal dispersal throughout the network, and the lack of definitive information on the quality of most local geodetic networks, the WGS 84 coordinate accuracies provided in this Chapter are necessarily rigorously applicable only at the Doppler stations. However, if the local geodetic systems are free of significant distortions and/or are of small geographical extent, the accuracy values available from Figures 9.4 - 9.9 and similar graphics in [9.1] may also be valid at non-Doppler sites in the datum area. The decision on whether such accuracy values are valid at non-Doppler sites must be made on a datum-by-datum basis based on the analyst's knowledge of the geodetic quality of the local datum involved.

For convenience, an attempt is made with Table 9.3 to summarize the discussion on WGS 84 coordinate accuracy. However, due to the many factors involved, Table 9.3 must be used carefully, and with special attention paid to the footnotes. In addition, the accuracies recorded in Table 9.3 are general accuracy values, while the accuracies associated with WGS 84 coordinates determined using either the Datum Transformation MREs ($\Delta\phi$, $\Delta\lambda$, ΔH) or the Standard Molodensky Datum Transformation Formulas with Mean Datum Shifts ($\overline{\Delta X}$, $\overline{\Delta Y}$, $\overline{\Delta Z}$) are largely datum dependent. Therefore, when either of these two datum conversion techniques are being used to obtain WGS 84 coordinates, Table 9.3 is not as appropriate as Tables 9.1 and 9.2, Figures 9.4 - 9.9, or similar graphics from [9.1], for obtaining accuracy values applicable to a specific local geodetic system.

To provide accuracy data supplemental to that available in this Chapter for WGS 84 Coordinates determined at non-Doppler sites, standard deviations ($\sigma_{\overline{\Delta X}}$, $\sigma_{\overline{\Delta Y}}$, $\sigma_{\overline{\Delta Z}}$) were computed for the mean datum shifts for each local geodetic system having two or more Doppler datum transformation stations using, for example, for $\sigma_{\overline{\Delta X}}$ the formula:

$$\sigma_{\overline{\Delta X}} = \pm \left[\sum_{i=1}^{n} \left(\Delta X_i - \overline{\Delta X} \right)^2 / (n-1) \right]^{1/2} \qquad (9\text{-}18)$$

In Equation (9-18), ΔX_i is the datum shift at Doppler datum transformation station i and n is the number of such stations used in determining $\overline{\Delta X}$. Analogous formulas were used to compute $\sigma_{\overline{\Delta Y}}$ and $\sigma_{\overline{\Delta Z}}$. Then, instituting in keeping with Equations (9-3) and (9-4) a minimum error threshold of $\sigma_{\overline{\Delta X}} = \sigma_{\overline{\Delta Y}} = \sigma_{\overline{\Delta Z}} = \pm 2$ meters, the standard deviations computed via Equation (9-18) and analogous formulas were modified by applying a multiplicative factor of 2 or 1.5 depending on whether the mean datum shift had been determined using two or more than two Doppler datum transformation stations, respectively. A multiplicative factor of 2.5 was applied to $\sigma_{\overline{\Delta X}} = \sigma_{\overline{\Delta Y}} = \sigma_{\overline{\Delta Z}} = \pm 2$ meters to obtain standard deviations for datum shifts developed for local geodetic systems having only one Doppler datum transformation station. Use of such multiplicative factors was deemed necessary to account for distortions of unknown magnitude assumed to exist in the local geodetic networks. The above procedure was not used with NAD 83, however, due to the consistency assumed to exist in the network. Instead, again keeping in mind Equations (9-3) and (9-4), the standard deviations of the mean datum shifts for NAD 83 were taken to be $\sigma_{\overline{\Delta X}} = \sigma_{\overline{\Delta Y}} = \sigma_{\overline{\Delta Z}} = \pm 2$ meters. The standard deviations discussed above, and the mean datum shifts to which they apply, are recorded in Table 10.1 [9.1]. Any Table 10.1 error values smaller than analogous quantities in Table 9.1 (and related graphics), when expressed in the form of Table 9.1, should be replaced by the latter due to the greater rigor used in their development.

Despite the shortcomings (e.g., Tables 9.1-9.3 do not contain entries for all 83 local geodetic systems), the accuracy data in this Chapter and in Sections 10 and 27 of [9.1], when used with care, should be of considerable value to those involved in the generation and use of WGS 84 coordinates. If this WGS 84 coordinate accuracy data proves to be inadequate for a particular application, the requirement for additional data or information should be forwarded to the address provided in the PREFACE.

REFERENCES

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Table 9.1

Accuracy (1σ) of WGS 84 Coordinates at Doppler Sites
- WGS 84 Coordinates Determined Using Molodensky Datum Transformation Formulas and Local Geodetic System-to-WGS 84 Mean Datum Shifts ($\overline{\Delta X}$, $\overline{\Delta Y}$, $\overline{\Delta Z}$) -

Local Geodetic Systems	Number of Comparison Points	Linear Error Geodetic Latitude ($\sigma_{D_{\ell_\phi}}$)	Linear Error Geodetic Longitude ($\sigma_{D_{\ell_\lambda}}$)	Linear Error Geodetic Height ($\sigma_{D_{\ell_H}}$)	Circular (Horizontal) Error (σ_{D_C})	Spherical (Positional) Error (σ_{D_S})
Adindan	25	±4.2m	±4.5m	±4.1m	5.1m	5.1m
Arc 1950	41	13.7	26.3	5.3	29.1	29.0
Arc 1960	19	5.2	7.1	4.2	7.5	7.4
Australian Geodetic 1966	105	3.1	2.9	3.5	3.1	3.3
Australian Geodetic 1984	90	2.8	2.9	3.5	2.9	3.1
Bellevue (IGN)	3	2.8	2.7	3.8	2.7	3.1
Bermuda 1957	3	2.8	2.9	4.2	2.9	3.3
Bogota Observatory	7	5.2	4.8	5.1	5.8	6.0
Campo Inchauspe	20	3.5	3.5	4.5	3.7	4.2
Canton Astro 1966	4	2.6	2.5	4.3	2.5	3.1
Cape	5	5.9	4.4	3.6	6.0	5.7
Cape Canaveral	16	2.3	2.2	3.4	2.3	2.6
Carthage	5	7.3	7.5	3.8	8.8	8.3
Chatham 1971	4	2.4	2.4	3.7	2.4	2.8
Chua Astro	6	5.0	6.3	5.6	6.7	7.0
Corrego Alegre	17	4.0	4.2	3.5	4.5	4.8
Djakarta	5	2.2	2.7	4.0	2.5	2.9
European 1950						
Western Europe	85	3.2	5.7	3.6	5.5	5.4
* UK/Ireland	47	2.2	2.3	3.4	2.2	2.6
* UK (Only)	40	2.2	2.3	3.5	2.2	2.6
Cyprus	4	2.3	2.3	3.7	2.3	2.7
Egypt	14	5.2	6.2	5.1	7.0	7.2

* ED 50 coordinates developed from OSGB Scientific Network 1980 (SN 80) coordinates.

Table 9.1 (Cont'd)

Accuracy (1σ) of WGS 84 Coordinates at Doppler Sites
- WGS 84 Coordinates Determined Using Molodensky Datum Transformation Formulas and Local Geodetic System-to-WGS 84 Mean Datum Shifts ($\overline{\Delta X}$, $\overline{\Delta Y}$, $\overline{\Delta Z}$) -

Local Geodetic Systems	Number of Comparison Points	Linear Error Geodetic Latitude ($\sigma_{D_{\ell_\phi}}$)	Linear Error Geodetic Longitude ($\sigma_{D_{\ell_\lambda}}$)	Linear Error Geodetic Height ($\sigma_{D_{\ell_H}}$)	Circular (Horizontal) Error (σ_{D_C})	Spherical (Positional) Error (σ_{D_S})
European 1950 (Cont'd)						
Iran	27	±5.5m	±8.0m	±9.6m	8.4m	10.8m
Geodetic Datum 1949	14	4.7	2.8	3.7	4.2	4.1
Guam 1963	5	2.6	2.4	3.9	2.5	3.0
Hjorsey 1955	6	2.5	2.9	5.5	2.7	3.9
Indian	14	6.3	6.8	3.4	7.9	7.5
Ireland 1965	7	2.3	2.4	3.3	2.4	2.6
Kandawala	3	2.9	3.3	3.8	3.1	3.3
Kertau 1948	6	3.1	3.0	3.6	3.2	3.3
Liberia 1964	4	4.4	9.4	3.8	8.9	8.3
Luzon	7	10.7	7.5	5.8	11.4	11.3
Merchich	9	2.4	2.7	5.3	2.6	3.8
Minna	6	4.2	4.7	3.7	4.9	4.8
NAD 27						
Alaska	47	4.6	6.4	4.3	6.9	6.7
Canada	112	8.3	10.8	4.2	12.7	11.8
CONUS	405	5.2	3.6	3.7	5.1	5.0
Mexico, Central America	44	4.9	9.1	5.3	9.0	8.9
Caribbean	26	8.1	5.4	4.8	8.6	8.5
NAD 83	203	2.1	2.3	3.5	2.2	2.6
Old Egyptian	14	5.4	4.5	5.2	5.7	6.1
Old Hawaiian	13	5.2	5.2	4.4	6.0	6.0
Oman	7	6.8	2.6	3.7	5.8	5.5
Ordnance Survey of Great Britain 1936	38	8.8	3.9	3.4	8.2	7.7

Table 9.1 (Cont'd)

Accuracy (1σ) of WGS 84 Coordinates at Doppler Sites
- WGS 84 Coordinates Determined Using Molodensky Datum Transformation Formulas and Local Geodetic System-to-WGS 84 Mean Datum Shifts ($\overline{\Delta X}$, $\overline{\Delta Y}$, $\overline{\Delta Z}$) -

Local Geodetic Systems	Number of Comparison Points	Linear Error Geodetic Latitude ($\sigma_{D_{\ell_\phi}}$)	Linear Error Geodetic Longitude ($\sigma_{D_{\ell_\lambda}}$)	Linear Error Geodetic Height ($\sigma_{D_{\ell_H}}$)	Circular (Horizontal) Error (σ_{D_C})	Spherical (Positional) Error (σ_{D_S})
Provisional South American 1956	65	±23.6	±12.9	±9.6	28.6	27.0
Puerto Rico	11	3.0	3.0	3.7	3.1	3.3
Qatar National	3	2.5	2.7	4.0	2.6	3.0
South American 1969	84	6.3	10.8	5.1	11.9	11.1
Southwest Base	5	2.4	3.1	3.4	2.8	3.0
Timbalai 1948	8	4.5	4.3	3.4	4.9	4.6
Tokyo	11	5.5	5.3	3.8	6.3	6.1
Wake-Eniwetok 1960	7	2.3	2.8	3.6	2.6	2.9
Zanderij	5	5.8	5.0	3.5	6.1	5.7

NOTE: The accuracies listed in this table are general accuracy values determined using data developed at Doppler sites. See Figures 27.1 - 27.21 in [9.1] before deciding to use accuracy values from this table.

Table 9.2

Accuracy (1σ) of WGS 84 Coordinates at Doppler Sites
- WGS 84 Coordinates Determined Using Local Geodetic System-to-WGS 84
Datum Transformation Multiple Regression Equations -

Local Geodetic Systems	Number of Comparison Points	Linear Error Geodetic Latitude ($\sigma_{D_{\ell_\phi}}$)	Linear Error Geodetic Longitude ($\sigma_{D_{\ell_\lambda}}$)	Linear Error Geodetic Height ($\sigma_{D_{\ell_H}}$)	Circular (Horizontal) Error (σ_{D_C})	Spherical (Positional) Error (σ_{D_S})
Adindan	25	±5.4m	±3.6m	±3.8m	5.6m	5.6m
Arc 1950	41	5.3	20.4	4.7	20.5	20.5
Arc 1960	19	3.2	2.8	3.9	3.2	3.5
Australian Geodetic 1966	105	2.4	2.4	3.4	2.4	2.8
Australian Geodetic 1984	90	2.3	2.3	3.5	2.3	2.7
Bellevue (IGN)	3	2.4	2.5	3.7	2.5	2.8
Bermuda 1957	3	2.5	2.5	3.8	2.5	2.9
Bogota Observatory	7	3.0	3.3	3.4	3.3	3.3
Campo Inchauspe	20	2.6	2.6	3.8	2.6	3.1
Canton Astro 1966	4	2.3	2.3	3.5	2.3	2.7
Cape	5	2.5	2.3	3.4	2.4	2.7
Cape Canaveral	16	2.2	2.3	3.3	2.3	2.6
Carthage	5	2.6	2.7	3.5	2.7	2.9
Chatham 1971	4	2.3	2.4	3.5	2.4	2.7
Chua Astro	6	3.0	2.3	3.5	2.7	3.0
Corrego Alegre	17	3.3	3.3	3.5	3.6	3.8
Djakarta	5	2.5	2.6	3.5	2.5	2.8
European 1950						
Western Europe	85	3.0	2.8	3.5	3.2	3.4
* UK/Ireland	47	2.1	2.3	3.3	2.2	2.5
* UK (Only)	40	2.1	2.3	3.4	2.2	2.6
Cyprus	4	2.3	2.3	3.5	2.3	2.7
Egypt	14	2.6	2.9	3.5	2.8	3.0

* ED 50 coordinates developed from OSGB Scientific Network 1980 (SN 80) coordinates.

Table 9.2 (Cont'd)

Accuracy (1σ) of WGS 84 Coordinates at Doppler Sites
- WGS 84 Coordinates Determined Using Local Geodetic System-to-WGS 84 Datum Transformation Multiple Regression Equations -

Local Geodetic Systems	Number of Comparison Points	Linear Error Geodetic Latitude ($\sigma_{D_{\ell_\phi}}$)	Linear Error Geodetic Longitude ($\sigma_{D_{\ell_\lambda}}$)	Linear Error Geodetic Height ($\sigma_{D_{\ell_H}}$)	Circular (Horizontal) Error (σ_{D_C})	Spherical (Positional) Error (σ_{D_S})
European 1950 (Cont'd)						
Iran	27	±4.8m	±4.5m	±5.6m	5.7m	6.6m
Geodetic Datum 1949	14	2.3	2.2	3.6	2.3	2.7
Guam 1963	5	2.5	2.3	3.8	2.4	2.8
Hjorsey 1955	6	2.7	2.5	3.8	2.6	3.0
Indian	14	4.9	2.9	4.1	4.6	4.7
Ireland 1965	7	2.3	2.4	3.3	2.4	2.7
Kandawala	3	2.5	2.6	3.7	2.5	2.9
Kertau 1948	6	2.6	2.6	3.6	2.6	2.9
Liberia 1964	4	2.3	3.0	3.5	2.6	2.9
Luzon	7	2.8	3.2	4.0	3.0	3.4
Merchich	9	2.8	2.2	4.0	2.6	3.0
Minna	6	2.9	2.6	3.5	2.8	3.0
NAD 27						
Alaska	47	3.2	3.2	4.0	3.4	3.7
Canada	112	3.1	3.4	3.5	3.5	3.6
CONUS	405	2.6	2.7	3.5	2.8	3.1
Mexico, Central America	44	3.5	4.0	4.3	4.1	4.5
Caribbean	26	2.7	4.4	4.9	4.1	4.8
Old Egyptian	14	2.5	3.7	4.7	3.4	4.3
Old Hawaiian	13	2.7	2.2	3.6	2.5	2.9
Oman	7	2.4	2.7	3.3	2.5	2.8
Ordnance Survey of Great Britain 1936	38	2.1	2.3	3.2	2.2	2.5

Table 9.2 (Cont'd)

Accuracy (1σ) of WGS 84 Coordinates at Doppler Sites
- WGS 84 Coordinates Determined Using Local Geodetic System-to-WGS 84
Datum Transformation Multiple Regression Equations -

Local Geodetic Systems	Number of Comparison Points	Linear Error Geodetic Latitude ($\sigma_{D_{\ell_\phi}}$)	Linear Error Geodetic Longitude ($\sigma_{D_{\ell_\lambda}}$)	Linear Error Geodetic Height ($\sigma_{D_{\ell_H}}$)	Circular (Horizontal) Error (σ_{D_C})	Spherical (Positional) Error (σ_{D_S})
Provisional South American 1956	65	±22.2	±4.1	±8.5	25.1m	23.6m
Puerto Rico	11	2.4	2.5	3.4	2.5	2.8
Qatar National	3	2.4	2.5	3.7	2.5	2.8
South American 1969	84	3.5	3.5	4.7	3.9	4.5
Southwest Base	5	2.4	2.4	3.4	2.4	2.7
Timbalai 1948	8	2.3	2.5	3.3	2.4	2.7
Tokyo	13**	6.1	5.0	4.2	6.8	6.7
Wake-Eniwetok 1960	7	2.2	2.2	3.3	2.2	2.6
Zanderij	5	2.7	2.9	3.6	2.8	3.0

** Number includes two Doppler stations on Okinawa. Related entry in Table 9.1 does not include these two stations.

NOTE: The accuracies listed in this table are general accuracy values determined using data developed at Doppler sites. See Figures 27.22 - 27.42 in [9.1] before deciding to use accuracy values from this table.

Table 9.3

Accuracy (1σ) of WGS 84 Coordinates
As a Function of Coordinate Determination Technique

WGS 84 Coordinates of Site Determined Using	Accuracies (1σ) Geodetic Latitude	Geodetic Longitude	Geodetic Height
Satellite Point Positioning Directly in WGS 84	±1 m	±1 m	±1-2 m
NSWC 9Z-2 to WGS 84 Transformation	2	2	2-3
Localized ΔX, ΔY, ΔZ Datum Shifts (Tabular or From ΔX, ΔY, ΔZ Datum Shift Contour Charts) and Standard Molodensky Datum Transformation Formulas	2*	2*	2-3*
Localized ΔX, ΔY, ΔZ Datum Shifts and Direct Coordinate Conversion (X, Y, Z to ϕ, λ, H)	2*	2*	2-3*
$\Delta\phi$, $\Delta\lambda$, ΔH Datum Shift Contour Charts	3**	3**	2-3**
Datum Shift Multiple Regression Equations ($\Delta\phi$, $\Delta\lambda$, ΔH)	3***	3***	4***
$\overline{\Delta X}$, $\overline{\Delta Y}$, $\overline{\Delta Z}$ Mean Datum Shifts and Standard Molodensky Datum Transformation Formulas	5***	4***	4***
$\overline{\Delta X}$, $\overline{\Delta Y}$, $\overline{\Delta Z}$ Mean Datum Shifts and Direct Coordinate Conversion (X, Y, Z to ϕ, λ, H)	5***	4***	4***

* Pertains only to the use of localized ΔX, ΔY, ΔZ datum shifts (tabular or from ΔX, ΔY, ΔZ Datum Shift Contour Charts). Applicable only in the vicinity of Doppler stations; the errors are larger elsewhere [and if mean datum shifts ($\overline{\Delta X}$, $\overline{\Delta Y}$, $\overline{\Delta Z}$) are used].

** Applicable only in the vicinity of Doppler stations. The errors are larger elsewhere.

*** These are general accuracy values pertaining to NAD 27 (CONUS), and will not necessarily be the same for other local geodetic systems. (See Tables 9.1 and 9.2 for these and other general accuracy values, and then Figures 27.1 - 27.42 from Reference 9.1 for how the accuracy values vary throughout the datum areas.)

Table 9.3 (Cont'd)

Accuracy (1σ) of WGS 84 Coordinates
As a Function of Coordinate Determination Technique

WGS 84 Coordinates of Site Determined Using	Accuracies (1σ) Geodetic Latitude	Geodetic Longitude	Geodetic Height
WGS 72 to WGS 84 Transformation Formulas:			
- At Doppler Stations (WGS 72 Coordinates from Satellite Point Positioning)	±2 m	±2 m	±2-3 m
- At Non-Doppler Geodetic Network Stations:			
- Near Doppler Stations, WGS 72 Coordinates from <u>Localized</u> Datum Shifts	3	3	3-4
- WGS 72 Coordinates from <u>Mean</u> Datum Shifts	[Use Only as a Last Resort; Large Errors. See Sections 7.2.3 and 9.3 of this Report and Section 26 (Figures 26.1 - 26.30) of Reference 9.1. Related Information Also Available in Section 11 and Section 27 (Figures 27.1 -27.21) of Reference 9.1.]		

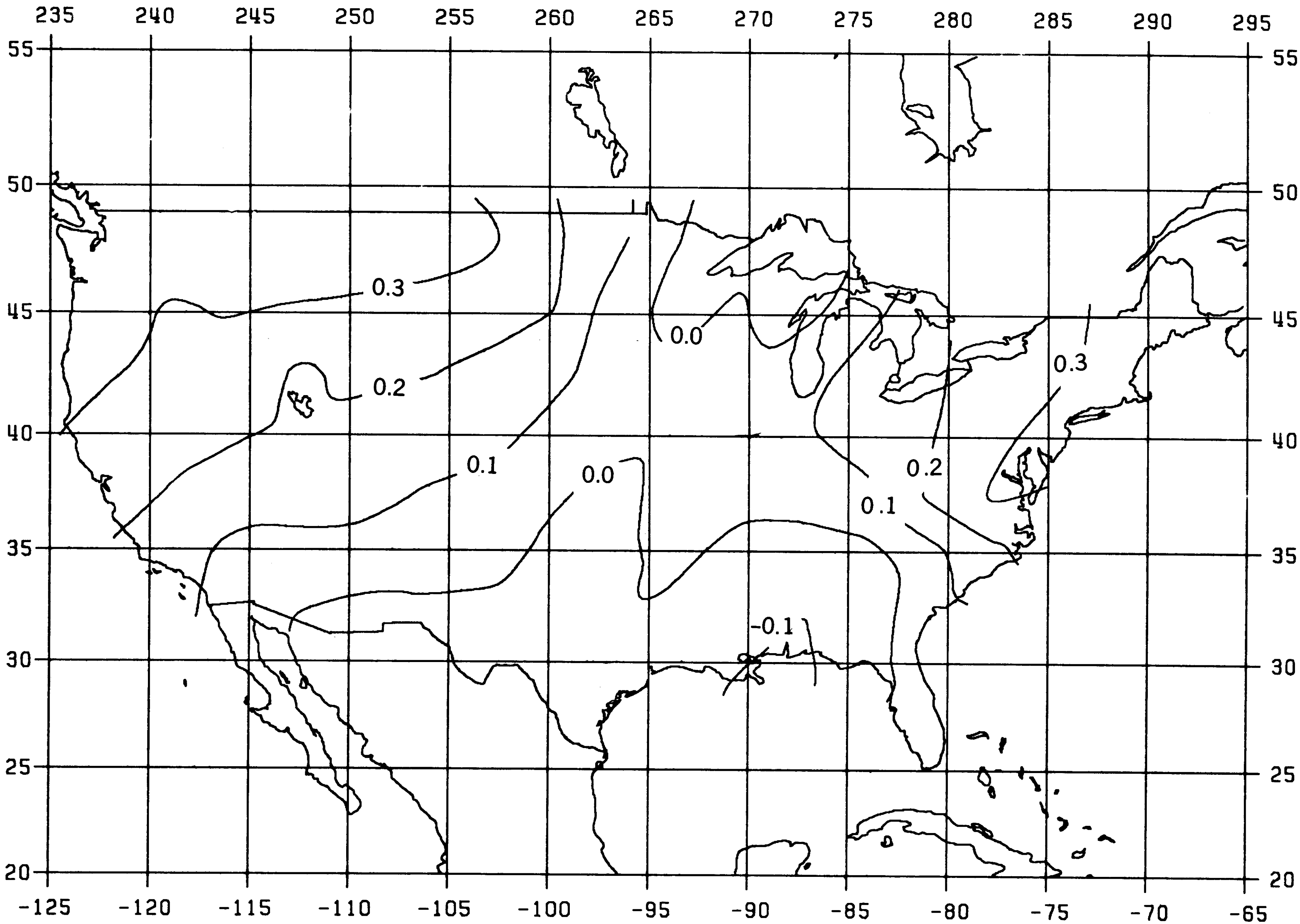

Figure 9.1. Maximum Latitude Differences in Converting WGS 72 Coordinates to WGS 84 (NAD 27 Area, CONUS)-(Units = 0.1 Arc Second)

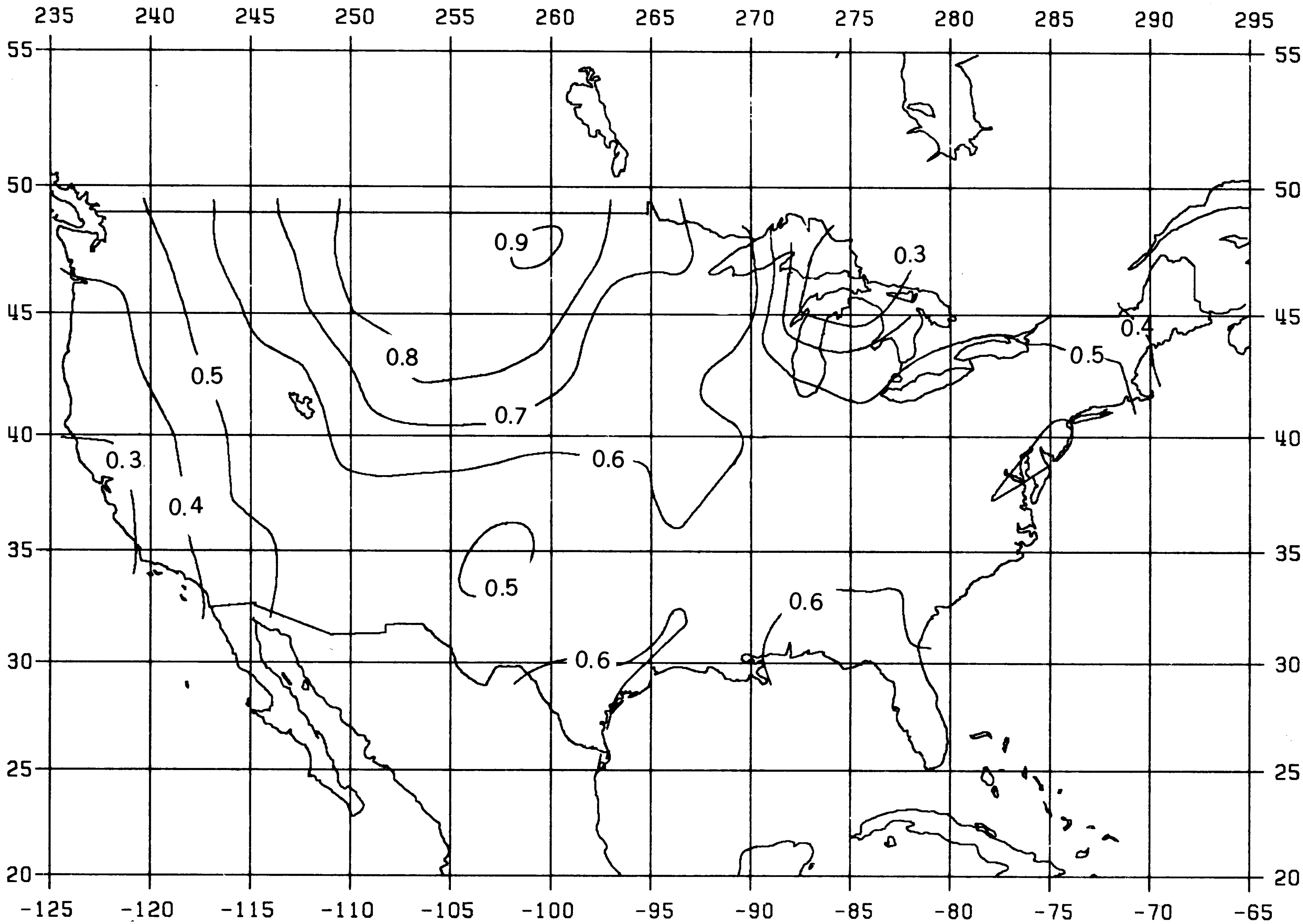

Figure 9.2. Maximum Longitude Differences in Converting WGS 72 Coordinates to WGS 84 (NAD 27 Area, CONUS)-(Units = 0.1 Arc Second)

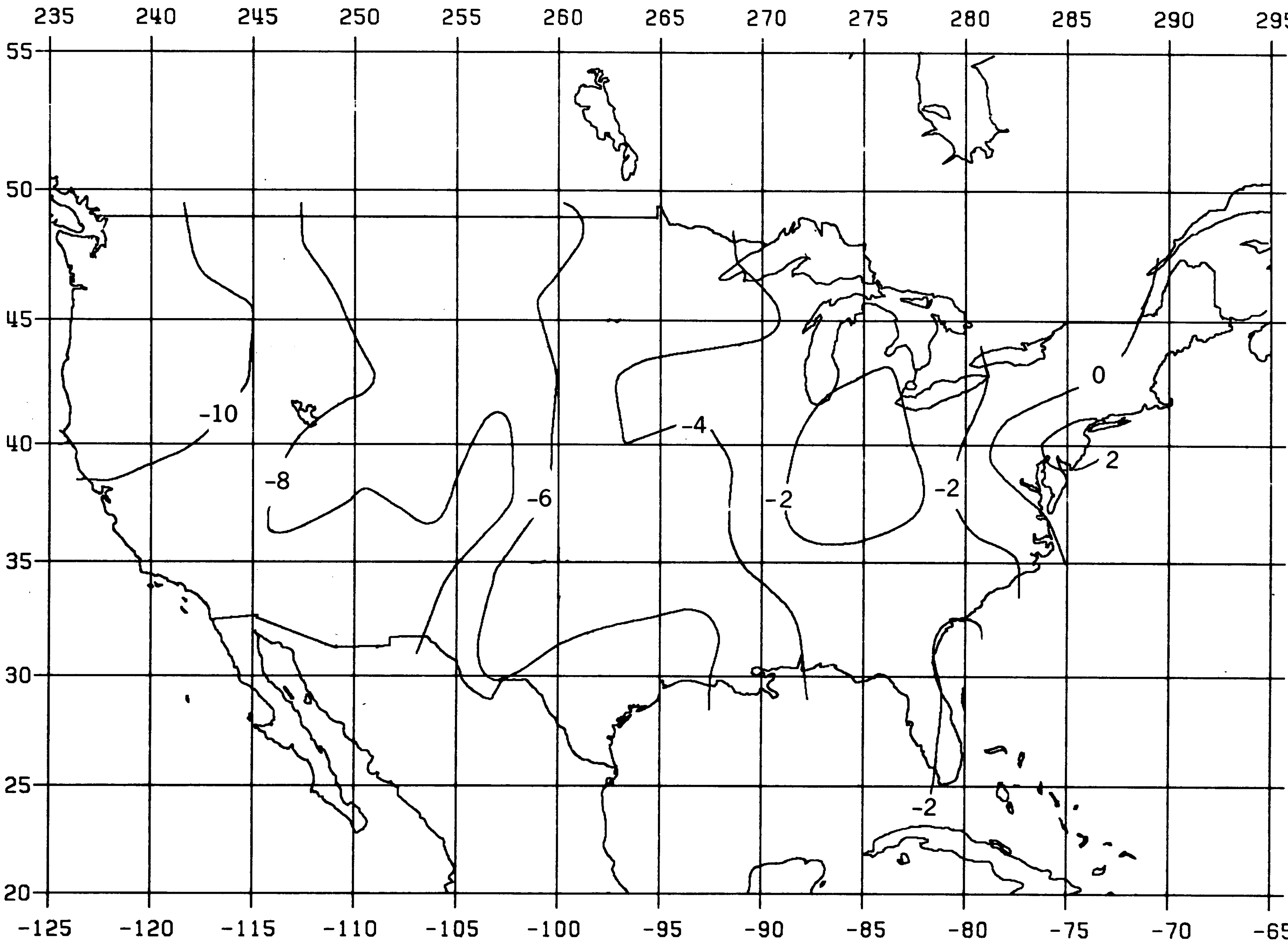

Figure 9.3. **Maximum Geodetic Height Differences in Converting WGS 72 Coordinates to WGS 84 (NAD 27 Area, CONUS)-(Units = 2 Meters)**

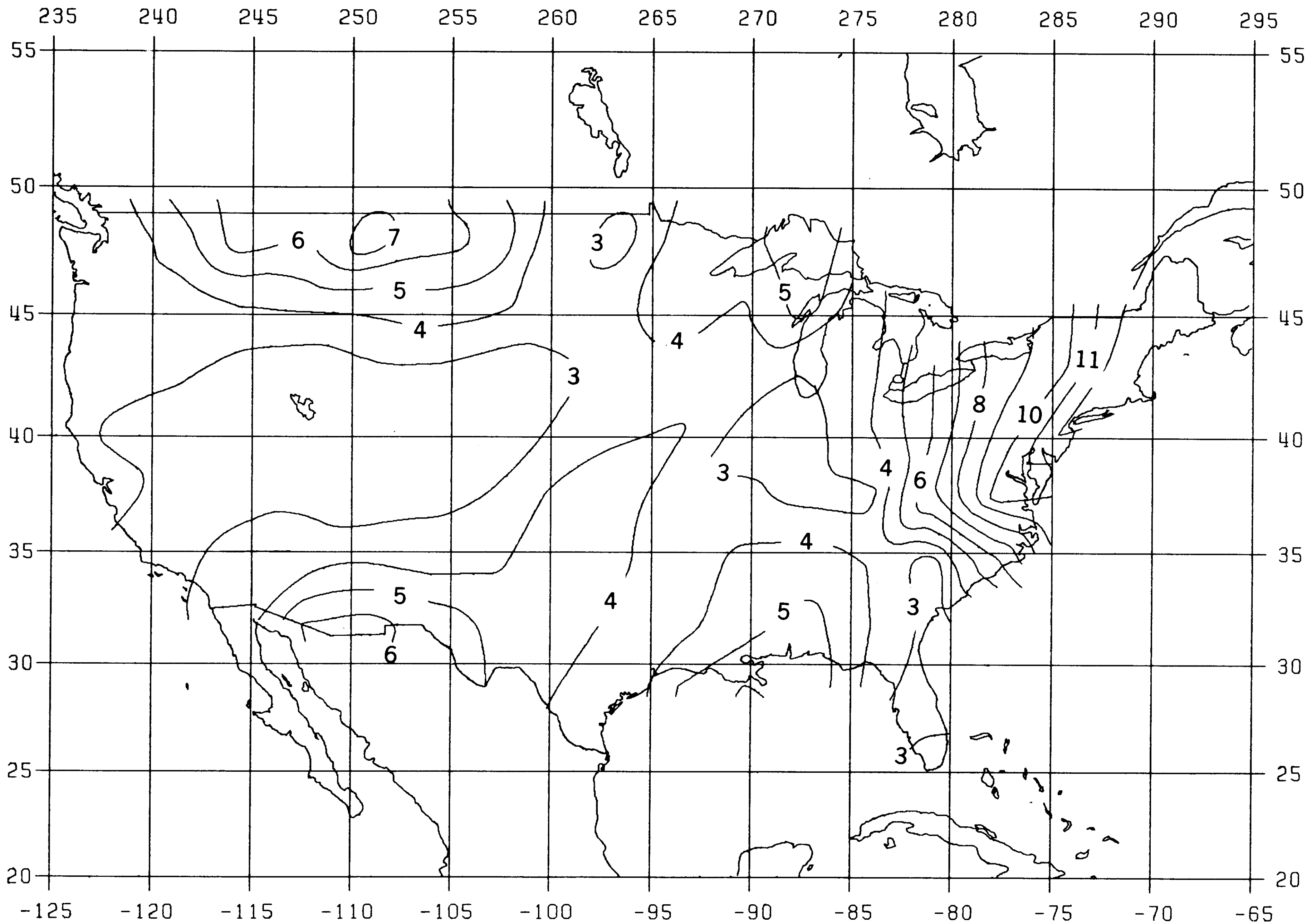

Figure 9.4. Accuracy (1σ) of WGS 84 Geodetic Latitudes at Doppler Sites (NAD 27 Area, CONUS), Latitude Determined Using Mean Datum Shifts (Contour Interval = 1 Meter)

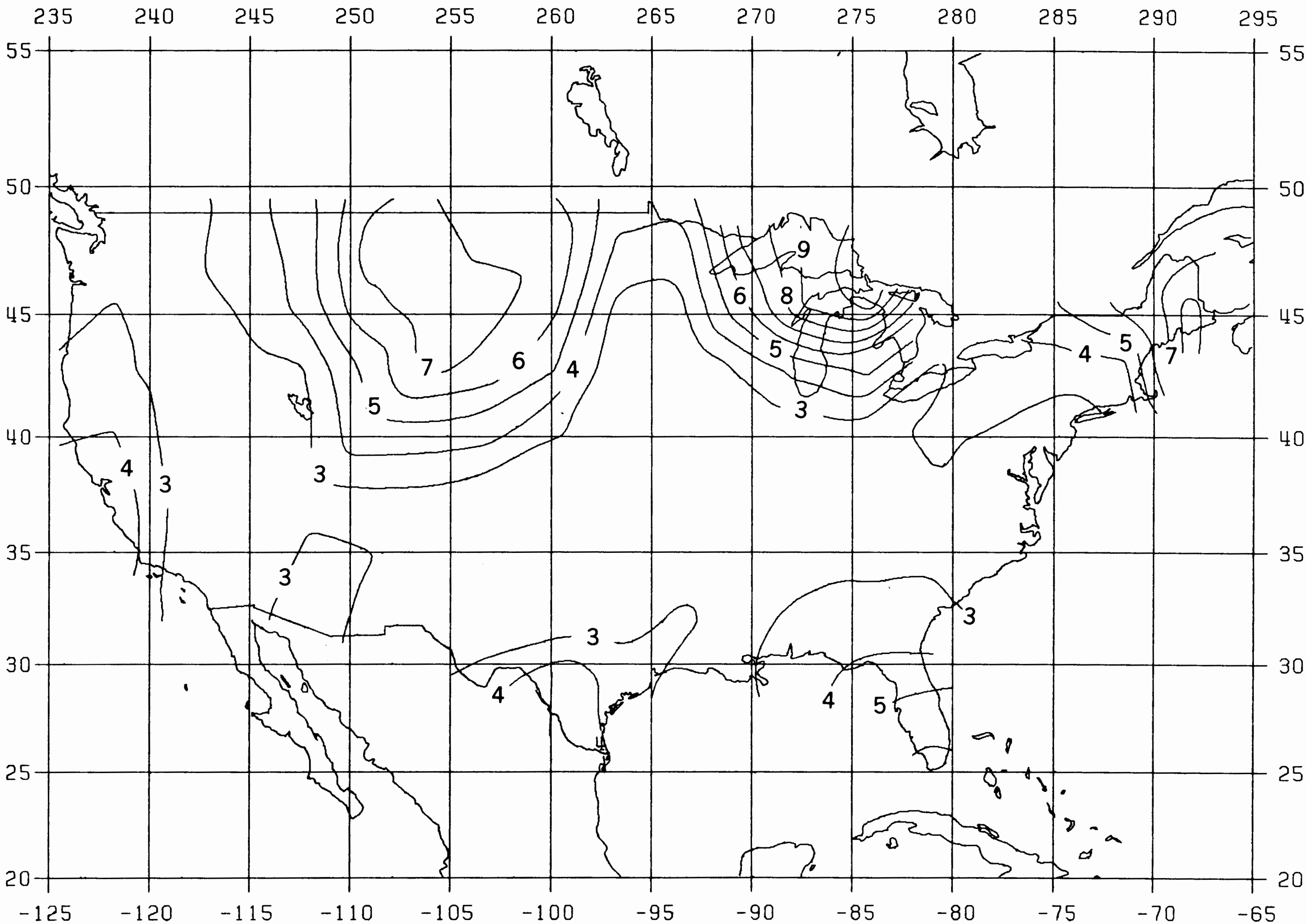

Figure 9.5. Accuracy (1σ) of WGS 84 Geodetic Longitudes at Doppler Sites (NAD 27 Area, CONUS), Longitude Determined Using Mean Datum Shifts (Contour Interval = 1 Meter)

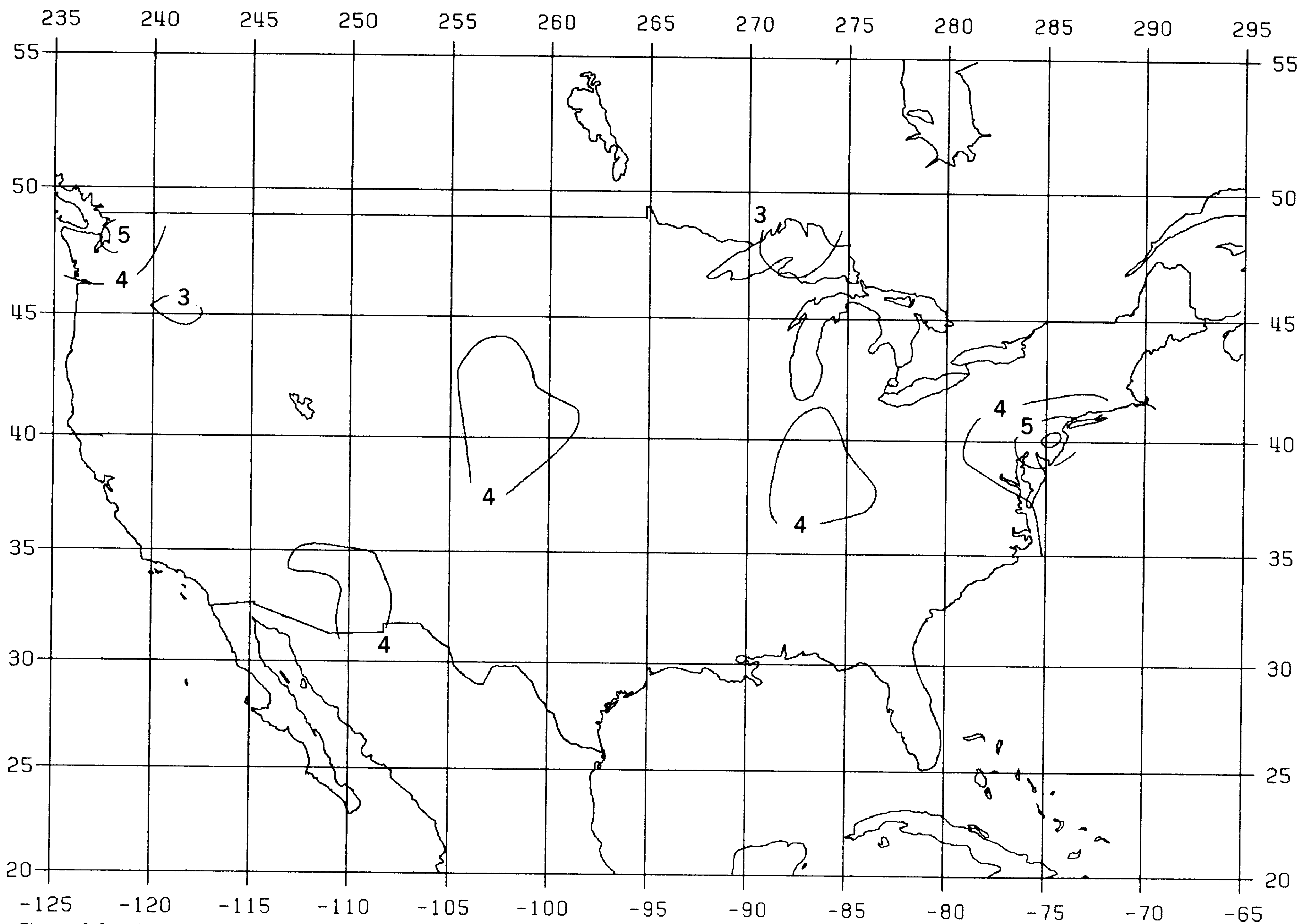

Figure 9.6. Accuracy (1σ) of WGS 84 Geodetic Heights at Doppler Sites (NAD 27 Area, CONUS), Geodetic Height Determined Using Mean Datum Shifts (Contour Interval = 1 Meter)

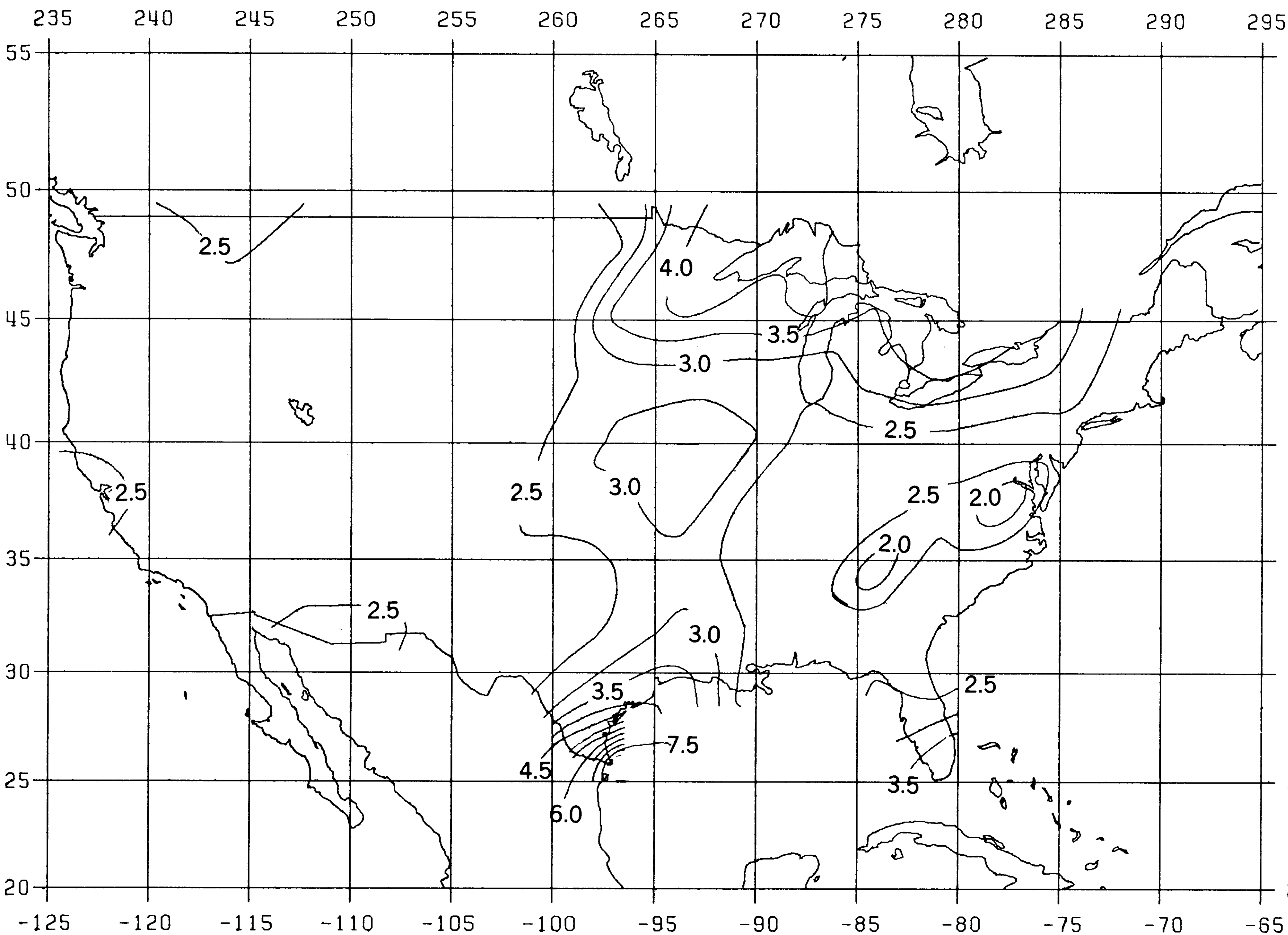

Figure 9.7. Accuracy (1σ) of WGS 84 Geodetic Latitudes at Doppler Sites (NAD 27 Area, CONUS), Latitude Determined Using Datum Transformation MREs (Contour Interval = 0.5 Meter)

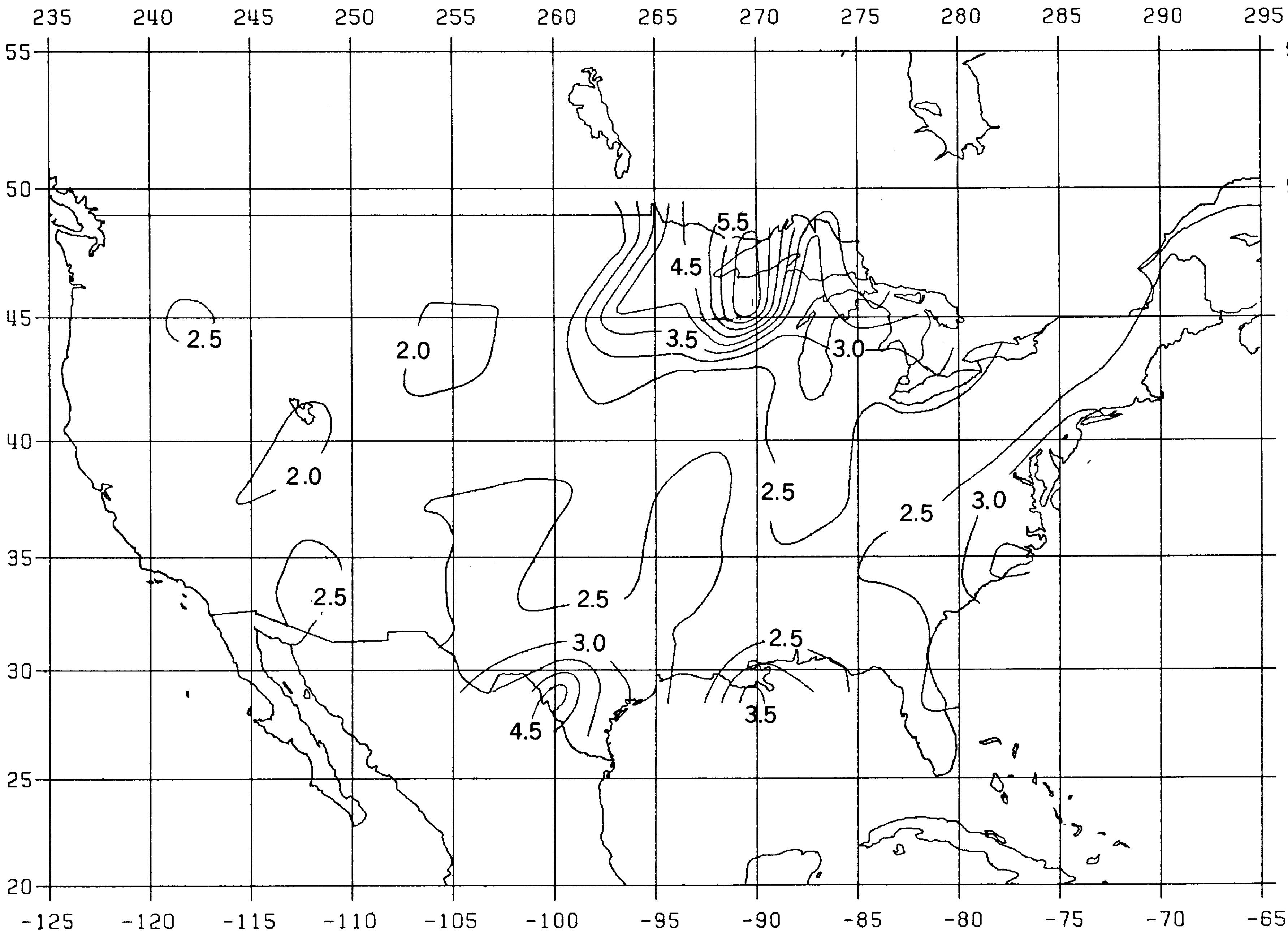

Figure 9.8. Accuracy (1σ) of WGS 84 Geodetic Longitudes at Doppler Sites (NAD 27 Area, CONUS), Longitude Determined Using Datum Transformation MREs (Contour Interval = 0.5 Meter)

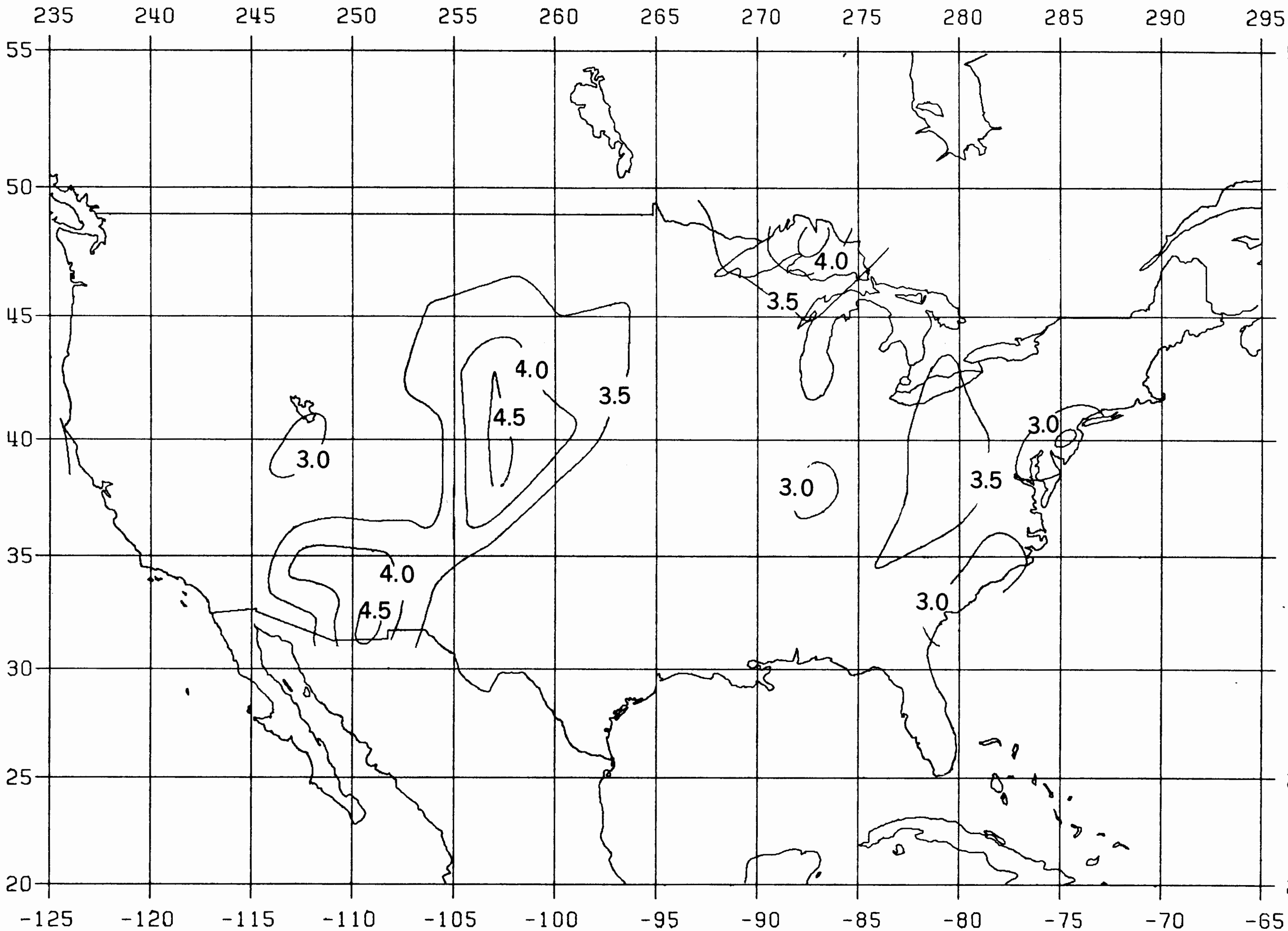

Figure 9.9. Accuracy (1σ) of WGS 84 Geodetic Heights at Doppler Sites (NAD 27 Area, CONUS), Geodetic Height Determined Using Datum Transformation MREs (Contour Interval = 0.5 Meter)