NOAA Technical Report NOS 121 NGS 39

# The National Geodetic Survey Gravity Network

Robert E. Moose

Rockville, MD

December 1986

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Gravity, Astronomy, and Space Geodesy Branch
National Geodetic Survey
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# THE NATIONAL GEODETIC SURVEY GRAVITY NETWORK

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ABSTRACT. In 1966, the U. S. National Gravity Base Network was established through the cooperative efforts of several government agencies and academic institutions involved in nationwide gravity observations. This network was reobserved between 1975 and 1979 by the National Geodetic Survey (NGS) using field procedures designed to give high-quality gravity differences. This newer set of gravity observations is called the National Geodetic Survey Gravity Network. The network is constrained to the U.S. Absolute Gravity Reference System, established by NGS using seven stations at which absolute gravity was observed. The adjustment of these observations was completed in 1984, and the gravity station values are now available as reference points for regional gravity surveys. This report discusses the adjustment and the areas where apparent gravity change was observed. NGS plans to densify and maintain this network and to improve the accuracy of the station values by additional high-quality relative ties and by making observations with a new, absolute gravity meter in each of the states.

## A BRIEF HISTORY OF U.S. NATIONAL GRAVITY NETWORKS

### U.S. Coast and Geodetic Survey Pendulum Gravity Stations

In 1891, the U.S. Coast and Geodetic Survey began observation of the first nationwide gravity network (Duerksen 1949). The purpose of the network was primarily for geoid definition and isostasy investigations. Pendulums were the only means available for these early gravity observations. When observations of the network ceased in 1949, a total of 1,185 pendulum base stations had been established. At that time, independent checks demonstrated that some of the gravity values may be in error by as much as 5 mgal (1 mgal = $10^{-3}$ cm/s$^2$) (Woollard 1958).

### Woollard's U.S. Gravity Network

Beginning in the late 1930's a large number of gravity observations were made by George P. Woollard of the University of Wisconsin. In 1939, he established the first gravity and magnetic traverse across the United States (Woollard and Rose 1963). Then, in 1941, he made a gravity survey of the Appalachian tectonic province covering the area between Newfoundland and the Gulf of Mexico, from the Atlantic Coast to the Cumberland-Allegheny Plateau, and all with pendulums! It was primarily through the urging of Woollard that S. P. Worden built the first geodetic (full range) gravity meter in 1948.

Woollard saw the need for a more accurate national network of conveniently located gravity stations to serve as control bases in regional geophysical, geological, and geodetic studies. Beginning in 1954, and continuing through 1958, he carried out observations to establish such a national gravity control network (Woollard 1958). For overall scale control of the network and for calibration of the gravimeters he observed three north-south traverses with the Gulf compound quartz pendulum. Then, using two Worden gravimeters he established 147 regional gravity base stations. He chose airports for the location of these regional bases because of their accessibility and general degree of permanence. This network has an accuracy of about ±0.1 to 0.2 mgal. By 1963 Woollard's network had expanded to worldwide coverage including 100 high-precision (±0.1 mgal) pendulum gravity bases, 1,100 airport gravimeter bases, and about 150 harbor bases (Woollard and Rose 1963).

## U.S. National Gravity Base Network

Navigation in the space age, marked by the launching of the first artificial Earth satellite in 1958, caused the accuracy requirement for gravity networks to increase again. In 1966, the U. S. National Gravity Base Net (NGBN) was established through a cooperative survey by the Army Map Service, the 1381st Geodetic Survey Squadron of the U.S. Air Force and the University of Hawaii (Whalen and Harris 1966). Using commercial airlines and four LaCoste & Romberg geodetic gravimeters, gravity base stations were established at airports in 59 cities throughout the country. Primary and secondary bases in the central region of the cities were then tied to the airport stations. (Secondary base stations are used to reestablish the primary station if it is destroyed). Figure 1 shows the NGBN network. The datum point for this network is WASHINGTON A (COMMERCE BASE) with a value of 980 118.00 mgals. The scale for the network was obtained from the American Calibration Line (ACL) interval HOUSTON A to GREAT FALLS A of 1228.48 mgals as determined by pendulum observation (Whalen 1967). The internal standard error of a gravity value in this network is 0.031 mgal.

## International Gravity Standardization Net (IGSN)

The International Union of Geodesy and Geophysics (IUGG) adopted the International Gravity Standardization Net 1971 (IGSN 1971) at its XV general assembly in Moscow (Morelli 1971). The IGSN is a worldwide gravity network, of 1,854 stations, the gravity values for which were determined by 24,000 gravimeter, 1,200 pendulum, and 10 absolute measurements collected over the 20 years preceding 1971. The IGSN was established to replace the earlier Potsdam gravity system with a gravity network having a more accurate datum and scale. The IGSN datum is the best fit least squares solution of the ten absolute measurements (eight sites). Table 1 gives the results of the absolute observations. The scale of the IGSN network is provided by the weighted combination of the pendulum and absolute measurements. Four of the eight absolute stations in the network are in the United States. (See fig. 2). This should assure that datum and scale are well determined in the United States. The adjustment results showed a worldwide scale uncertainty of about 1 part in 40,000 to 1 part in 50,000, or a gravity station accuracy of 0.1 mgal or better.

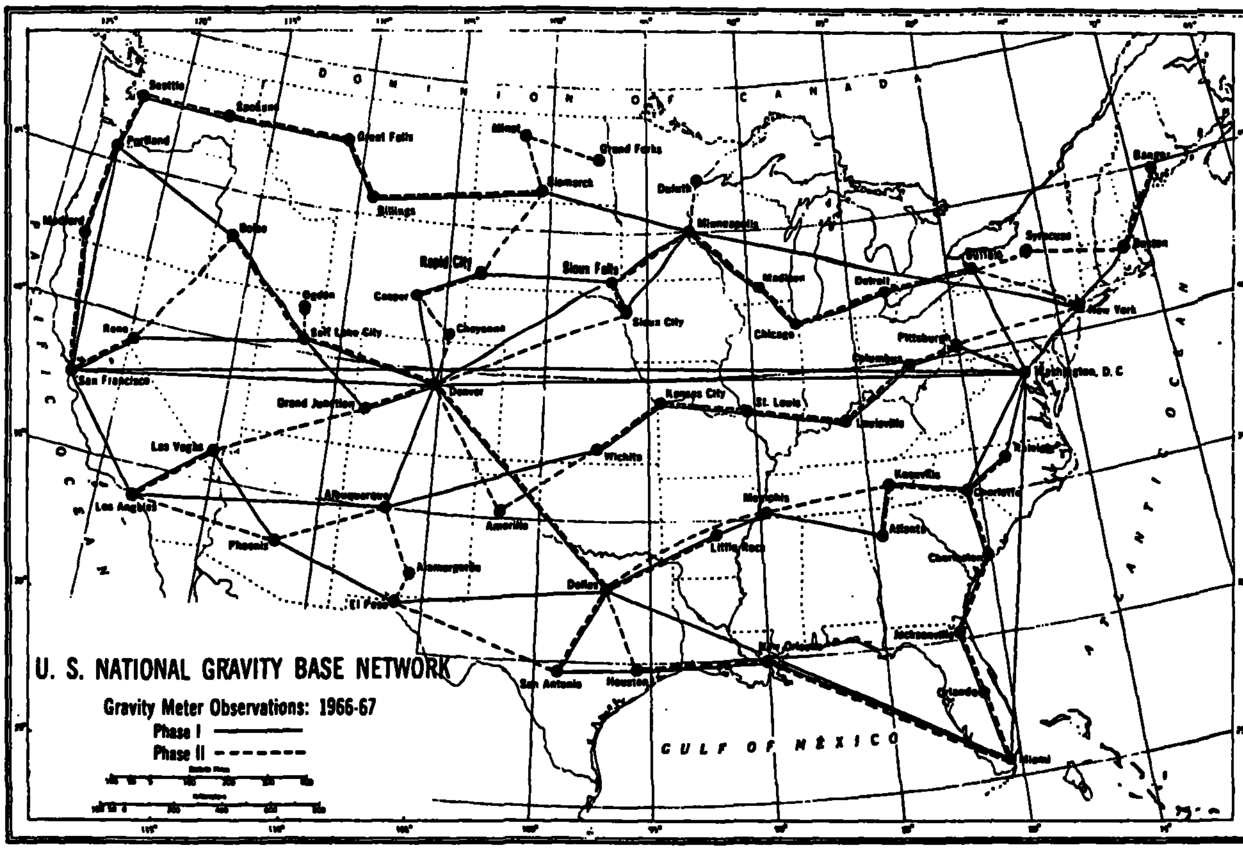


Figure 1.--The U.S. National Gravity Base Network (Whalen 1967).

## THE IGSN IN THE UNITED STATES

Of the 1,854 IGSN stations, 379 are in the conterminous United States. The IGSN data in the United States are comprised of (a) all the NGBN observations, which account for 59 cities, (b) observations connecting primary and secondary stations in 36 additional cities, from various sources, and (c) a number of calibration line pendulum observations. Figure 3 shows the distribution of the 94 cities in which there are IGSN stations.

From analysis of the adjusted values at the absolute stations Woollard (1979) believed a scale problem exists in the IGSN network in the United States. He pointed out that in the line from Bogota, Colombia, to Fairbanks, AK, the IGSN absolute station adjusted values differ systematically from the observed values. (See table 1.) Woollard's best fit line gives a correction factor of about +30 μGal/1000 mgal. (See fig. 4). He believed the error might be due to incorrect reduction of the pendulum observations (Woollard 1979).

Bulanzhe (1981) also investigated the IGSN accuracy and found that the correction factor for IGSN stations in Europe was +9.9 ±4.0 μGal/1000 mgal, while in the United States it was +37.8 ±10.1 μGal/1000 mgal.

### New Gravity Observations

Since 1971 new absolute and relative gravity observations have been made to improve the accuracy of the IGSN reference system in the United States. In 1977, the Italian absolute gravity meter was used by Marson to measure gravity at six stations (Marson and Alasia 1977). Hammond measured the absolute gravity at eight

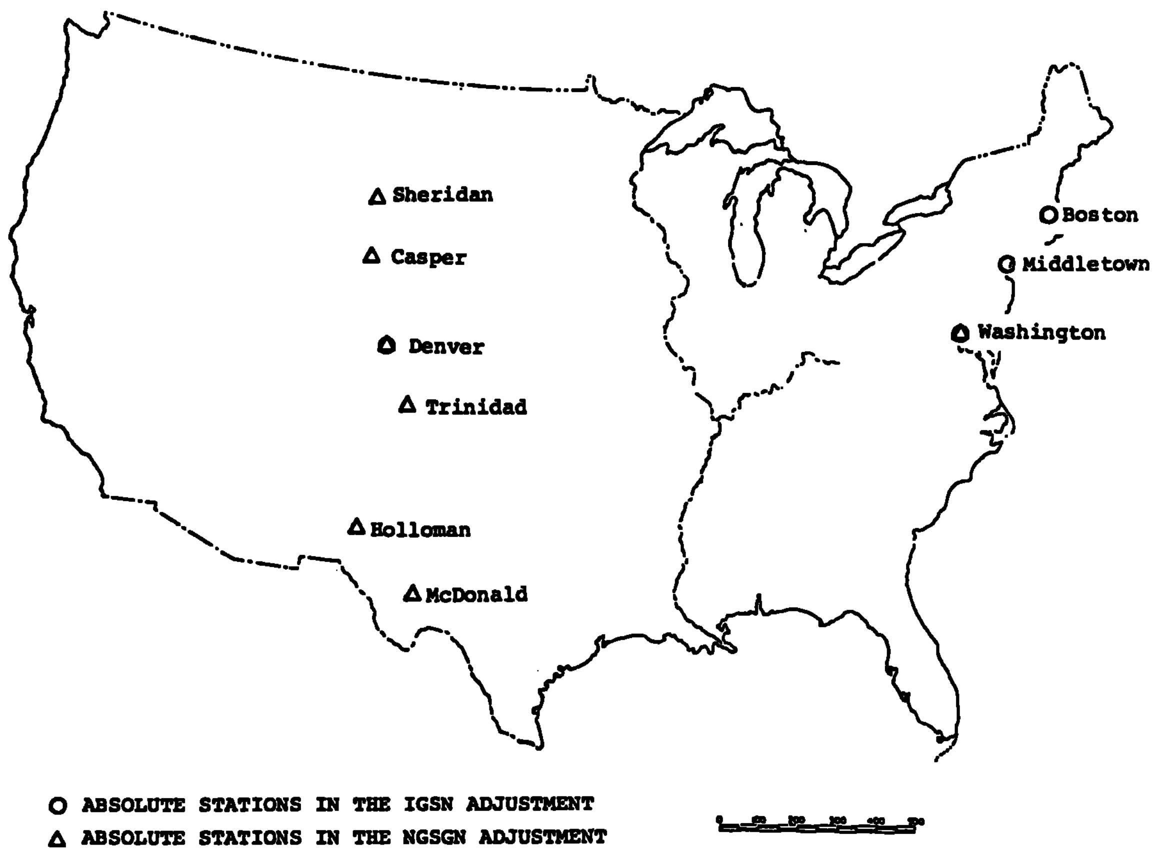


Figure 2.--Absolute gravity stations in National Geodetic Survey Gravity Net and International Gravity Standardization Net.

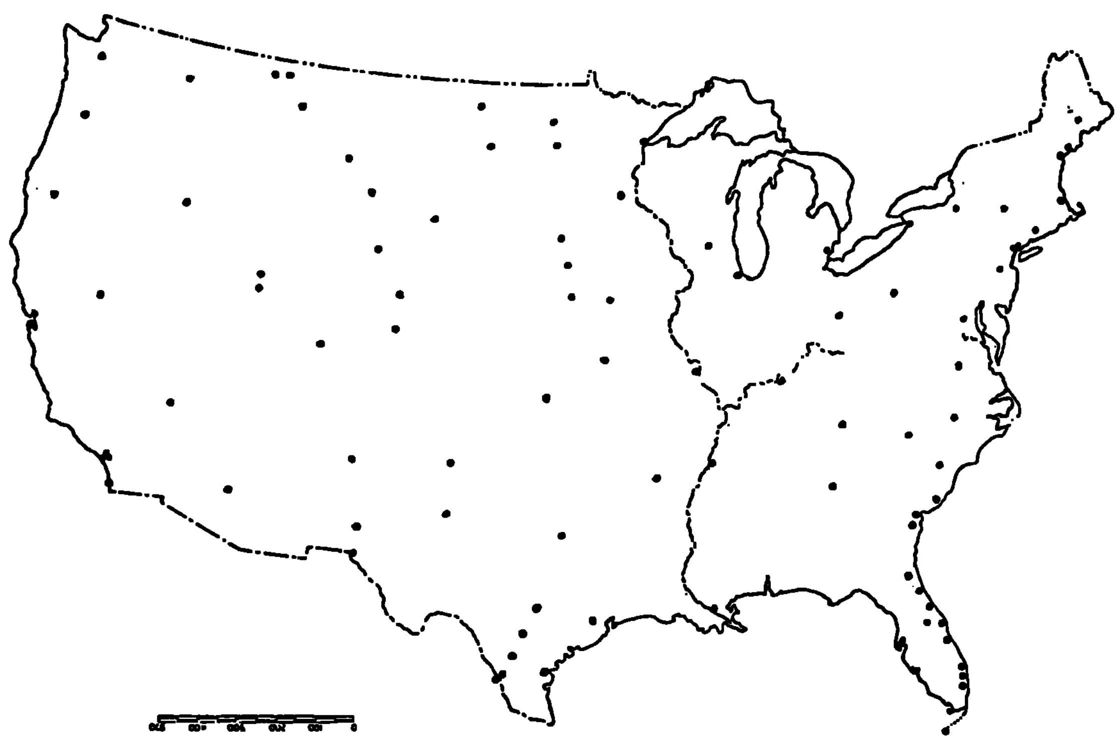

Figure 3.--U.S. stations of the International Gravity Standardization Net.

Table 1.--Absolute gravity stations in the IGSN

| Station location | Observed by | Gravity (mgal) Observed | Adjusted | Adjusted-observed |
|---|---|---|---|---|
| Bogota, Colombia | Hammond & Faller | 977 389.979 (0.087) | 977 390.140 (0.027) | +0.161 |
| Denver, CO | Hammond & Faller | 979 597.716 (0.042) | 979 597.680 (0.012) | -0.036 |
| Washington, DC | Hammond & Faller | 980 101.271 (0.055) | 980 101.320 (0.016) | +0.049 |
| Middletown, RI | Hammond & Faller | 980 305.318 (0.041) | 980 305.320 (0.022) | +0.002 |
| Boston, MA | Hammond & Faller | 980 378.685 (0.042) | 980 378.700 (0.014) | +0.015 |
| Paris, France | Hammond & Faller | 980 925.986 (0.041) | 980 925.970 (0.014) | -0.016 |
| Paris, France | Sakuma | 980 925.957 (0.030) | 980 925.970 (0.014) | +0.013 |
| Teddington, Eng. | Cook | 981 181.84 (0.13) | 981 181.780 (0.015) | -0.060 |
| Teddington, Eng. | Hammond & Faller | 981 181.891 (0.050) | 981 181.780 (0.015) | -0.111 |
| Fairbanks, AK | Hammond & Faller | 982 235.007 (0.042) | 982 235.000 (0.014) | -0.007 |

stations in 1979 (Hammond 1979). The Italian instrument was used again in 1980 to measure gravity at six stations. Also in 1980, Hammond measured gravity at five stations. In 1982, the Faller instrument was used to measure gravity at eleven stations (Zumberge et al. 1982). In addition to these absolute measurements, the Defense Mapping Agency (DMA) and the National Geodetic Survey have made about 4,500 new relative gravity meter observations at IGSN stations.

## THE NATIONAL GEODETIC SURVEY GRAVITY NETWORK (NGSGN)

Between 1975 and 1979, as part of the continuing effort to improve the IGSN reference system, NGS reobserved most of the 1966 gravity network (the National Gravity Base Network) using only ground transportation. The normal field procedure included simultaneous observations with four LaCoste Romberg G meters, in ladder sequence, keeping the elapsed time for completion of a loop as short as possible. Figure 5 shows the NGSGN network connecting most of the same sites that were in the NGBN. The new network consists of 224 stations in 54 cities connected by 2,713 gravity difference observations. Forty-nine of these stations were temporary, intermediate, or drift stations. These new relative gravity observations and seven absolute observations made after 1975 comprise the National Geodetic Survey Gravity Network.

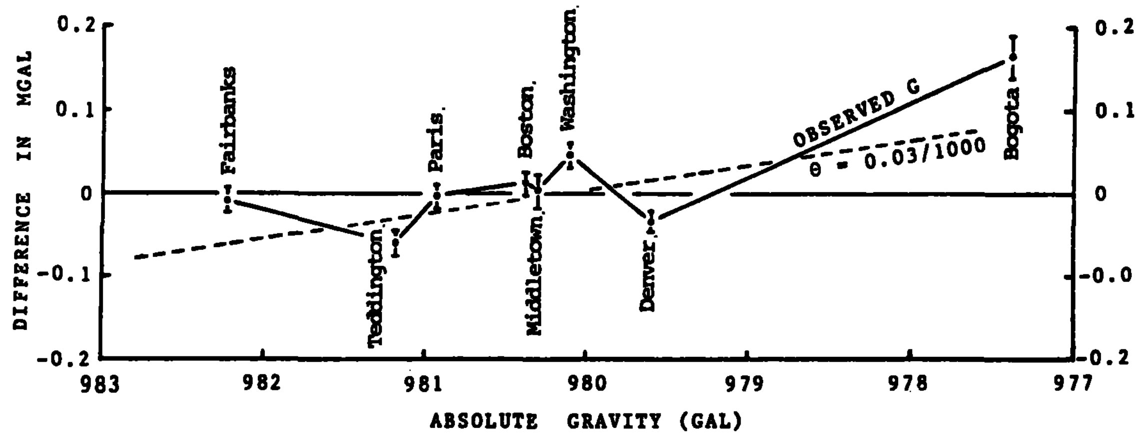


Figure 4.--Differences between IGSN 71 values and adopted absolute values plotted versus absolute gravity (Woollard 1979).

Table 2 lists the absolute gravity observations in the five data sets mentioned in the previous section. In all but a few cases the differences between observations at the same station in the various occupations exceed the observation error of about 10 μGals, which various investigators normally compute for their instruments. This suggests that the differences between occupations are not due to random error but to site-specific error or uncorrected instrument systematic error. Therefore, it would not be correct to compute a mean value at each station using some or all of the occupations, but rather to select at each station that determination which is probably closer to being correct. This selection was made through a number of preliminary adjustments of the network. Various combinations of the available absolute observations were used until the set with the smallest adjusted residuals was found. The absolute observations that were selected as weighted constraints in the network are highlighted in table 2 by two asterisks. The datum and the scale of the NGSGN are established by constraining the network to the absolute gravity observed at seven stations, six of which are along the Midcontinent Gravity Base Line (MGBL) and one in the Washington, DC, area. (See fig. 2.) The IMGC 1977 absolute gravity values at San Francisco and Boston were not constrained in this adjustment because of the generally large residuals for all of the IMGC 1977 observations. This may indicate instrumental problems. At GREAT FALLS AA, no gravity value was chosen because the large variability in the observations was traced to floor movement (Zumburge et al. 1982).

## THE ADJUSTMENT OF THE NGSGN

Adjustment of the NGSGN observations was performed by using the NGS gravimeter observations reduction and adjustment program (CCDAGOBS) version V, May 1983 (Chin 1980). This program used the Cartwright-Taylor-Edden model (Cartwright and Taylor 1971, Cartwright and Edden, 1973) to compute the lunar-solar gravitational attraction. The Earth response factor is assumed to be 16 percent of the total lunar-solar attraction. Correction for the ocean tide effect was not applied. The absolute gravity observations were entered as weighted constraints based on the error analysis of the absolute observation. The unknowns in this adjustment program are the gravity values, instrument scale factors, and instrument drift rates. A drift rate is computed for each loop, but there is only one scale factor for all the loops made with each meter. Any systematic error in the operation of a meter during a loop would show up as an abnormal drift rate. The meter drift rates

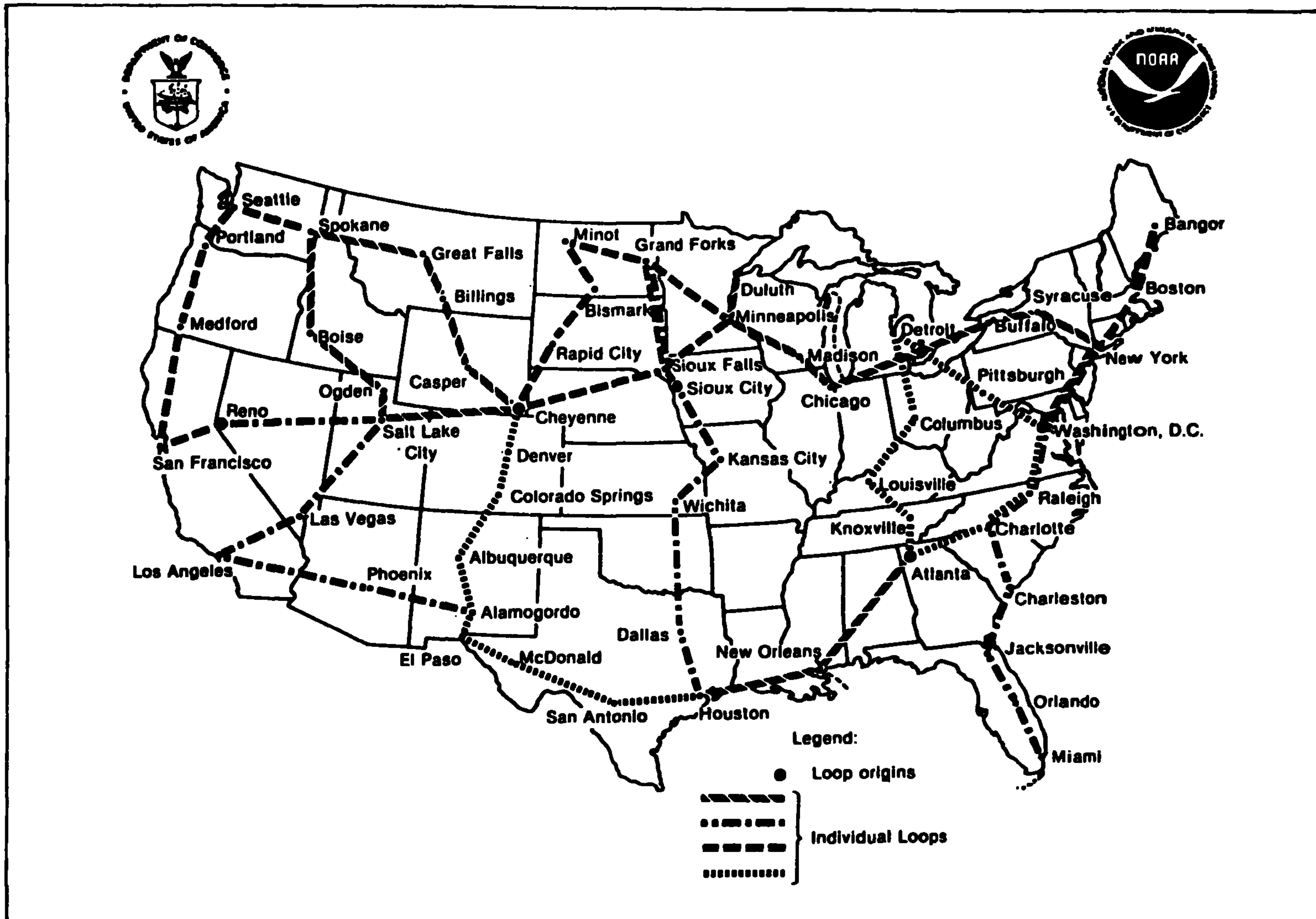


Figure 5.--The U.S. National Geodetic Survey Gravity Network.

Table 2.--Absolute gravity stations observed after 1975

| Station name | Source* | Observation (mgal) | Standard error (mgal) | Adjusted (mgal) | Difference (mgal) |
|---|---|---|---|---|---|
| MCDONALD AB | IMGC 1980 | 978 820.097 | 0.011 | (not connected to NGSGN) | |
| | AFGL 1980 | .087 | 0.010 | | |
| MCDONALD AA | AFGL 1979 | 978 828.655** | 0.008 | 978 828.645 | -0.010 |
| MIAMI C | IMGC 1977 | 979 004.303 | 0.010 | (not connected to NGSGN) | |
| HOLLOMAN A | IMGC 1977 | 979 139.509 | 0.011 | | +0.112 |
| | IMGC 1980 | .584 | 0.012 | | +0.037 |
| | AFGL 1979 | .600 | 0.010 | | +0.021 |
| | AFGL 1980 | .600 | 0.010 | | +0.021 |
| | JILA 1982 | .615** | 0.008 | 979 139.621 | +0.006 |
| MT EVANS AA | AFGL 1979 | 979 256.059 | 0.008 | (not connected to NGSGN) | |
| TRINIDAD AA | AFGL 1979 | 979 330.370** | 0.010 | 979 330.377 | +0.007 |
| | AFGL 1980 | .393 | 0.010 | | -0.016 |
| DENVER H | IMGC 1977 | 979 598.268 | 0.010 | | +0.049 |
| | AFGL 1979 | .277 | 0.010 | | +0.040 |
| | JILA 1981 | .322 | 0.012 | 979 598.317 | -0.005 |
| | JILA 1982 | .302** | 0.012 | | +0.015 |
| CASPER AA | AFGL 1979 | 979 947.244** | 0.025 | 979 947.250 | +0.006 |
| BOULDER D | IMGC 1980 | 979 608.498 | 0.011 | (not connected to NGSGN) | |
| | AFGL 1980 | .601 | 0.010 | | |
| SAN FRANCISCO A | IMGC 1977 | 979 972.065 | 0.011 | 979 972.094 | +0.029 |
| WASHINGTON AA | AFGL 1980 | .257 | 0.009 | | |
| | JILA 1982 | 980 103.259** | 0.009 | 980 103.253 | -0.006 |
| SHERIDAN AA | AFGL 1979 | 980 208.912 | 0.010 | | +0.036 |
| | JILA 1982 | .952** | 0.009 | 980 208.948 | -0.004 |
| | AFGL 1980 | .964 | 0.010 | | -0.016 |
| SHERIDAN AB | IMGC 1980 | 980 209.007 | 0.011 | (not connected to NGSGN) | |
| LICK OBS. | AFGL 1980 | 979 635.503 | 0.008 | (not connected to NGSGN) | |
| | JILA 1982 | .503 | | | |
| VANDENBERG | AFGL 1980 | 979 628.190 | 0.017 | (not connected to NGSGN) | |
| | JILA 1982 | .137 | | | |
| BOSTON A | IMGC 1977 | 980 378.673 | 0.011 | 980 378.624 | -0.049 |
| GREAT FALLS AA | AFGL 1979 | 980 497.311 | 0.010 | ( observation rejected ) | |
| | AFGL 1980 | .367 | 0.010 | see page 6 in text | |
| | IMGC 1980 | .412 | 0.010 | | |
| BISMARCK | IMGC 1977 | 980 612.904 | 0.010 | (not connected to NGSGN) | |
| ANCHORAGE, AK | IMGC 1980 | 981 928.998 | 0.010 | (not connected to NGSGN) | |

*Explanation of source codes:
IMGC 1977 - (Marson and Alasia 1977)
AFGL 1979 - (Hammond 1979)
AFGL 1980 - (Hammond 1980)
IMGC 1980 - (Marson and Alasia 1980)
JILA 1982 - (Zumberge et al. 1982)

**These absolute gravity observations were selected for use as weighted constraints in this adjustment.

may then be used as an indicator of how well the meters used in each loop were functioning. Any drift rate greater than 10 times the expected rate, that is 10 μGal/hr, was investigated. Table 3 gives the scale factors and drift rates for each loop computed by the program. There were five instances when one of the four meters showed a computed drift rate greater than 10 μGal/hr, while the other three showed normal drift rates. However, the abnormal situation was adequately controlled by the other meters, and did not introduce significant errors into the adjustment. In the loop that connected the stations in San Francisco, the drift rates were more of a problem. In that loop the drift rates for all the meters were about 20 μGal/hr. No reason for this was found.

The most troublesome problem in the adjustment of these data was a variable scale factor for one of the meters. It was necessary to solve for a different scale factor for about half of the trips made with meter G-81. These scale factors (dial units/mgal) varied from 1.00004 to 1.00083 and were directly correlated with the increase in gravity value. The relationship was quite linear at $6.15 \times 10^{-4}$ du/1000 mgal. (See fig. 6.) The fact that the other meters were able to present such a clear picture of G-81's variability is an indication of how well their scale factors could be represented by a constant. Two other meters, G-111 and G-125, also showed a variability of scale factor at the extremes of the gravity range. As for the rest of the meters, the computed scale factors are all close to one, as expected for a correctly operating meter.

The fit of the constraints in the network was also investigated. Table 2 lists the adjusted gravity values at the absolute stations. The difference of the observed absolute gravity from the adjusted gravity, with error bars on the observed absolute gravity, is shown in figure 7. With the exception of Denver, the adjusted values are all within the error limits of the observations. The NGSGN is a new and independent data set, the relative measurements made between 1975 and 1979 and the absolute measurements made between 1979 and 1982.

The NGSGN network is believed to be free of significant distortion for the following reasons:

1. The scale and datum are determined by only absolute gravity observation and there is no significant difference between adjusted and observed absolute gravity.

2. Except for 3 meters, a single scale factor per meter is adequate over the entire range of gravity for the conterminous United States.

3. The computed drift rates, with a few exceptions, are small.

4. The average standard error of a gravity value in this adjustment is 15 μGal.

There are 25 instances where the standard error of the adjusted value (19 μGal) is more than 1 sigma above the average. In all cases these stations are the most distant stations from the absolute stations that are the constraints in this network. This result illustrates the need for additional absolute stations to serve as constraints in the national gravity network. Appendix A lists the NGSGN adjusted gravity values.

Table 3.—Computed scale factor and drift rates (mgal/hr) for loops in the NGSGN adjustment

| Meter No. | Scale | Drift | Meter No. | Scale | Drift |
|---|---|---|---|---|---|
| 1081 | 1.0002650 | 0.0033 | 111 | 1.0002120 | -0.0011 |
| 111 | 1.0002120 | -0.0057 | 8081 | 1.0008180 | -0.0006 |
| 115 | 1.0003360 | -0.0033 | 111 | 1.0002120 | -0.0021 |
| 157 | 1.0003000 | 0.0004 | 115 | 1.0003360 | 0.0005 |
| 81 | 1.0007130 | -0.0008 | 157 | 1.0003000 | 0.0035 |
| | | | | | |
| 111 | 1.0002120 | -0.0044 | 115 | 1.0003360 | -0.0020 |
| 115 | 1.0003360 | -0.0017 | 157 | 1.0003000 | 0.0043 |
| 157 | 1.0003000 | -0.0008 | 81 | 1.0007130 | -0.0008 |
| 81 | 1.0007130 | 0.0044 | 111 | 1.0002120 | -0.0013 |
| 111 | 1.0002120 | -0.0018 | 81 | 1.0007130 | 0.0035 |
| | | | | | |
| 81 | 1.0007130 | 0.0033 | 111 | 1.0002120 | 0.0015 |
| 111 | 1.0002120 | 0.0029 | 115 | 1.0003360 | 0.0013 |
| 115 | 1.0003360 | -0.0021 | 157 | 1.0003000 | 0.0052 |
| 157 | 1.0003000 | 0.0001 | 115 | 1.0003360 | -0.0019 |
| 115 | 1.0003360 | -0.0091 | 157 | 1.0003000 | 0.0020 |
| | | | | | |
| 157 | 1.0003000 | -0.0015 | 7081 | 1.0005370 | -0.0047 |
| 3081 | 1.0006020 | 0.0020 | 111 | 1.0002120 | -0.0058 |
| 111 | 1.0002120 | -0.0022 | 115 | 1.0003360 | 0.0008 |
| 115 | 1.0003360 | -0.0016 | 157 | 1.0003000 | 0.0023 |
| 157 | 1.0003000 | 0.0008 | 115 | 1.0002360 | -0.0010 |
| | | | | | |
| 8081 | 1.0008180 | -0.0011 | 157 | 1.0003000 | 0.0001 |
| 111 | 1.0002120 | -0.0025 | 1081 | 1.0002650 | 0.0007 |
| 115 | 1.0003360 | -0.0005 | 111 | 1.0002120 | 0.0019 |
| 157 | 1.0003000 | 0.0011 | 68 | 0.9999340 | -0.0054 |
| 81 | 1.0007130 | -0.0013 | 81 | 1.0007130 | 0.0036 |
| | | | | | |
| 111 | 1.0002120 | -0.0026 | 111 | 1.0002120 | -0.0019 |
| 115 | 1.0003360 | -0.0014 | 157 | 1.0003000 | 0.0019 |
| 157 | 1.0003000 | -0.0038 | 6081 | 1.0003020 | -0.0022 |
| 4081 | 1.0008340 | -0.0049 | 111 | 1.0002120 | -0.0012 |
| 157 | 1.0003000 | 0.0003 | 2125 | 0.9982180 | -0.0027 |
| | | | | | |
| 142 | 1.0003000 | -0.0089* | 915 | 1.0002640 | 0.0096 |
| 191 | 1.0002400 | 0.0058 | 268 | 1.0003760 | -0.0040 |
| 103 | 0.9994280 | -0.0033 | 253(G)** | 1.0364750 | 0.0052 |
| 915 | 1.0002640 | -0.0044 | 5081 | 1.0000900 | 0.0071 |
| 142 | 1.0003000 | -0.0040 | 111 | 1.0002120 | 0.0001 |
| | | | | | |
| 811 | 1.0008060 | -0.0039 | 157 | 1.0003000 | 0.0003 |
| 957 | 1.0008190 | 0.0091* | 2081 | 1.0000480 | -0.0468* |
| 811 | 1.0008060 | 0.0012 | 57 | 1.0003000 | -0.0021 |

Table 3.--Continued.

| | | | | | |
|---|---|---|---|---|---|
| 957 | 1.0008190 | 0.0003 | 111 | 1.0002120 | 0.0004 |
| 142 | 1.0003000 | 0.0016 | 915 | 1.0002640 | -0.0029 |
| | | | | | |
| 103 | 0.9994280 | 0.0048 | 191 | 1.0002400 | -0.0020 |
| 957 | 1.0008190 | 0.0019 | 191 | 1.0002400 | 0.0007 |
| 915 | 1.0002640 | 0.0115* | 103 | 0.9994280 | 0.0098* |
| 811 | 1.0008060 | 0.0018 | 103 | 0.9994280 | 0.0052 |
| 142 | 1.0003000 | -0.0025 | 125 | 1.0001040 | -0.0014 |
| | | | | | |
| 103 | 0.9994280 | -0.0025 | 125 | 1.0001040 | 0.0047 |
| 142 | 1.0003000 | 0.0043 | 915 | 1.0002640 | 0.0033 |
| 191 | 1.0002400 | -0.0063 | 131 | 1.0001120 | -0.0026 |
| 125 | 1.0001040 | 0.0179* | 10 | 1.0017380 | 0.0014 |
| 103 | 0.9994280 | 0.0047 | 130 | 1.0001090 | -0.0034 |
| | | | | | |
| 915 | 1.0002640 | -0.0038 | 17(D)** | 1.3665000 | 0.0002 |
| 103 | 0.9994280 | 0.0014 | 10 | 1.0017380 | 0.0033 |
| 915 | 1.0002640 | -0.0036 | 130 | 1.0001090 | -0.0204* |
| 125 | 1.0001040 | 0.0004 | 130 | 1.0001090 | 0.0047 |
| 191 | 1.0002400 | -0.0029 | 10 | 1.0017380 | 0.0018 |
| | | | | | |
| 915 | 1.0002640 | -0.0020 | 17(D)** | 1.3665000 | -0.0030 |
| 125 | 1.0001040 | 0.0010 | 269 | 1.0000160 | 0.0003 |
| 103 | 0.9994280 | 0.0049 | 220 | 1.0000560 | 0.0139* |
| 103 | 0.9994280 | 0.0021 | 269 | 1.0000160 | 0.0049 |
| 125 | 1.0001040 | -0.0069 | 220 | 1.0000560 | -0.0056 |
| | | | | | |
| 915 | 1.0002640 | -0.0073 | 220 | 1.0000560 | 0.0258* |
| 103 | 0.9994280 | -0.0001 | 269 | 1.0000160 | 0.0028 |
| 915 | 1.0002640 | -0.0030 | 220 | 1.0000560 | 0.0083 |
| 269 | 1.0000160 | 0.0006 | 220 | 1.0000560 | 0.0030 |
| 269 | 1.0000160 | 0.0019 | 220 | 1.0000560 | -0.0017 |
| | | | | | |
| 269 | 1.0000160 | 0.0072 | 220 | 1.0000560 | -0.0038 |
| 269 | 1.0000160 | 0.0020 | 220 | 1.0000560 | -0.0072 |
| 269 | 1.0000160 | 0.0009 | 220 | 1.0000560 | -0.0036 |
| 269 | 1.0000160 | 0.0041 | 220 | 1.0000560 | 0.0029 |
| 269 | 1.0000160 | 0.0046 | 220 | 1.0000560 | -0.0039 |
| | | | | | |
| 10 | 1.0017380 | -0.0130* | 130 | 1.0000109 | 0.0230* |
| 1111 | 0.9944180 | -0.0358* | 17(D)** | 1.3665000 | -0.0051 |
| 1111 | 0.9944180 | -0.0051 | 17(D)** | 1.3665000 | -0.0049 |

*Trips with large drift rates.
** LaCoste-Romberg direct reading meters.
Notes:
Meter 811 is a recalibration of meter 81.
Meter 957 is a recalibration of meter 157.
Meter 915 is a recalibration of meter 115.
Meter 1111 is meter 111 used in a different gravity range.
Meter 2125 is meter 125 used in a different gravity range.
Meter numbers 81, 1081, 2081, 3081, 4081, 5081, 6081, 7081, and 8081 are used for meter G-81 in a different gravity range.

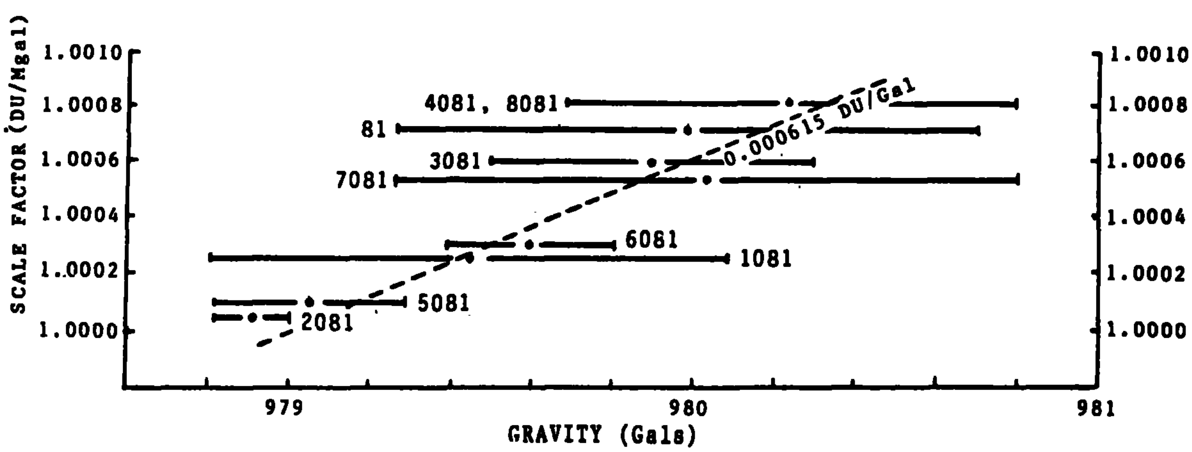


Figure 6.--Meter G-81 scale factor variability.

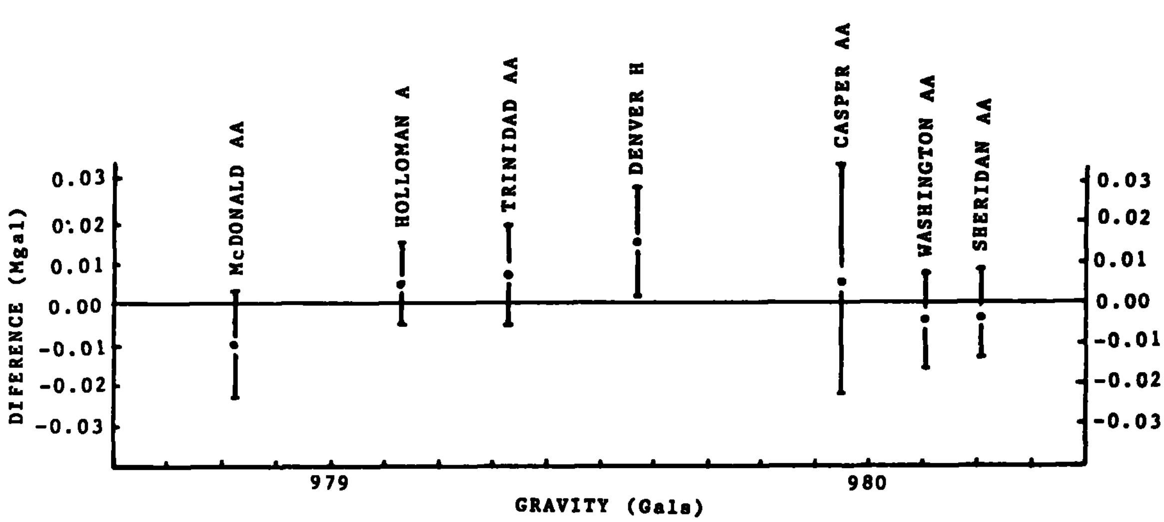


Figure 7.--Difference between adjusted and observed gravity at absolute stations in the National Geodetic Survey Gravity Network.

The descriptive text for the stations in the NGSGN may be obtained by contacting:

National Geodetic Information Center (N/CG174)
National Oceanic and Atmospheric Administration
Rockville, MD 20852

Tel: (301) 443-8623

## COMPARISON OF GRAVITY NETWORKS

The differences at the common stations between the three gravity networks (IGSN, NGBN, NGSGN) were plotted and analyzed.

### IGSN-NGBN

The scale and datum in these two networks are achieved by different means. The NGBN is scaled by a pendulum interval along the American Calibration Line (ACL) and has a single datum point at WASHINGTON A. The NGBN gravity values have been changed by -13.7 mgals to correct for the Potsdam datum error.

The IGSN is a more complex network. In the United States the IGSN contains all the gravimeter observations that are in the NGBN plus gravimeter observations in 36 more cities. In addition, there are 35 Gulf pendulum stations, 43 Cambridge pendulum stations, and four absolute gravity observations using the Hammond and Faller instrument. Scale in the U.S. portion of the IGSN is determined by the combination of these four absolute gravity observations and a number of pendulum gravity intervals. Based on the error estimate of the observation the absolute gravity observations are given relatively greater weight than the pendulum observations in the adjustment. The datum should then be (almost) the least squares fit of the four absolute gravity observations in the United States. Figure 8 shows the gravity differences between IGSN-NGBN. They are latitude dependent, increasing for the larger latitudes at the rate of 6 μGal/degree of latitude. Morelli (1971) states that the Honkasalo correction was applied to the absolute and pendulum observations in the IGSN. These modified absolute and pendulum observations would have enforced the Honkasalo correction upon the whole IGSN network at the time of adjustment. The Honkasalo correction was not applied in the NGBN network. Making this modification to the NGBN results reduces the differences between the two networks by one-third. The remaining two-thirds of the difference is still latitude dependent. This could be due to a scale error in one network or the other. If we select a similar north-south gravity interval in the same area as the ACL (see table 4) the scale correction going from NGBN to IGSN is 38 μGal/1000 mgal. A possible explanation of this scale problem is given later.

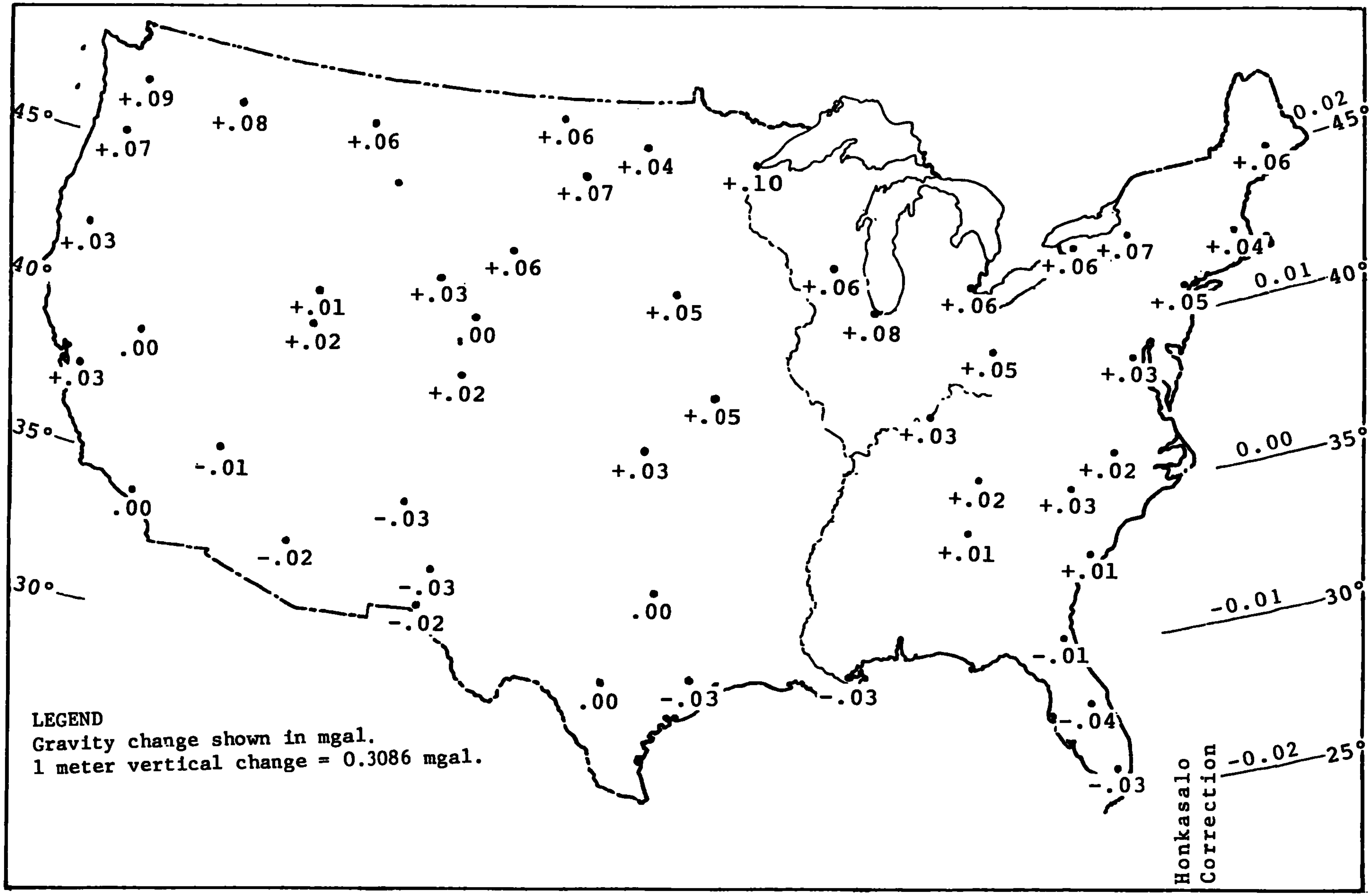


Figure 8.--Gravity difference between the International Gravity Standardization Net and the National Gravity Base Net after the National Gravity Base Net has been corrected for the Potsdam datum error of +13.7 m gal.

Table 4.--North-south gravity interval in the United States

| Station Name | Gravity (mgal) | IGSN-NGBN difference |
|---|---|---|
| ALAMOGORDO, NM | 979 148. | -0.02 |
| FARGO, ND | 980 727. | +0.04 |
| Gravity interval | 1 579. | |

NGSGN-IGSN

These two data sets are completely independent of each other, with the NGSGN observations being made 10 years after the IGSN observations. The absolute stations held in the NGSGN and the IGSN adjustments are shown in figure 2. As can be seen, the distribution of constraints in both adjustments is not good. The IGSN is only well constrained in the north-east, and the NGSGN is only well constrained in the middle region of the United States. The unbalanced arrangement of the constraints in the two networks makes the comparison of gravity values less reliable.

Appendix B lists the difference in gravity between NGSGN and IGSN, after the Honkasalo term is removed from the IGSN gravity values. This is graphically represented in figure 9. The following general observations can be made: First, the distribution of + and - differences appears random, small values predominating. Second, there is good agreement at the two stations of common constraint, i.e., Washington (10 μGal) and Denver (0 μGal). Third, a plot of the gravity difference NGSGN-IGSN as a function of the gravity value (fig. 10) shows no apparent scale difference between the two gravity networks.

Based on the standard errors of the adjusted gravity values in the two adjustments, a significant difference in figure 9 is one that is larger than about 0.03 mgal. Subsequent error analysis of the IGSN adjustment indicated that the standard error quoted in this adjustment was probably optimistic. A more realistic standard error for the IGSN would give 0.05 mgal for the threshold value of a significant change. Cities where significant gravity change has been verified by having more than one station in each of the networks are circled in figure 9.

The largest difference is at Houston, TX, where the more recent gravity observations are larger by 0.17 mgal. This gravity change is known to be due to ground subsidence caused by the removal of ground water (Strange 1975). The results of leveling in the area are highly variable, giving a subsidence rate from 23 to 57 mm/yr. The height change can be derived from gravity change, if the gravity change is due entirely to vertical movement with no anomalous mass redistribution. Using the normal gradient of gravity (0.3086 mgal/meter) (it would be more correct to use the observed gradient) to compute a subsidence rate, the gravity difference indicates 55 mm/yr, which is in good agreement with the leveling.

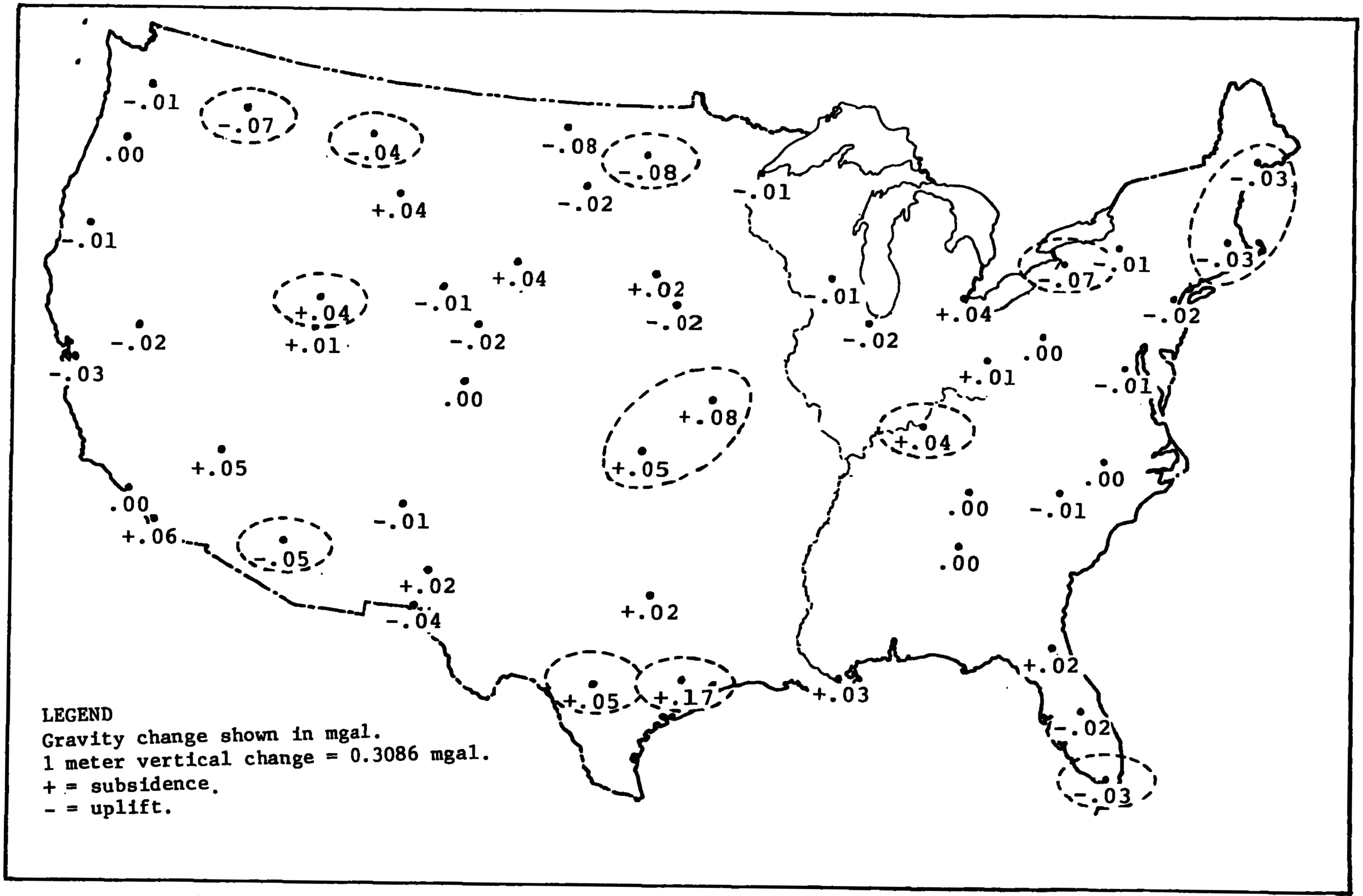


Figure 9.--Gravity difference between the National Geodetic Survey Gravity Network and the International Gravity Standardization Net--a time difference of 10 years.

In Las Vegas, NV, the gravity difference indicates a subsidence of 17 mm/yr. Subsidence in the Las Vegas area of about 26 mm/yr is reported in a Cornell study of leveling (Chi et al. 1982).

Other comparisons of gravity and leveling in the southwest do not agree as well. The gravity difference indicates a subsidence rate of 16 mm/yr at San Antonio, TX, that is many times larger than the leveling rate of 0.62 mm/yr (Holdahl and Morrison 1974). There is disagreement between the gravity change and the leveling change at Phoenix, AZ, where the gravity difference suggests 16 mm/yr uplift, when in fact, the area around Phoenix is known to be subsiding at a rate of 11 cm/yr (Byars 1975). The gravity stations in question are in the city and are located on bedrock. It is not known why there should be a negative gravity change here.

In Los Angeles, CA, the gravity indicates a subsidence of 20 mm/yr. Although several leveling projects in the area indicate subsidence, there is no project close enough to the gravity stations for comparison.

In the northwest, in the regions of Spokane, WA, and Great Falls, MT, the gravity difference indicates uplift of 18 mm/yr. Some confirmation of this uplift comes from Vaníček and Nagy (1980), who analyzed the leveling in southern Canada: "The northern tip of the Rocky Mountains in the U.S. shows a sign of uplift." They further state, "Farther east, one begins to distinguish the pattern of postglacial uplift in the region of the Great Lakes. It is of interest to note the southeast-trending uplift ridge east of Lake Ontario." This could be the -0.07 and -0.02 mgal feature in the gravity differences east of Lake Ontario.

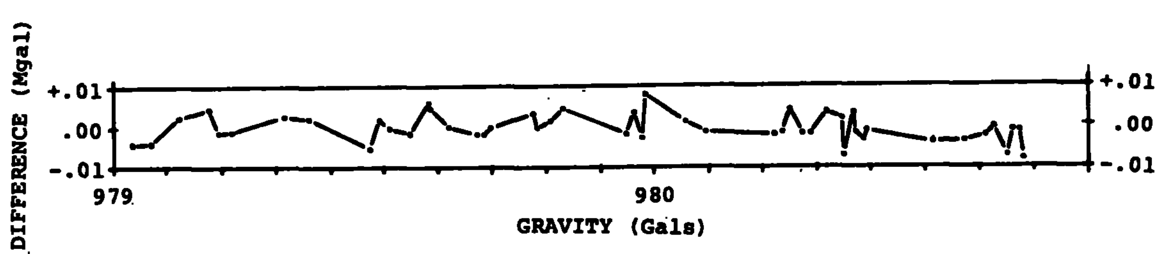


Figure 10.--Gravity difference for National Geodetic Survey Gravity Network and the International Gravity Standardization Net as a function of gravity.

Jurkowski and Reilinger (1981) have published the results of leveling projects in the east, including a map of recent vertical movements (fig. 11). Along the east coast the leveling change indicates subsidence at 2 to 4 mm/yr. In figure 9 the gravity differences indicate uplift for this area but below the level of significance. Inland from the coast there is uplift of 2 mm/yr centered in the Appalachian Mountains in North Carolina. Jurkowski and Reilinger caution that this uplift "correlates with topography and could be indicative of a complicated terrain correlated leveling error." Uplift is not indicated in the gravity difference for this area.

In the midwest, centered in Ohio, is a region of subsidence of as much as 4 mm/yr. This feature, extending from Lake Erie to Louisville, KY, is shown in the gravity differences as subsiding more on the ends producing an arch in the Cincinnati, OH, area. The largest rate of subsidence indicated by the leveling change is 6 mm/yr centered on the Adirondack Massif. This disagrees with the findings of a previous investigator of leveling changes (Isachsen 1975) who found

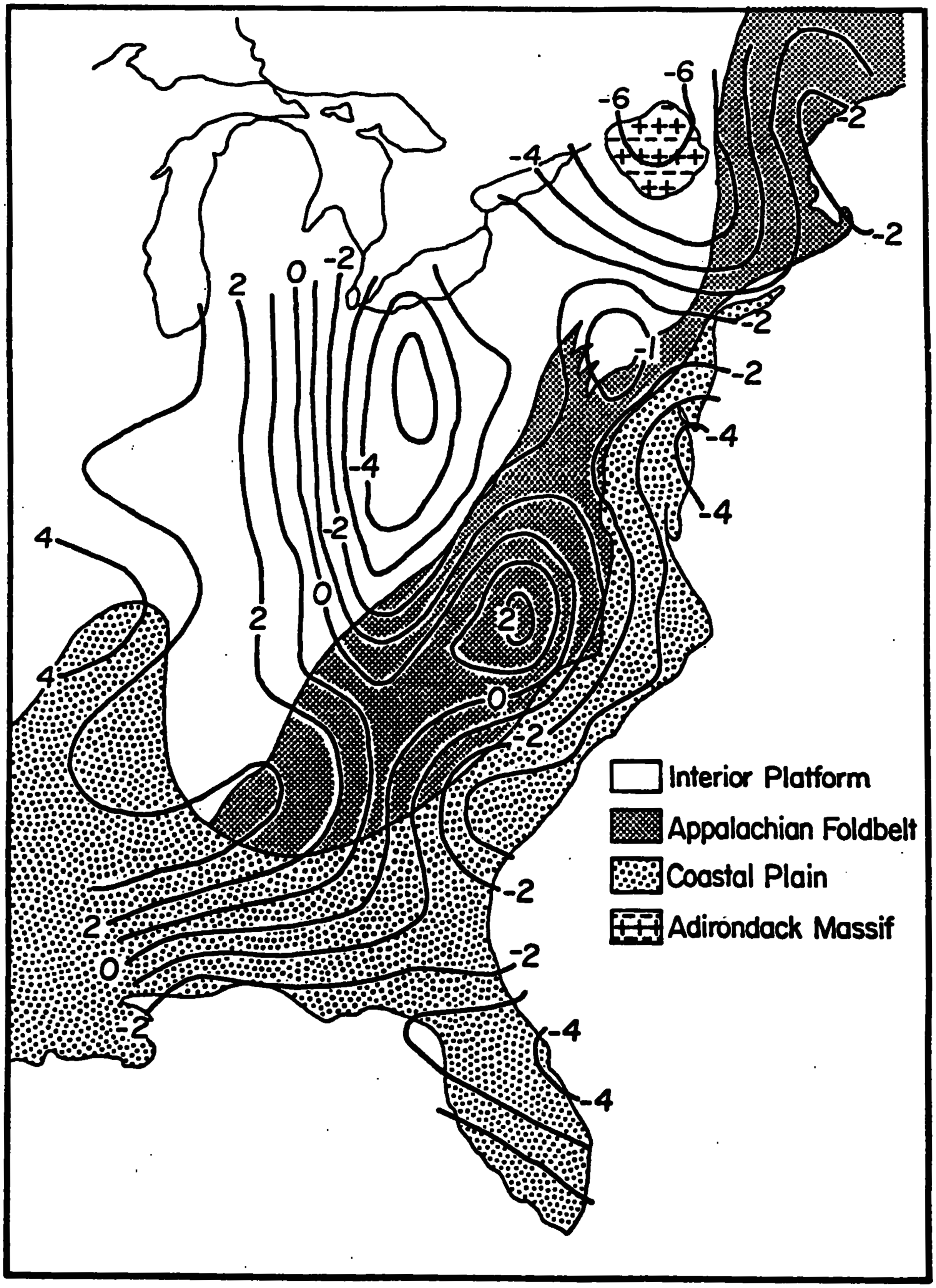


Figure 11.--Vertical motion on east coast of the United States.

the Adirondacks to be an area of uplift. There is no gravity difference for this area. Thus it is not clear whether this area is uplifting or subsiding. All of these leveling derived rates of vertical change are below the 1 cm/yr (0.003 mgal/yr) detection level of the gravity difference.

In general, these low rates of vertical change in the east are reflected in figure 9 where a majority of the gravity changes are below the significance level. The gravity difference (+0.04 mgal) at Louisville, KY, and Detroit, MI, indicating a subsidence rate of 13 mm/yr, tends to agree with the midwest subsidence found by Jurkowski, but is three times too big. In Miami, FL, the gravity difference suggests 14 mm/yr uplift and is in disagreement with the leveling difference of 2 mm/yr subsidence. In Boston, MA, there is a similar disagreement where the gravity difference suggests 10 mm/yr uplift and the leveling difference gives 2 mm/yr subsidence. The southeast-trending uplift ridge east of Lake Ontario, mentioned by Vaníček and Nagy, is much more pronounced in the gravity difference than in the leveling map of Jurkowski.

On the Gulf Coast at New Orleans the gravity difference indicates a subsidence rate of 10 mm/yr that is several times smaller than the leveling rate of 4.3 cm/yr (Swanson and Thurlow 1973).

No leveling information could be found concerning the gravity indicated 20 mm/yr subsidence in the Wichita, KS, and Kansas City, MO, area, nor the 24 mm/yr uplift in the Minot, ND, and Grand Forks, ND, area. However, the fact that there is corroborating evidence from leveling changes for a number of the gravity changes lends some credence to the unsubstantiated gravity changes shown in figure 9.

The discussion of the gravity differences between the IGSN and the NGBN, introduced previously, can now be concluded. A possible explanation for the scale problem in the NGBN could be large vertical changes at the gravimeter calibration stations HOUSTON A and GREAT FALLS A. The scale correction of 38 μGals/1000 mgal found in table 4 indicates the ACL interval HOUSTON A to GREAT FALLS A is short by 47 μGals. If we assume that the gravity change rates shown in figure 9 are correct, then this scale error could have occurred by using this gravity interval to calibrate the gravimeters, used in the NGBN survey, 2 years after the pendulum measurements had been made.

In summary, the gravity differences between NGSGN and IGSN are generally small and many of the larger differences may be due to vertical motion. There does not appear to be a scale problem between the two networks, at least not in the limited gravity range of the United States (1600 mgal).

## CONCLUSIONS

There is no significant scale problem with the IGSN in the United States. No systematic difference between the IGSN in the United States and the new NGSGN network is evident.

The excellent agreement shown in the gravity difference map (fig. 9) proves the accuracy of both the IGSN in the United States and the new NGSGN network. In the United States, the IGSN standard error is probably 30 μGal instead of 0.1 mgal, quoted by Morelli (1971).

The NGSGN derived from the new relative gravimeter observations, along with the new absolute observations, forms a stand-alone gravity network of high accuracy with the standard error of a gravity value of about 15 μGal.

A high accuracy gravity reference network must be regularly reobserved for temporal changes to be determined.

## PLANS

The National Geodetic Survey and the Defense Mapping Agency are supporting development of a new transportable absolute gravity meter. NGS plans to use this instrument to establish a network of absolute stations throughout the United States, perhaps one station in each State. When these stations are tied, the NGSGN will be greatly strengthened. More than 10 years have elapsed since the beginning of the NGSGN reobservation. There should be another reobservation of the network to verify or disprove the changes noted between IGSN and NGSGN.

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## APPENDIX A.--NATIONAL GEODETIC SURVEY GRAVITY NETWORK ADJUSTED GRAVITY VALUES

| Station name | Latitude (deg)(min) | Longitude (deg)(min) | Elev. (m) | Gravity (mgal) | Std. Dev. (mgal) | Order |
|---|---|---|---|---|---|---|
| ARIZONA | | | | | | |
| PHOENIX J | 33 26.20 | 112 00.70 | 342.00 | 979 476.783 | 0.016 | 2nd |
| PHOENIX K | 33 26.20 | 112 00.90 | 342.00 | 979 476.919 | 0.011 | 2nd |
| PHOENIX L | 33 26.20 | 112 01.10 | 342.00 | 979 476.928 | 0.016 | 2nd |
| CALIFORNIA | | | | | | |
| LOS ANGELES C | 34 04.20 | 118 26.40 | 131.00 | 979 583.082 | 0.020 | 2nd |
| LOS ANGELES J | 33 56.60 | 118 24.10 | 40.00 | 979 582.312 | 0.020 | 2nd |
| LOS ANGELES K | 33 56.70 | 118 24.40 | 38.00 | 979 582.542 | 0.016 | 2nd |
| SAN FRANCISCO K | 37 37.00 | 122 23.00 | 3.00 | 979 973.718 | 0.017 | 2nd |
| SAN FRANCISCO N | 37 37.00 | 122 23.00 | 3.00 | 979 972.417 | 0.015 | 2nd |
| SAN FRANCISCO O | 37 37.00 | 122 23.00 | 7.00 | 979 972.344 | 0.014 | 2nd |
| COLORADO | | | | | | |
| DENVER H | 39 40.50 | 104 57.80 | 1634.00 | 979 598.317 | 0.008 | 1st |
| DENVER N | 39 45.60 | 104 53.50 | 1623.10 | 979 618.203 | 0.008 | 2nd |
| DENVER O | 39 45.70 | 104 53.50 | 1623.00 | 979 618.629 | 0.008 | 2nd |
| DENVER P | 39 45.60 | 104 53.50 | 1618.00 | 979 618.864 | 0.013 | 2nd |
| DENVER U | 39 34.70 | 104 50.80 | 1768.00 | 979 572.332 | 0.007 | 2nd |
| MT EVANS AA | 39 39.30 | 105 35.60 | 3247.00 | 979 256.181 | 0.030(4)* | 2nd |
| MT EVANS DA | 39 39.40 | 105 35.80 | 3250.00 | 979 255.355 | 0.030(4) | 2nd |
| TRINIDAD AA | 37 10.40 | 104 30.80 | 1849.60 | 979 330.377 | 0.008 | 1st |
| TRINIDAD BA | 37 10.40 | 104 30.80 | 1849.60 | 979 330.407 | 0.010 | 2nd |
| DISTRICT OF COLUMBIA | | | | | | |
| WASHINGTON D | 38 56.60 | 77 03.40 | 87.50 | 980 086.013 | 0.016 | 2nd |
| FLORIDA | | | | | | |
| JACKSONVILLE L | 30 19.70 | 81 40.30 | 2.80 | 979 362.816 | 0.012 | 2nd |
| R 2 RESET 1977 | 30 19.60 | 81 34.70 | 4.46 | 979 361.856 | 0.013 | 2nd |
| JACKSONVILLE WB | 30 25.20 | 81 38.80 | 7.00 | 979 375.402 | 0.015 | 2nd |
| MIAMI O | 25 29.70 | 80 23.20 | 2.00 | 978 972.784 | 0.016 | 2nd |
| MIAMI R | 25 47.70 | 80 16.70 | 6.00 | 979 037.062 | 0.016 | 2nd |
| MIAMI S | 25 47.70 | 80 16.70 | 2.70 | 979 038.048 | 0.013 | 2nd |
| ORLANDO J1 | 28 32.90 | 81 20.30 | 28.00 | 979 204.080 | 0.015 | 2nd |
| ORLANDO K | 28 33.90 | 81 19.60 | 31.57 | 979 207.731 | 0.015 | 2nd |
| ORLANDO L1 | 28 27.00 | 81 18.90 | 29.00 | 979 185.836 | 0.012 | 2nd |

GEORGIA

| | | | | | | |
|---|---|---|---|---|---|---|
| ATLANTA B | 33 47.50 | 84 19.50 | 290.00 | 979 524.491 | 0.014 | 2nd |
| ATLANTA C | 33 47.50 | 84 19.50 | 290.00 | 979 524.551 | 0.014 | 2nd |
| ATLANTA J | 33 39.10 | 84 25.60 | 312.00 | 979 506.304 | 0.014 | 2nd |
| ATLANTA K | 33 39.20 | 84 25.60 | 304.00 | 979 506.887 | 0.009 | 2nd |

IDAHO

| | | | | | | |
|---|---|---|---|---|---|---|
| BOISE CITY | 43 37.00 | 116 12.00 | 824.07 | 980 202.016 | 0.016 | 2nd |
| U 141 | 43 36.10 | 116 12.80 | 840.23 | 980 197.893 | 0.013 | 2nd |

ILLINOIS

| | | | | | | |
|---|---|---|---|---|---|---|
| CHICAGO C | 41 47.40 | 87 35.90 | 175.00 | 980 271.007 | 0.014 | 2nd |
| CHICAGO D | 41 47.40 | 87 35.90 | 182.00 | 980 270.351 | 0.016 | 2nd |
| CHICAGO J | 41 47.30 | 87 44.60 | 188.40 | 980 271.756 | 0.016 | 2nd |

IOWA

| | | | | | | |
|---|---|---|---|---|---|---|
| SIOUX CITY B | 42 29.30 | 96 24.40 | 341.00 | 980 294.933 | 0.015 | 2nd |
| SIOUX CITY J | 42 24.10 | 96 22.70 | 334.00 | 980 292.973 | 0.018 | 2nd |
| SIOUX CITY 1933 | 42 29.80 | 96 24.60 | 338.54 | 980 295.233 | 0.018 | 2nd |

KANSAS

| | | | | | | |
|---|---|---|---|---|---|---|
| WICHITA B | 37 41.50 | 97 20.20 | 412.00 | 979 832.833 | 0.012 | 2nd |
| WICHITA J | 37 38.10 | 97 25.70 | 403.00 | 979 826.284 | 0.015 | 2nd |
| WICHITA L | 37 38.10 | 97 25.70 | 406.00 | 979 831.181 | 0.015 | 2nd |

KENTUCKY

| | | | | | | |
|---|---|---|---|---|---|---|
| LOUISVILLE BASE | 38 11.10 | 85 44.50 | 145.00 | 979 943.626 | 0.012 | 2nd |
| LOUISVILLE B | 38 12.80 | 85 45.60 | 140.00 | 979 946.743 | 0.015 | 2nd |
| LOUISVILLE J | 38 11.10 | 85 44.40 | 151.00 | 979 943.711 | 0.015 | 2nd |

LOUISIANA

| | | | | | | |
|---|---|---|---|---|---|---|
| NEW ORLEANS J | 29 59.10 | 90 15.40 | 1.00 | 979 314.977 | 0.011 | 2nd |
| NEW ORLEANS BOBET | 29 59.10 | 90 07.10 | 2.00 | 979 312.322 | 0.014 | 2nd |
| NEW ORLEANS QUAD | 29 56.80 | 90 07.20 | 2.00 | 979 312.299 | 0.014 | 2nd |

MASSACHUSETTS

| | | | | | | |
|---|---|---|---|---|---|---|
| BOSTON B | 42 27.90 | 71 18.10 | 42.60 | 980 380.288 | 0.017 | 2nd |
| BOSTON J | 42 27.90 | 71 17.10 | 38.50 | 980 381.946 | 0.015 | 2nd |
| BOSTON Q | 42 22.00 | 71 01.10 | 5.80 | 980 389.495 | 0.018 | 2nd |

MAINE

| | | | | | | |
|---|---|---|---|---|---|---|
| BANGOR B | 44 48.10 | 68 46.30 | 19.30 | 980 580.710 | 0.017 | 2nd |
| BANGOR J | 44 48.00 | 68 49.00 | 61.90 | 980 576.392 | 0.020(2) | 2nd |
| SN 9X C of BANGOR | 44 48.00 | 68 46.30 | 4.35 | 980 583.657 | 0.020(2) | 2nd |

MARYLAND

| | | | | | | |
|---|---|---|---|---|---|---|
| WASHINGTON AA | 39 07.60 | 77 13.30 | 123.00 | 980 103.253 | 0.008 | 1st |
| WASHINGTON CA | 39 07.60 | 77 13.30 | 123.30 | 980 103.010 | 0.012 | 2nd |

MICHIGAN

| | | | | | | |
|---|---|---|---|---|---|---|
| C 185 | 42 17.20 | 83 19.80 | 195.27 | 980 315.937 | 0.016 | 2nd |
| F 185 | 42 14.40 | 83 19.70 | 189.99 | 980 308.436 | 0.017 | 2nd |
| DETROIT K | 42 13.20 | 83 21.00 | 195.00 | 980 304.490 | 0.017 | 2nd |

MINNESOTA

| | | | | | | |
|---|---|---|---|---|---|---|
| DULUTH B | 46 47.00 | 92 06.40 | 400.00 | 980 746.615 | 0.021(4) | 2nd |
| H 218 | 46 50.00 | 92 11.00 | 431.77 | 980 694.800 | 0.018 | 2nd |
| DULUTH J | 46 50.40 | 92 11.40 | 432.00 | 980 695.749 | 0.020(4) | 2nd |
| STA A AP 1966 | 44 56.20 | 93 03.70 | 219.94 | 980 593.462 | 0.019(2) | 2nd |
| H 254 | 44 56.40 | 93 03.70 | 213.78 | 980 593.839 | 0.019(2) | 2nd |
| J 254 | 44 56.50 | 93 03.90 | 215.05 | 980 593.399 | 0.016 | 2nd |

MISSOURI

| | | | | | | |
|---|---|---|---|---|---|---|
| KANSAS CITY B | 39 05.90 | 94 34.60 | 229.00 | 979 972.827 | 0.016 | 2nd |
| KANSAS CITY J | 39 07.20 | 94 35.40 | 231.00 | 979 985.543 | 0.013 | 2nd |
| KANSAS CITY K | 39 07.20 | 94 35.40 | 231.00 | 979 985.521 | 0.014 | 2nd |

MONTANA

| | | | | | | |
|---|---|---|---|---|---|---|
| BILLINGS | 45 47.00 | 108 30.20 | 952.32 | 980 356.316 | 0.014 | 2nd |
| BILLINGS A | 45 48.20 | 108 32.30 | 1101.50 | 980 356.392 | 0.017 | 2nd |
| BILLINGS M | 45 48.20 | 108 32.20 | 1085.70 | 980 357.306 | 0.017 | 2nd |
| GREAT FALLS B | 47 31.00 | 111 15.80 | 1050.00 | 980 512.293 | 0.018 | 2nd |
| U 386 USE | 47 30.80 | 111 11.00 | 1074.00 | 980 514.433 | 0.016 | 2nd |
| GREAT FALLS O | 47 29.10 | 111 21.20 | 1119.70 | 980 498.865 | 0.015 | 2nd |

NEVADA

| | | | | | | |
|---|---|---|---|---|---|---|
| LAS VEGAS B | 36 10.40 | 115 08.40 | 646.00 | 979 586.499 | 0.016 | 2nd |
| K 169 | 36 10.40 | 115 08.40 | 613.91 | 979 586.958 | 0.011 | 2nd |
| RENO J | 39 30.40 | 119 46.40 | 1344.00 | 979 675.198 | 0.016 | 2nd |
| RENO K USAF | 39 30.40 | 119 46.40 | 1344.00 | 979 675.832 | 0.011 | 2nd |
| RENO K1 | 39 30.50 | 119 46.40 | 1343.90 | 979 676.169 | 0.013 | 2nd |

NEW MEXICO

| | | | | | | |
|---|---|---|---|---|---|---|
| C 306 | 32 51.70 | 105 59.60 | 1267.82 | 979 116.397 | 0.009 | 2nd |
| LA LUZ D DMA | 32 57.50 | 105 56.50 | 1432.60 | 979 106.037 | 0.009 | 2nd |
| ALAMOGORDO J | 32 51.00 | 105 60.00 | 1280.00 | 979 116.343 | 0.007 | 2nd |
| ALBUQUERQUE J | 35 02.90 | 106 37.00 | 1623.00 | 979 194.004 | 0.008 | 2nd |
| ALBUQUERQUE K | 35 02.90 | 106 37.20 | 1625.00 | 979 193.493 | 0.008 | 2nd |
| WEST USGS | 35 02.80 | 106 37.30 | 1618.56 | 979 193.480 | 0.011 | 2nd |
| HOLLOMAN A | 32 53.50 | 106 06.00 | 1250.00 | 979 139.621 | 0.006 | 2nd |

NEW YORK

| | | | | | | |
|---|---|---|---|---|---|---|
| BUFFALO A | 42 57.10 | 78 49.30 | 175.00 | 980 352.662 | 0.017 | 2nd |
| B 371 | 42 57.70 | 78 44.30 | 204.78 | 980 356.281 | 0.017 | 2nd |
| BUFFALO J | 42 56.00 | 78 43.80 | 212.10 | 980 350.636 | 0.014 | 2nd |
| NEW YORK M | 40 38.60 | 73 46.90 | 4.60 | 980 211.589 | 0.017 | 2nd |
| NEW YORK R | 40 38.50 | 73 47.40 | 4.60 | 980 212.553 | 0.013 | 2nd |
| NEW YORK S | 40 46.50 | 73 52.30 | 6.40 | 980 267.752 | 0.017 | 2nd |
| SYRACUSE J | 43 06.80 | 76 06.70 | 128.30 | 980 382.687 | 0.015 | 2nd |
| SYRACUSE K | 43 06.40 | 76 07.10 | 121.00 | 980 382.048 | 0.017 | 2nd |
| 91 A | 43 06.90 | 76 06.80 | 127.08 | 980 382.923 | 0.017 | 2nd |

NORTH CAROLINA

| | | | | | | |
|---|---|---|---|---|---|---|
| CHARLOTTE A | 35 18.40 | 80 43.90 | 230.00 | 979 728.050 | 0.016 | 2nd |
| CHARLOTTE J | 35 12.70 | 80 56.30 | 228.00 | 979 713.432 | 0.010 | 2nd |
| CHARLOTTE K | 35 12.70 | 80 56.20 | 224.00 | 979 714.301 | 0.015 | 2nd |
| RALEIGH B | 35 46.50 | 78 38.70 | 104.00 | 979 769.867 | 0.015 | 2nd |
| RALEIGH K | 35 52.50 | 78 47.50 | 133.00 | 979 787.247 | 0.010 | 2nd |
| T 230 | 35 52.50 | 78 47.40 | 131.05 | 979 787.227 | 0.014 | 2nd |

NORTH DAKOTA

| | | | | | | |
|---|---|---|---|---|---|---|
| BISMARCK B | 46 48.50 | 100 47.20 | 515.10 | 980 611.724 | 0.017 | 2nd |
| BISMARCK J | 46 46.80 | 100 45.70 | 503.80 | 980 612.713 | 0.020(2) | 2nd |
| BISMARCK K | 46 46.00 | 100 45.00 | 503.80 | 980 612.999 | 0.020(2) | 2nd |
| GRAND FORKS J | 47 55.60 | 97 05.20 | 254.40 | 980 794.118 | 0.019(4) | 2nd |
| GRAND FORKS K | 47 56.80 | 97 23.40 | 277.40 | 980 782.283 | 0.021(4) | 2nd |
| GRAND FORKS M | 47 57.00 | 97 10.60 | 257.00 | 980 791.840 | 0.021(4) | 2nd |
| MINOT J | 48 25.00 | 101 21.00 | 508.40 | 980 782.691 | 0.021(4) | 2nd |
| MINOT 29 A | 48 25.00 | 101 21.00 | 495.00 | 980 782.599 | 0.021(4) | 2nd |
| MINOT 31 | 48 25.00 | 101 21.00 | 495.50 | 980 783.071 | 0.019(4) | 2nd |

OHIO

| | | | | | | |
|---|---|---|---|---|---|---|
| COLUMBUS C | 39 59.90 | 83 02.60 | 245.00 | 980 081.388 | 0.015 | 2nd |
| COLUMBUS J | 39 59.90 | 82 53.00 | 244.80 | 980 064.206 | 0.015 | 2nd |
| TT 16 WQ | 41 33.40 | 83 37.70 | 192.64 | 980 228.359 | 0.012 | 2nd |
| V 189 1954 | 40 00.40 | 82 52.20 | 248.21 | 980 064.285 | 0.012 | 2nd |

OGDEN

| | | | | | | |
|---|---|---|---|---|---|---|
| MEDFORD B | 42 19.50 | 122 52.60 | 417.70 | 980 213.973 | 0.015 | 2nd |
| F 168 USGS | 42 19.50 | 122 52.60 | 421.29 | 980 213.773 | 0.018 | 2nd |
| MEDFORD J | 42 22.20 | 122 52.30 | 403.80 | 980 221.946 | 0.018 | 2nd |
| PORTLAND B | 45 31.50 | 122 40.60 | 9.10 | 980 632.645 | 0.019(8) | 2nd |
| PORT. Q 14 RESET | 45 31.80 | 122 40.50 | 9.70 | 980 631.926 | 0.021(4) | 2nd |
| R 14 | 45 31.50 | 122 40.60 | 9.40 | 980 632.792 | 0.021(4) | 2nd |

PENNSYLVANIA

| | | | | | | |
|---|---|---|---|---|---|---|
| PITTSBURGH BASE | 40 29.80 | 80 13.20 | 317.00 | 980 084.800 | 0.013 | 2nd |
| PITTS. WEATHER A | 40 31.90 | 80 13.10 | 360.60 | 980 083.870 | 0.015 | 2nd |
| PITTS. WEATHER 1 | 40 31.90 | 80 13.10 | 360.30 | 980 084.018 | 0.015 | 2nd |

SOUTH CAROLINA

| | | | | | | |
|---|---|---|---|---|---|---|
| CHARLESTON K1 | 32 53.90 | 80 02.10 | 12.00 | 979 552.168 | 0.011 | 2nd |
| CHARLESTON L1 | 32 54.00 | 80 02.40 | 14.50 | 979 552.942 | 0.015 | 2nd |
| V 67 | 32 54.00 | 80 02.10 | 13.46 | 979 551.921 | 0.015 | 2nd |

SOUTH DAKOTA

| | | | | | | |
|---|---|---|---|---|---|---|
| RAPID CITY B | 44 04.90 | 103 13.60 | 976.00 | 980 257.183 | 0.014 | 2nd |
| H 11 | 44 04.80 | 103 13.30 | 887.32 | 980 256.429 | 0.017 | 2nd |
| J 11 | 44 04.80 | 103 13.80 | 989.70 | 980 256.748 | 0.017 | 2nd |
| SIOUX FALLS B | 43 32.60 | 96 43.40 | 442.00 | 980 345.233 | 0.014 | 2nd |
| E 328 | 43 33.20 | 96 43.60 | 425.60 | 980 347.208 | 0.017 | 2nd |
| SIOUX FALLS K | 43 34.40 | 96 44.20 | 435.00 | 980 347.521 | 0.017 | 2nd |

TENNESSEE

| | | | | | | |
|---|---|---|---|---|---|---|
| KNOXVILLE A | 35 57.40 | 83 55.60 | 277.00 | 979 700.265 | 0.014 | 2nd |
| KNOXVILLE J | 35 48.60 | 83 59.20 | 324.00 | 979 688.156 | 0.010 | 2nd |
| KNOXVILLE K | 35 57.40 | 83 55.50 | 289.00 | 979 697.130 | 0.014 | 2nd |
| KNOXVILLE L | 35 57.40 | 83 55.60 | 292.00 | 979 697.440 | 0.014 | 2nd |

TEXAS

| | | | | | | |
|---|---|---|---|---|---|---|
| DALLAS AP | 32 50.60 | 96 51.00 | 142.00 | 979 498.042 | 0.015 | 2nd |
| DALLAS K | 32 50.60 | 96 51.00 | 142.00 | 979 499.210 | 0.012 | 2nd |
| KERNS 2 | 32 07.90 | 96 13.90 | 110.00 | 979 475.089 | 0.013 | 2nd |
| EL PASO FLAGPOLE | 31 49.70 | 106 23.10 | 1193.00 | 979 069.984 | 0.013 | 2nd |
| EL PASO M | 31 50.00 | 106 22.90 | 1204.00 | 979 070.396 | 0.008 | 2nd |
| V 912 | 31 49.70 | 106 23.00 | 1195.36 | 979 069.852 | 0.010 | 2nd |
| EL PASO WB | 31 47.80 | 106 23.50 | 1198.34 | 979 065.944 | 0.013 | 2nd |
| McDONALD AA | 30 40.00 | 104 01.00 | 2028.10 | 978 828.645 | 0.007 | 1st |
| McDONALD CA | 30 40.20 | 104 01.50 | 2028.00 | 978 828.666 | 0.011 | 2nd |
| SAN ANTONIO K | 29 31.70 | 98 28.40 | 242.90 | 979 182.627 | 0.013 | 2nd |
| SAN ANTONIO L | 29 31.70 | 98 28.40 | 243.80 | 979 182.621 | 0.009 | 2nd |
| SAN ANTONIO N | 29 31.70 | 98 28.40 | 244.00 | 979 182.818 | 0.013 | 2nd |

UTAH

| | | | | | | |
|---|---|---|---|---|---|---|
| OGDEN J | 41 07.00 | 111 58.90 | 1459.40 | 979 786.088 | 0.011 | 2nd |
| OGDEN K | 41 07.80 | 111 58.30 | 1460.00 | 979 785.801 | 0.014 | 2nd |
| OGDEN L | 41 07.80 | 111 58.30 | 1460.00 | 979 793.735 | 0.014 | 2nd |
| SALT LAKE CITY J | 40 47.20 | 111 58.70 | 1288.00 | 979 801.599 | 0.014 | 2nd |
| SALT LAKE CITY K | 40 47.10 | 111 58.70 | 1288.00 | 979 801.704 | 0.010 | 2nd |
| SALT LAKE CITY L | 40 46.40 | 111 57.50 | 1287.00 | 979 792.449 | 0.014 | 2nd |

VIRGINIA

| | | | | | | |
|---|---|---|---|---|---|---|
| WASHINGTON L | 38 51.00 | 77 02.50 | 4.60 | 980 094.289 | 0.011 | 2nd |

**WASHINGTON**

| | | | | | |
|---|---|---|---|---|---|
| SEATTLE A | 47 39.30 | 122 18.50 | 58.00 | 980 724.310 | 0.022(4)2nd |
| SEATTLE C | 47 36.10 | 122 19.80 | 17.80 | 980 724.021 | 0.020(4)2nd |
| SEATTLE Q | 47 39.30 | 122 18.50 | 42.70 | 980 723.441 | 0.022(4)2nd |
| SPOKANE B | 47 39.50 | 117 25.50 | 573.50 | 980 659.621 | 0.017 2nd |
| SPOKANE J | 47 37.50 | 117 32.00 | 723.00 | 980 632.936 | 0.019(4)2nd |
| SPOKANE L | 47 37.70 | 117 38.30 | 751.00 | 980 628.340 | 0.019(4)2nd |
| W 25 | 47 39.50 | 117 29.40 | 573.36 | 980 659.698 | 0.020(4)2nd |

**WISCONSIN**

| | | | | | |
|---|---|---|---|---|---|
| MADISON J | 43 08.40 | 89 19.60 | 261.80 | 980 357.799 | 0.017 2nd |
| MADISON K | 43 08.40 | 89 19.60 | 261.90 | 980 357.829 | 0.017 2nd |
| MADISON O | 43 08.20 | 89 20.70 | 262.00 | 980 358.890 | 0.014 2nd |

**WYOMING**

| | | | | | |
|---|---|---|---|---|---|
| CASPER A | 42 53.80 | 106 26.70 | 1628.50 | 979 941.655 | 0.014 2nd |
| CASPER AA | 42 51.00 | 106 19.40 | 1558.00 | 979 947.250 | 0.014 2nd |
| CASPER K | 42 53.80 | 106 27.90 | 1629.80 | 979 941.391 | 0.013 2nd |
| CASPER L | 42 53.80 | 106 27.90 | 1629.80 | 979 941.291 | 0.009 2nd |
| CHEYENNE K | 41 09.20 | 104 49.10 | 1876.00 | 979 686.387 | 0.013 2nd |
| CHEYENNE M | 41 09.70 | 104 49.40 | 1876.35 | 979 686.158 | 0.011 2nd |
| CHEYENNE N | 41 08.50 | 104 52.00 | 1875.50 | 979 684.265 | 0.009 2nd |
| CHEYENNE O | 41 09.20 | 104 49.10 | 1876.35 | 979 686.701 | 0.008 2nd |
| SHERIDAN AA | 44 45.60 | 106 58.10 | 1205.00 | 980 208.948 | 0.008 1st |

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*The number of gravity difference observations in the gravity determination is given in parentheses for all adjusted gravity standard errors greater than 1 sigma (0.004 mgal) above the mean for the entire data set (0.015 mgal).

The station order is defined in Standards and Specifications for Geodetic Control Networks (FGCC 1984).

<u>APPENDIX B.--COMMON STATIONS IN NGSGN AND IGSN</u>

| Station name | NGSGN Gravity | NGSGN std.err. | IGSN Gravity | IGSN std.err. | Difference NGSGN-IGSN |
|---|---|---|---|---|---|
| ARIZONA | | | | | |
| PHOENIX J | 979 476.783 | 0.016 | 76.83 | 0.017 | -0.05 |
| PHOENIX K | 979 476.919 | 0.011 | 76.95 | 0.021 | -0.03 |
| PHOENIX L | 979 476.928 | 0.016 | 76.98 | 0.025 | -0.05 |
| CALIFORNIA | | | | | |
| LOS ANGELES C | 979 583.082 | 0.016* | 83.88 | 0.022 | +0.80 |
| LOS ANGELES J | 979 582.312 | 0.016 | 82.32 | 0.020 | -0.01 |
| LOS ANGELES K | 979 582.542 | 0.011 | 82.52 | 0.016 | +0.02 |
| SAN FRANCISCO K | 979 973.718 | 0.017 | 73.75 | 0.016 | -0.03 |
| SAN FRANCISCO N | 979 972.417 | 0.015 | 72.45 | 0.030 | -0.03 |
| SAN FRANCISCO O | 979 972.344 | 0.014 | 72.37 | 0.012 | -0.03 |
| COLORADO | | | | | |
| DENVER N | 979 618.203 | 0.008 | 18.21 | 0.012 | -0.01 |
| DENVER O | 979 618.629 | 0.008 | 18.63 | 0.014 | 0.00 |
| DENVER P | 979 618.864 | 0.013 | 18.84 | 0.013 | +0.02 |
| DISTRICT OF COLUMBIA | | | | | |
| WASHINGTON D | 980 086.013 | 0.016 | 86.04 | 0.012 | -0.03 |
| FLORIDA | | | | | |
| JACKSONVILLE L | 979 362.816 | 0.012 | 62.80 | 0.017 | +0.02 |
| MIAMI O | 978 972.784 | 0.016 | 72.82 | 0.019 | -0.04 |
| MIAMI R | 979 037.062 | 0.016 | 37.06 | 0.015 | -0.02 |
| MIAMI S | 979 038.048 | 0.013 | 38.07 | 0.018 | -0.02 |
| ORLANDO J1 | 979 204.080 | 0.015* | 04.10 | 0.016 | -0.02 |
| ORLANDO K | 979 207.731 | 0.015* | 07.75 | 0.014 | -0.02 |
| ORLANDO L1 | 979 185.836 | 0.012* | 85.85 | 0.015 | -0.01 |
| GEORGIA | | | | | |
| ATLANTA B | 979 524.491 | 0.014 | 24.49 | 0.022 | 0.00 |
| ATLANTA C | 979 524.551 | 0.014 | 24.55 | 0.025 | 0.00 |
| ATLANTA J | 979 506.304 | 0.014 | 06.31 | 0.018 | -0.01 |
| ATLANTA K | 979 506.887 | 0.009 | 06.90 | 0.019 | -0.01 |

ILLINOIS

| | | | | | |
|---|---|---|---|---|---|
| CHICAGO C | 980 271.007 | 0.014 | 71.03 | 0.024 | -0.02 |
| CHICAGO D | 980 270.351 | 0.016 | 70.36 | 0.020 | -0.01 |
| CHICAGO J | 980 271.756 | 0.016 | 71.78 | 0.023 | -0.02 |

IOWA

| | | | | | |
|---|---|---|---|---|---|
| SIOUX CITY B | 980 294.933 | 0.015 | 94.97 | 0.019 | -0.04 |
| SIOUX CITY J | 980 292.973 | 0.018 | 92.97 | 0.015 | 0.00 |

KANSAS

| | | | | | |
|---|---|---|---|---|---|
| WICHITA B | 979 832.833 | 0.012 | 32.75 | 0.022 | +0.08 |
| WICHITA J | 979 826.284 | 0.015 | 26.26 | 0.018 | +0.02 |

KENTUCKY

| | | | | | |
|---|---|---|---|---|---|
| LOUISVILLE B | 979 946.743 | 0.015 | 46.70 | 0.023 | +0.04 |
| LOUISVILLE J | 979 943.711 | 0.015 | 43.67 | 0.020 | +0.04 |

LOUISIANA

| | | | | | |
|---|---|---|---|---|---|
| NEW ORLEANS J | 979 314.977 | 0.011 | 14.95 | 0.016 | +0.03 |

MASSACHUSETTS

| | | | | | |
|---|---|---|---|---|---|
| BOSTON A | 980 378.624 | 0.018 | 98.69 | 0.014 | -0.07 |
| BOSTON B | 980 380.288 | 0.017 | 80.31 | 0.015 | -0.02 |
| BOSTON J | 980 381.946 | 0.015 | 81.98 | 0.012 | -0.03 |
| BOSTON Q | 980 389.495 | 0.018 | 89.53 | 0.014 | -0.03 |

MAINE

| | | | | | |
|---|---|---|---|---|---|
| BANGOR B | 980 580.710 | 0.017 | 80.74 | 0.016 | -0.03 |
| BANGOR J | 980 576.392 | 0.020 | 76.43 | 0.015 | -0.04 |

MICHIGAN

| | | | | | |
|---|---|---|---|---|---|
| DETROIT K | 980 304.490 | 0.017 | 04.45 | 0.016 | +0.04 |

MINNESOTA

| | | | | | |
|---|---|---|---|---|---|
| DULUTH B | 980 746.615 | 0.021 | 46.59 | 0.020 | +0.03 |
| DULUTH J | 980 695.749 | 0.020 | 95.80 | 0.015 | -0.05 |

MISSOURI

| | | | | | |
|---|---|---|---|---|---|
| KANSAS CITY B | 979 972.827 | 0.016 | 72.66 | 0.023 | +0.17 |
| KANSAS CITY J | 979 985.543 | 0.013 | 85.45 | 0.020 | +0.09 |
| KANSAS CITY K | 979 985.521 | 0.014 | 85.45 | 0.019 | +0.07 |

| | | | | | | |
|---|---|---|---|---|---|---|
| MONTANA | | | | | | |
| BILLINGS A | 980 | 356.392 | 0.017 | 56.35 | 0.014 | +0.04 |
| BILLINGS M | 980 | 357.306 | 0.017 | 57.27 | 0.012 | +0.04 |
| GREAT FALLS B | 980 | 512.293 | 0.018 | 12.33 | 0.012 | -0.04 |
| GREAT FALLS L | 980 | 514.433 | 0.016 | 14.47 | 0.011 | -0.04 |
| GREAT FALLS O | 980 | 498.865 | 0.015 | 98.91 | 0.013 | -0.04 |
| NEVADA | | | | | | |
| LAS VEGAS B | 979 | 586.499 | 0.016 | 86.45 | 0.024 | +0.05 |
| RENO J | 979 | 675.198 | 0.016 | 75.21 | 0.015 | +0.01 |
| RENO K | 979 | 675.832 | 0.011 | 75.87 | 0.020 | -0.04 |
| NEW MEXICO | | | | | | |
| ALAMOGORDO J | 979 | 116.343 | 0.007 | 16.32 | 0.019 | +0.02 |
| ALBUQUERQUE J | 979 | 194.004 | 0.008 | 94.01 | 0.016 | -0.01 |
| ALBUQUERQUE K | 979 | 193.493 | 0.008 | 93.51 | 0.021 | -0.02 |
| NEW YORK | | | | | | |
| BUFFALO A | 980 | 352.662 | 0.017* | 52.25 | 0.020 | +0.41 |
| BUFFALO J | 980 | 350.636 | 0.014 | 50.71 | 0.014 | -0.07 |
| NEW YORK M | 980 | 211.589 | 0.017 | 11.60 | 0.021 | -0.01 |
| NEW YORK R | 980 | 212.553 | 0.013 | 12.58 | 0.013 | -0.03 |
| NEW YORK S | 980 | 267.752 | 0.017 | 67.76 | 0.014 | -0.01 |
| SYRACUSE J | 980 | 382.687 | 0.015 | 82.69 | 0.015 | 0.00 |
| SYRACUSE K | 980 | 382.048 | 0.017 | 82.07 | 0.021 | -0.02 |
| NORTH CAROLINA | | | | | | |
| CHARLOTTE A | 979 | 728.050 | 0.015 | 28.06 | 0.020 | -0.01 |
| CHARLOTTE J | 979 | 713.432 | 0.010 | 13.43 | 0.014 | 0.00 |
| CHARLOTTE K | 979 | 714.301 | 0.015 | 14.33 | 0.015 | -0.03 |
| RALEIGH B | 979 | 769.867 | 0.015 | 69.86 | 0.019 | +0.01 |
| RALEIGH K | 979 | 787.247 | 0.010 | 87.26 | 0.016 | -0.01 |
| NORTH DAKOTA | | | | | | |
| BISMARCK B | 980 | 611.724 | 0.017 | 11.74 | 0.023 | -0.02 |
| BISMARCK J | 980 | 612.713 | 0.020 | 12.73 | 0.019 | -0.02 |
| BISMARCK K | 980 | 612.999 | 0.020 | 13.02 | 0.014 | -0.02 |
| GRAND FORKS J | 980 | 794.118 | 0.019 | 94.19 | 0.026 | -0.07 |
| GRAND FORKS K | 980 | 782.283 | 0.021 | 82.36 | 0.026 | -0.08 |
| GRAND FORKS M | 980 | 791.840 | 0.021 | 91.94 | 0.022 | -0.10 |
| MINOT J | 980 | 782.691 | 0.021 | 82.77 | 0.022 | -0.08 |

| | | | | | |
|---|---|---|---|---|---|
| OHIO | | | | | |
| COLUMBUS C | 980 081.388 | 0.015 | 81.39 | 0.021 | 0.00 |
| COLUMBUS J | 980 064.206 | 0.015 | 64.20 | 0.018 | +0.01 |
| OREGON | | | | | |
| PORTLAND B | 980 632.645 | 0.019 | 32.64 | 0.022 | 0.00 |
| MEDFORD B | 980 213.973 | 0.015 | 13.98 | 0.020 | -0.01 |
| MEDFORD J | 980 221.946 | 0.018 | 21.89 | 0.015 | +0.06 |
| SOUTH CAROLINA | | | | | |
| CHARLESTON K1 | 979 552.168 | 0.011* | 52.27 | 0.019 | -0.10 |
| CHARLESTON L1 | 979 552.942 | 0.015* | 52.98 | 0.016 | -0.04 |
| SOUTH DAKOTA | | | | | |
| RAPID CITY B | 980 257.183 | 0.014 | 57.14 | 0.019 | +0.04 |
| SIOUX FALLS B | 980 345.233 | 0.014 | 45.20 | 0.020 | +0.03 |
| SIOUX FALLS K | 980 347.521 | 0.017 | 47.51 | 0.020 | +0.01 |
| TENNESSEE | | | | | |
| KNOXVILLE A | 979 700.265 | 0.014 | 00.23 | 0.021 | +0.03 |
| KNOXVILLE J | 979 688.156 | 0.010 | 88.16 | 0.016 | 0.00 |
| KNOXVILLE K | 979 697.130 | 0.014 | 97.14 | 0.024 | -0.01 |
| KNOXVILLE L | 979 697.440 | 0.014 | 97.45 | 0.028 | -0.01 |
| TEXAS | | | | | |
| AUSTIN B | 979 270.319 | 0.011 | 70.31 | 0.016 | +0.01 |
| DALLAS K | 979 499.210 | 0.012 | 99.19 | 0.016 | +0.02 |
| EL PASO M | 979 070.396 | 0.008 | 70.44 | 0.021 | -0.04 |
| HOUSTON B | 979 283.876 | 0.014 | 83.73 | 0.018 | +0.15 |
| HOUSTON D | 979 283.091 | 0.014 | 82.92 | 0.019 | +0.17 |
| HOUSTON M | 979 278.877 | 0.009 | 78.71 | 0.014 | +0.17 |
| HOUSTON N | 979 278.847 | 0.014 | 78.67 | 0.023 | +0.18 |
| SAN ANTONIO K | 979 182.627 | 0.013* | 82.84 | 0.020 | -0.21 |
| SAN ANTONIO L | 979 182.621 | 0.009 | 82.58 | 0.015 | +0.03 |
| SAN ANTONIO N | 979 182.818 | 0.013 | 82.76 | 0.016 | +0.06 |
| UTAH | | | | | |
| OGDEN J | 979 786.088 | 0.011 | 86.07 | 0.019 | +0.02 |
| OGDEN K | 979 785.801 | 0.014 | 85.75 | 0.023 | +0.05 |
| OGDEN L | 979 793.735 | 0.014 | 93.70 | 0.026 | +0.04 |

| | | | | | |
|---|---|---|---|---|---|
| SALT LAKE CITY J | 979 801.599 | 0.014 | 01.60 | 0.014 | 0.00 |
| SALT LAKE CITY K | 979 801.704 | 0.010 | 01.69 | 0.016 | +0.01 |
| SALT LAKE CITY L | 979 792.449 | 0.014 | 92.43 | 0.020 | -0.02 |
| VIRGINIA | | | | | |
| WASHINGTON L | 980 094.289 | 0.011 | 94.29 | 0.012 | 0.00 |
| WASHINGTON R | 980 078.420 | 0.017 | 78.44 | 0.011 | -0.02 |
| WASHINGTON | | | | | |
| SEATTLE A | 980 724.310 | 0.022 | 24.32 | 0.017 | -0.01 |
| SEATTLE C | 980 724.021 | 0.020 | 24.03 | 0.023 | -0.01 |
| SEATTLE Q | 980 723.441 | 0.022 | 23.47 | 0.025 | -0.03 |
| SPOKANE B | 980 659.621 | 0.017 | 59.69 | 0.019 | -0.07 |
| SPOKANE J | 980 632.936 | 0.019 | 33.02 | 0.014 | -0.08 |
| SPOKANE L | 980 628.340 | 0.019 | 28.39 | 0.023 | -0.05 |
| WISCONSIN | | | | | |
| MADISON J | 980 357.799 | 0.017 | 57.81 | 0.012 | -0.01 |
| MADISON K | 980 357.829 | 0.017 | 57.83 | 0.016 | 0.00 |
| MADISON O | 980 358.890 | 0.014 | 58.90 | 0.017 | -0.01 |
| WYOMING | | | | | |
| CASPER K | 979 941.391 | 0.013 | 41.40 | 0.014 | -0.01 |
| CASPER L | 979 941.291 | 0.009 | 41.31 | 0.013 | -0.02 |
| CHEYENNE J | 979 686.233 | 0.007 | 86.22 | 0.015 | +0.01 |
| CHEYENNE K | 979 686.387 | 0.013 | 86.41 | 0.013 | -0.02 |
| CHEYENNE M | 979 686.158 | 0.011 | 86.16 | 0.013 | 0.00 |
| CHEYENNE N | 979 684.265 | 0.009 | 84.31 | 0.013 | -0.04 |
| CHEYENNE O | 979 686.701 | 0.008 | 86.73 | 0.014 | -0.03 |
| SHERIDAN C | 980 228.408 | 0.013 | 28.33 | 0.015 | +0.08 |
| SHERIDAN K | 980 212.074 | 0.011 | 12.04 | 0.012 | +0.03 |

* The correct station was probably not recovered.



* U.S.Government Printing Office: 1987 0-181-076 (40221)