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Abstract. A three-component aeromagnetic survey of British Columbia and the northeastern Pacific Ocean was carried out in early 1969. The survey data are in the form of averages over 30 seconds of time, or roughly 3.5 km of flight track. The International Geomagnetic Reference Field (IGRF) was removed from these data, and the resulting residuals plotted as profiles. A 3rd-degree polynomial was fitted to the survey data by least-squares to determine how well the IGRF represents the average regional field over the survey area. The polynomial was also used to obtain vector residuals, which require a residual mean close to zero. Lines of zero gradient in the component parallel to the flight tracks are also given.

Résumé. Un relevé aéromagnétique à trois composantes de la Colombie-Britannique et du nord-est de l'océan Pacifique a été effectué au début de 1969. Les données obtenues se présentent sous forme de moyennes sur 30 secondes de temps, ou approximativement sur 3.5 km de ligne de vol. On a soustrait de ces données la valeur du champ géomagnétique international de référence (International Geomagnetic Reference Field – IGRF), et les données rédisuelles ont été tracées sous forme de profils. Un polynome du 3^e degré a été appliqué aux données du levé par la méthode des moindres carrés afin de vérifier dans quelle mesure la valeur de IGRF représente bien la valeur du champ régional moyen dans la région étudiée. Le polynome a également servi à obtenir des données résiduelles de vecteurs, ce qui demande une moyenne résiduelle située près de zéro. On donne également les lignes de gradient zéro dans la composante parallèle aux lignes de vol.

Introduction

In 1969, between January 26 and March 20, the Dominion Observatory (now the Earth Physics Branch), Department of Energy, Mines and Resources, carried out a three-component aeromagnetic survey of British Columbia and the northeastern Pacific Ocean. An index map of the survey area is shown in Figure 1. The aircraft used was a DC 6, chartered from Pacific Western Airlines. The fluxgate magnetometer and direction-reference system have been described by Serson, *et al.* (1957) and Hannaford, *et al.* (1967).

The total number of line-kilometres flown was approximately 90,000 (of which about 15,000 were ferry and calibration flights) and the area covered was 3.4×10^6 square kilometres. The average flight-line spacing was 37 km (20 naut. mi.) over British Columbia and 74 km (40 naut. mi.) over the adjacent ocean. Flight altitudes ranged from 4.6 to 6.8 km, the average altitude being 5.5 km.

The data

A gyro-stabilized fluxgate magnetometer produced values of the declination D, the horizontal intensity H, and the vertical intensity Z. A Barringer OM-104 proton precession magnetometer measured the total field F. Because of the high accuracy of the proton magnetometer the fluxgate measurements of Z were discarded whenever H and F were available, and a new Z was calculated. This was possible because the error in Z resulting from an error in H is proportional to H/Z, and for the survey area this ratio was only about 0.3. The analysis of the aircraft fields, altitude corrections to sea level, and a discussion of various other problems will be given by Hannaford and Haines (1972).

Representation of the anomaly field

An anomaly field was obtained by subtracting from the $^1/_2$-minute average values of the International Geomagnetic Reference Field (IGRF). This spherical harmonic reference field has been described by the International Association of Geomagnetism and Aeronomy Commission 2 Working Group 4 (1969). Means and standard deviations of the differences, or residuals, are given in Table I. They are, however, not too meaningful.

To see how well the IGRF represents the average regional field over the survey area a 3rd-degree polynomial was fitted, in three orthogonal components, to 5-minute averages of the survey data. The coefficients of this polynomial and the appropriate formulas for their use are given in Table II. Means and standard deviations for the differences between the $^1/_2$-minute averages and the 3rd-degree polynomial are given in Table III. The means of Table III are not exactly zero because not every $^1/_2$-minute average forms part of a 5-minute average. The sample size used in Table I is larger than that used in Table III because many of the observations lie outside the main survey area to which the polynomial was fitted.

The 3rd-degree polynomial of Table II was subtracted from the IGRF, and the resulting difference field was contoured in Figure 2 for the geographic north component X, the geographic east component Y, the vertical downward component Z, the declination D, the horizontal intensity H, and the total force F. It is immediately evident that the IGRF does not accurately represent the average field over the region. This is particularly noticeable in the case of Z and F where there is a feature approximately 2000 km in wavelength and over 300γ in amplitude which is not present in the IGRF. (Indeed, the lowest wavelength which can be represented in a spherical harmonic expansion of degree 8 is 5000 km.) The horizontal components of the IGRF seem to fit much better, with differences generally being less than 100γ.

Figure 2 shows why the means and standard deviations of Table I are not very meaningful. When the residuals in one quarter of the survey area, for example, differ systematically from the residuals in another quarter, the over-all mean has little significance. It could be made to equal zero by choosing appropriate boundaries for the survey area. The over-all standard deviation is also misleading, since it is affected by the non-zero regional means and depends on the choice of the survey boundaries. This demonstrates a basic difficulty in specifying the goodness of fit of a smooth reference field, such as the IGRF, to survey data from an area even as large as several million square kilometres.

Although it is felt the 3rd-degree polynominal field of Table II would be a much better reference field than the IGRF, in that much smaller wavelengths (in this case, of appreciable amplitude) can be represented, it was decided to use the IGRF for plotting residual profiles (Figures 3-8). The IGRF was favoured because it is an international standard, and residuals from any other overlapping survey can be compared directly with those of this survey if they too are derived from the IGRF. This of course was one of the main reasons for the adoption of an international reference field. For deriving and plotting residual vectors (Figures 9-10), however, the polynomial reference field was used since zero means in all components are necessary. For the zero-gradients of Figure 11 the IGRF was used.

The $^1/_2$-minute residuals were plotted, in Figures 3-11, on a Lambert conformal conic map with standard parallels 37° and 65° N and convergence 0.785. The flight lines are parallel to the Greenwich meridian so this direction was chosen as the x-axis of the map. The y-axis is then parallel to 90° divided by the convergence, or 114° 36′W on the map.

In Figures 3-8, the IGRF-subtracted residuals were plotted in profile form, parallel to the y-axis. A residual was plotted toward the top of the map when positive and toward the bottom when negative. The polynomial-subtracted residuals were represented as two-dimensional vector residuals in the horizontal plane (Figure 9) and in a vertical plane parallel to the x-axis (Figure 10). Their directions follow the same convention as those of the profiles: positive components of the residual vector are plotted toward the top of the map, negative components toward the bottom.

Table I. Means and standard deviations of the observed minus IGRF field

	D	H	X	Y	Z	F
Sample size	20679	20679	20679	20679	20690	20694
Mean	−.06°	45γ	46γ	1γ	126γ	137γ
Standard deviation	.52	144	143	142	182	168

Table II. 3rd-degree polynomial reference field from least-squares fit of survey data

θ = colatitude $\qquad \lambda$ = east longitude

$a = -\tan(\theta/2)\cos(\lambda+117°) + .3072$

$b = \tan(\theta/2)\sin(\lambda+117°) + .0709$

$$U = \sum_{1}^{10} u_i x_i \qquad V = \sum_{1}^{10} v_i x_i \qquad Z = \sum_{1}^{10} z_i x_i$$

$$X = U\cos(\lambda+117°) - V\sin(\lambda+117°)$$
$$Y = U\sin(\lambda+117°) + V\cos(\lambda+117°)$$

i	x_i	u_i	v_i	z_i
1	1	1.2239+4	1.0364+4	5.5262+4
2	a	−6.2556+4	−1.0855+4	3.7613+4
3	b	−6.5451+3	−6.1180+4	5.6891+4
4	a^2	6.3980+3	−4.9853+4	−1.7066+5
5	ab	−1.4139+5	−4.8740+4	−4.6326+4
6	b^2	−2.7125+4	−6.1475+4	−1.2595+5
7	a^3	4.3951+5	1.4481+5	−2.0118+5
8	a^2b	−1.6407+5	−9.0320+4	−7.1641+5
9	ab^2	−9.2440+4	6.1401+4	−1.9050+5
10	b^3	7.4499+4	1.1052+5	−2.3696+5

Note: Coefficients are in floating-point notation, a decimal fraction followed by a power of ten.

Table III. Means and standard deviations of the observed minus polynomial field

	D	H	X	Y	Z	F
Sample size	19751	19751	19751	19751	19791	19795
Mean	.00°	−2γ	−3γ	0γ	1γ	0γ
Standard deviation	.48	134	130	135	144	136

Figure 11 shows contour-segments of the residuals of the geomagnetic component in the direction of the x-axis. Suppose this component is called X′ and the component in the y-direction is called Y′. Their respective residuals will be called ΔX′ and ΔY′. Then, since the flight lines lie parallel to the x-axis the partial gradients $\partial(\Delta X')/\partial x$ and $\partial(\Delta Y')/\partial x$ are both known. If the field is derivable from a potential, $\partial(\Delta X')/\partial y = \partial(\Delta Y')/\partial x$, and the gradient of ΔX′ is given by

$$\text{grad}\,(\Delta X') = \frac{\partial(\Delta X')}{\partial x}\,\mathbf{i} + \frac{\partial(\Delta X')}{\partial y}\,\mathbf{j}$$

$$= \frac{\partial(\Delta X')}{\partial x}\,\mathbf{i} + \frac{\partial(\Delta Y')}{\partial x}\,\mathbf{j}$$

where **i** and **j** are unit vectors in the x and y directions, respectively. Rotating this gradient vector 90° counterclockwise gives the vector plotted in Figure 11:

contour − segment

$$= -\frac{\partial(\Delta Y')}{\partial x}\,\mathbf{i} + \frac{\partial(\Delta X')}{\partial x}\,\mathbf{j}$$

These contour-segments give the direction of the contour lines of ΔX′ as they intersect the flight lines.

When the distance between adjacent flight tracks is much larger than the distance between successive measurements on the tracks themselves, the contour-segments give additional information about the behaviour of $\Delta X'$ between the flight lines. The method, in fact, is equivalent to an extrapolation (or continuation) of the field beyond the actual point of measurement. The advantage of this representation is that linear and other trends, and changes in trends, are immediately apparent.

A contoured Z-residual map, comparable to Figure 7, has been published by Haines, *et al.* (1971), with an interpretation in terms of geology and tectonics.

Acknowledgments

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Serson, P.H., S.Z. Mack and K. Whitham. 1957. A three-component airborne magnetometer. *Pub. Dom. Obs.*, Vol. XIX, No. 2, pp. 15-97.

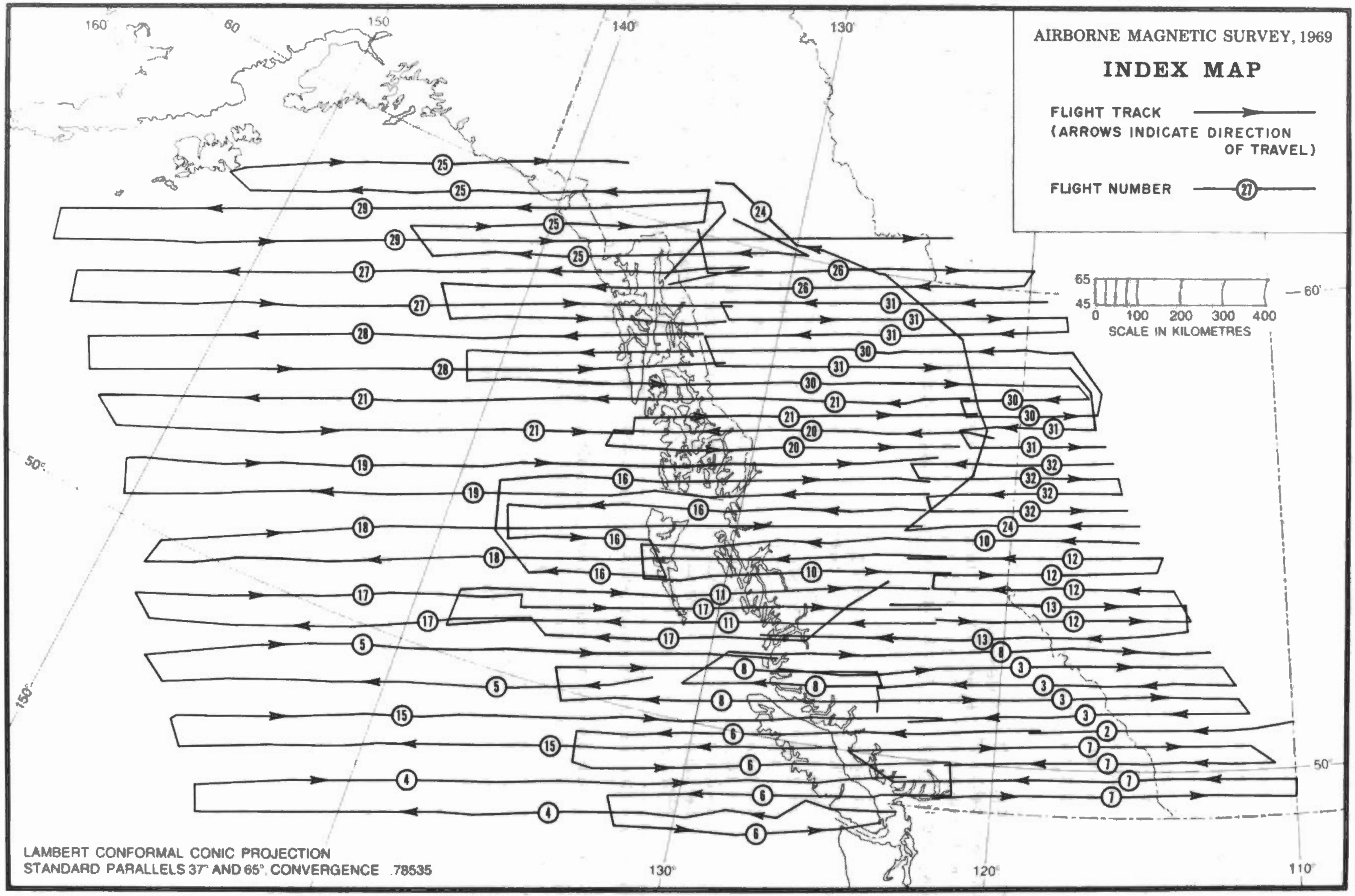

Figure 1. Flight lines of the British Columbia-northeastern Pacific Ocean aeromagnetic survey, 1969. Flight numbers are circled and arrowheads indicate direction of travel.

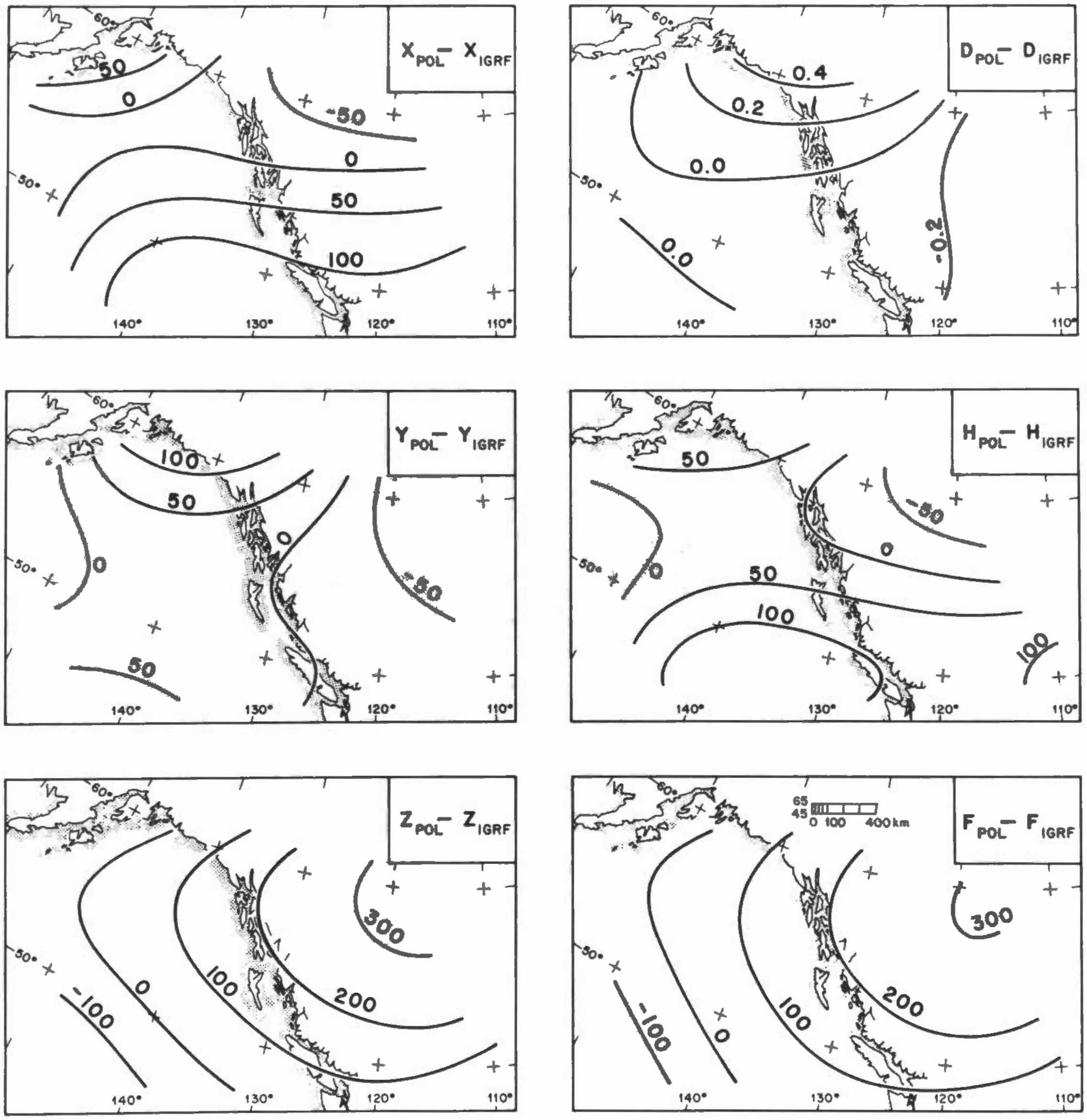

Figure 2. Comparison of International Geomagnetic Reference Field (IGRF) with 3rd-degree polynomial (POL). Declination D is in degrees; all other components are in gammas.

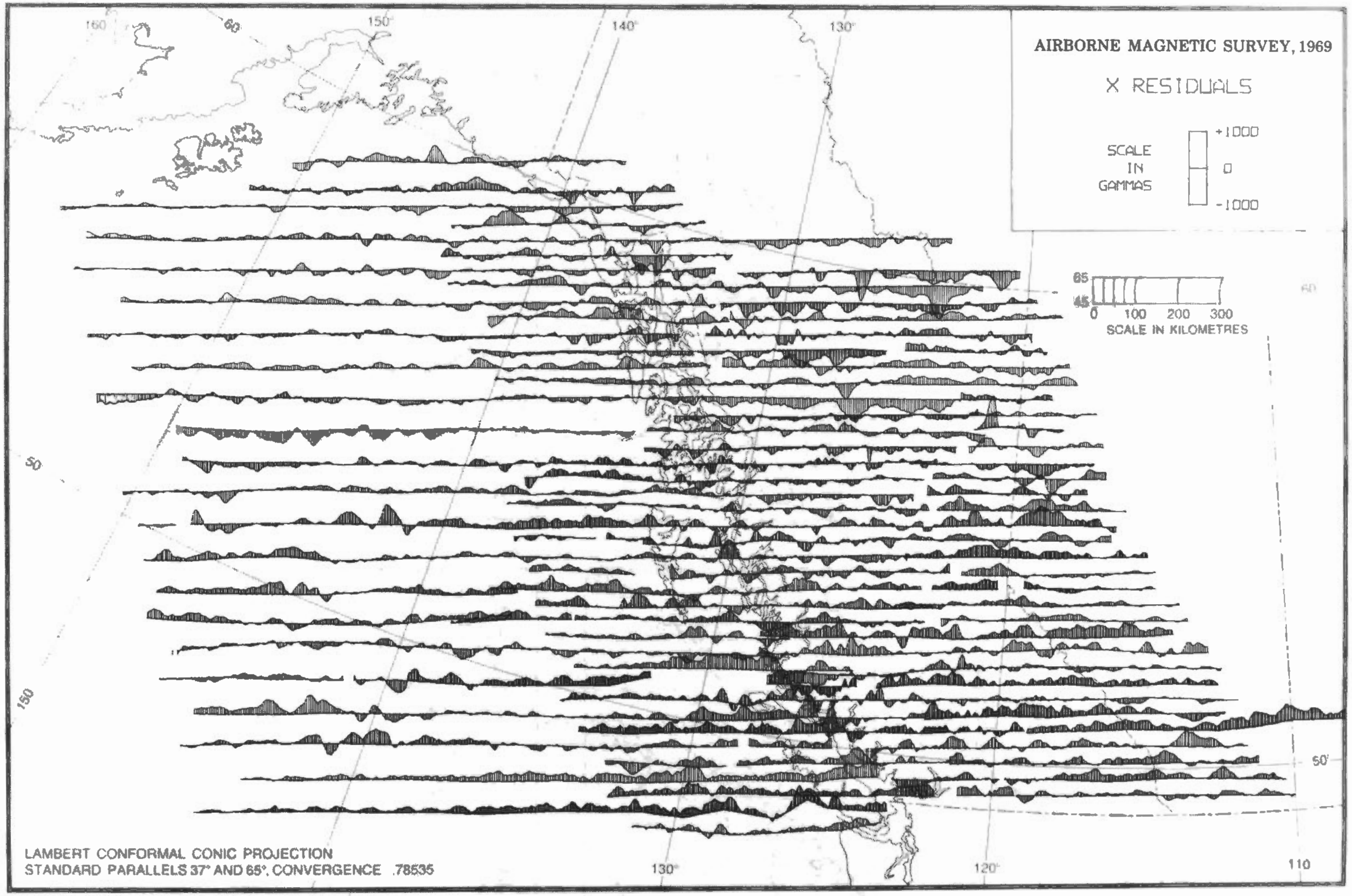

Figure 3. Residual profiles of the geographic north component of the earth's magnetic field, relative to the International Geomagnetic Reference Field (IGRF). A residual is an observed value minus the reference-field value.

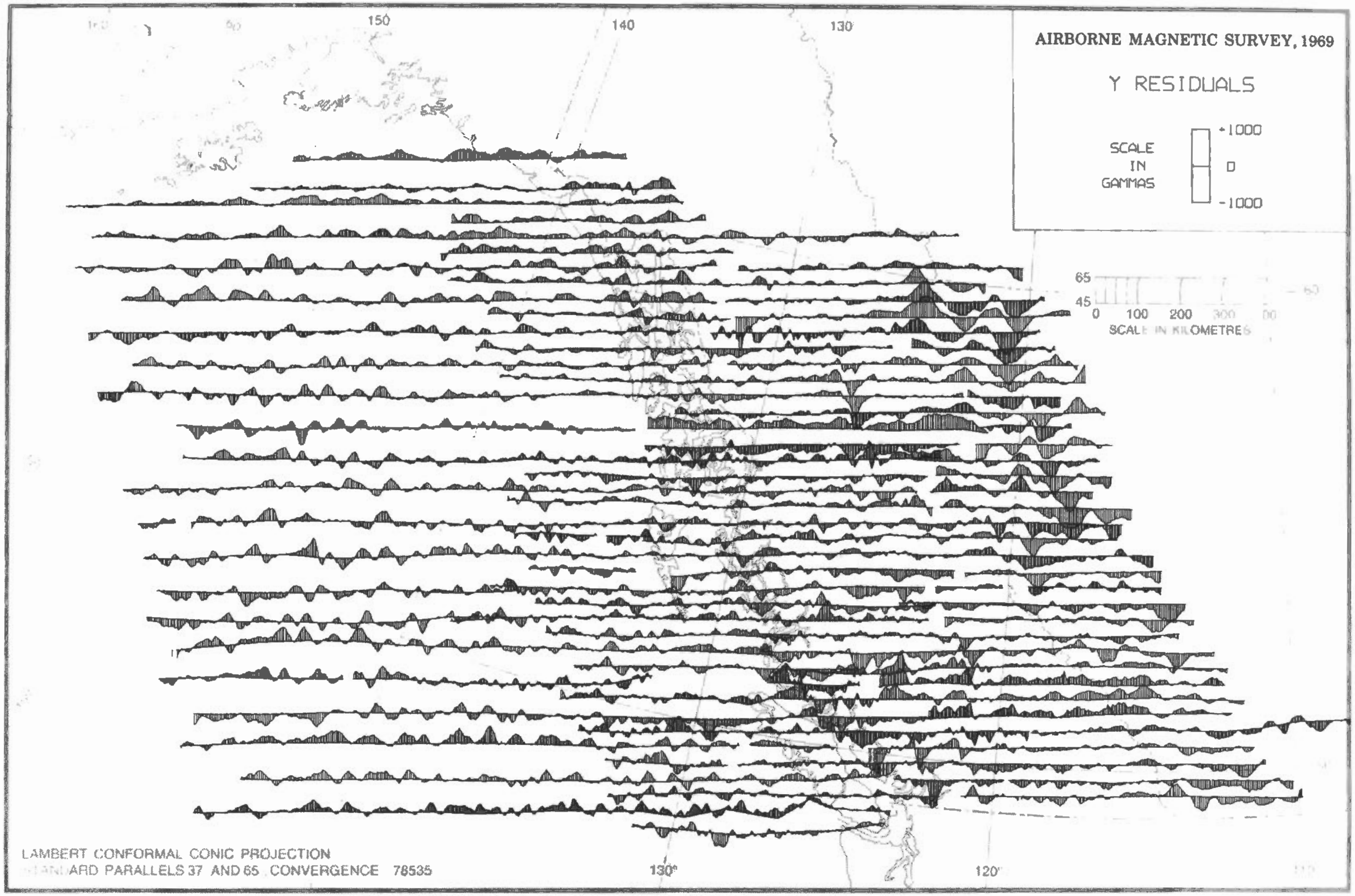

Figure 4. Residual profiles of geographic east component, relative to the IGRF.

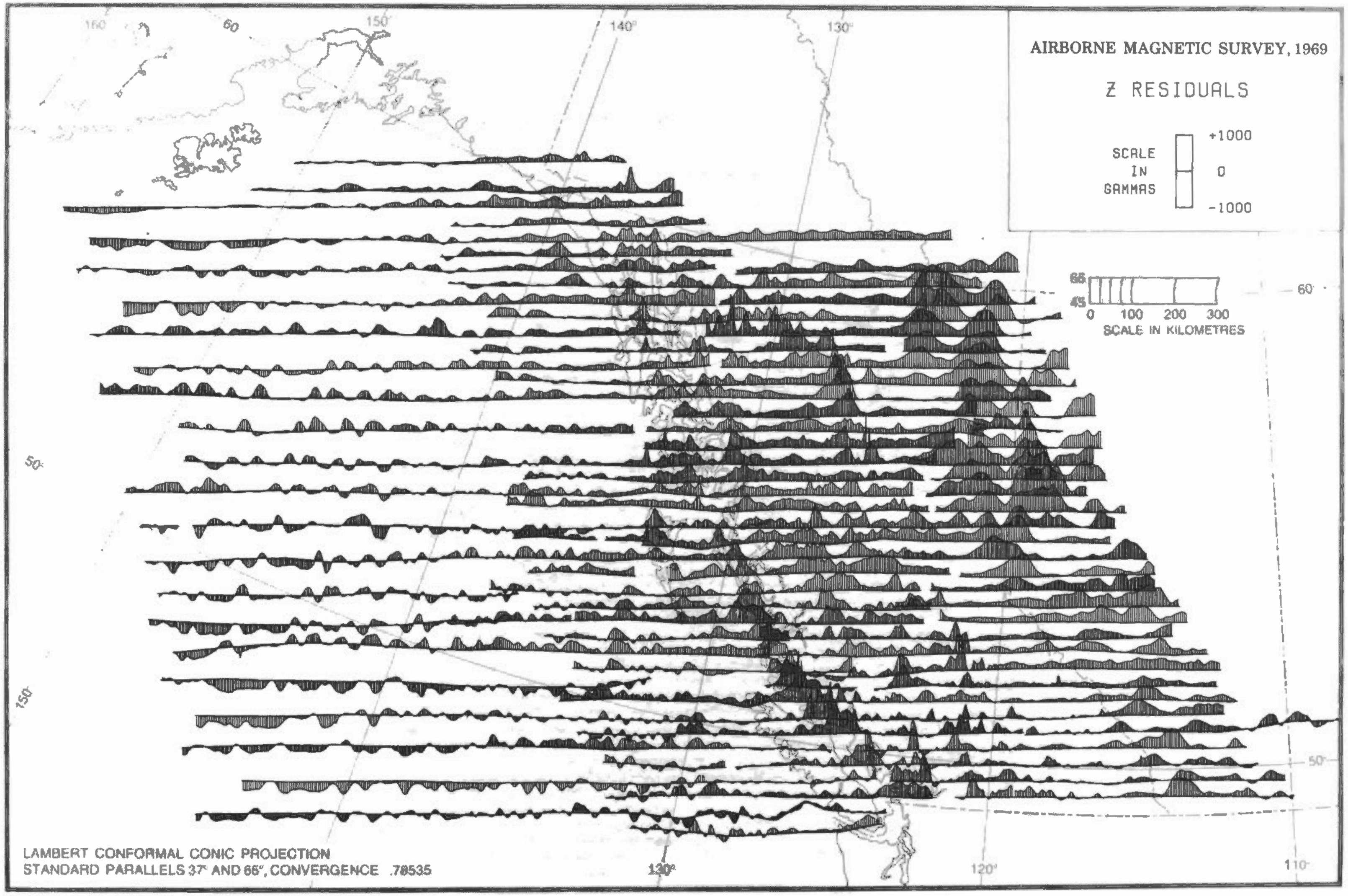

Figure 5. Residual profiles of vertical downward component, relative to the IGRF.

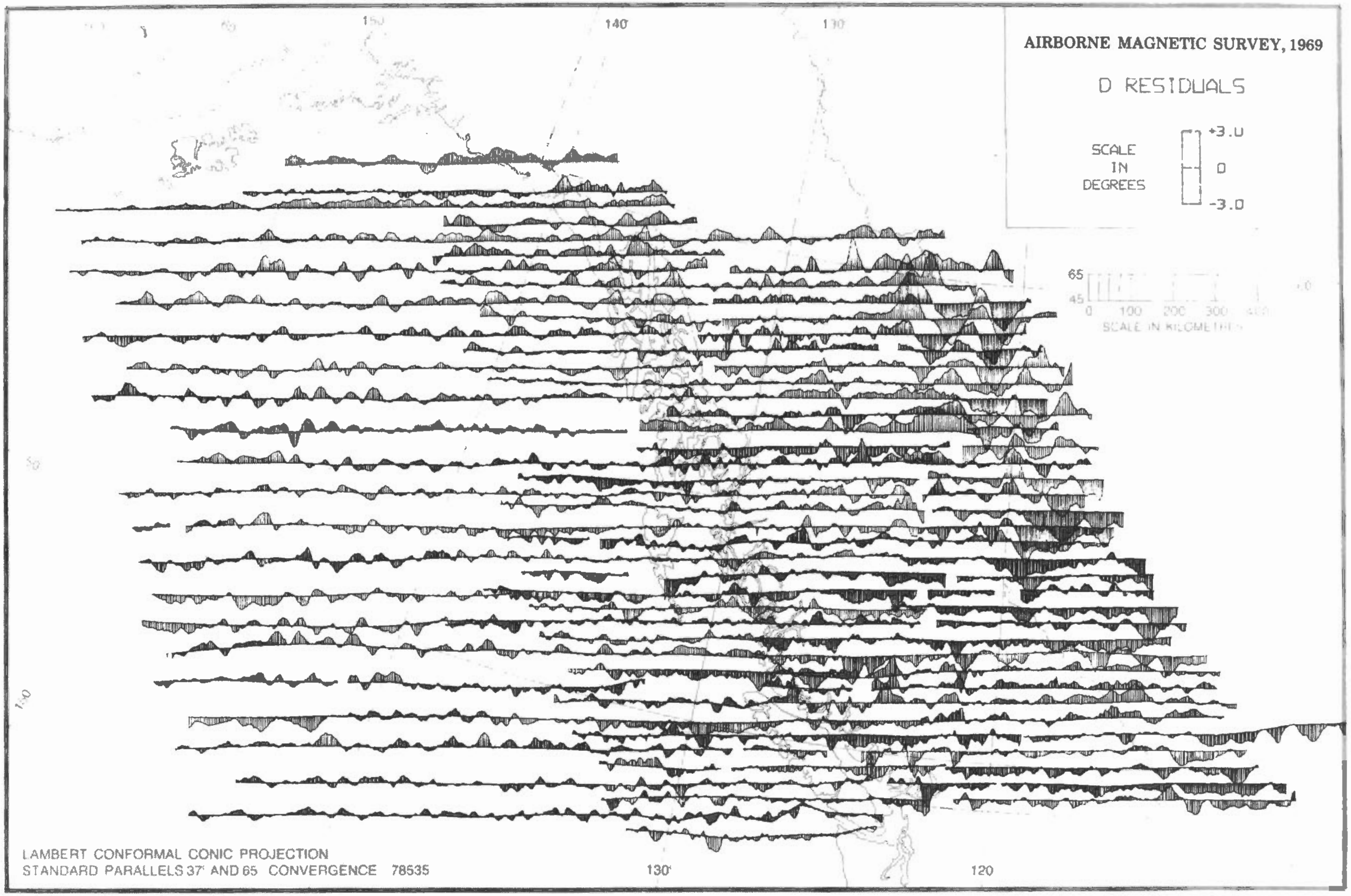

Figure 6. Residual profiles of declination, relative to the IGRF.

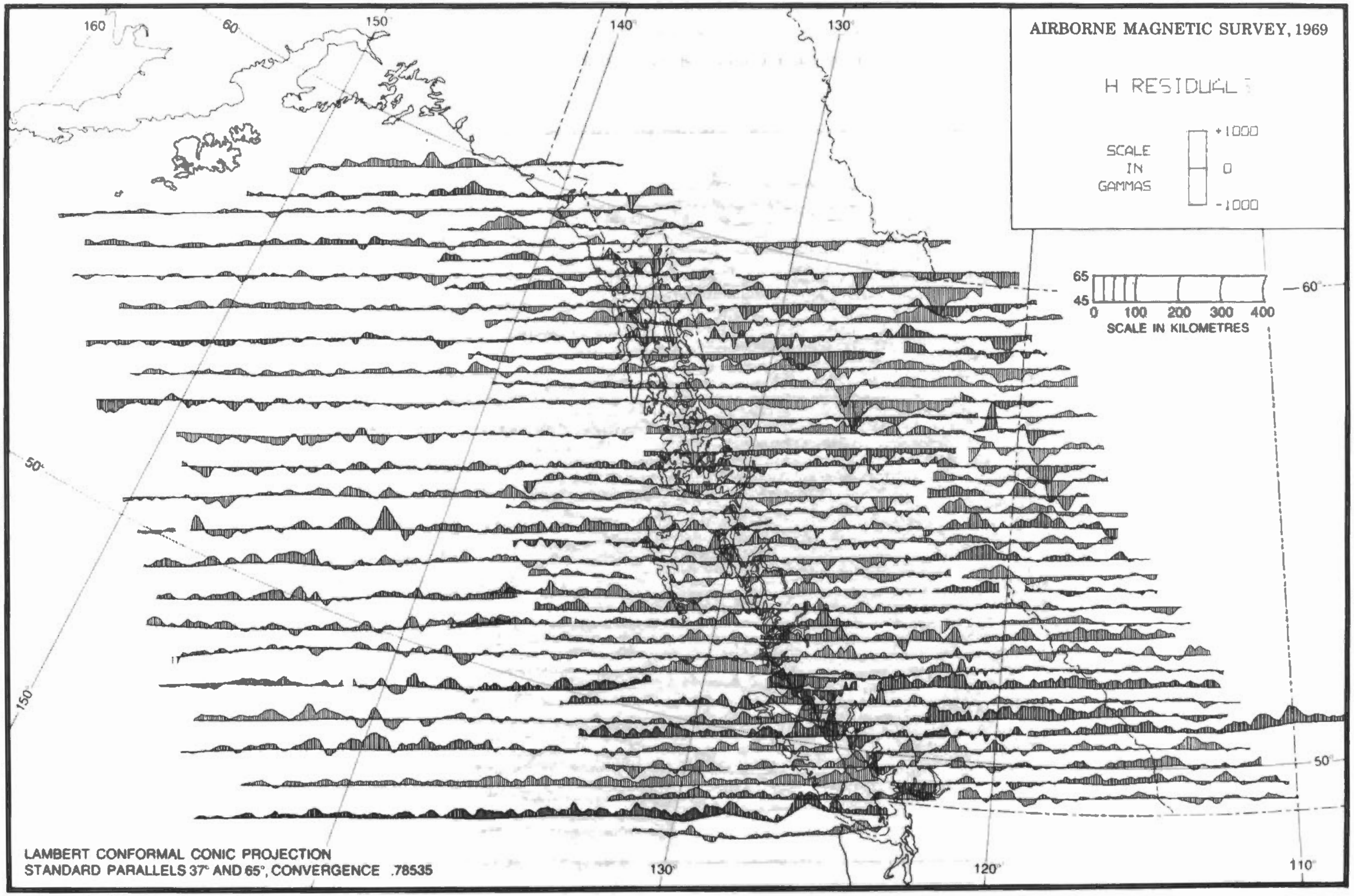

Figure 7. Residual profiles of horizontal intensity, relative to the IGRF.

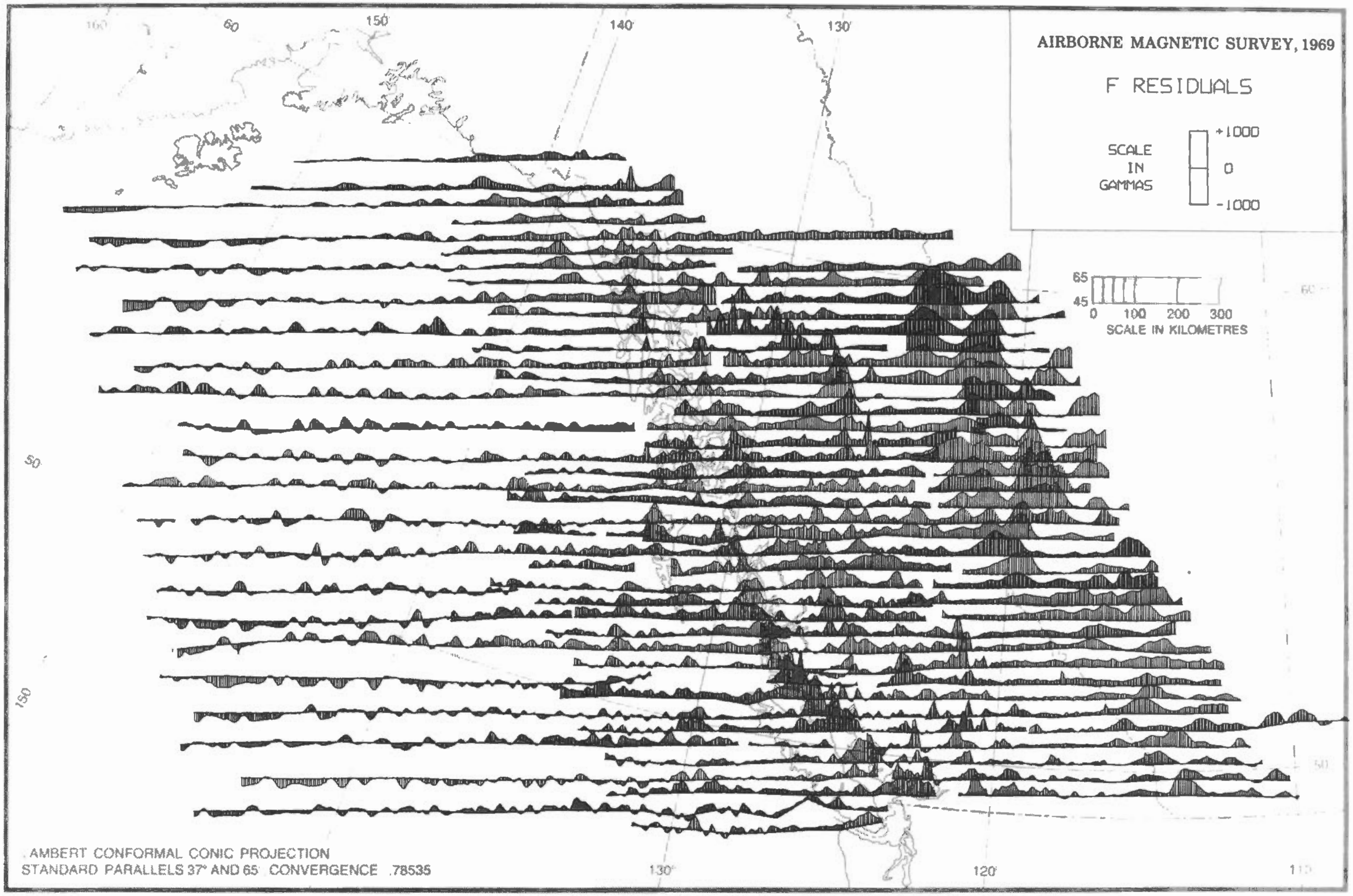

Figure 8. Residual profiles of total force, relative to the IGRF.

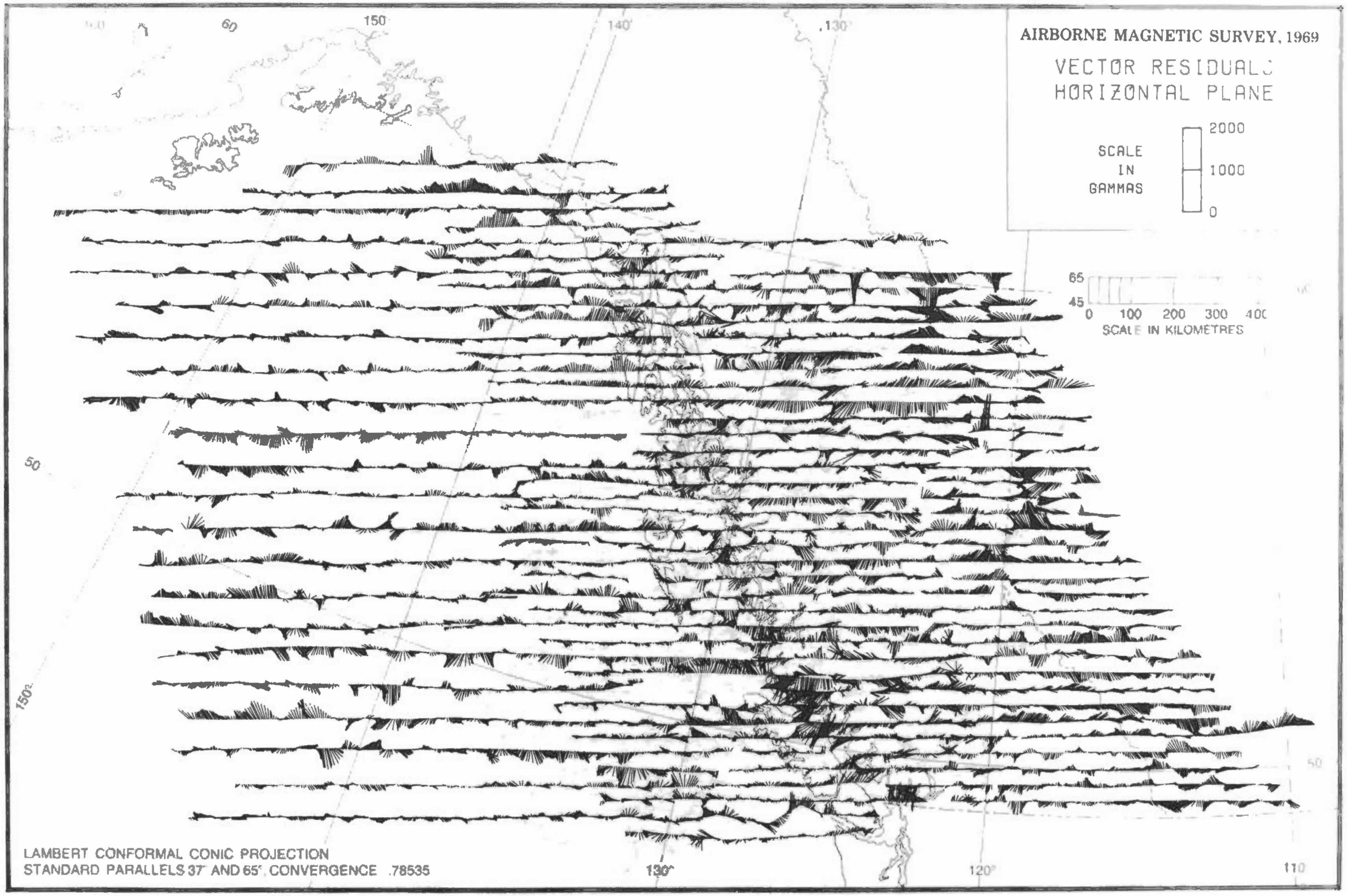

Figure 9. Projection of total residual vector onto horizontal plane. Residual vector is taken relative to 3rd-degree polynomial of Table II.

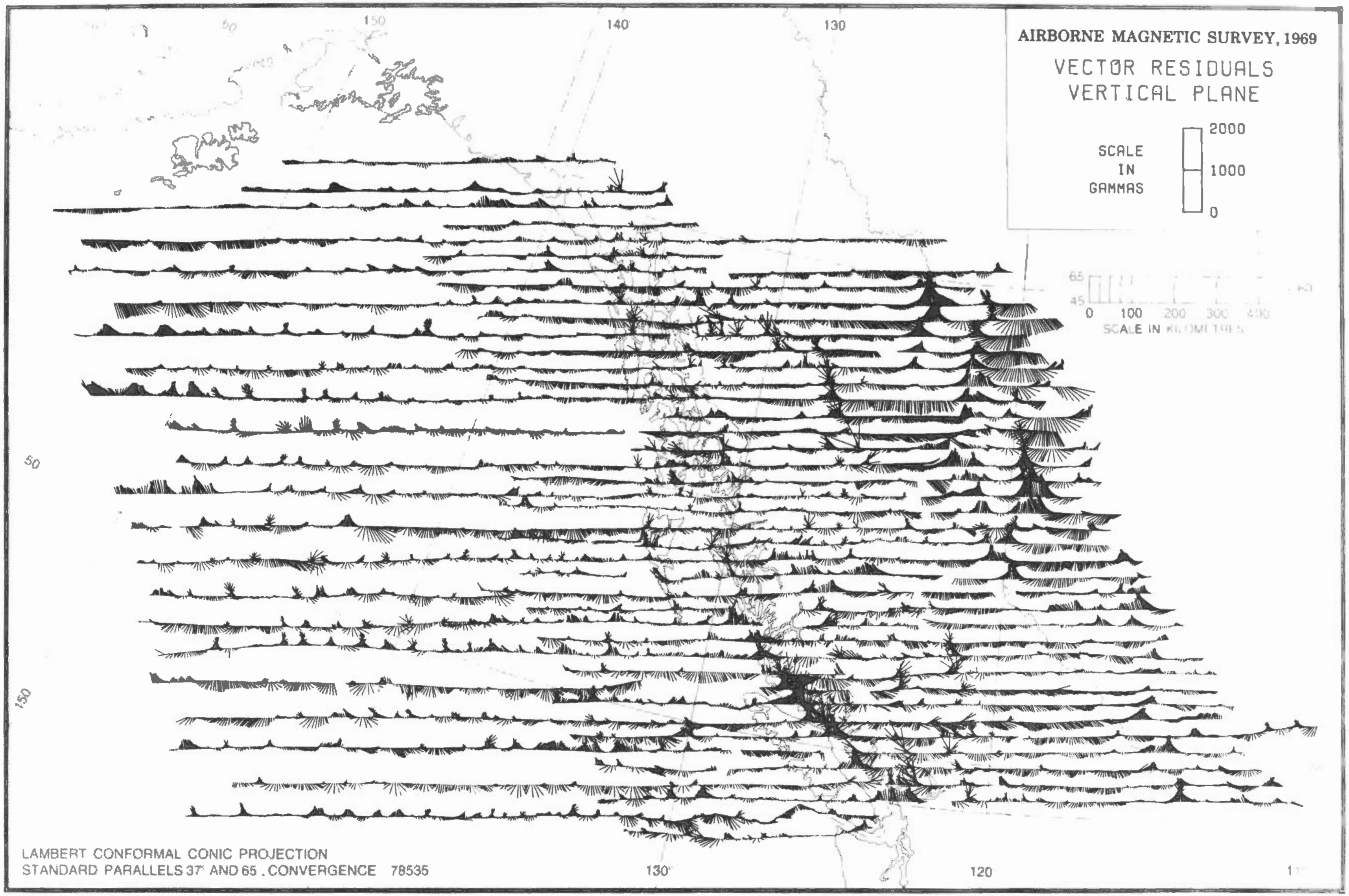

Figure 10. Projection of total residual vector onto vertical plane parallel to *x*-axis (from left to right, in figure). Residual vector relative to 3rd-degree polynominal.

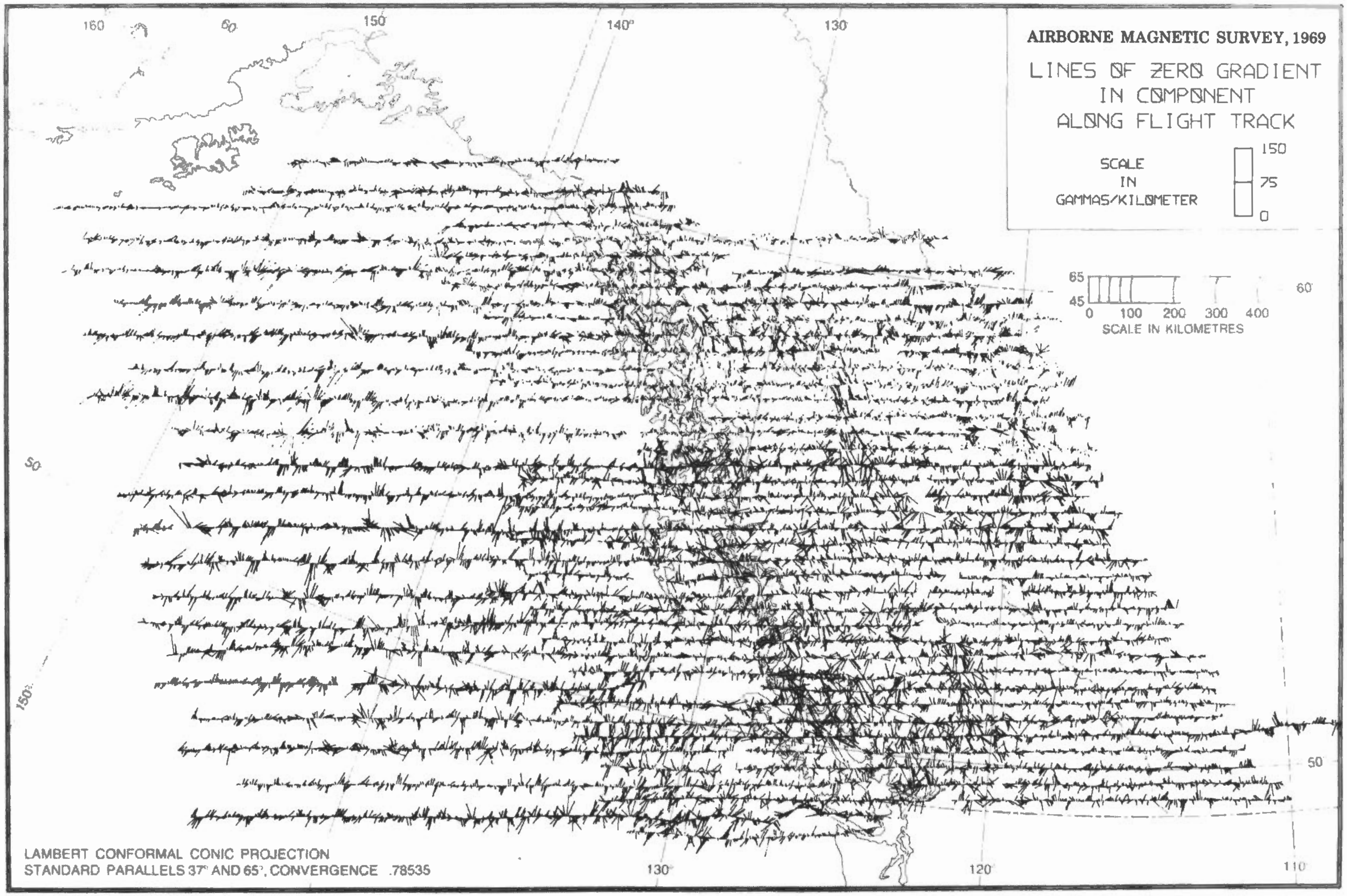

Figure 11. Contour line segments of the magnetic component parallel to the *x*-axis (from left to right, in figure). Rotating line segments 90° clockwise would give gradient vector.