DEPARTMENT OF INTERIOR

U.S. GEOLOGICAL SURVEY

Models of Total Magnetic Intensity in the United States for 1980

By

Eugene B. Fabiano[1], Norman W. Peddie[2], and Audronis K. Zunde[2]

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[1] Retired

[2] U.S. Geological Survey
Denver Federal Center
P.O. Box 25046
Mail Stop 968
Denver, Colorado 80225

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DISCLAIMER

Please note that the magnetic models described in this report have been superseded, and that they should not be used for dates later than December 31, 1984. For more information, please contact Norman Peddie. Mailing address: U.S. Geological Survey, Mail Stop 968, Denver Federal Center, Box 25046, Denver, CO 80225. Telephone: 303-236-1364. FTS: 776-1364.

ABSTRACT

Six mathematical models of the geomagnetic field in the United States, one pair each for the conterminous States, Alaska, and Hawaii, have been developed. Each pair comprises a model of the field's total intensity (F) at the beginning of 1980 and a model of the expected rate of change of total intensity ($\dot{F}$) for the period 1980-1985. Field values can be computed directly from the models or scaled from the chart Magnetic Total Intensity in the United States--Epoch 1980 (U.S. Geological Survey Map I-1370), which is based on the models. The models and chart are of particular interest to exploration geophysicists who often need a smoothed representation of geomagnetic total intensity for processing magnetic-survey data.

The models are expressed as polynomial functions of geographic latitude and longitude. For the conterminous States and Alaska, the models are of degree 6 (28 coefficients), and for Hawaii they are of degree 4 (15 coefficients). The F models, which are probably the most accurate ever developed for the United States, were derived mainly from data from the Project MAGNET aerial survey of the conterminous States made in 1976-77 and the global MAGSAT satellite survey of 1979-80. The $\dot{F}$ models were derived from measurements taken at magnetic observatories and repeat stations.

INTRODUCTION

The Earth's magnetic field constantly changes with time. The aggregate change, as observed over a period of several or more years, is called the secular variation. Thus far, accurately predicting the secular variation has eluded our best attempts. As a result, it is necessary periodically to revise mathematical models and charts of the geomagnetic field. It may also be desirable to produce revised models and charts wherever a significant amount of new data becomes available.

We developed six geomagnetic field models for the United States, one pair each for the conterminous States, Alaska, and Hawaii. One model in each pair describes the field's total intensity (F) at the beginning of 1980; the other describes the expected rate of change of total intensity ($\dot{F}$) for the period 1980-1985. Because much new F data were available, we believe that the F models are more reliable than any previously issued for the United States. In this report, we describe the method used to develop the models and present the model coefficients along with information on their use.

The models served as the basis for the chart Magnetic Total Intensity in the United States--Epoch 1980, published by the U.S. Geological Survey as Map I-1370 (Fabiano and Peddie, 1981). The chart contains maps of the conterminous States, Alaska, and Hawaii, drawn on the Lambert conformal conic projection at scales of 1:7,500,000 for Hawaii, and 1:5,000,000 for the other two regions. Figures 1 and 2 are simplified small-scale charts showing F and $\dot{F}$ in the United States for 1980. (Note that for these small-scale charts, the Albers equal-area conic map projection was used instead of the Lambert projection.)

The 1980 chart is the latest of a continuing series of U.S. magnetic charts that began in 1850 with a chart of magnetic declination. Many other charts showing various geomagnetic field elements have been published since then, normally at 5- or 10-year intervals. The previous chart of total intensity was published in 1976 (Fabiano and others, 1976). Before 1970, the charts were compiled manually. Since then, they have been compiled using computer programs that contour mathematical models derived from the data. Historical summaries related to U.S. magnetic surveys and charts have been given by Deel and Howe (1948) and Svendsen (1962).

Models and charts of this type are used as convenient references by Earth scientists, teachers, and others. They are also useful in the mineral and petroleum exploration industry for processing magnetic survey data. For example, small-scale features of the magnetic field, and the geologic features that cause them, become more apparent when the larger-scale magnetic field, as described by an F model or chart of this type, is removed from the survey data.

METHOD

The method we used generally followed that described by Fabiano and others (1979). As was done for earlier U.S. chart models, we chose to represent F and $\dot{F}$ as polynomial functions of latitude (ϕ) and east longitude (λ) (here negative east longitude is equivalent to west longitude). For example,

$$F = F_c + \sum_{i=o}^{n} \sum_{j=o}^{n-i} A_{ij}(\phi - \phi_c)^i(\lambda - \lambda_c)^j, \quad (1)$$

where n is the degree of the polynomial; A_{ij} are the polynomial coefficients; and F_c, ϕ_c, and λ_c are constants used to normalize F, ϕ, and λ, respectively. The values adopted for these constants and for the similarly defined $\dot{F}_c$ are given in table 1. The values of the coefficients were determined by the method of least squares. The number of coefficients in a polynomial model of degree n is equal to (n + 1)(n + 2) / 2.

TABLE 1.--Normalizing constants

	F_c (nT)	$\dot{F}_c$ (nT/yr)	ϕ_c (degrees)	λ_c (degrees)
Conterminous States	50,000	0	38	-92
Alaska	51,000	0	60	-155
Hawaii	37,000	0	23	-157

F DATA

Fortunately, many new measurements of F were available for this work. About 92 percent of the measurements were taken since 1976, most of them from two large-scale surveys: an aerial survey of the conterminous States and a global survey by satellite. The aerial survey was carried out during 1976-1977 by the U.S. Naval Oceanographic Office Project MAGNET (NOAA, 1980). The satellite survey, referred to as MAGSAT, was carried out during 1979-1980 by the National Aeronautics and Space Administration in cooperation with the U.S. Geological Survey (Langel and others, 1980).

F MODEL FOR THE CONTERMINOUS UNITED STATES

The Project MAGNET survey comprised 44 north-south and seven east-west flight lines, totaling 103,000 km in length (fig. 3). For 80-85 percent of the survey, the aircraft was flown at about 600 m above the ground, and for the remainder, generally over mountainous regions, at 1220 m. The ground speed of the aircraft ranged from about 380 to 500 km/hr. F measurements were taken at the rate of one per second. From the resulting set of about 600,000 measurements, we formed a subset consisting of every 50th measurement. The spacing of measurement points in the subset is about 6 km.

The data were then processed in the following way:

1. We rejected measurements taken when the K index was greater than 2 (as recorded at the Fredericksburg Geomagnetic Center, located near Corbin, Virginia). The K index is a measure of the magnitude of geomagnetic field disturbance (see, for example, Mayaud, 1980).

2. We rejected measurements that differed by more than 1000 nT from the International Geomagnetic Reference Field 1975 (IAGA Division I Study Group on Geomagnetic Reference Fields, 1977) main-field model adjusted to the date of the observations using a secular-variation model (unpublished) that was derived from observatory and repeat-station data.

3. We computed the aircraft's elevation above mean sea level using the height-above-ground and topographic-elevation data. Measurements were rejected if either the height or the elevation was not available.

4. We adjusted each measurement to its corresponding value at mean sea level by applying the factor 2123/(2123 - h), where h is the height of the measurement in kilometers (Chapman, 1936).

5. We adjusted each measurement for the secular variation of F that occurred from the date of measurement to January 1, 1980, using the global secular-variation model mentioned in item 2.

The Project MAGNET data points did not cover the whole region represented by the map of the conterminous States. We filled most of the area not covered with mean values for 1500 1° quadrangles (1° of latitude by 1° of longitude) (Fabiano and others, 1979, p. 1), adjusted for the secular variation during 1975-1980. Secular-variation estimates were obtained from the same model (referred to earlier) that was used to adjust the Project MAGNET data. The few remaining gaps were filled with values computed from MAGSAT 6/80, a global model derived from MAGSAT data (Langel and others, 1980). This data set was then augmented with additional MAGSAT 6/80 F values, one for each Project-MAGNET and quadrangle-mean data point. The final set comprised about 20,000 F values, from ground, airborne, and satellite surveys.

For the model of F in the conterminous States we chose n equal to 6, resulting in 28 coefficients. This choice, based on previous experience with polynomial models (Fabiano and others, 1979), represents a reasonable compromise between model accuracy and efficiency. Statistics related to the fit of this model to the data are given in table 2. The repeat-station data referred to in the table resulted from surveys conducted by the U.S. Geological Survey at ground stations during 1978-1980 (fig. 4). Because these and the observatory data were not part of the modeled data, statistics derived from them provide an independent check of the accuracy of the model. Table 3 lists the mean residual for each observatory and repeat station. The distribution of the Project MAGNET residuals is indicated by the histogram in figure 5.

TABLE 2.--Statistics for the model of F in the conterminous United States

Data type	No. of points	Mean residual (nT)	RMS[1] residual (nT)
All	19,792	8	110
Project MAGNET	8,236	-13	156
Observatories & repeat stations	63	-17	179

[1] Root-mean-square.

TABLE 3.--Conterminous United States observatories and repeat stations, 1978-80

Name	State code	Latitude (degrees)	Longitude (degrees)	Date	Residual (nT)
Observatories					
Tucson	AZ	32.247	-110.833	79.500	77
Boulder	CO	40.138	-105.238	79.500	-202
Fredericksburg	VA	38.205	-77.373	79.500	155
Newport	WA	48.263	-117.120	79.500	-109
Repeat stations					
Mena (East	AR	34.567	-94.252	79.599	163
Mena (Golf)	AR	34.568	-94.252	79.599	172
Castle Rock	CA	37.240	-122.130	79.727	-52
Lompoc	CA	34.637	-120.532	79.738	-172
San Diego (Miramar)	CA	32.840	-117.163	79.747	427
Cortez (Airport)	CO	37.298	-108.633	80.616	-125
Fort Myers	FL	26.610	-81.883	77.026	-43
Fort Myers	FL	26.610	-81.883	79.160	-46
Key West (Golf)	FL	24.573	-81.743	79.171	-55
Key West (Golf Aux-2)	FL	24.573	-81.743	79.171	-70
Spruce Creek (1958)	FL	29.077	-81.032	79.149	121
Spruce Creek (Telemetry)	FL	29.070	-81.047	79.149	142
Bainbridge (1958)	GA	30.907	-84.600	79.114	-124
Waycross	GA	31.235	-82.350	79.136	1
Waycross (Airport)	GA	31.255	-82.400	79.136	5
Colfax	IA	41.663	-93.242	78.470	-493
Joliet (Country Club-2)	IL	41.502	-88.055	78.516	-95
Joliet (Woodruff)	IL	41.535	-88.007	78.516	77
Bangor (Broadway)	ME	44.828	-68.788	78.585	-98
Bangor (Griffin)	ME	44.825	-68.808	78.585	-55
Detroit (Park)	MI	42.355	-83.262	78.527	-271
Detroit (River Rouge)	MI	42.343	-83.253	78.527	-290
Marquette (Golf-2-72)	MI	46.538	-87.422	78.500	-238
Marquette (Golf-47)	MI	46.538	-87.423	78.500	-252
Rolla (East)	MO	37.948	-91.775	78.456	200
Rolla (West)	MO	37.950	-91.778	78.456	239
Brooklyn	MS	31.030	-89.170	79.097	-59
Havre	MT	48.553	-109.703	80.567	-79

TABLE 3.--Conterminous United States observatories and repeat stations, 1978-80--Continued

Name	State code	Latitude (degrees)	Longitude (degrees)	Date	Residual (nT)
Repeat stations					
Goldsboro (Airport)	NC	35.385	-77.983	78.722	-186
Wilmington (Golf-1)	NC	34.208	-77.873	78.821	304
Wilmington (Golf-2)	NC	34.208	-77.873	78.821	286
Bowbells	ND	48.800	-102.242	80.551	-64
Fremont (Airport-64)	NE	41.448	-96.520	80.520	-222
Fremont (Airport-73)	NE	41.450	-96.515	80.523	-214
Keene (Airport)	NH	42.902	-72.263	78.615	65
Surry	NH	43.007	-72.322	78.612	79
Soccoro (Airport-72)	NM	34.022	-106.898	80.624	-130
Syracuse (Drumlins)	NY	43.017	-76.103	78.558	-59
Syracuse (Drumlins-B)	NY	43.017	-76.105	78.558	-41
Carmen (Park)	OK	36.573	-98.455	79.777	-79
Eugene (Reservoir)	OR	44.057	-123.290	79.716	-47
Indiantown Gap (AF)	PA	40.453	-76.545	78.642	8
Indiantown Gap (Lake)	PA	40.417	-76.597	78.642	-30
Kingston (Campus)	RI	41.480	-71.518	78.626	-48
Kingston (Turf)	RI	41.488	-71.545	78.626	183
Huron (Airport)	SD	44.383	-98.228	80.534	213
Huron (Country Club)	SD	44.398	-98.218	80.534	452
Dallas	TX	32.982	-96.753	79.588	-65
Laredo (North)	TX	27.557	-99.467	79.547	-40
Orange "C"	TX	30.063	-93.802	79.558	129
Van Horn (1979)	TX	31.062	-104.787	79.536	-154
Lynchburg	VA	37.328	-79.200	78.763	156
Burlington (Lone Pine)	VT	44.457	-73.155	78.577	12
Burlington (Red Stone)	VT	44.470	-73.197	78.577	4
Seattle (St. Thomas)	WA	47.732	-122.257	79.703	-145
Eau Claire	WI	44.833	-91.532	79.486	-287
Parkersburg (Golf)	WV	39.283	-81.513	78.558	242
Summersville (Golf-78)	WV	38.318	-80.830	78.681	7
Sheridan	WY	44.845	-106.975	80.578	-264

F MODELS FOR ALASKA AND HAWAII

The models of F in Alaska and Hawaii were derived from the MAGSAT 6/80 model. Polynomials, of degree 6 (28 coefficients) for Alaska and degree 4 (15 coefficients) for Hawaii, were fitted to MAGSAT 6/80 F values for the beginning of 1980 that were calculated for grids of points, at sea level, spaced 1° in latitude and longitude, covering the two regions.

A comparison of the Alaska F model with recent data from three observatories and 13 repeat stations resulted in a mean residual of -18 nT and a RMS (root-mean-square) residual of 143 nT. The mean residual for each observatory and repeat station is listed in table 4, and their locations are shown in figure 6. A similar comparison for the Hawaii model could not be done because Hawaii has only one observatory and no repeat stations.

TABLE 4.-- Alaska observatories and repeat stations, 1978-80

Name	State Code	Latitude (degrees)	Longitude (degrees)	Date	Residual (nT)
Observatories					
Barrow	AK	71.323	-156.620	79.500	-42
College	AK	64.860	-147.837	79.500	-99
Sitka	AK	57.058	-135.325	79.500	-62
Repeat stations					
Anchorage (NBS)	AK	61.235	-149.869	80.411	457
Barter Island (1980)	AK	70.133	-143.647	80.553	-76
Bethel (Airport-20)	AK	60.783	-161.833	80.523	123
Chitina (1980)	AK	61.515	-144.442	80.493	-152
Cordova (1980)	AK	60.555	-145.723	80.619	17
Fort Yukon (IGY)	AK	66.563	-145.260	80.570	-93
Homer-1	AK	59.640	-151.493	80.452	-99
Kodiak (1975)	AK	57.800	-152.365	80.469	-11
Kotzebue (1975)	AK	66.877	-162.637	80.589	-71
Nome (Airport-30)	AK	64.515	-165.383	80.597	-121
Northway (IGY)	AK	63.018	-141.797	80.488	87
Unalakleet (1975)	AK	63.890	-160.797	80.605	-54
Yakutat-6	AK	59.508	-139.657	80.540	-105

$\dot{F}$ MODELS

We first derived a global spherical harmonic model of secular variation following the method described by Peddie and Fabiano (1976, 1982). This model was derived using data from 146 worldwide magnetic observatories, including 5 in the conterminous States (fig. 4), 3 in Alaska (fig. 6), and 1 in Hawaii; and from 36 U.S. magnetic repeat stations--29 in the conterminous States and 7 in Alaska. The data comprised values of the geomagnetic field's northward component (X), eastward component (Y), and vertically downward component (Z), from the period 1974-1980. For the observatories these values were usually annual means and, for the repeat stations, either means for several hours centered around midnight or means of absolute observations. They were used to obtain estimates of the rates of change of X, Y, and Z ($\dot{X}$, $\dot{Y}$, and $\dot{Z}$). The rates-of-change estimates were taken as the slopes of straight lines fitted to the values using the method of unweighted least squares. The rates of change were subjected to spherical harmonic analysis of degree and order 8 (80 terms). Statistics related to the analysis are given in table 5.

Following the method described by Fabiano and others (1979), we next derived regional secular-variation models from the global model. We computed $\dot{F}$ values from the global model for 1° grids of points covering the 3 regions. The regional $\dot{F}$ models were obtained by fitting polynomials, of degree 6 for the conterminous States and Alaska, and of degree 4 for Hawaii, to the grid values.

Table 5.--Statistics for the global model of secular variation

Element	No. of points	Mean residual (nT/year)	RMS[2] residual (nT/year)
$\dot{X}$	181	0.7	6.4
$\dot{Y}$	181	0.5	6.2
$\dot{Z}$	181	-0.3	6.7
(1)	543	0.3	6.4

[1]Combined $\dot{X}$, $\dot{Y}$, and $\dot{Z}$.
[2]Root-mean-square.

CONCLUSION AND DISCUSSION

The boundaries of the three regions for which the models are valid are given in table 6. The coefficients of the models are listed, in exponential form, in tables 7 and 8. The model coefficients and a computer program for using them are available on magnetic tape or punched cards from the National Geophysical Data Center (mailing address: 325 Broadway, Boulder, CO 80303).

A qualitative comparison of the new models with those for 1975 shows some significant changes. For example, the cell of rapid secular variation in F that was centered in the eastern Caribbean Sea in 1975 has moved northward. $\dot{F}$ in the southeastern United States, which in 1975 ranged from -50 to -90 nT/yr, now ranges from -100 to -120 nT/yr. The line along which $\dot{F}$ is zero, which cut across the north central United States in 1975, has now moved out of the conterminous States and into the Arctic. On the other hand, $\dot{F}$ in Alaska and Hawaii has changed relatively little since 1975.

TABLE 6.--Boundaries of the regions for which the models are considered valid

Region	Latitude (ϕ)		E. Longitude (λ)	
	Min.	Max.	Min.	Max.
Conterminous U.S.	25	50	-126	-66
Alaska	54	72	-190	-129
Hawaii	15	25	-170	-150

TABLE 7.--Polynomial coefficients of the 1980 models of F and $\dot{F}$ in the conterminous States and Alaska

		Conterminous United States		Alaska	
i	j	F	$\dot{F}$	F	$\dot{F}$
0	0	.57608E+04	-.8412E+02	.36292E+04	.5876E+01
1	0	.53893E+03	.1963E+01	.37514E+03	.6403E-01
0	1	.37849E+02	-.1575E+01	.14398E+03	.2942E-01
2	0	-.93316E+01	.9848E-01	-.10766E+02	-.2316E-01
1	1	-.31456E+01	.8116E-01	-.76107E+01	.3171E-01
0	2	-.51731E+01	.1080E-02	.18072E+01	-.1655E-01
3	0	-.19608E+00	-.9732E-03	-.13923E+00	.8004E-03
2	1	-.11600E+00	.1131E-02	-.14478E+00	-.1089E-02
1	2	.98084E-03	.9530E-03	-.86876E-01	.1003E-02
0	3	-.45306E-01	.4836E-03	-.39205E-01	.1054E-04
4	0	-.17503E-02	-.7095E-04	.55242E-02	.2941E-04
3	1	.93869E-03	-.1102E-03	.66687E-02	-.3984E-04
2	2	.46185E-02	-.1680E-04	-.15606E-02	.1565E-04
1	3	.18769E-02	-.1476E-04	.14210E-02	-.6350E-05
0	4	.27782E-03	.8086E-05	-.21106E-03	.5911E-05
5	0	.28419E-04	.4033E-06	.56097E-04	-.7134E-07
4	1	.93117E-04	.5026E-06	.11517E-03	.8506E-06
3	2	-.20499E-04	-.7951E-06	.76029E-04	-.1067E-05
2	3	.53886E-04	-.9959E-06	.42428E-04	.1052E-06
1	4	.42998E-05	-.1668E-06	.72245E-05	-.2101E-06
0	5	.15217E-04	.1264E-07	.29450E-05	-.1644E-07
6	0	.65172E-05	.2222E-07	-.15085E-05	-.1682E-07
5	1	.22139E-05	.3510E-07	-.10032E-05	.2033E-07
4	2	-.12084E-06	.2381E-07	.10428E-05	-.1054E-08
3	3	-.11990E-05	.3279E-07	-.71535E-06	.5712E-08
2	4	-.29067E-06	-.1725E-07	.42333E-06	-.3862E-08
1	5	-.30363E-06	-.1439E-08	-.35599E-07	.1416E-08
0	6	.22171E-06	-.9367E-10	.16651E-07	-.8798E-09

TABLE 8.--Polynomial coefficients of the 1980 models of F and $\dot{F}$ in Hawaii

i	j	F	$\dot{F}$
0	0	-.43891E+03	-.2212E+02
1	0	.33732E+03	.5246E+00
0	1	.11254E+03	-.5445E+00
2	0	.69664E+01	.3147E-01
1	1	.65761E+01	-.8221E-02
0	2	.16876E+01	.5878E-02
3	0	-.28541E-01	.3099E-03
2	1	-.61309E-01	-.1605E-03
1	2	.69443E-01	-.9762E-03
0	3	.24369E-02	-.2972E-03
4	0	.74545E-03	-.3413E-04
3	1	-.13435E-02	.2690E-04
2	2	.11293E-02	-.6781E-04
1	3	-.20333E-02	.1918E-04
0	4	-.14788E-03	-.3271E-05

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Magnetic Total Intensity in the United States – 1980

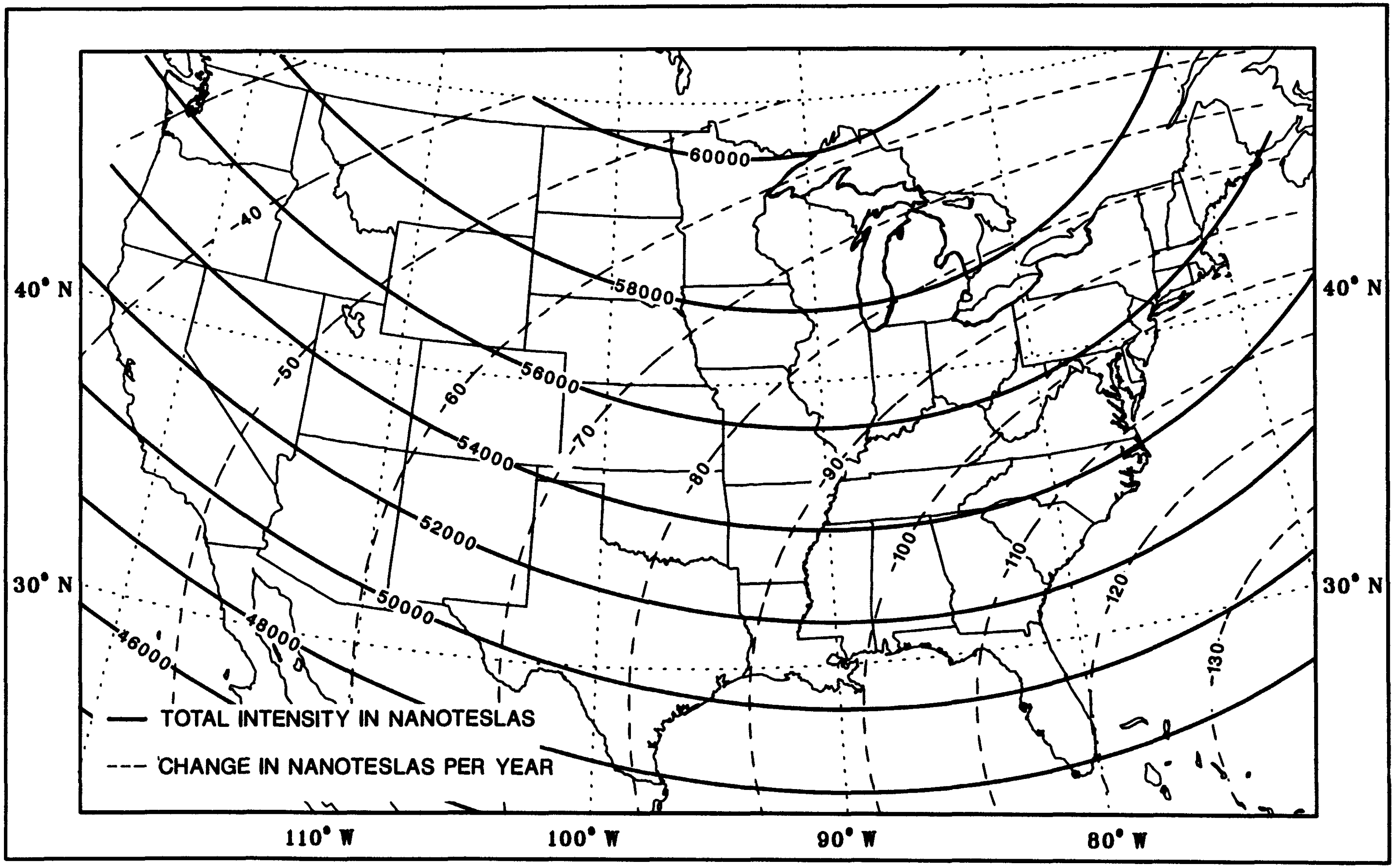

Figure 1.--Magnetic total intensity and its annual change in the conterminous United States in 1980.

Magnetic Total Intensity in the United States - 1980

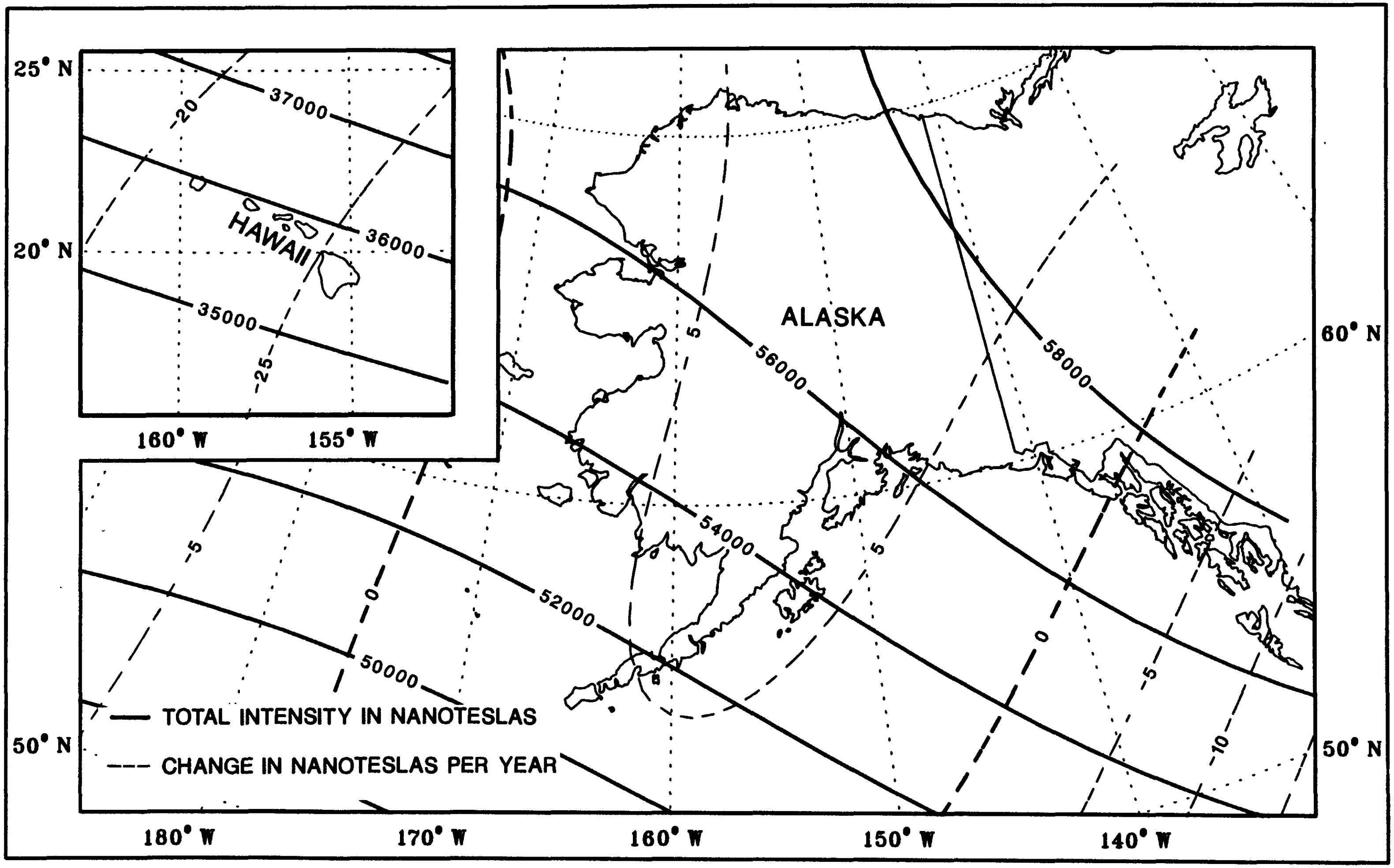

Figure 2.--Magnetic total intensity and its annual change in Alaska and Hawaii in 1980.

Project MAGNET Track Lines 1976–77

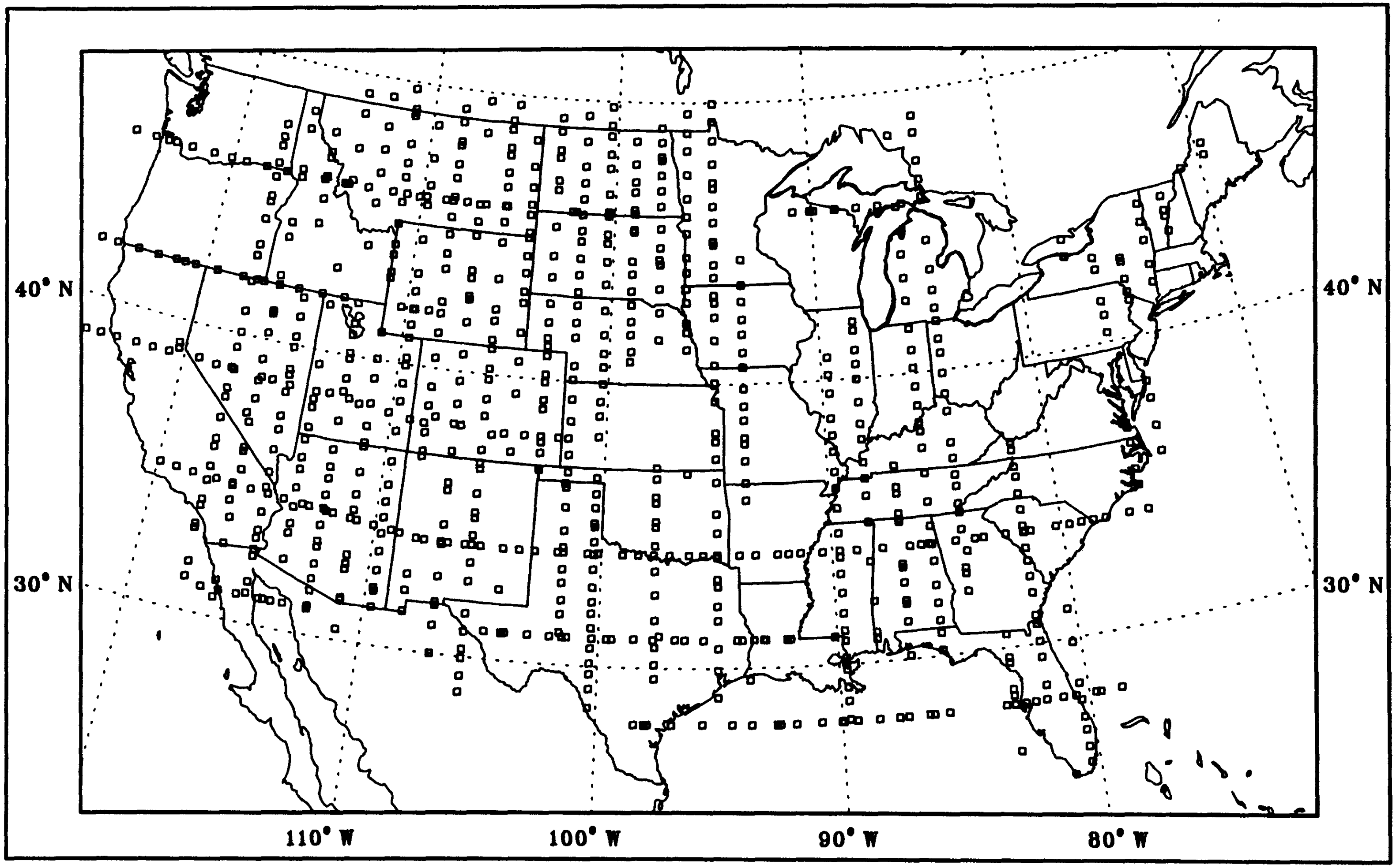

Figure 3.--Flight lines of the Project MAGNET survey of the United States in 1976-1977.

Magnetic Observatories and Repeat Stations

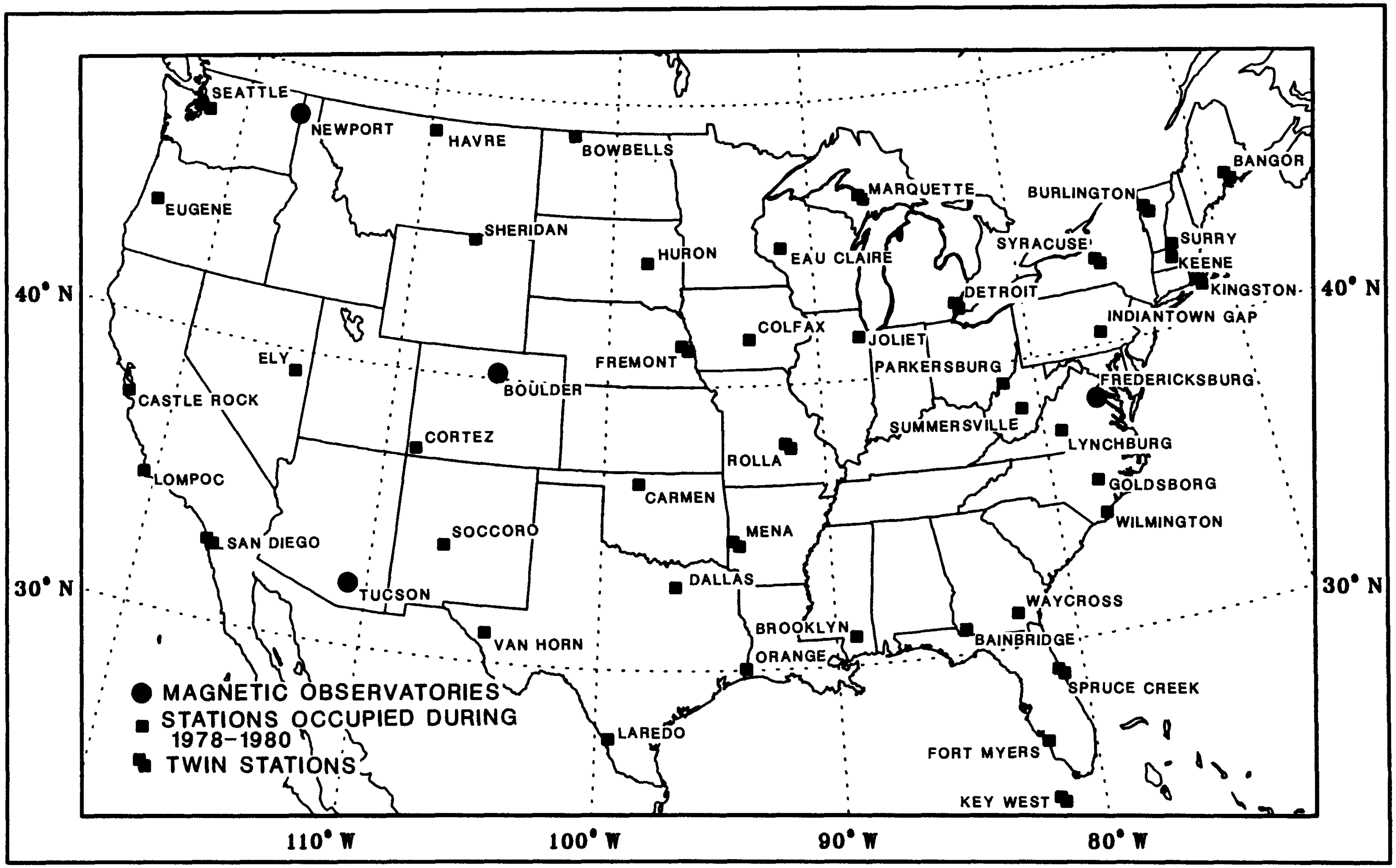

Figure 4.--Magnetic observatories (filled circles) and repeat stations (squares) in the conterminous States that were occupied during 1978-1980.

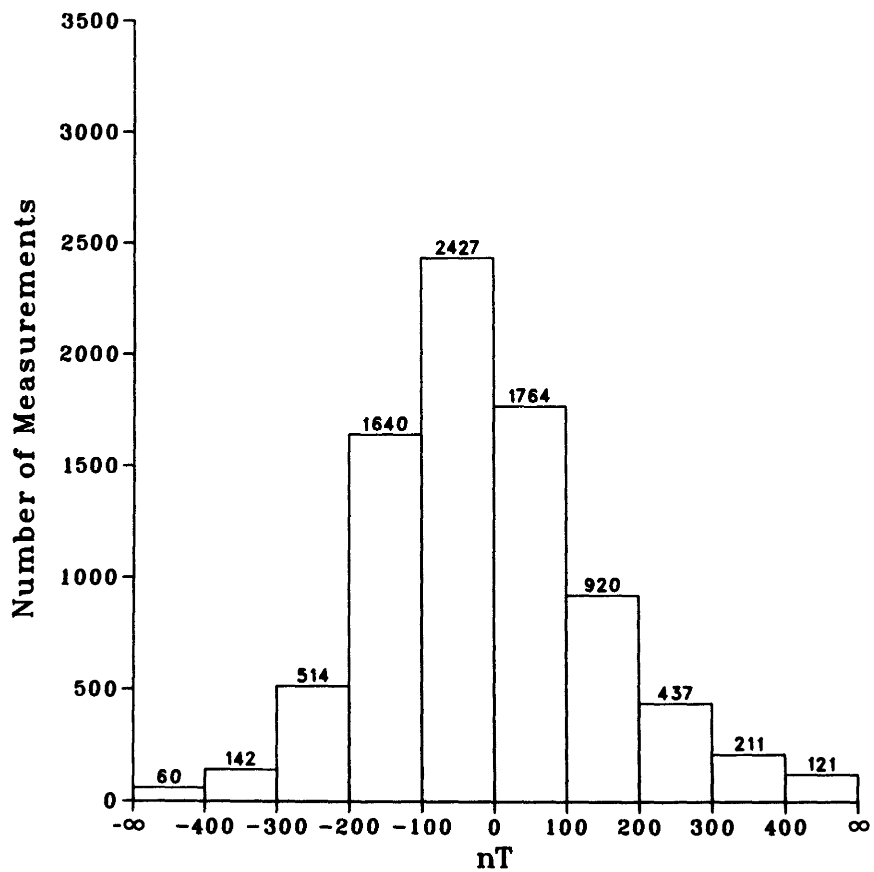

Figure 5.--Distribution of Project MAGNET residuals.

Magnetic Observatories and Repeat Stations

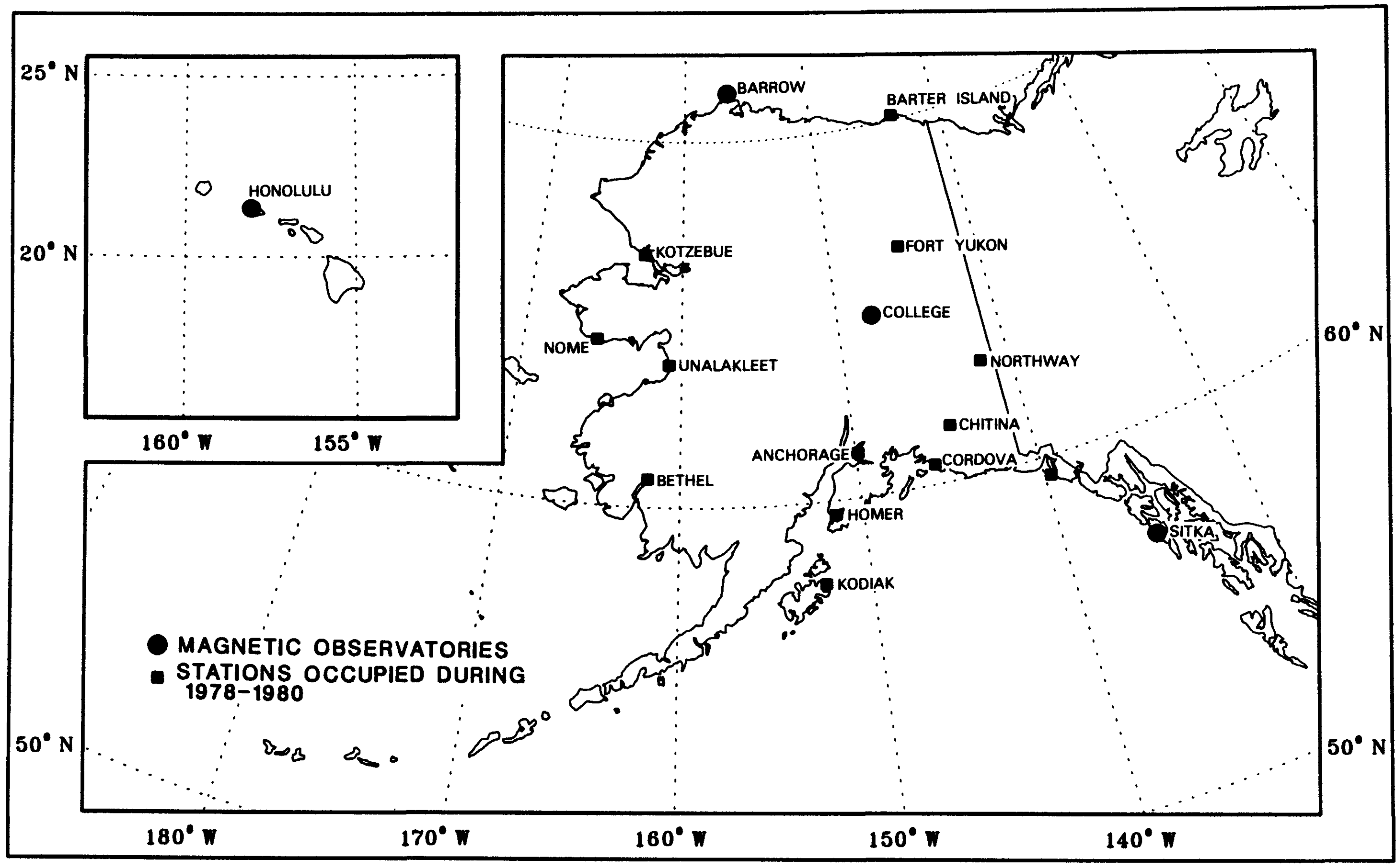

Figure 6.--Magnetic observatories (filled circles) and repeat stations (squares) in Alaska that were occupied during 1978-1980.