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# Invariant Geomagnetic Co-ordinates for Epoch 1977.25

J.S. Boyd

ANTARCTIC DIVISION
DEPARTMENT OF SCIENCE AND TECHNOLOGY

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# INVARIANT GEOMAGNETIC CO-ORDINATES FOR EPOCH 1977.25

by

J.S. Boyd

Antarctic Division,
Department of Science and Technology,
Hobart, Tasmania, Australia.

## ABSTRACT

Invariant geomagnetic co-ordinates were calculated for points on a $5^{\circ} \times 5^{\circ}$ grid over the earth, at altitudes of 105 km and 250 km. The calculation was based on the International Geomagnetic Reference Field (IGRF) for 1975, updated to 1977.25 to correspond approximately to the middle of the International Magnetosphere Survey period. Global charts of the invariant co-ordinates at 105 km altitude are presented. The invariant co-ordinates were expanded into a set of spherical harmonic co-efficients and FORTRAN subroutines are described which allow the rapid re-calculation of the invariant co-ordinates from the co-efficients.

## 1. INTRODUCTION

Magnetic co-ordinate systems based on the adiabatic drift of charged particles in empirical models of the geomagnetic field have been in use for some time (following their original introduction by McIlwain (1961)). The calculation of invariant latitude for a given station involves a numerical integration along the magnetic field line connecting the station to the magnetic mirror point in the opposite hemisphere.

The core space and computation time required to incorporate the ability to calculate invariant co-ordinates into other analysis programs may be unacceptable, resulting in the use of a less valid co-ordinate system. Some effects of using such less valid systems have been discussed by Bond (1976), among others.

This report presents a recalculation of invariant geomagnetic co-ordinates, based on the International Geomagnetic Reference Field (IGRF) for 1975.0, updated to 1977.25 in order to correspond to approximately to the middle of the International Magnetosphere Survey.

Also described is a simple computer program which is short and fast enough to be easily incorporated as a subroutine into existing data analysis programs. It is based on a spherical harmonic expansion performed on a global grid (35 x 72) of invariant co-ordinates.

## 2. CALCULATION OF THE INVARIANT CO-ORDINATES

The IGRF 1975.0 geomagnetic field model, updated to 1977.25 was used in the manner described by McIlwain (1961), Hassit & McIlwain (1967), and adapted by Bond (1968) and Thomas (1971) to generate the invariant latitude and longitude at an altitude of 105 km on a 35 x 72 equispaced grid of geographic co-ordinates.

The ranges covered were:

geographic latitude : $+ 85^{\circ}$ by $5^{\circ}$ steps to $- 85^{\circ}$

longitude : $0^{\circ}$ by $5^{\circ}$ steps to $360^{\circ}$

The invariant longitude was determined as described in Thomas (1971) with the modification (following Kilfoyle and Jacka, 1968) that the zero degree reference point is taken as the point at 105 km altitude at the intersection of the equator and the Greenwich meridian. This was done so that the resultant geomagnetic longitude and the geographic longitude are reasonably close in value over the major part of the earth's surface.

Maps showing lines of invariant co-ordinates superimposed on geographic co-ordinates are shown in Figures 1 to 3 (pocket inside back cover).

The accuracy of the resulting co-ordinates as determined by the error resulting from performing the integral over the double length of the field-line is $\leqslant 0.01^{\circ}$ for latitude between $40^{\circ}$ and $70^{\circ}$ either hemisphere. At lower latitudes errors result from distortions in the magnetic field, and the relative magnitude of the step size used. At the higher latitudes, the error increases due to the rapidly increasing length of the field line reducing the accuracy of the numerical integration.

## 3. SPHERICAL HARMONIC EXPANSION OF INVARIANT CO-ORDINATES

As the IGRF, on which the calculations were based, contains components up to eight order, it would be expected that the invariant co-ordinates would not contain higher order variations. Thus, in principal, it should be possible to reproduce the input data to within $0.01^{o}$ by taking the expansion to high enough order. However, the errors encountered at the high and low ends of the latitude range, as well as the relative coarseness of the numerical integration in the expansion result in some degradation of the accuracy.

The expansions of invariant latitude and longitude were treated separately. This was for two reasons:

(a) the expansion of longitude is more complicated than for latitude;

(b) accuracy in the invariant latitude determination is more important than for invariant longitude.

Consequently, the results are presented as two separate subroutines:

(i) INVLAT - calculates invariant latitude directly from the expansion co-efficients

(ii) INVEXP - calculates invariant longitude and latitude by expansion.

### 3.1 SPHERICAL HARMONIC EXPANSION PROGRAM

The principles of spherical harmonic expansions are well known and described in many texts. For the present purpose, the expansions were performed in terms of the Schmidt-normalised Ferrer associated Legendre functions, designated $P_n^m$. For m > o these functions correspond exactly to the functions $P_n^m(\theta)$ of Chapman and Bartels (1940) p.617. For m=0, they differ by a factor $\sqrt{2}$. For computational convenience, the indices m and n were both raised by 1, for the functions $P_n^m$ only. This was done so that summations ran from 1 instead of zero. The use of zero as a subscript is possible on the ARL PDP - 10, but is not generally available in FORTRAN systems.

The functions $P_n^m(\theta)$ are found for a given value of θ using subroutine ASHMIT. The derivation of the recurrence relation used is as follows:

With the raised indices, the expansion of a function becomes (cf. Chapman and Bartels, p.611)

$$f(\theta,\phi) = \sum_{n=1}^{N} \sum_{m=1}^{n} \{A_n^m \cos(m-1)\phi + B_n^m \sin(m-1)\phi\} P_n^m(\theta)$$

where

$$A_n^m = \frac{2n-1}{4\pi\delta} \int_o^{2\pi} d\phi \int_o^{\pi} \sin\theta d\theta \; f(\theta,\phi) \; P_n^m(\theta) \; \cos(m-1)\phi$$

$$B_n^m = \frac{2n-1}{4\pi} \int_o^{2\pi} d\phi \int^{\pi} \sin\theta d\theta \; f(\theta,\phi) \; P_n^m(\theta) \; \sin(m-1)\phi$$

and $\delta = 2$ for $m = 1$, $\delta = 1$ for $m > 1$

The functions

$$P_n^m(\theta) = \{2\frac{(n-m)!}{(n+m-2)!}\}^{\frac{1}{2}} T_{n-1}^{m-1}(\theta) \tag{1}$$

Remembering that the indices have been raised only on the $P_n^m$;

$$T_n^m(\theta) = (1-\mu^2)^{M/s} \frac{d^m}{d\mu^m} P_n(\theta)$$

are the Ferrer Associated Legendre functions, $P_n(\theta)$ is the Legendre function $\mu = \cos\theta$ as usual.

Subroutine ASHMIT

This subroutine uses the recurrence of relations for the $P_n^m$ defined above to generate an array of $P_n^m$, $n = 1, N$, $m = 1, n$ for a given value of $\theta$.

The recurrence relations were derived as follows:

(a) Increment n:

from (1): $$P_{n+1}^m = \{2\frac{(n-m+1)!}{(n+m-1)!}\}^{\frac{1}{2}} T_n^{m-1} \tag{2}$$

also from (1) $$T_n^m = \{\tfrac{1}{2}\frac{(n+m)!}{(n-m)!}\}^{\frac{1}{2}} P_{n+1}^{m+1} \tag{3}$$

The appropriate recurrence relation for the $T_n^m$ is (Sneddon, 1961, p.98).

$$T^m_{n+1} = \frac{1}{n-m+1} \{(2n+1)\mu T^m_n - (n+m)\ T^m_{n-1}\} \qquad (4)$$

Substituting for $T^m_n$ and $T^m_{n-1}$ in (4) using (3) and the substituting in (2), re-arranging indices as required, gives:

$$P^m_n = \frac{(2n-3)\mu P^m_{n-1}}{\left[(n-m)(n+m-2)\right]^{1/2}} - \left[\frac{(n+m-3)(n-m-1)}{(n-m)(n+m-2)}\right]^{1/2} P^m_{n-2} \qquad (5)$$

(b) Increment m:

$$\text{from (1);}\quad P^{m+1}_n = \{2\frac{(n-m-1)!}{(n+m-1)!}\}^{1/2}\ T^m_{n-1} \qquad (6)$$

The appropriate recurrence relation for $T^m_n$ (Sneddon, 1961, p.98) is

$$T^{m+1}_{n+1} = T^{m+1}_{n+1} + (2n+1)(1-\mu^2)^{1/2}\ T^m_n$$

A similar procedure to that outlined above gives

$$P^m_n = \{\frac{(n-m)(n-m-1)}{(n+m-2)(n+m-3)}\}^{1/2}\ P^m_{n-2} + (2n-3)(1-\mu^2)^{1/2}\ \frac{P^{m-1}_{n-1}}{(n+m-2)(n+m-3)}^{1/2} \qquad (7)$$

The computational scheme used in the subroutine is as follows:

Given $P^1_1 = \sqrt{2}$

$P^1_2 = \sqrt{2}\mu$

$P^2_2 = (1-\mu^2)^{1/2} = \sin\theta$

(5) allows immediate calculation of $P^2_n$, n=3, N.

Using (7), $P_3^3$ is found, noting that for m=n, $P_{m-2}^m = 0$, so (7) reduced to

$$P_n^m = (2m-3)(1-\mu^2)^{\frac{1}{2}} \frac{P_{m-1}^{m-1}}{\{(2m-2)(2m-3)\}^{\frac{1}{2}}}$$

The row $P_n^3$, n=4, N is then calculated from using (5), and the process repeated up to m=M.

Subroutine SPHER

(For a listing of this subroutine see Appendix A).

This subroutine computes the co-efficients $A_n^m$, $B_n^m$ for a function $f(\theta,\phi)$ specified on an equispaced grid with $0 \leqslant \theta \leqslant \pi$ $0 \leqslant \phi \leqslant 2\pi$ as usual. The integrals are carried out numerically using Simpson's rule. This rule requires that the number of divisions of the range of integration be even. The option of using Richardson's deferred approach to the limit was added if the number of divisions was a multiple of 4.

Taking as an example

$$A_n^m = \frac{2n-1}{4\delta} \int_o^{2\pi} d\phi \int_o^{\pi} \sin\theta d\theta \; f(\theta, \phi). \cos(m-1)\phi. \; P_n^m(\theta)$$

the scheme of integration is as follows:

1. For given $\theta_i$, generate entire array of $P_n^m(\theta_i)$ using subroutine ASHMIT

2. Form a vector

$$y_j = f(\theta_i, \phi_j). \quad \cos(m-1)\phi_j$$

Noting that $y_o = y_J$ this vector is integrated over the range 2 by subroutine SIMPS. The result is an array, called AA (, I) in the subroutine, which is the set of M fourier co-efficients for the expansion of $f(\theta_i, \phi)$ around a line of constant co-latitude given by $\theta_i$.

3. A new vector was formed

$$y_i = \frac{2n-1}{\delta} (AA)_i^m \; P_n^m(\theta_i) \; \sin\theta_i \; \left\{ \begin{matrix} 1 \leqslant m \leqslant M \\ 1 \leqslant n \leqslant N \end{matrix} \right\}$$

In this case $y_o = y_I = 0$ because of the $\sin \theta_i$ factor. The vector was then integrated over the range 0 to $\pi$ again using subroutine SIMPS, for each m and n. The result for each pair m, n is the co-efficient $A_n^m$. A similar process gives $B_n^m$.

### 3.2 INVARIANT LATITUDE

In order to increase the accuracy of the result, the tabulated values of invariant latitude were modified before expansion.

(i) values between geographic latitudes $\pm 40^o$ were smoothed by linear interpolation. This was done to reduce the effect of the errors encountered at low L-values as described above

(ii) the difference between the invariant latitude as modified in (i) above, and the latitude determined for an eccentric dipole defined by the two invariant poles as described by Cole (1963), was calculated

(iii) this difference was weighted by a quantity $\cos^2\theta$ where $\theta$ is the geographic co-latitude.

The program used to expand invariant latitude is given in Appendix A as an illustration of the use of the method.

## 4. RECALCULATION OF INVARIANT CO-ORDINATES FROM SPHERICAL HARMONIC CO-EFFICIENTS

### 4.1 INVARIANT LATITUDE λ4

Subroutine INVLAT (for a listing of this subroutine see Appendix B)

Usage:

CALL INVLAT (GGLAT, GGLONG, NMAX, VLAT, NOREAD, P)

Arguments:

GGLAT - Geographic latitude (radians) specified in range $\pm \pi/2$

GGLONG - Geographic longitude, (radians) in range $0 - 2\pi$

NMAX - order of expansion required (maximum 14)

VLAT - invariant latitude radians (output) in range $\pm \pi/2$

NOREAD - set = 0 in calling program, is reset to 1 by

INVLAT to inhibit re-reading co-efficients.

P - array of spherical harmonics, returned so as to be available for longitude calculation

Subroutine called : ASHMIT, EDPLAT.

As written, INVLAT calculates invariant latitude using the co-efficients for 105 km from file 'ABC' (Appendix B). To obtain the values for the invariant latitude at 250 km, the file 'LAT250' listed in Appendix F should be directly substituted for 'ABC'.

## 4.2 ACCURACY OF THE INVARIANT LATITUDE CALCULATION

As described earlier, accuracy is lost due to several causes:

(i) loss of significance of high L-values

(ii) loss of accuracy and the interpolation used at low L-values

(iii) the coarseness of the grid limiting the accuracy of the numerical integrations in the calculations of the co-efficients.

To obtain an idea of the resulting accuracy, a program was used to compare values of the original invariant latitude with the value obtained from the expansion over a grid at 10° intervals in geographic latitude and 20° in gg longitude. The comparison was restricted to the geographic latitude range 40-90° and to invariant latitude between 40° and 80°. The r.m.s. error for different orders of the expansion are shown in Table 1.

| | Order of expansion | r.m.s. error |
|---|---|---|
| <u>105 km</u> | 14 | .07 |
| | 12 | .06 |
| | 10 | .12 |
| | 8 | .19 |
| | 6 | .35 |
| | 4 | .86 |
| <u>250 km</u> | 4 | .816 |
| | 8 | .158 |
| | 12 | .053 |

*Table 1*

Appendix D is a listing of auroral and magnetic observations taken from Akasofu and Chapman (1972). Shown for each station are the geographic co-ordinates, the invariant co-ordinates computed directly, and the invariant latitude recomputed from an expansion to eighth order.

Appendix E is a list of IMS stations in order of geographic latitude, obtained from IMS Bulletin No.2, May 1975, with the same quantities shown.

## 4.3 INVARIANT LONGITUDE $\phi_4$

The expansion of $\phi_4$ is not as straightforward as for the expansion of invariant latitude $\phi_4$. The principal additional problems are as follows:

(i) there is a discontinuity in tabulated values at $\phi_4 = 360^\circ$. This problem is handled by expanding sin $\phi_4$ and cos $\phi_4$ separately which also allows immediate determination of the angular quadrant

(ii) discontinuities occur at the invariant poles. To avoid this problem, sin $\phi_4$ and cos $\phi_4$ were weighted by sin $\lambda 4$ before expansion. In a subsequent determination of $\phi_4$ from the resultant co-efficients. $\lambda 4$ must first be found using INVLAT.

The determination of both invariant longitude and latitude is accomplished by subroutine INVEXP.

Subroutine INVEXP

(For a listing of this subroutine see Appendix C).

Usage:

```
CALL INVEXP (GGLAT, GGLONG, NMAX, VLAT, VLONG, NXREAD, NOREAD)
```

Arguments:

GGLAT, GGLONG, NMAX, NOREAD as for subroutine INVLAT

VLONG - invariant longitude (output), radians in range $0 - 2\pi$

NXREAD - set = 0 in calling program, is reset to 1 by INVEXP to inhibit re-reading co-efficients for longitude.

Subroutines called : INVLAT, EXPAND.

Subroutine EXPAND

This is a simple program to sum the terms of the expansion.

As listed, INVEXP calculates invariant longitude using the co-efficients for 105 km listed in file 'ABUSE' in Appendix C. To obtain the invariant longitude at altitude 250 km, the file 'LNG250' (Appendix G) should be substituted directly for 'ABUSE'.

### 4.4 ACCURACY OF THE INVARIANT LONGITUDE RECALCULATION

As might be expected, the extra steps necessary in the expansion of longitude reduce the accuracy compared to that of the latitude calculation. Applying the same test as for latitude, the r.m.s. error for different orders of the expansion are shown in Table 2.

| | Order of expansion | r.m.s. error |
|---|---|---|
| 105 km | 14 | .23 |
| | 12 | .14 |
| | 10 | .14 |
| | 8 | .29 |
| | 6 | .35 |
| | 4 | 1.35 |
| 250 km | 4 | 1.26 |
| | 8 | .223 |
| | 12 | .111 |

*Table 2*

## 5. ECCENTRIC DIPOLE CO-ORDINATES AND MAGNETIC TIME

In cases for which high accuracy is not required, eccentric dipole co-ordinates may suffice. This may be more likely true for calculations of longitude and for magnetic time.

An eccentric dipole which produced a best least-squares fit to the true values of invariant co-ordinates between latitudes 40° to 75° was found by a method of successive approximations. The eccentric dipole co-ordinates were calculated as described by Cole (1963). The constants corresponding to the dipole of best fit are tabulated below:

$l_1 = -0.45210 \quad m_1 = -0.88147 \quad n_1 = -0.13645$

$l_2 = 0.88922 \quad m_2 = -0.43341 \quad n_2 = -0.14642$

$l_3 = 0.06992 \quad m_3 = -0.18752 \quad n_3 = 0.97977$

$X = -309.45 \quad Y = 150.78 \quad Z = 50.938$

where the co-ordinates of the dipole X, Y, Z are in km.

With these constants, the r.m.s. error in latitude is approximately 2.5° and in longitude 4.6°.

Eccentric dipole time can then be calculated as described by Cole (1963).

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APPENDIX A. Program for the expansion of Invariant Latitude.

```
C  CHECK SPHERCAL HARMONIC EXPANSION
      DIMENSION DPLAT(36,72),Y(30),A(15,15),B(15,15),
     1VLAT(36,72),DIFF(36,72)
      OPEN(UNIT=1,FILE='DATOUT')
      OPEN(UNIT=2,FILE='TH4')
      OPEN(UNIT=3,FILE='ABC')
C  DIMENSIONS OF INPUT DATA
      II=36
      JJ=72
C
C  ORDER OF POLYNOMIALS
      NN=15
      MM=NN
C
C  COMPUTE INPUT DATA
      THETA=0.
      GLONG=0.
      DO 6 I=1,II-1
      THETA=THETA+180./FLOAT(II)
      DO 6 J=1,JJ
      GLONG=GLONG+360./FLOAT(JJ)
      GGLAT=1.57079635-THETA/57.2957795
      PHI=GLONG/57.2957795
      CALL EDPLAT(GGLAT,PHI,EDPTH)
    6 DPLAT(I,J)=90.-EDPTH*57.2957795
    7 READ(2,104,END=5)ALAT,ALONG,BLAT
  104 FORMAT(3F)
      I=(90.1-ALAT)/5.
      J=(ALONG+.1)/5.
      VLAT(I,J)=BLAT
      GO TO 7
    5 CONTINUE
      TYPE 102,I,J,ALAT,ALONG,BLAT
C  FORM DIFFERENCES BETWEEN ECCENTRIC DIPOLE AND INVARIANT
      DO 2 I=1,35
      DO 2 J=1,JJ
    2 DIFF(I,J)=DPLAT(I,J)-VLAT(I,J)
C  STRAIGHT LINE ACROSS EQUATOR
      DO 19 J=1,72
      CHANGE=(DIFF(22,J)-DIFF(12,J))/10.
      DO 19 I=13,21
      DIFF(I,J)=DIFF(I-1,J)+CHANGE
   19 CONTINUE
C
      DO 1 I=2,10,2
    1 TYPE 103,(DIFF(I,J),J=4,16,4)
      DO 4 I=2,34,2
    4 WRITE(1,100)(DIFF(I,J),J=4,72,4)
  100 FORMAT(//18F7.2)
  103 FORMAT(1X,4F8.3)
      DO 18 I=1,35
      COSFAC=COS(.08726646*I)**2
      DO 18 J=1,72
   18 DIFF(I,J)=DIFF(I,J)*COSFAC
      CALL SPHER(DIFF,II,JJ,MM,NN,A,B)
```

```
C  PRINT COEFFTS
      DO 3 N=1,NN
      DO 3 M=1,N
    3 WRITE(3,102)M,N,A(M,N),B(M,N)
  102 FORMAT(1X,2I4,4E15.6)
      STOP
      END
      SUBROUTINE EDPLAT(GGLAT,PHI,EDPTH)
C  CONVERT TO GEOCENTRIC LAT
      GCLAT=ATAN2(.99330546*SIN(GGLAT)/COS(GGLAT),1.)
      THETA=1.57079635-GCLAT
      R=6356.775+21.38528*SIN(THETA)**2+.049*SIN(2.*THETA)
     1**2
      X=R*SIN(THETA)*COS(PHI)
      Y=R*SIN(THETA)*SIN(PHI)
      Z=R*COS(THETA)
      XD=X+451.8605
      YD=Y-181.6317
      ZD=Z-79.0293
      DELTA=SQRT(XD**2+YD**2+ZD**2)
      EDPTH=ACOS((1./(6338.7792*DELTA))*(594.18164*XD
     1-1231.4974*YD+6189.5465*ZD))
      RETURN
      END




      SUBROUTINE SPHER(DATA,II,JJ,MM,NN,A,B)
C  COMPUTES COEFFICIENTS A(M,N); B(M,N) OF SPHERICAL HARMONIC
C  EXPANSION OF MAGNETIC LAT AND LONG AS FUNCTIONS OF
C  GEOCENTRIC LAT AND LONG.
C  INPUT DATA IS ARRANGED IN STANDARD SPHERICAL COORD SYSTEM
C  IE.,DATA(THETA,PHI), WHERE 0..LE.THETA.LE.PI;
C  0..LE.PHI.LE.2*PI.
C  MM AND NN ARE 1+ THE ORDER OF COEFFICIENT REQUIRED, IE INDICES
C  HAVE BEEN RAISED BY 1
C
C  SUBROUTINES CALLED: ASHMIT
C
      DIMENSION DATA(36,72),P(15,15,36),F(20,20),A(15,15)
     1,B(15,15),AA(20,36),BB(20,36),YA(100),YB(100)
C
      TYPE 101,(DATA(6,J),J=4,16,4)
C  GENERATE ENTIRE ARRAY OF P(M,N) FOR EACH THETA(I)
      THETA=0.
      DO 12 I=1,II
      THETA=THETA+3.1415927/FLOAT(II)
      CALL ASHMIT(THETA,MM,NN,F)
      DO 12 M=1,MM
      DO 12 N=1,NN
      P(M,N,I)=F(M,N)
   12 CONTINUE
      TYPE 100,THETA,P(3,4,6)
```

```
C
      DO 6 M=1,MM
      DELTA=1.
      IF(M.GT.1) GO TO 3
      DELTA=2.
    3 CONTINUE
      DO 2 I=1,35
      PHI=0.
      DO 1 J=1,JJ
      PHI=2.*3.1415927/FLOAT(JJ)+PHI
      YA(J)=DATA(I,J)*COS((M-1)*PHI)
      YB(J)=DATA(I,J)*SIN((M-1)*PHI)
    1 CONTINUE
  101 FORMAT(/18F8.3)
      YOA=DATA(I,JJ)
      YOB=0.
      XN=2.*3.1415927
      CALL SIMPS2(YA,YOA,JJ,XN,SUM)
      AA(M,I)=SUM*1./(3.1415927*DELTA)
      CALL SIMPS2(YB,YOB,JJ,XN,SUM)
C
      BB(M,I)=SUM*1./(3.1415927*DELTA)
    2 CONTINUE
    6 CONTINUE
C  NOW HAVE ARRAYS AA,BB TO INTEGRATE OVER THETA
      DO 5 N=1,NN
      DO 5 M=1,N
      THETA=0.
      DO 4 I=1,II
      THETA=THETA+3.1415927/FLOAT(II)
      YA(I)=AA(M,I)*SIN(THETA)*P(M,N,I)
      YB(I)=BB(M,I)*SIN(THETA)*P(M,N,I)
    4 CONTINUE
      IF(N.GT.4) GO TO 98
      IF(M.NE.3) GO TO 98
      TYPE 101,(YA(I),I=1,18)
  103 FORMAT(1X,4E12.3)
   98 CONTINUE
      YOA=0.
      YOB=0.
      XN=3.1415927
      CALL SIMPS2(YA,YOA,II,XN,SUM)
  102 FORMAT(1X,2I3,E15.6)
      A(M,N)=SUM*(2*N-1)/4.
      CALL SIMPS2(YB,YOB,II,XN,SUM)
      B(M,N)=SUM*(2*N-1)/4.
    5 CONTINUE
      TYPE 100,((AA(M,3),BB(M,3)),M=1,4)
      TYPE 101,(AA(3,I),I=1,17)
  100 FORMAT(1X,4(/2E15.6))
   99 CONTINUE
      RETURN
      END
      SUBROUTINE ASHMIT(THETA,MMAX,NMAX,P)
      DIMENSION P(20,20)
      DO 2 N=1,NMAX
      DO 2 M=1,MMAX
```

```
    2 P(M,N)=0.
      AMU=COS(THETA)
      SAMU=SIN(THETA)
      P(1,1)=1.41421356
      P(1,2)=1.41421356*AMU
      P(2,2)=SAMU
      DO 3 M=1,MMAX
      IF(M.GE.3) GO TO 5
      MM=3
      GO TO 4
    5 CONTINUE
      P(M,M)=(2*M-3)*SAMU*P(M-1,M-1)/SQRT(FLOAT((2*M-2)*(2*M-3)))
      MM=M+1
    4 CONTINUE
      DO 1 N=MM,NMAX
    1 P(M,N)=(2*N-3)*AMU*P(M,N-1)/SQRT(FLOAT((N-M)*(N+M-2)))-
     1SQRT(FLOAT((N+M-3)*(N-M-1))/FLOAT((N-M)*(N+M-2)))*P(M,N-2)
    3 CONTINUE
      RETURN
      END
      SUBROUTINE SIMPS2(Y,YO,NY,XN,SUM)
C   SIMPSON'S RULE INTEGRATION WITH RICHARDSON'S DEFERRED
C   APPROACH IF NY IS MULTIPLE OF 4
      DIMENSION Z(99),Y(100)
      CALL SIMPS(Y,YO,NY,XN,SUM)
      SUM1=SUM
      SUM2=SUM
C   IS NY A MULTIPLE OF 4?
      F1=FLOAT(NY)/4.
      F2=F1-INT(F1)
      IF(F2.GT..1) GO TO 5
C   NY IS A MULTIPLE OF 4
      NZ=NY/2
      DO 3 N=1,NZ
      Z(N)=Y(2*N)
    3 CONTINUE
      CALL SIMPS(Z,YO,NZ,XN,SUM)
      SUM2=SUM
C
    5 CONTINUE
      SUM=1.0666667*SUM1-.0666667*SUM2
      RETURN
      END
      SUBROUTINE SIMPS(Y,YO,NY,XN,SUM)
C   SIMPSON'S RULE INTEGRATION OF VECTOR Y
C   OVER NY EQUAL INTERVALS FROM X=0. TO XN
      DIMENSION Y(1)
      SUMODD=0.
      DO 1 I=1,NY-1,2
    1 SUMODD=SUMODD+Y(I)
      SMEVEN=0.
      DO 2 I=2,NY-2,2
    2 SMEVEN=SMEVEN+Y(I)
      SUM=(YO+Y(NY)+SMEVEN*2.+SUMODD*4.)*XN/(3.*FLOAT(NY))
      RETURN
      END
```

APPENDIX B.

```
      SUBROUTINE INVLAT(GGLAT,GGLONG,NMAX,VLAT,NOREAD,P)
C  CALCULATES INVARIANT LATITUDE VLAT
C  FOR GIVEN GEODETIC LATITUDE GGLAT, IN RANGE +PI/2 TO -PI/2
C  AND LONGITUDE GGLONG,  IN RANGE 0. TO 2*PI
C  NOREAD MUST BE SET =0 TO READ IN COEFFICIENTS
C  NMAX IS ORDER OF EXPANSION REQUIRED
C
      DIMENSION A(15,15),B(15,15),P(15,15)
      IF(NOREAD.NE.0) GO TO 10
C  RAISE ORDER OF COEFFICIENTS BY 1
      NN=NMAX+1
      OPEN(UNIT=2,FILE='ABC')
      DO 7 N=1,NN
      DO 5 M=1,N
    5 READ(2,100)K,L,A(M,N),B(M,N)
    7 CONTINUE
  100 FORMAT(2I,2F)
      NOREAD=1
   10 CONTINUE
      THETA=1.57079633-GGLAT
C  CALCULATE ARRAY OF POLYMOMIALS P(THETA)
      CALL ASHMIT(THETA,NN,NN,P)
C  CALCULATE LATITUDE DIFFERENCE (SEE NOTES)
      F=0.
      DO 20 N=1,NN
      DO 20 M=1,N
   20 F=F+(A(M,N)*COS((M-1)*GGLONG)+B(M,N)*SIN((M-1)*GGLONG))*P(M,N)
C  REMOVE COS(THETA)**2 WEIGHTING
      F=F/COS(THETA)**2
C  REMOVE ECCENTRIC DIPOLE
      CALL EDPLAT(GGLAT,GGLONG,EDPTH)
      VLAT=1.57079633-EDPTH-F/57.2957795
      RETURN
      END
      SUBROUTINE ASHMIT(THETA,NMAX,MMAX,P)
C  CALCULATES ARRAY OF SCHMIDT-NORMALISED ASSOCIATED LEGENDRE
C  FUNCTIONS P(M,N) OF THETA
C  REF CHAPMAN AND BARTELS, GEOMAGNETISM, OXFORD, 1940, P 612
      DIMENSION P(15,15)
      MMAX=NMAX
      DO 6 N=1,NMAX
      DO 2 M=1,MMAX
      P(M,N)=0.
    2 CONTINUE
    6 CONTINUE
      AMU=COS(THETA)
      SAMU=SIN(THETA)
      P(1,1)=1.41421356
      P(1,2)=1.41421356*AMU
      P(2,2)=SAMU
      DO 3 M=1,MMAX
      IF(M.GE.3) GO TO 5
      MM=3
      GO TO 4
    5 CONTINUE
```

```
      P(M,M)=(2*M-3)*SAMU*P(M-1,M-1)/SQRT(FLOAT((2*M-2)*(2*M-3)))
      IF(M.EQ.MMAX) GO TO 3
      MM=M+1
    4 CONTINUE
      DO 1 N=MM,NMAX
    1 P(M,N)=(2*N-3)*AMU*P(M,N-1)/SQRT(FLOAT((N-M)*(N+M-2)))-
     1SQRT(FLOAT((N+M-3)*(N-M-1))/FLOAT((N-M)*(N+M-2)))*P(M,N-2)
    3 CONTINUE
      RETURN
      END
      SUBROUTINE EDPLAT(GGLAT,PHI,EDPTH)
C   CALCULATES ECCENTRIC DIPOLE LATITUDE
C   REF COLE, K.D.,AUST. J. PHYS., VOL. 16. PP 423-9,1963
C   CONVERT TO GEOCENTRIC LAT
      GCLAT=ATAN2(.99330546*SIN(GGLAT)/COS(GGLAT),1.)
      THETA=1.57079635-GCLAT
      R=6356.775+21.38528*SIN(THETA)**2+.049*SIN(2.*THETA)
     1**2
      X=R*SIN(THETA)*COS(PHI)
      Y=R*SIN(THETA)*SIN(PHI)
      Z=R*COS(THETA)
      XD=X+451.8605
      YD=Y-181.6317
      ZD=Z-79.0293
      DELTA=SQRT(XD**2+YD**2+ZD**2)
      EDPTH=ACOS((1./(6338.7792*DELTA))*(594.18164*XD
     1-1231.4974*YD+6189.5465*ZD))
      RETURN
      END
```

FILE ABC

| | | | |
|---|---|---|---|
| 1 | 1 | 0.200 | 0.000 |
| 1 | 2 | -0.489 | 0.000 |
| 2 | 2 | 0.716 | -0.298 |
| 1 | 3 | -0.090 | 0.000 |
| 2 | 3 | -1.009 | -0.151 |
| 3 | 3 | 0.646 | 0.202 |
| 1 | 4 | 0.004 | 0.000 |
| 2 | 4 | 0.680 | -0.471 |
| 3 | 4 | 0.360 | -0.224 |
| 4 | 4 | 0.250 | -0.077 |
| 1 | 5 | -0.598 | 0.000 |
| 2 | 5 | -0.154 | -0.692 |
| 3 | 5 | 1.314 | 0.469 |
| 4 | 5 | -0.015 | -0.122 |
| 5 | 5 | 0.075 | -0.070 |
| 1 | 6 | 0.186 | 0.000 |
| 2 | 6 | -0.658 | -0.227 |
| 3 | 6 | 0.582 | -0.199 |
| 4 | 6 | 0.487 | -0.214 |
| 5 | 6 | -0.031 | -0.083 |
| 6 | 6 | 0.006 | 0.032 |

| | | | |
|---|---|---|---|
| 1 | 7 | 0.076 | 0.000 |
| 2 | 7 | 0.432 | -0.307 |
| 3 | 7 | 0.485 | 0.167 |
| 4 | 7 | -0.177 | -0.069 |
| 5 | 7 | 0.128 | -0.157 |
| 6 | 7 | -0.021 | -0.005 |
| 7 | 7 | -0.014 | -0.004 |
| 1 | 8 | -0.039 | 0.000 |
| 2 | 8 | -0.064 | -0.301 |
| 3 | 8 | 0.317 | 0.046 |
| 4 | 8 | 0.103 | -0.173 |
| 5 | 8 | -0.090 | -0.066 |
| 6 | 8 | -0.014 | 0.047 |
| 7 | 8 | -0.017 | 0.008 |
| 8 | 8 | 0.000 | -0.008 |
| 1 | 9 | -0.031 | 0.000 |
| 2 | 9 | 0.041 | 0.051 |
| 3 | 9 | 0.166 | -0.034 |
| 4 | 9 | -0.136 | -0.004 |
| 5 | 9 | 0.000 | -0.058 |
| 6 | 9 | -0.007 | 0.011 |
| 7 | 9 | -0.032 | -0.003 |
| 8 | 9 | -0.005 | 0.006 |
| 9 | 9 | -0.002 | -0.007 |
| 1 | 10 | -0.004 | 0.000 |
| 2 | 10 | -0.071 | -0.069 |
| 3 | 10 | 0.053 | 0.054 |
| 4 | 10 | -0.009 | -0.111 |
| 5 | 10 | -0.096 | -0.020 |
| 6 | 10 | -0.037 | 0.008 |
| 7 | 10 | -0.002 | 0.003 |
| 8 | 10 | -0.001 | -0.012 |
| 9 | 10 | 0.003 | 0.004 |
| 10 | 10 | -0.002 | 0.001 |
| 1 | 11 | -0.044 | 0.000 |
| 2 | 11 | 0.115 | -0.161 |
| 3 | 11 | 0.108 | 0.011 |
| 4 | 11 | 0.028 | -0.048 |
| 5 | 11 | -0.030 | 0.011 |
| 6 | 11 | 0.011 | 0.018 |
| 7 | 11 | -0.007 | 0.003 |
| 8 | 11 | -0.001 | -0.003 |
| 9 | 11 | -0.002 | -0.008 |
| 10 | 11 | 0.001 | 0.001 |
| 11 | 11 | -0.000 | -0.001 |
| 1 | 12 | -0.040 | 0.000 |
| 2 | 12 | -0.030 | -0.148 |
| 3 | 12 | 0.034 | 0.003 |
| 4 | 12 | 0.050 | -0.076 |
| 5 | 12 | -0.042 | -0.034 |
| 6 | 12 | -0.015 | 0.018 |
| 7 | 12 | 0.015 | 0.005 |
| 8 | 12 | 0.001 | 0.000 |
| 9 | 12 | 0.002 | -0.001 |
| 10 | 12 | -0.003 | 0.001 |
| 11 | 12 | 0.003 | -0.003 |
| 12 | 12 | 0.001 | 0.000 |

| | | | |
|---|---|---|---|
| 1 | 13 | -0.019 | 0.000 |
| 2 | 13 | -0.019 | -0.034 |
| 3 | 13 | 0.074 | 0.005 |
| 4 | 13 | 0.011 | -0.034 |
| 5 | 13 | -0.020 | -0.002 |
| 6 | 13 | 0.000 | 0.011 |
| 7 | 13 | 0.009 | 0.001 |
| 8 | 13 | 0.004 | -0.006 |
| 9 | 13 | 0.004 | 0.003 |
| 10 | 13 | -0.003 | 0.002 |
| 11 | 13 | -0.000 | -0.001 |
| 12 | 13 | -0.000 | -0.002 |
| 13 | 13 | 0.000 | -0.001 |
| 1 | 14 | -0.001 | 0.000 |
| 2 | 14 | 0.033 | -0.049 |
| 3 | 14 | 0.019 | 0.014 |
| 4 | 14 | -0.004 | -0.020 |
| 5 | 14 | -0.020 | -0.021 |
| 6 | 14 | -0.018 | 0.018 |
| 7 | 14 | 0.005 | 0.015 |
| 8 | 14 | 0.006 | 0.002 |
| 9 | 14 | -0.001 | -0.003 |
| 10 | 14 | -0.001 | -0.000 |
| 11 | 14 | 0.002 | -0.002 |
| 12 | 14 | 0.002 | -0.000 |
| 13 | 14 | 0.002 | -0.001 |
| 14 | 14 | 0.000 | -0.001 |
| 1 | 15 | -0.064 | 0.000 |
| 2 | 15 | -0.024 | 0.021 |
| 3 | 15 | 0.058 | -0.002 |
| 4 | 15 | -0.011 | -0.036 |
| 5 | 15 | -0.027 | -0.006 |
| 6 | 15 | -0.003 | 0.003 |
| 7 | 15 | -0.000 | 0.001 |
| 8 | 15 | 0.001 | 0.003 |
| 9 | 15 | -0.002 | -0.002 |
| 10 | 15 | -0.003 | 0.000 |
| 11 | 15 | 0.000 | -0.000 |
| 12 | 15 | -0.001 | -0.002 |
| 13 | 15 | 0.002 | -0.003 |
| 14 | 15 | -0.002 | -0.000 |
| 15 | 15 | 0.001 | 0.001 |

APPENDIX C.

```
      SUBROUTINE INVEXP(GGLAT,GGLONG,NMAX,VLAT,VLONG,NXREAD,NOREAD)
C  CALCULATES INVARIANT LATITUDE,VLAT, AND LONGITUDE,VLONG,
C  FOR GIVEN GEODETIC LATITUDE,GGLAT,IN RANGE +PI/2 TO -PI/2;
C  AND LONGITUDE GGLONG, IN RANGE 0. TO 2*PI.
C  NXREAD MUST BE INITIALLY SET =0 TO READ IN COEFFICIENTS
C  FOR LONGITUDE
C  NOREAD SET =0 TO READ COEFFICIENTS FOR LATITUDE
C  NMAX IS  ORDER REQUIRED IN EXPANSION
C  INVARIANT LONGITUDE IS EXPANDED IN TERMS OF ITS SIN AND COS
C  WITH COEFFICIENTS ASN, BSIN; ACS, BCOS
C
      DIMENSION ALAT(15,15),BLAT(15,15),ASN(15,15),BSIN(15,15),
     1ACS(15,15),BCOS(15,15),P(15,15)
C  HAVE COEFFICIENTS BEEN READ IN?
      IF(NXREAD.NE.0) GO TO 5
C  READ IN COEFFICIENTS FOR LONGITUDE
      OPEN(UNIT=4,FILE='ABUSE')
      NN=NMAX+1
      DO 1 N=1,NN
      DO 1 M=1,N
      READ(4,100,END=5)LM,NL,ASN(M,N),BSIN(M,N),
     1ACS(M,N),BCOS(M,N)
    1 CONTINUE
  100 FORMAT(2I,4F)
    5 CONTINUE
C  RAISE ORDER OF COEFFICIENTS BY 1
      NN=NMAX+1
      NXREAD=1
C  INVARIANT LATITUDE
      CALL INVLAT(GGLAT,GGLONG,NMAX,VLAT,NOREAD,P)
C
C  INVARIANT LONGITUDE
C  EXPAND SIN(INVARIANT LONGITUDE)
      CALL EXPAND(GGLONG,SINL,NN,ASN,BSIN,P)
C  EXPAND COS(INV LONG)
      CALL EXPAND(GGLONG,COSL,NN,ACS,BCOS,P)
C  REMOVE SIN(THETA) WEIGHTING
      SINLAT=SIN(1.5707963-VLAT)
      ABSIN=ABS(SINL/SINLAT)
      ABCOS=ABS(COSL/SINLAT)
C PROTECT AGAINST SIN OR COS GT. 1.
      IF(ABSIN.LT.1.) GO TO 13
      ABSIN=1.
   13 IF(ABCOS.LT.1.) GO TO 14
      ABCOS=1.
   14 CONTINUE
      IF(ABSIN.GT..707) GO TO 15
      VLONG=ASIN(ABSIN)
      GO TO 17
   15 VLONG=ACOS(ABCOS)
   17 CONTINUE
C  FIND QUADRANT FOR VLONG
      IF(SINL.GT.0.) GO TO 18
      IF(COSL.GT.0.) GO TO 20
      VLONG=3.141593+VLONG
```

```
      GO TO 22
   18 IF(COSL.GT.0.) GO TO 22
      VLONG=3.141593-VLONG
      GO TO 22
   20 VLONG=6.2831845-VLONG
   22 CONTINUE
      RETURN
      END
      SUBROUTINE EXPAND(GGLONG,F,NN,A,B,P)
C EXPANDS FUNCTION F IN SPHERICAL HARMONIC COEFFICIENTS A,B.
      DIMENSION P(15,15),A(15,15),B(15,15)
C  EXPAND F
      F=0.
      DO 1 N=1,NN
      DO 1 M=1,N
    1 F=F+(A(M,N)*COS((M-1)*GGLONG)+B(M,N)*SIN((M-1)*GGLONG))*
     1      P(M,N)
      RETURN
      END
```

FILE ABUSE

| | | | | | |
|---|---|---|---|---|---|
| 1 | 1 | -0.01191 | 0.00000 | 0.02451 | 0.00000 |
| 1 | 2 | 0.12829 | 0.00000 | -0.05287 | 0.00000 |
| 2 | 2 | 0.02640 | 0.96268 | 0.99107 | -0.01417 |
| 1 | 3 | -0.02092 | 0.00000 | 0.01944 | 0.00000 |
| 2 | 3 | 0.00819 | -0.01229 | 0.06373 | 0.01550 |
| 3 | 3 | -0.03143 | -0.05664 | -0.05124 | 0.01991 |
| 1 | 4 | -0.00061 | 0.00000 | -0.02277 | 0.00000 |
| 2 | 4 | -0.00873 | -0.02595 | 0.01108 | -0.00155 |
| 3 | 4 | -0.00295 | -0.00785 | 0.03264 | -0.00390 |
| 4 | 4 | -0.00820 | -0.00354 | -0.00868 | -0.00724 |
| 1 | 5 | 0.00426 | 0.00000 | 0.00897 | 0.00000 |
| 2 | 5 | -0.00054 | -0.00822 | -0.00919 | -0.00483 |
| 3 | 5 | -0.00409 | 0.00177 | -0.01457 | 0.00340 |
| 4 | 5 | -0.00732 | -0.01414 | 0.00144 | -0.00877 |
| 5 | 5 | -0.00674 | 0.00957 | -0.00214 | -0.00244 |
| 1 | 6 | -0.00359 | 0.00000 | 0.00540 | 0.00000 |
| 2 | 6 | 0.00673 | -0.00237 | 0.00178 | 0.00224 |
| 3 | 6 | -0.00449 | 0.00395 | -0.00010 | 0.00018 |
| 4 | 6 | 0.00119 | -0.00456 | -0.00884 | -0.00024 |
| 5 | 6 | -0.00065 | -0.00400 | -0.00365 | 0.00322 |
| 6 | 6 | -0.00214 | 0.00788 | -0.00025 | 0.00333 |
| 1 | 7 | 0.00145 | 0.00000 | 0.00020 | 0.00000 |
| 2 | 7 | 0.00011 | -0.00399 | -0.00304 | 0.00119 |
| 3 | 7 | 0.00225 | 0.00087 | -0.00292 | 0.00197 |
| 4 | 7 | 0.00147 | -0.00296 | -0.00337 | -0.00167 |
| 5 | 7 | 0.00303 | 0.00211 | 0.00411 | 0.00115 |
| 6 | 7 | -0.00202 | 0.00085 | -0.00304 | 0.00088 |
| 7 | 7 | 0.00265 | 0.00461 | 0.00134 | 0.00313 |

| | | | | | |
|---|---|---|---|---|---|
| 1 | 8 | 0.00243 | 0.00000 | -0.00062 | 0.00000 |
| 2 | 8 | -0.00120 | 0.00152 | -0.00024 | -0.00060 |
| 3 | 8 | 0.00218 | 0.00068 | -0.00063 | -0.00032 |
| 4 | 8 | 0.00087 | 0.00048 | -0.00003 | 0.00154 |
| 5 | 8 | 0.00055 | 0.00083 | 0.00047 | -0.00097 |
| 6 | 8 | -0.00131 | -0.00035 | 0.00173 | 0.00013 |
| 7 | 8 | 0.00049 | 0.00123 | 0.00020 | -0.00173 |
| 8 | 8 | 0.00206 | 0.00051 | 0.00186 | 0.00106 |
| 1 | 9 | -0.00041 | 0.00000 | 0.00027 | 0.00000 |
| 2 | 9 | -0.00122 | 0.00380 | 0.00126 | -0.00128 |
| 3 | 9 | -0.00069 | -0.00042 | -0.00013 | 0.00037 |
| 4 | 9 | -0.00095 | 0.00134 | 0.00101 | 0.00083 |
| 5 | 9 | -0.00027 | 0.00024 | 0.00024 | -0.00035 |
| 6 | 9 | -0.00085 | -0.00026 | 0.00025 | 0.00090 |
| 7 | 9 | -0.00045 | -0.00011 | 0.00026 | -0.00090 |
| 8 | 9 | -0.00061 | 0.00077 | 0.00035 | -0.00118 |
| 9 | 9 | 0.00132 | -0.00082 | 0.00115 | -0.00020 |
| 1 | 10 | -0.00276 | 0.00000 | 0.00026 | 0.00000 |
| 2 | 10 | -0.00022 | -0.00038 | 0.00034 | 0.00034 |
| 3 | 10 | -0.00317 | -0.00117 | 0.00049 | 0.00106 |
| 4 | 10 | 0.00005 | -0.00015 | -0.00035 | -0.00057 |
| 5 | 10 | -0.00183 | -0.00100 | -0.00081 | 0.00113 |
| 6 | 10 | 0.00007 | 0.00004 | -0.00006 | -0.00027 |
| 7 | 10 | 0.00048 | 0.00012 | -0.00014 | 0.00018 |
| 8 | 10 | -0.00111 | 0.00024 | 0.00002 | -0.00015 |
| 9 | 10 | -0.00007 | 0.00055 | -0.00053 | 0.00030 |
| 10 | 10 | -0.00060 | -0.00105 | 0.00027 | -0.00060 |
| 1 | 11 | -0.00008 | 0.00000 | -0.00015 | 0.00000 |
| 2 | 11 | 0.00083 | -0.00363 | -0.00132 | 0.00087 |
| 3 | 11 | -0.00042 | -0.00010 | 0.00038 | 0.00017 |
| 4 | 11 | 0.00129 | -0.00127 | -0.00104 | -0.00107 |
| 5 | 11 | -0.00004 | -0.00059 | -0.00029 | 0.00009 |
| 6 | 11 | 0.00000 | -0.00003 | 0.00019 | -0.00028 |
| 7 | 11 | 0.00018 | -0.00008 | -0.00003 | -0.00005 |
| 8 | 11 | -0.00041 | -0.00055 | -0.00005 | 0.00024 |
| 9 | 11 | 0.00040 | 0.00045 | -0.00033 | -0.00006 |
| 10 | 11 | -0.00025 | -0.00070 | -0.00026 | 0.00057 |
| 11 | 11 | 0.00002 | -0.00045 | -0.00001 | -0.00026 |
| 1 | 12 | 0.00175 | 0.00000 | -0.00019 | 0.00000 |
| 2 | 12 | 0.00025 | -0.00031 | 0.00016 | 0.00016 |
| 3 | 12 | 0.00316 | 0.00110 | -0.00010 | -0.00093 |
| 4 | 12 | 0.00018 | -0.00051 | 0.00023 | 0.00011 |
| 5 | 12 | 0.00112 | 0.00073 | 0.00077 | -0.00120 |
| 6 | 12 | 0.00035 | -0.00018 | -0.00000 | -0.00002 |
| 7 | 12 | -0.00041 | -0.00008 | 0.00012 | -0.00005 |
| 8 | 12 | 0.00019 | -0.00073 | -0.00020 | -0.00008 |
| 9 | 12 | 0.00017 | 0.00013 | 0.00004 | -0.00010 |
| 10 | 12 | -0.00020 | -0.00006 | -0.00009 | -0.00001 |
| 11 | 12 | -0.00004 | 0.00021 | 0.00029 | 0.00038 |
| 12 | 12 | -0.00067 | 0.00029 | -0.00007 | -0.00019 |
| 1 | 13 | 0.00041 | 0.00000 | -0.00045 | 0.00000 |
| 2 | 13 | -0.00003 | 0.00279 | 0.00105 | -0.00061 |
| 3 | 13 | 0.00144 | 0.00051 | -0.00025 | -0.00022 |
| 4 | 13 | -0.00123 | 0.00095 | 0.00107 | 0.00111 |
| 5 | 13 | 0.00014 | 0.00058 | 0.00054 | -0.00025 |
| 6 | 13 | 0.00068 | 0.00035 | -0.00009 | 0.00013 |

| | | | | | |
|---|---|---|---|---|---|
| 7 | 13 | -0.00002 | -0.00027 | 0.00006 | 0.00028 |
| 8 | 13 | 0.00007 | 0.00013 | 0.00012 | -0.00013 |
| 9 | 13 | 0.00009 | 0.00032 | 0.00004 | -0.00006 |
| 10 | 13 | -0.00067 | 0.00003 | 0.00013 | -0.00025 |
| 11 | 13 | 0.00055 | 0.00002 | -0.00015 | 0.00005 |
| 12 | 13 | -0.00033 | -0.00094 | 0.00039 | 0.00011 |
| 13 | 13 | 0.00053 | -0.00039 | 0.00006 | 0.00003 |
| 1 | 14 | -0.00206 | 0.00000 | 0.00135 | 0.00000 |
| 2 | 14 | -0.00005 | 0.00315 | 0.00299 | -0.00033 |
| 3 | 14 | -0.00237 | -0.00068 | -0.00031 | 0.00093 |
| 4 | 14 | -0.00085 | 0.00048 | 0.00036 | 0.00018 |
| 5 | 14 | -0.00015 | -0.00036 | -0.00057 | 0.00080 |
| 6 | 14 | 0.00012 | 0.00004 | -0.00002 | 0.00002 |
| 7 | 14 | 0.00009 | -0.00027 | -0.00009 | 0.00021 |
| 8 | 14 | -0.00008 | 0.00052 | 0.00018 | 0.00033 |
| 9 | 14 | 0.00046 | 0.00017 | -0.00000 | 0.00008 |
| 10 | 14 | -0.00020 | -0.00064 | 0.00005 | -0.00014 |
| 11 | 14 | 0.00043 | 0.00072 | -0.00026 | -0.00039 |
| 12 | 14 | -0.00021 | -0.00034 | 0.00005 | 0.00012 |
| 13 | 14 | -0.00018 | 0.00053 | 0.00051 | -0.00005 |
| 14 | 14 | -0.00046 | -0.00035 | 0.00026 | 0.00005 |
| 1 | 15 | 0.00063 | 0.00000 | -0.00039 | 0.00000 |
| 2 | 15 | -0.00017 | -0.00192 | 0.00049 | 0.00066 |
| 3 | 15 | -0.00189 | 0.00004 | -0.00008 | 0.00032 |
| 4 | 15 | 0.00082 | -0.00024 | -0.00056 | -0.00057 |
| 5 | 15 | 0.00010 | -0.00011 | -0.00064 | 0.00019 |
| 6 | 15 | -0.00110 | -0.00014 | -0.00000 | 0.00032 |
| 7 | 15 | -0.00076 | 0.00022 | 0.00007 | -0.00009 |
| 8 | 15 | 0.00053 | 0.00003 | -0.00015 | 0.00019 |
| 9 | 15 | 0.00016 | -0.00041 | 0.00001 | 0.00026 |
| 10 | 15 | -0.00010 | -0.00043 | -0.00011 | 0.00028 |
| 11 | 15 | -0.00019 | 0.00064 | -0.00002 | -0.00008 |
| 12 | 15 | -0.00008 | 0.00007 | -0.00027 | -0.00018 |
| 13 | 15 | 0.00039 | -0.00011 | 0.00013 | -0.00013 |
| 14 | 15 | -0.00038 | -0.00047 | 0.00018 | -0.00014 |
| 15 | 15 | -0.00038 | -0.00086 | 0.00025 | 0.00036 |

APPENDIX D.

| | Geographic | | Invariant | | |
|---|---|---|---|---|---|
| | Lat. | Long. | Lat. | Long. | Lat.* |
| ABISKO | 68.35 | 18.82 | 65.04 | 33.39 | 65.06 |
| ADAK | 51.87 | 183.35 | 46.32 | 176.00 | 46.14 |
| ADDIS ABABA | 9.03 | 38.77 | 0.00 | 37.06 | 2.04 |
| AGINCOURT | 43.78 | 280.73 | 56.62 | 284.45 | 57.00 |
| ALERT | 82.50 | 297.50 | 86.52 | 46.26 | 86.89 |
| ALIBAG | 18.63 | 72.87 | 0.00 | 70.67 | 9.52 |
| ALMA ATA | 43.25 | 76.92 | 36.73 | 76.37 | 36.37 |
| ALMERIA | 36.85 | 357.53 | 33.82 | 3.45 | 34.19 |
| ALOUSHTA | 44.68 | 34.42 | 40.19 | 36.01 | 40.22 |
| AMBERLEY | -43.15 | 172.72 | -50.05 | 186.90 | -49.82 |
| ANCHORAGE | 61.23 | 210.13 | 60.68 | 193.16 | 60.63 |
| ANNAMALAINAGAR | 11.40 | 79.68 | 0.00 | 76.95 | 0.11 |
| APIA | -13.80 | 188.22 | -16.57 | 194.73 | -16.45 |
| ARAIRA | 10.45 | 293.52 | 28.09 | 299.05 | 22.37 |
| ARCTIC ICE FLOW A | 81.63 | 195.43 | 78.24 | 151.32 | 78.42 |
| ARCTIC ICE FLOE A | 81.83 | 195.43 | 78.40 | 150.56 | 78.57 |
| ARCTIC ICE FLOE A | 85.38 | 190.67 | 80.51 | 132.44 | 80.33 |
| AREQUIPA | -16.47 | 288.52 | -15.92 | 293.04 | -12.31 |
| ARGENTINE ISLANDS | -65.25 | 295.73 | -49.84 | 301.41 | -49.81 |
| ASHKHABAD | 37.95 | 58.10 | 32.11 | 57.24 | 31.93 |
| ASO | 32.88 | 131.02 | 22.41 | 130.83 | 22.62 |
| AVERROES | 33.30 | 352.58 | 30.94 | 358.79 | 31.01 |
| BAGUIO | 16.42 | 120.60 | 0.00 | 118.92 | 5.10 |
| BAJA | 46.18 | 19.00 | 42.36 | 23.05 | 42.38 |
| BAKER LAKE | 64.33 | 263.97 | 75.01 | 254.00 | 74.50 |
| BANGUI | 4.43 | 18.57 | -8.19 | 18.28 | 2.98 |
| BARENTSBURG | 78.63 | 16.38 | 74.98 | 45.88 | 75.01 |
| BARROW | 71.30 | 203.25 | 69.62 | 178.64 | 69.94 |
| BARTER ISLAND | 70.13 | 216.33 | 70.81 | 189.77 | 71.17 |
| BEAR ISLAND | 74.50 | 19.20 | 70.97 | 40.32 | 71.03 |
| BELOIT | 39.48 | 261.87 | 50.19 | 258.71 | 50.46 |
| BELSK | 51.83 | 20.80 | 48.22 | 26.20 | 48.12 |
| BIG DELTA | 64.00 | 214.27 | 64.35 | 194.49 | 64.42 |
| BINZA | -4.27 | 15.37 | -16.44 | 14.42 | -5.41 |
| BOROK | 58.03 | 38.97 | 53.68 | 43.44 | 53.75 |
| BOULDER | 40.13 | 254.77 | 49.43 | 249.86 | 49.67 |
| BRISBANE | -27.53 | 152.92 | -36.65 | 158.45 | -36.81 |
| BUDKOV | 49.07 | 14.02 | 45.75 | 19.78 | 45.65 |
| BUNIA | 1.53 | 30.18 | -8.62 | 28.94 | 48.71 |
| BURLINGTON | 39.28 | 257.73 | 49.16 | 253.65 | 49.41 |
| BYRD | -80.00 | 240.50 | -68.18 | 284.92 | -68.13 |
| CAPE CHELYUSKIN | 77.72 | 104.28 | 71.22 | 104.67 | 70.87 |
| CAPE HALLETT | -72.32 | 170.22 | -77.57 | 229.28 | -77.37 |
| CAPE WELLEN | 66.17 | 190.17 | 62.34 | 174.44 | 62.35 |
| CAPRI | 40.55 | 14.22 | 36.48 | 17.72 | 36.69 |
| CARROLLTON | 39.37 | 266.53 | 50.90 | 264.71 | 51.19 |
| CASPERR | 42.85 | 253.70 | 52.04 | 247.73 | 52.30 |
| CASPER | 42.85 | 253.70 | 52.04 | 247.73 | 52.30 |
| CASTEL TESINO | 46.05 | 11.65 | 42.67 | 17.00 | 42.67 |
| CASTELLACCIO | 44.43 | 8.93 | 41.11 | 14.42 | 41.17 |

*Expanded to 8th order.

| | | | | | |
|---|---|---|---|---|---|
| CASTLE ROCK | 37.23 | 237.87 | 42.67 | 232.27 | 42.67 |
| CEBU | 10.30 | 123.90 | 0.00 | 122.29 | -0.32 |
| CHA-PA | 22.35 | 103.83 | 0.00 | 101.71 | 10.81 |
| CHAMBON-LA-FORET | 48.02 | 2.27 | 45.65 | 10.24 | 45.53 |
| CHARCOT | -69.38 | 139.02 | -83.43 | 171.97 | -83.58 |
| CHICLAYO | -6.80 | 280.20 | 14.99 | 284.49 | -4.77 |
| CHIMBOTE | -9.10 | 281.40 | 15.43 | 285.86 | -6.52 |
| CHITTAGONG | 22.35 | 91.82 | 0.00 | 89.60 | 11.21 |
| COIMBRA | 40.22 | 351.58 | 38.46 | 359.67 | 38.70 |
| COLLEGE | 64.87 | 212.17 | 64.79 | 192.05 | 64.88 |
| CUZCO | -13.53 | 288.03 | 15.67 | 292.44 | -10.45 |
| DALLAS | 32.98 | 263.25 | 43.75 | 261.68 | 43.64 |
| DAR ES SALAAM | -6.78 | 39.22 | -16.48 | 36.92 | -15.89 |
| DAVAO | 7.08 | 125.58 | 0.00 | 124.08 | -2.51 |
| DIXON ISLAND | 73.55 | 80.57 | 67.76 | 85.33 | 67.64 |
| DOMBAS | 62.07 | 9.12 | 59.60 | 21.80 | 59.44 |
| DOURBES | 50.10 | 4.60 | 47.64 | 12.75 | 47.46 |
| DUMONT D'URVILLE | -66.67 | 140.00 | -80.57 | 164.78 | -80.88 |
| EASTER ISLAND | -27.17 | 250.58 | -21.41 | 260.40 | -21.45 |
| EBRO | 40.82 | 0.50 | 37.90 | 6.78 | 38.12 |
| EIELSON AFB | 64.67 | 212.92 | 64.74 | 192.84 | 64.83 |
| EIGHTS | -75.23 | 282.83 | -59.92 | 297.54 | -59.97 |
| ELIZABETHVILLE | -11.63 | 27.42 | -22.94 | 25.19 | -22.23 |
| ESKDALEMUIR | 55.32 | 356.80 | 54.06 | 8.93 | 53.76 |
| ESPANOLA | 35.82 | 253.93 | 44.74 | 250.17 | 44.82 |
| FANNING ISLAND | 3.90 | 200.62 | 0.00 | 204.24 | -2.94 |
| FORT CHURCHILL | 58.80 | 265.90 | 70.08 | 259.79 | 69.78 |
| FORT YUKON | 66.57 | 214.70 | 67.00 | 192.53 | 67.19 |
| FREDERICKSBURG | 38.20 | 282.63 | 51.35 | 286.97 | 51.53 |
| FREETOWN | 8.47 | 346.78 | 11.29 | 349.15 | 4.61 |
| FUQUENE | 5.47 | 286.27 | 23.28 | 290.22 | 20.02 |
| FURSTENFELDBRUCK | 48.17 | 11.28 | 44.99 | 17.35 | 44.90 |
| G GONZALES VIDELA | -64.82 | 297.15 | -49.43 | 302.14 | -49.39 |
| GARCHY | 47.30 | 3.10 | 44.78 | 10.61 | 44.69 |
| GENERAL BELGRANO | -77.97 | 321.20 | -62.46 | 313.88 | -62.51 |
| GIBILMANNA | 37.98 | 14.02 | 33.66 | 17.17 | 33.93 |
| GILGIT | 35.92 | 74.30 | 28.41 | 73.19 | 28.17 |
| GNANGARA | -31.78 | 115.95 | -43.49 | 114.77 | -43.39 |
| GODHAVN | 69.23 | 306.48 | 76.84 | 333.71 | 76.94 |
| GOOSE BAY AFB | 53.30 | 299.55 | 63.73 | 313.62 | 63.89 |
| GOUGH ISLAND | -40.35 | 350.12 | -40.59 | 338.84 | -40.72 |
| GOTTINGEN | 51.53 | 9.97 | 48.66 | 17.42 | 48.48 |
| GREAT WHALE RIVER | .55.27 | 282.22 | 67.48 | 287.47 | 67.38 |
| GROCKA | 44.63 | 20.77 | 40.61 | 24.16 | 40.68 |
| GUAM | 13.58 | 144.87 | 0.00 | 144.31 | 3.13 |
| HACHIJO | 33.13 | 139.80 | 22.83 | 139.64 | 23.00 |
| HALLEY BAY | -75.52 | 333.38 | -61.05 | 319.64 | -61.07 |
| HARTLAND | 51.00 | 355.52 | 49.68 | 6.13 | 49.44 |
| HAVANA | 22.97 | 277.85 | 36.60 | 280.30 | 34.64 |
| HEALY | 63.85 | 211.03 | 63.53 | 191.97 | 63.57 |

| | | | | | |
|---|---|---|---|---|---|
| HEISS ISLAND | 80.62 | 58.05 | 74.61 | 74.39 | 74.24 |
| HEL | 54.60 | 18.82 | 51.20 | 25.56 | 51.07 |
| HELWAN | 29.87 | 31.33 | 24.59 | 31.11 | 24.41 |
| HERMANUS | -34.42 | 19.23 | -41.93 | 10.04 | -41.95 |
| HOLLANDIA | -2.57 | 140.52 | 0.00 | 140.49 | 4.03 |
| HONOLULU | 21.32 | 202.00 | 20.34 | 201.74 | 19.92 |
| HUANCAYO | -12.05 | 284.67 | 14.93 | 289.19 | -9.01 |
| HURBANOVO | 47.87 | 18.18 | 44.21 | 22.83 | 44.17 |
| HYDERABAD | 17.42 | 78.55 | 0.00 | 76.21 | 7.30 |
| IBADAN | 7.43 | 3.90 | -9.62 | 4.89 | 1.02 |
| IRKUTSK | 52.17 | 104.45 | 45.67 | 105.04 | 45.70 |
| IVALO | 68.60 | 27.48 | 64.71 | 39.98 | 64.74 |
| JARVIS ISLAND | 0.38 | 199.97 | 0.00 | 204.22 | 129.38 |
| JASSY | 47.18 | 27.53 | 43.04 | 30.44 | 43.05 |
| JULIANEHAAB | 60.72 | 313.97 | 67.63 | 334.90 | 67.67 |
| KAKIOKA | 36.23 | 140.18 | 26.45 | 140.16 | 26.45 |
| KANDILLI | 41.07 | 29.07 | 36.49 | 30.57 | 36.61 |
| KANOYA | 31.42 | 130.88 | 20.60 | 130.58 | 20.99 |
| KANOZAN | 35.25 | 139.97 | 25.31 | 139.91 | 25.35 |
| KAP TOBIN | 70.42 | 338.03 | 71.98 | 6.37 | 72.30 |
| KARAGANDA | 49.82 | 73.08 | 44.17 | 73.23 | 44.06 |
| KAZAN | 55.83 | 48.85 | 51.16 | 51.37 | 51.26 |
| KIEV | 50.72 | 30.30 | 46.61 | 33.72 | 46.60 |
| KIRUNA | 67.83 | 20.42 | 64.41 | 34.17 | 64.43 |
| KODAIKANAL | 10.23 | 77.47 | 0.00 | 74.69 | -1.11 |
| KONTAGORA | 10.40 | 5.45 | 9.20 | 6.61 | 3.14 |
| KOROR | 7.33 | 134.50 | 0.00 | 133.52 | -1.58 |
| KOTZEBUE | 66.88 | 197.40 | 64.16 | 179.06 | 64.24 |
| KSARA | 33.82 | 35.88 | 29.05 | 35.61 | 28.66 |
| KUYPER | -6.03 | 106.73 | -7.73 | 104.54 | -13.61 |
| L'AQUILA | 42.38 | 13.32 | 38.55 | 17.40 | 38.70 |
| LA MADDALENA | 41.23 | 9.40 | 37.54 | 14.00 | 37.74 |
| LA QUIACA | -22.10 | 294.40 | -18.05 | 298.41 | -16.43 |
| LAS ACACIAS | -35.00 | 302.32 | -25.35 | 304.13 | -25.47 |
| LEADVILLE | 39.28 | 253.72 | 48.32 | 248.89 | 48.53 |
| LEGON | 5.63 | 0.18 | -10.79 | 1.21 | 0.85 |
| LEIRVOGUR | 64.18 | 338.30 | 65.96 | 359.94 | 65.98 |
| LENINGRAD | 59.95 | 30.70 | 55.95 | 37.35 | 55.96 |
| LERWICK | 60.13 | 358.82 | 58.76 | 12.90 | 58.52 |
| LITTLE AMERICA | -78.18 | 197.80 | -73.91 | 265.67 | -73.67 |
| LOGRONO | 42.45 | 357.50 | 40.08 | 4.81 | 40.22 |
| LORING AFB | 46.95 | 292.12 | 59.00 | 301.65 | 59.36 |
| LOURENCO MARQUES | -25.92 | 32.58 | -35.85 | 26.80 | -35.84 |
| LOVO | 59.35 | 17.83 | 56.12 | 26.89 | 55.99 |
| LOVOZERO | 67.97 | 35.02 | 63.69 | 45.19 | 63.75 |
| LUANDA | -8.92 | 13.17 | -21.01 | 11.55 | -18.53 |
| LUNPING | 25.00 | 121.17 | 11.03 | 119.97 | 13.85 |
| LVOV | 49.90 | 23.75 | 46.05 | 28.03 | 46.01 |
| LWIRO | -2.25 | 28.80 | -12.94 | 27.46 | 14.66 |
| M'BOUR | 14.40 | 343.03 | 15.91 | 347.43 | 11.70 |

| | | | | | |
|---|---|---|---|---|---|
| MACQUARIE ISLAND | -54.50 | 158.95 | -64.47 | 177.67 | -64.60 |
| MAGADAN | 60.12 | 151.02 | 52.91 | 148.18 | 52.92 |
| MAJURO | 7.08 | 171.38 | 0.00 | 172.93 | -0.74 |
| MANHAY | 50.30 | 5.68 | 47.75 | 13.68 | 47.57 |
| MARION ISLAND | -46.85 | 37.87 | -51.66 | 21.30 | -51.63 |
| MAWSON | -67.60 | 62.88 | -70.11 | 19.61 | -70.14 |
| MEANOOK | 54.62 | 246.67 | 62.52 | 234.25 | 62.57 |
| MELVILLE AFB | 53.28 | 299.47 | 63.73 | 313.50 | 63.88 |
| MEMAMBETSU | 43.90 | 144.20 | 35.11 | 144.10 | 35.05 |
| MIDWAY | 28.22 | 182.63 | 23.17 | 179.39 | 23.16 |
| MINSK | 54.10 | 26.52 | 50.25 | 31.70 | 50.19 |
| MIRNY | -66.55 | 93.02 | -77.14 | 52.42 | -76.90 |
| MISALLAT | 29.52 | 30.90 | 24.19 | 30.70 | 24.02 |
| MOCA | 3.35 | 8.67 | -10.69 | 8.91 | 8.12 |
| MONTE CAPELLINO | 44.55 | 8.95 | 41.24 | 14.48 | 41.29 |
| MOSCOW | 55.48 | 37.32 | 51.18 | 41.23 | 51.22 |
| MOULD BAY | 76.20 | 240.60 | 80.89 | 197.02 | 81.43 |
| MOUNT WILSON | 34.22 | 241.93 | 40.44 | 237.68 | 40.39 |
| MUNTINLUPA | 14.37 | 121.02 | 0.00 | 119.31 | 3.16 |
| MURCHISON BAY | 80.05 | 18.25 | 76.09 | 50.29 | 76.04 |
| MURMANSK | 68.25 | 33.08 | 64.06 | 43.92 | 64.11 |
| NAGYCENK | 47.63 | 16.72 | 44.04 | 21.55 | 44.00 |
| NAIROBI | -1.32 | 36.82 | -10.58 | 35.01 | 35.56 |
| NARSSARSSUAQ | 61.10 | 314.80 | 67.81 | 336.06 | 67.85 |
| NEWPORT | 48.27 | 242.88 | 55.21 | 232.92 | 55.34 |
| NIEMEGK | 52.07 | 12.68 | 49.01 | 19.77 | 48.84 |
| NITSANIM | 31.73 | 34.60 | 26.71 | 34.23 | 26.42 |
| NORTH POLE 6 | 80.93 | 150.03 | 74.64 | 131.64 | 74.40 |
| NORTH POLE 6 | 86.25 | 39.38 | 79.79 | 79.94 | 79.34 |
| NORTH POLE 7 | 86.35 | 210.37 | 82.08 | 127.93 | 81.89 |
| NORTH POLE 7 | 85.28 | 325.92 | 83.55 | 64.02 | 83.40 |
| NORTH POLE 8 | 75.53 | 197.22 | 72.93 | 168.28 | 73.30 |
| NORTH POLE 8 | 79.10 | 179.38 | 74.53 | 151.11 | 74.64 |
| NORTH POLE 10 | 75.18 | 160.87 | 69.35 | 146.46 | 69.35 |
| NORTH POLE 10 | 78.03 | 171.90 | 72.91 | 149.12 | 72.97 |
| NORTH POLE 12 | 76.83 | 179.98 | 72.34 | 155.85 | 72.51 |
| NORTH POLE 12 | 81.32 | 194.43 | 77.89 | 152.04 | 78.08 |
| NORTHWAY | 62.97 | 218.05 | 64.13 | 198.58 | 64.18 |
| NORWAY STATION | -70.50 | 357.47 | -60.02 | 334.17 | -59.98 |
| NOVOKAZALINSK | 45.77 | 62.12 | 40.32 | 62.04 | 40.13 |
| NOVOLAZAREVSKAYA | -70.77 | 11.82 | -62.32 | 342.24 | -62.31 |
| NURMIJARVI | 60.52 | 24.65 | 56.85 | 32.79 | 56.80 |
| OASIS | -66.30 | 100.72 | -78.82 | 65.26 | -78.52 |
| ODESSA | 46.78 | 30.88 | 42.50 | 33.33 | 42.52 |
| ONAGAWA | 38.43 | 141.47 | 28.99 | 141.52 | 28.92 |
| ORCADAS DEL SUR | -60.73 | 315.22 | -46.80 | 311.54 | -46.71 |
| OTTAWA | 45.40 | 284.45 | 58.13 | 290.10 | 58.50 |
| PALMYRA ISLAND | 5.88 | 197.92 | 0.00 | 201.05 | 0.18 |
| PANAGYURISHTE | 42.52 | 24.18 | 38.20 | 26.58 | 38.32 |
| PARAMARIBO | 5.82 | 304.78 | 25.05 | 311.79 | 18.32 |

| | | | | | |
|---|---|---|---|---|---|
| PENDELI | 38.05 | 23.87 | 33.34 | 25.57 | 33.56 |
| PETROPAVLOVSK | 53.10 | 158.63 | 45.39 | 155.90 | 45.33 |
| PILAR1.67 | 296.12 | 0.00 | -56.18 | 339.33 | -56.10 |
| PETROPAVLOVSK | 53.10 | 158.63 | 45.39 | 155.90 | 45.33 |
| PILAR | -31.67 | 296.12 | -22.67 | 299.78 | -22.68 |
| PIONERSKAYA | -69.73 | 95.50 | -79.80 | 43.79 | -79.62 |
| PLAISANCE | -20.43 | 57.67 | -29.63 | 51.87 | -29.64 |
| PLATEAU | -79.25 | 40.50 | -71.52 | 341.96 | -71.70 |
| PONZA | 40.92 | 12.95 | 36.97 | 16.77 | 37.16 |
| PORT-AUX-FRANCAIS | -49.35 | 70.20 | -58.24 | 50.37 | -58.32 |
| PORT MORESBY | -9.40 | 147.15 | -16.36 | 148.59 | -18.23 |
| PRICE | 39.62 | 249.22 | 47.69 | 243.60 | 47.85 |
| PRUHONICE | 49.98 | 14.55 | 46.67 | 20.53 | 46.56 |
| QUETTA | 30.18 | 66.95 | 22.19 | 65.51 | 22.69 |
| RACIBORZ | 50.08 | 18.18 | 46.54 | 23.50 | 46.46 |
| REGENSBURG | 47.48 | 8.45 | 44.47 | 14.86 | 44.40 |
| RESOLUTE BAY | 74.70 | 265.10 | 84.17 | 241.71 | 83.98 |
| ROBURENT | 44.30 | 7.88 | 41.05 | 13.52 | 41.11 |
| ROI BAUDOUIN | -70.43 | 24.30 | -64.11 | 349.93 | -64.13 |
| RUDE SKOV | 55.85 | 12.45 | 52.96 | 21.09 | 52.75 |
| SABHAWALA | 30.33 | 77.80 | 20.62 | 76.28 | 21.50 |
| SAN FERNANDO | 36.47 | 353.80 | 33.92 | 359.55 | 34.30 |
| SAN JUAN | 18.12 | 293.85 | 33.85 | 300.24 | 29.83 |
| SAN MIGUEL | 37.77 | 334.35 | 39.71 | 345.78 | 39.87 |
| SANAE STATION | -70.30 | 357.65 | -59.91 | 334.38 | -59.87 |
| SANTA CRUZ | -17.80 | 296.83 | -17.45 | 300.66 | -14.09 |
| SCOTT BASE | -77.85 | 166.78 | -80.04 | 257.98 | -79.69 |
| SEOUL | 37.58 | 127.05 | 28.30 | 127.11 | 28.00 |
| SHATSK | 53.98 | 41.85 | 49.51 | 44.56 | 49.56 |
| SIMFEROPOL | 44.83 | 34.07 | 40.36 | 35.73 | 40.39 |
| SIMOSATO | 33.57 | 135.93 | 23.29 | 135.83 | 23.43 |
| SITKA | 57.07 | 224.67 | 59.75 | 208.87 | 59.70 |
| SODANKYLA | 67.37 | 26.63 | 63.55 | 38.42 | 63.58 |
| SOKOTO | 13.05 | 5.25 | 11.39 | 6.67 | 5.88 |
| SOROA | 22.78 | 277.00 | 36.27 | 279.26 | 34.32 |
| SREDNIKAN | 62.43 | 152.32 | 55.44 | 148.51 | 55.45 |
| ST. JOHN'S | 47.60 | 307.32 | 56.86 | 322.08 | 57.15 |
| STONYHURST | 53.85 | 357.53 | 52.43 | 8.84 | 52.14 |
| SUKKERTOPPEN | 65.42 | 307.10 | 73.36 | 330.19 | 73.35 |
| SURLARI | 44.68 | 26.25 | 40.45 | 28.84 | 40.50 |
| SVERDLOVSK | 56.73 | 61.07 | 51.75 | 62.68 | 51.89 |
| SWIDER | 52.12 | 21.25 | 48.49 | 26.68 | 48.40 |
| SYOWA BASE | -69.00 | 39.58 | -65.98 | 1.22 | -66.03 |
| TAHITI | -17.55 | 210.38 | -17.33 | 218.32 | -17.31 |
| TALARA | -4.63 | 278.70 | 15.14 | 282.83 | -2.45 |
| TAMANRASSET | 22.80 | 5.53 | 18.05 | 7.84 | 17.19 |
| TANANARIVE | -18.92 | 47.55 | -28.74 | 42.91 | -28.57 |
| TANGERANG | -6.17 | 106.63 | -8.08 | 104.44 | -13.81 |
| TASHKENT | 41.33 | 69.62 | 35.03 | 68.88 | 34.70 |
| TATUOCA | -1.20 | 311.48 | 21.09 | 317.36 | -73.80 |

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|---|---|---|---|---|---|
| TBILISI | 42.08 | 44.70 | 37.16 | 44.93 | 37.11 |
| TEHRAN | 35.73 | 51.38 | 30.09 | 50.37 | 30.05 |
| TENERIFE | 28.48 | 343.72 | 27.60 | 350.89 | 27.40 |
| TEOLOYUCAN | 19.75 | 260.82 | 29.81 | 261.54 | 28.29 |
| THULE | 77.48 | 290.83 | 86.07 | 332.35 | 86.43 |
| THULE AFB | 76.52 | 291.17 | 85.38 | 326.92 | 85.57 |
| TIHANY | 46.90 | 17.90 | 43.19 | 22.27 | 43.18 |
| TIKHAYA BAY | 80.30 | 52.80 | 74.51 | 70.77 | 74.17 |
| TIXIE BAY | 71.58 | 129.00 | 65.15 | 126.10 | 65.10 |
| TOLEDO | 39.88 | 355.95 | 37.41 | 2.93 | 37.68 |
| TOMSK | 56.47 | 84.93 | 50.89 | 85.68 | 51.04 |
| TOOLANGI | -37.53 | 145.47 | -48.40 | 152.01 | -48.09 |
| TRELEW | -43.25 | 294.68 | -30.50 | 299.05 | -30.69 |
| TRIVANDRUM | 8.48 | 76.95 | 0.00 | 74.06 | -3.65 |
| TROMSO | 69.67 | 18.95 | 66.33 | 34.64 | 66.37 |
| TSUMEB | -19.22 | 17.70 | -30.42 | 13.87 | -30.14 |
| TUCSON | 32.25 | 249.17 | 39.97 | 246.02 | 39.85 |
| TULSA | 35.92 | 264.22 | 46.96 | 262.33 | 47.07 |
| ULAN BATOR | 47.85 | 106.75 | 40.78 | 107.05 | 40.59 |
| VALENTIA | 51.93 | 349.75 | 51.52 | 2.11 | 51.26 |
| VASSOURAS | -22.40 | 316.35 | -20.99 | 316.21 | -20.01 |
| VICTORIA | 48.52 | 236.58 | 53.98 | 225.87 | 54.03 |
| VLADIVOSTOK | 43.68 | 132.17 | 35.15 | 132.63 | 34.96 |
| VOSTOK | -78.45 | 106.87 | -83.37 | 344.72 | -83.48 |
| WATHEROO | -30.32 | 115.88 | -41.75 | 114.73 | -41.68 |
| WESTON | 42.38 | 288.68 | 55.10 | 296.03 | 55.46 |
| WIEN-KOBENZL | 48.27 | 16.32 | 44.75 | 21.44 | 44.69 |
| WILKES | -66.25 | 110.58 | -80.72 | 85.67 | -80.44 |
| WINGST | 53.75 | 9.07 | 51.07 | 17.58 | 50.85 |
| WITTEVEEN | 52.82 | 6.67 | 50.32 | 15.33 | 50.09 |
| YAKUTSK | 62.02 | 129.72 | 55.29 | 129.49 | 55.46 |
| YAUCA | -15.53 | 285.33 | -15.18 | 290.07 | -11.34 |
| YELLOWKNIFE | 62.43 | 245.60 | 69.92 | 227.75 | 69.84 |
| YUZHNO-SAKHALINSK | 46.95 | 142.72 | 38.51 | 142.75 | 38.47 |
| ZARIA | 11.15 | 7.65 | 8.91 | 8.68 | 3.68 |

APPENDIX E.

| | Geographic | | Invariant | |
|---|---|---|---|---|
| | Lat. | Long. | Lat. | Long. |
| HEISS IS | 80.70 | 56.20 | 74.74 | 73.41 |
| ARRAY BOUNDARY | 80.00 | 235.00 | 82.35 | 174.75 |
| NY-ALESUND | 79.00 | 12.00 | 75.66 | 44.26 |
| SPITSBERGEN | 78.50 | 15.00 | 74.97 | 44.80 |
| SPITSBERGEN | 78.50 | 15.10 | 74.97 | 44.86 |
| THULE | 77.50 | 290.80 | 86.25 | 332.43 |
| DANMARKSHAVEN | 76.77 | 341.37 | 77.13 | 20.92 |
| THULE | 76.60 | 291.30 | 85.39 | 327.68 |
| THULE/CAMP TUTO | 76.55 | 291.17 | 85.37 | 327.08 |
| THULE | 76.40 | 291.30 | 85.24 | 326.59 |
| MOULD BAY | 76.30 | 240.60 | 80.96 | 196.64 |
| ARRAY BOUNDARY | 75.00 | 265.00 | 84.40 | 240.39 |
| ARRAY BOUNDARY | 75.00 | 235.00 | 78.86 | 195.82 |
| RESOLUTE BAY | 74.70 | 265.10 | 84.17 | 241.71 |
| BEAR ISLAND | 74.50 | 19.20 | 70.97 | 40.32 |
| SACHS HARBOUR | 72.00 | 235.00 | 76.35 | 203.01 |
| BARROW | 71.30 | 203.25 | 69.62 | 178.64 |
| SKARSVAG | 71.11 | 25.83 | 67.25 | 40.94 |
| BERLEVAG | 70.83 | 29.08 | 66.79 | 43.08 |
| SOROYA | 70.60 | 22.22 | 67.00 | 37.91 |
| KAP TOBIN | 70.42 | 338.03 | 71.98 | 6.37 |
| KUNES | 70.35 | 26.51 | 66.47 | 40.75 |
| KUNES | 70.34 | 26.52 | 66.46 | 40.75 |
| CAPE PARRY | 70.17 | 235.28 | 74.80 | 206.59 |
| MIKKELVIK | 70.07 | 19.03 | 66.71 | 35.10 |
| MATTISDALEN | 69.85 | 22.92 | 66.22 | 37.68 |
| KEVO | 69.75 | 27.02 | 65.86 | 40.57 |
| KEVO | 69.75 | 27.03 | 65.86 | 40.57 |
| TROMSO | 69.70 | 18.90 | 66.36 | 34.64 |
| TROMSO | 69.70 | 19.00 | 66.35 | 34.71 |
| TROMSO | 69.67 | 18.95 | 66.33 | 34.64 |
| SVANVIK | 69.43 | 29.98 | 65.37 | 42.54 |
| ANDOYA | 69.30 | 16.00 | 66.20 | 32.23 |
| ANDENES | 69.30 | 16.17 | 66.18 | 32.35 |
| GODHAVN | 69.30 | 306.17 | 76.97 | 333.39 |
| GODHAVN | 69.30 | 306.50 | 76.90 | 333.83 |
| MIERON | 69.12 | 23.27 | 65.48 | 37.32 |
| CAMBRIDGE BAY | 69.10 | 255.10 | 77.94 | 234.06 |
| CAMBRIDGE BAY | 69.10 | 255.00 | 77.92 | 233.89 |
| ROSTADALEN | 68.97 | 19.67 | 65.59 | 34.57 |
| SHEPHERD BAY | 68.82 | 266.57 | 79.36 | 255.58 |
| IVALO | 68.60 | 27.46 | 64.71 | 39.96 |
| IVALO | 68.60 | 27.47 | 64.71 | 39.97 |
| IVALO | 68.59 | 27.47 | 64.70 | 39.96 |
| PELLY BAY | 68.53 | 270.49 | 79.46 | 264.09 |
| EVENES | 68.47 | 16.75 | 65.32 | 32.00 |
| INUVIK | 68.35 | 226.20 | 71.15 | 200.41 |
| PALLASTUNTURI | 68.12 | 23.88 | 64.46 | 36.90 |
| MUONIO | 68.03 | 23.56 | 64.39 | 36.65 |
| ABISKO | 68.00 | 19.00 | 64.68 | 33.27 |

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|---|---|---|---|---|
| ARRAY BOUNDARY | 68.00 | 250.00 | 75.99 | 227.82 |
| MOSKENES | 67.88 | 13.00 | 65.05 | 28.81 |
| KIRUNA | 67.84 | 20.42 | 64.42 | 34.18 |
| KIRUNA | 67.83 | 20.42 | 64.41 | 34.17 |
| KIRUNA | 67.80 | 20.40 | 64.38 | 34.13 |
| RITSEMJOKK | 67.68 | 17.50 | 64.48 | 31.90 |
| APATITY | 67.55 | 33.30 | 63.36 | 43.64 |
| MARTTI | 67.47 | 28.28 | 63.55 | 39.74 |
| MARTTI | 67.47 | 28.29 | 63.55 | 39.75 |
| SODANKYLA | 67.42 | 26.40 | 63.61 | 38.28 |
| SODANKYLA | 67.40 | 26.60 | 63.58 | 38.42 |
| SODANKYLA | 67.37 | 26.63 | 63.55 | 38.42 |
| SODANKYLA | 67.36 | 26.63 | 63.54 | 38.41 |
| SODANKYLA | 67.36 | 26.64 | 63.54 | 38.42 |
| ROVANIEMI | 67.35 | 25.83 | 63.58 | 37.80 |
| SODANKYLA | 67.35 | 26.63 | 63.53 | 38.40 |
| BODO | 67.00 | 14.00 | 64.10 | 28.78 |
| SDR STROMF JORD | 67.00 | 310.00 | 74.20 | 335.43 |
| KVIKKJOKK | 66.97 | 17.75 | 63.76 | 31.49 |
| GLOMFJORD | 66.90 | 13.58 | 64.03 | 28.39 |
| PELLO | 66.85 | 24.63 | 63.16 | 36.52 |
| NATTAVARA | 66.75 | 21.00 | 63.30 | 33.72 |
| FORT YUKON | 66.60 | 214.80 | 67.05 | 192.58 |
| FORT YUKON | 66.57 | 214.75 | 67.01 | 192.57 |
| LEIRSKARDALEN | 66.05 | 14.07 | 63.15 | 28.11 |
| DOLGOSCHELIE | 66.03 | 43.24 | 61.46 | 50.51 |
| ARJEPLOG | 66.00 | 18.10 | 62.77 | 31.05 |
| ICELAND | 66.00 | 340.00 | 67.44 | 2.97 |
| SIGLUFJORDUR | 66.00 | 341.00 | 67.27 | 3.75 |
| KUUSAMO | 65.91 | 29.04 | 61.97 | 39.26 |
| KUUSAMO | 65.91 | 29.05 | 61.97 | 39.27 |
| ANGMAGSSALIK | 65.61 | 322.34 | 70.42 | 347.38 |
| DULU | 65.33 | 25.40 | 61.61 | 36.07 |
| PITEA | 65.25 | 21.58 | 61.77 | 33.11 |
| DULU | 65.11 | 25.48 | 61.38 | 35.98 |
| DULU | 65.10 | 25.48 | 61.37 | 35.97 |
| DULU | 65.10 | 25.49 | 61.37 | 35.98 |
| POKER FLAT | 65.10 | 212.50 | 65.08 | 192.12 |
| CHATANIKA | 65.10 | 212.55 | 65.09 | 192.16 |
| DULU | 65.08 | 25.87 | 61.33 | 36.26 |
| KLIMPFJALL | 65.05 | 14.80 | 62.09 | 27.96 |
| BRONNOJSUND | 65.00 | 12.00 | 62.28 | 25.83 |
| KEM | 65.00 | 34.40 | 60.80 | 42.86 |
| COLLEGE | 64.90 | 212.00 | 64.78 | 191.87 |
| COLLEGE | 64.90 | 212.20 | 64.82 | 192.05 |
| COLLEGE | 64.87 | 212.17 | 64.79 | 192.05 |
| COLLEGE | 64.86 | 212.15 | 64.77 | 192.02 |
| COLLEGE | 64.85 | 212.17 | 64.77 | 192.05 |
| POKER FLAT | 64.80 | 212.37 | 64.76 | 192.25 |
| LYCKSELE | 64.70 | 18.80 | 61.42 | 30.69 |

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|---|---|---|---|---|
| EIELSON AFB | 64.70 | 213.00 | 64.78 | 192.87 |
| LYCKSELE | 64.62 | 18.67 | 61.35 | 30.54 |
| PORT CLARENCE | 64.50 | 194.57 | 61.22 | 178.80 |
| NAMSOS | 64.43 | 11.00 | 61.80 | 24.68 |
| BAKER LAKE | 64.33 | 263.97 | 75.01 | 254.00 |
| LEIRVOGUR | 64.20 | 338.30 | 65.98 | 359.92 |
| GODTHAB | 64.19 | 308.27 | 72.02 | 330.63 |
| ESTER DOME | 64.05 | 211.91 | 63.91 | 192.52 |
| ICELAND | 64.00 | 339.00 | 65.66 | 359.53 |
| ICELAND | 64.00 | 345.00 | 64.64 | 5.16 |
| STROMSUND | 63.92 | 15.47 | 60.90 | 27.65 |
| JOKIKYLA | 63.80 | 25.97 | 60.05 | 35.57 |
| SOGRA | 62.80 | 46.25 | 58.19 | 51.47 |
| RANKIN INLET | 62.80 | 267.66 | 74.01 | 261.35 |
| FAEROES | 62.50 | 353.00 | 61.93 | 10.07 |
| YELLOWKNIFE | 62.43 | 245.60 | 69.92 | 227.75 |
| JYVASKYLA | 62.40 | 25.67 | 58.67 | 34.57 |
| STADLANDET | 62.17 | 5.12 | 60.11 | 18.87 |
| THORSHAVN | 62.03 | 353.24 | 61.42 | 9.94 |
| KANGASNIEMI | 62.02 | 26.65 | 58.24 | 35.12 |
| ANGEBO | 61.98 | 16.42 | 58.88 | 27.17 |
| NARSSARSSUAQ | 61.20 | 314.60 | 67.94 | 335.93 |
| ESKIMO POINT | 61.10 | 265.94 | 72.25 | 259.03 |
| NURMIJARVI | 60.52 | 24.65 | 56.85 | 32.79 |
| NURMIJARVI | 60.51 | 24.65 | 56.84 | 32.79 |
| NURMIJARVI | 60.51 | 24.66 | 56.84 | 32.79 |
| NURMIJARVI | 60.50 | 24.70 | 56.83 | 32.82 |
| BORLANGE | 60.29 | 15.25 | 57.26 | 25.35 |
| LERWICK | 60.13 | 358.82 | 58.76 | 12.90 |
| SW NORWAY | 60.00 | 12.00 | 57.24 | 22.78 |
| FORT SMITH | 60.00 | 248.00 | 68.11 | 232.67 |
| LENINGRAD | 59.95 | 30.70 | 55.95 | 37.35 |
| UPPSALA | 59.80 | 17.60 | 56.59 | 26.96 |
| HOMER | 59.73 | 208.49 | 58.82 | 192.79 |
| LOVO | 59.40 | 17.80 | 56.17 | 26.89 |
| CHURCHILL | 58.80 | 265.80 | 70.06 | 259.63 |
| CHURCHILL | 58.80 | 265.90 | 70.08 | 259.79 |
| EIGERSUND | 58.65 | 6.10 | 56.42 | 17.61 |
| STORNOWAY | 58.20 | 354.50 | 57.35 | 8.63 |
| BOROK | 58.03 | 38.97 | 53.68 | 43.44 |
| HERCHMER | 57.40 | 265.90 | 68.74 | 260.24 |
| SOUTH UIST | 57.20 | 352.86 | 56.55 | 6.85 |
| ABERDEEN (UK) | 57.17 | 357.93 | 55.83 | 10.65 |
| SITKA | 57.06 | 224.67 | 59.74 | 208.88 |
| ST ANTHONY | 57.06 | 308.65 | 65.38 | 326.81 |
| GILLAM | 56.85 | 265.59 | 68.17 | 259.89 |
| FORT MCMURRAY | 56.70 | 248.60 | 65.02 | 235.53 |
| ALSBJERG | 56.68 | 9.10 | 54.10 | 18.85 |
| SITKINAK | 56.58 | 205.83 | 55.07 | 192.37 |
| TOMSK | 56.00 | 84.00 | 50.42 | 84.78 |

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|---|---|---|---|---|
| COPENHAGEN | 55.85 | 12.45 | 52.96 | 21.09 |
| EARLY BURN | 55.73 | 356.77 | 54.49 | 9.06 |
| GOOSE BAY | 55.33 | 299.50 | 65.61 | 314.21 |
| ESKDALEMUIR | 55.32 | 356.80 | 54.06 | 8.93 |
| GREAT WHALE | 55.27 | 282.22 | 67.48 | 287.47 |
| KUHLUNGSBORN | 55.00 | 12.70 | 52.06 | 20.90 |
| THOMPSON | 55.00 | 263.00 | 66.03 | 256.44 |
| THOMPSON | 54.90 | 261.40 | 65.69 | 254.08 |
| COLLIN MOUNTAIN | 54.80 | 353.92 | 53.91 | 6.50 |
| JORDANSTOWN | 54.70 | 354.10 | 53.78 | 6.59 |
| MEANOOK | 54.62 | 246.67 | 62.52 | 234.25 |
| HAMBURGER HALLIG | 54.60 | 8.83 | 51.98 | 17.81 |
| JULIUSRUH/RUGEN | 54.60 | 13.40 | 51.59 | 21.27 |
| WARNKENHAGEN | 54.00 | 11.07 | 51.16 | 19.25 |
| NORWAY HOUSE | 53.98 | 262.17 | 64.91 | 255.52 |
| YORK | 53.97 | 358.92 | 52.38 | 9.91 |
| STONYHURST | 53.85 | 357.53 | 52.43 | 8.84 |
| SHEFFIELD | 53.43 | 358.42 | 51.87 | 9.29 |
| EDGEMOUNT | 53.40 | 358.50 | 51.83 | 9.34 |
| DWINGELOO | 53.00 | 6.00 | 50.57 | 14.89 |
| LUECHOW | 53.00 | 11.20 | 50.10 | 18.92 |
| LANCASTER | 53.00 | 358.00 | 51.47 | 8.79 |
| ATTU | 52.83 | 186.83 | 47.83 | 178.50 |
| WITTEVEEN | 52.82 | 6.67 | 50.32 | 15.33 |
| EAST ANGLIA | 52.63 | 1.30 | 50.68 | 11.18 |
| PARATUNKA | 52.58 | 158.14 | 44.81 | 155.60 |
| POTSDAM | 52.55 | 13.07 | 49.48 | 20.20 |
| ABERYSTWYTH | 52.43 | 355.93 | 51.14 | 6.98 |
| ABERYSTWYTH | 52.42 | 355.93 | 51.13 | 6.98 |
| CAMBRIDGE | 52.17 | 0.03 | 50.35 | 10.00 |
| MALVERN | 52.13 | 357.67 | 50.60 | 8.22 |
| DE BILT | 52.10 | 5.20 | 49.71 | 13.95 |
| SASKATOON | 52.10 | 253.40 | 61.45 | 243.99 |
| UTRECHT | 52.08 | 5.13 | 49.69 | 13.88 |
| NIEMEGK | 52.07 | 12.68 | 49.01 | 19.77 |
| LEICESTER | 52.00 | 359.00 | 50.29 | 9.15 |
| VALENTIA | 51.93 | 349.75 | 51.52 | 2.11 |
| BELSK | 51.83 | 20.80 | 48.22 | 26.20 |
| LINDAU | 51.65 | 10.13 | 48.78 | 17.60 |
| LINDAU | 51.62 | 10.09 | 48.75 | 17.55 |
| MOOSONEE | 51.50 | 279.33 | 63.97 | 282.57 |
| REMOTE OBSERVATORY | 48.60 | 252.90 | 57.80 | 244.74 |
| VICTORIA | 48.52 | 236.58 | 53.98 | 225.87 |
| VICTORIA | 48.46 | 236.70 | 53.94 | 226.03 |
| LANNION | 48.45 | 356.73 | 46.78 | 6.14 |
| ROBERVAL | 48.31 | 287.87 | 60.67 | 295.56 |
| NEWPORT | 48.26 | 242.88 | 55.20 | 232.93 |
| FURSTENFELDBRUCK | 48.17 | 11.28 | 44.99 | 17.35 |
| GLASGOW/MONTANA | 48.12 | 253.62 | 57.46 | 245.83 |
| CHAMBON-LA-FORET | 48.02 | 2.27 | 45.65 | 10.24 |

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|---|---|---|---|---|
| HURBANOVO | 47.87 | 18.18 | 44.21 | 22.83 |
| LAC REBOURS | 47.87 | 287.55 | 60.28 | 295.04 |
| WEISSENAU | 47.77 | 9.59 | 44.69 | 15.86 |
| NAGYCENK | 47.63 | 16.72 | 44.04 | 21.55 |
| ST JOHNS | 47.60 | 307.30 | 56.87 | 322.06 |
| BUDAPEST | 47.49 | 18.96 | 43.76 | 23.35 |
| ZUGSPITZE | 47.42 | 10.98 | 44.20 | 16.85 |
| GARCHY | 47.30 | 3.10 | 44.78 | 10.61 |
| GARMISCH | 47.29 | 11.05 | 44.06 | 16.86 |
| GRAZ | 47.10 | 15.50 | 43.55 | 20.38 |
| GRAZ | 47.08 | 15.49 | 43.53 | 20.37 |
| NEUCHATEL | 47.00 | 6.95 | 44.08 | 13.51 |
| LORING AFB | 46.95 | 292.12 | 59.00 | 301.65 |
| TIHANY | 46.90 | 17.90 | 43.19 | 22.27 |
| UECHT NEAR BERNE | 46.85 | 7.45 | 43.87 | 13.85 |
| KANZELHOHE | 46.68 | 13.90 | 43.20 | 18.93 |
| POITIERS | 46.60 | 0.30 | 44.32 | 8.20 |
| JUNGFRAUJOCH | 46.55 | 7.90 | 43.51 | 14.10 |
| RICHLAND | 46.40 | 240.40 | 52.71 | 231.02 |
| OTTAWA | 45.40 | 284.40 | 58.13 | 290.03 |
| OTTAWA | 45.20 | 284.50 | 57.94 | 290.17 |
| TORINO | 45.05 | 7.75 | 41.88 | 13.57 |
| PITTSBURG | 45.03 | 288.56 | 57.57 | 296.18 |
| GENOVA | 44.55 | 8.95 | 41.24 | 14.48 |
| BOLOGNA | 44.55 | 11.63 | 41.04 | 16.62 |
| BOLOGNA | 44.50 | 11.35 | 41.01 | 16.36 |
| BUCHAREST | 44.41 | 26.10 | 40.16 | 28.64 |
| NANCAY | 44.20 | 2.20 | 41.47 | 9.02 |
| MOSHIRI | 44.37 | 142.27 | 35.66 | 142.37 |
| ROBURENT | 44.30 | 7.88 | 41.05 | 13.52 |
| SAINT SANTIN | 44.11 | 2.03 | 41.39 | 8.86 |
| MEMAMBETSU | 43.90 | 144.20 | 35.11 | 144.10 |
| TORONTO | 43.90 | 280.60 | 56.73 | 284.26 |
| ARCETRI | 43.75 | 11.25 | 40.19 | 16.04 |
| MEMAMBETSU | 43.58 | 144.20 | 34.76 | 144.15 |
| ALMA ATA | 43.25 | 76.92 | 36.73 | 76.37 |
| DURHAM | 43.10 | 289.10 | 55.74 | 296.70 |
| HOKKAIDO | 42.75 | 143.71 | 33.83 | 143.66 |
| MCMATH-HULBERT | 42.67 | 276.70 | 55.38 | 278.55 |
| SAGAMORE HILL | 42.61 | 289.20 | 55.28 | 296.80 |
| MILLSTONE HILL | 42.60 | 288.50 | 55.32 | 295.78 |
| LONDON/ONTARIO | 42.59 | 278.86 | 55.42 | 281.69 |
| MAYNARD | 42.43 | 288.55 | 55.16 | 295.84 |
| HAYSTACK OBS | 42.40 | 289.00 | 55.10 | 296.49 |
| L'AQUILA | 42.38 | 13.31 | 38.55 | 17.39 |
| HAMILTON | 42.25 | 289.00 | 54.96 | 296.48 |
| ANN ARBOR | 42.24 | 276.27 | 54.94 | 277.92 |
| ROME | 41.90 | 12.50 | 38.07 | 16.59 |
| NANTUCKET ISLAND | 41.27 | 289.90 | 53.99 | 297.62 |
| PENN STATE U | 40.82 | 282.13 | 53.82 | 286.38 |

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|---|---|---|---|---|
| CAPRI F | 40.55 | 14.22 | 36.48 | 17.72 |
| LAUREL RIDGE | 40.16 | 280.84 | 53.16 | 284.47 |
| BOULDER | 40.13 | 254.77 | 49.43 | 249.86 |
| BOULDER | 40.10 | 254.70 | 49.39 | 249.79 |
| BOULDER | 40.03 | 254.70 | 49.31 | 249.81 |
| BOULDER | 40.00 | 254.70 | 49.28 | 249.82 |
| DENVER | 39.75 | 255.00 | 49.08 | 250.25 |
| MORIOKA | 39.70 | 141.12 | 30.43 | 141.23 |
| COLORADO SPRINGS | 38.50 | 255.51 | 47.89 | 251.21 |
| PATRAS | 38.23 | 23.81 | 33.53 | 25.34 |
| FREDERICKSBURG | 38.20 | 282.63 | 51.35 | 286.97 |
| ZAO | 38.10 | 140.55 | 28.62 | 140.57 |
| ATHENS | 38.00 | 23.81 | 33.28 | 25.51 |
| ATHENS | 37.99 | 23.75 | 33.27 | 25.45 |
| ATHENS | 37.97 | 23.72 | 33.25 | 25.42 |
| ATHENS | 37.96 | 23.70 | 33.24 | 25.40 |
| WALLOPS ISLAND | 37.90 | 284.50 | 51.09 | 289.61 |
| FUKUSHIMA | 37.75 | 140.46 | 28.22 | 140.47 |
| NIIGATA | 37.70 | 138.82 | 28.18 | 138.93 |
| CATANIA | 37.50 | 15.08 | 33.07 | 17.89 |
| STANFORD | 37.43 | 237.83 | 42.87 | 232.15 |
| SEOUL | 37.32 | 126.56 | 28.01 | 126.61 |
| CASTLE ROCK | 37.23 | 237.87 | 42.67 | 232.27 |
| OSAN AB | 37.11 | 127.04 | 27.75 | 127.10 |
| SICILY | 37.00 | 14.00 | 32.58 | 16.85 |
| SUGADAIRA | 36.51 | 138.35 | 26.81 | 138.38 |
| HIRAISO | 36.37 | 140.63 | 26.62 | 140.60 |
| HIDA | 36.25 | 137.30 | 26.46 | 137.35 |
| MISATO | 36.23 | 138.57 | 26.44 | 138.59 |
| KAKIOKA | 36.23 | 140.18 | 26.45 | 140.16 |
| MT NORIKURA | 36.12 | 137.50 | 26.31 | 137.54 |
| HUNTSVILLE | 34.44 | 273.65 | 47.01 | 274.57 |
| VANDENBURG AFB | 34.43 | 239.67 | 40.17 | 235.24 |
| BIG BEAR | 34.16 | 243.49 | 40.72 | 239.33 |
| GULMARG | 34.07 | 74.40 | 25.92 | 73.16 |
| SAN FERNANDO OBS | 34.05 | 241.51 | 40.17 | 237.30 |
| SOCORRO | 34.04 | 253.07 | 42.69 | 249.72 |
| SRINAGAR | 34.00 | 74.60 | 25.81 | 73.35 |
| CALTECH | 34.00 | 242.00 | 40.23 | 237.83 |
| KYUSHU UNIV | 33.00 | 131.00 | 22.56 | 130.82 |
| DALLAS | 32.98 | 263.25 | 43.75 | 261.68 |
| LA POSTA | 32.80 | 243.57 | 39.32 | 239.90 |
| SACRAMENTO PEAK | 32.72 | 254.25 | 41.57 | 251.41 |
| LA JOLLA | 32.51 | 242.48 | 38.79 | 238.87 |
| TUCSON | 32.25 | 249.17 | 39.97 | 246.02 |
| TEL AVIV | 32.10 | 34.50 | 27.13 | 34.18 |
| KANOYA | 31.42 | 130.88 | 20.60 | 130.58 |
| @UCHINOURA | 31.25 | 131.07 | 20.39 | 130.76 |
| FORT DAVIS | 30.63 | 256.48 | 39.88 | 254.44 |
| SABHAWALA | 30.33 | 77.80 | 20.62 | 76.28 |

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|---|---|---|---|---|
| CAIRO | 30.03 | 31.15 | 24.77 | 30.96 |
| DELHI | 28.60 | 77.10 | 18.36 | 75.48 |
| PATRICK AFB | 28.20 | 279.40 | 41.71 | 282.23 |
| CANARY ISLANDS | 28.00 | 344.70 | 26.84 | 351.55 |
| ALIGARH | 27.90 | 78.07 | 17.19 | 76.39 |
| OGASAWARA | 27.15 | 142.30 | 15.62 | 141.86 |
| JUPITER | 27.02 | 279.88 | 40.66 | 282.84 |
| JAIPUR | 26.92 | 75.79 | 16.19 | 74.08 |
| MARCUS | 26.51 | 128.15 | 13.89 | 127.40 |
| OKINARA | 26.30 | 127.80 | 13.55 | 127.01 |
| SHILLONG | 25.56 | 91.88 | 11.34 | 89.86 |
| LUNPING | 25.00 | 121.17 | 11.03 | 119.97 |
| TAIPEI | 25.00 | 121.20 | 11.03 | 120.00 |
| CARNARVON | -25.00 | 1110.00 | -35.12 | 24.49 |
| HARTEBEESTHOEK | -25.88 | 27.71 | -35.89 | 22.03 |
| JOHANNESBURG | -26.10 | 28.10 | -36.07 | 22.33 |
| KEETMANSHOOP | -26.53 | 18.12 | -36.23 | 12.03 |
| POTCHEFSTROOM | -26.70 | 27.10 | -36.56 | 21.08 |
| SAN MIGUEL | -27.00 | 295.00 | -20.07 | 298.91 |
| BRIBIE ISLAND | -27.30 | 153.00 | -36.39 | 158.55 |
| BRISBANE | -27.50 | 152.90 | -36.62 | 158.42 |
| BRISBANE | -27.53 | 152.92 | -36.65 | 158.45 |
| NGOYA | -28.83 | 31.88 | -38.27 | 24.99 |
| NORFOLK ISLAND | -29.00 | 168.00 | -36.17 | 176.41 |
| CULGOORA | -30.32 | 149.57 | -40.04 | 155.14 |
| ARMIDALE | -30.50 | 151.50 | -40.04 | 157.50 |
| PILAR | -31.01 | 296.07 | -22.28 | 299.74 |
| WOOMERA | -31.10 | 136.78 | -41.86 | 139.92 |
| SAN JUAN (ARG) | -31.50 | 294.50 | -22.44 | 298.58 |
| PERTH | -31.56 | 115.50 | -43.24 | 114.24 |
| GNANGARA | -31.78 | 115.95 | -43.49 | 114.77 |
| EL LEONCITO | -31.80 | 290.70 | -22.39 | 295.73 |
| MUNDARING | -32.00 | 116.20 | -43.74 | 115.07 |
| SUTHERLAND | -32.38 | 20.70 | -40.64 | 12.37 |
| CAMDEN | -32.75 | 151.50 | -42.50 | 158.10 |
| GRAHAMSTOWN | -33.28 | 26.48 | -41.56 | 17.86 |
| GRAHAMSTOWN | -33.30 | 26.51 | -41.58 | 17.88 |
| SYDNEY/FLEURS | -33.87 | 150.77 | -43.80 | 157.50 |
| HERMANUS | -34.42 | 19.23 | -41.93 | 10.04 |
| HERMANUS | -34.43 | 19.23 | -41.94 | 10.04 |
| BUENOS AIRES | -34.50 | 301.50 | -24.93 | 303.58 |
| BUENOS AIRES | -34.55 | 301.27 | -24.93 | 303.42 |
| ADELAIDE | -34.60 | 138.40 | -45.75 | 142.53 |
| LAS ACACIAS | -35.00 | 302.32 | -25.35 | 304.13 |
| CANBERRA | -35.30 | 149.00 | -45.56 | 155.73 |
| DENILIQUIN | -35.32 | 144.58 | -46.04 | 150.32 |
| AUCKLAND | -36.51 | 174.45 | -42.88 | 186.04 |
| AUCKLAND | -37.00 | 175.00 | -43.28 | 186.84 |
| BEVERIDGE | -37.47 | 144.93 | -48.39 | 151.32 |
| TOOLANGI | -37.53 | 145.47 | -48.40 | 152.01 |

| | | | | |
|---|---|---|---|---|
| ASPENDALE | -38.02 | 145.07 | -48.98 | 151.66 |
| FUTURE STATION | -40.00 | 290.00 | -27.94 | 295.76 |
| WELLINGTON | -41.23 | 174.92 | -47.65 | 188.51 |
| LAUNCESTON | -42.00 | 213.00 | -40.89 | 228.54 |
| HOBART | -42.50 | 147.20 | -53.66 | 155.73 |
| HOBART | -42.90 | 147.20 | -54.09 | 155.83 |
| HOBART | -42.92 | 147.20 | -54.11 | 155.84 |
| AMBERLEY | -43.15 | 172.72 | -50.05 | 186.90 |
| TRELEW | -43.20 | 294.70 | -30.47 | 299.06 |
| TRELEW | -43.25 | 294.68 | -30.50 | 299.05 |
| GODLEY HEAD | -43.57 | 172.80 | -50.47 | 187.21 |
| CHRISTCHURCH | -43.60 | 172.80 | -50.50 | 187.22 |
| BIRDLINGS FLAT | -44.00 | 173.00 | -50.87 | 187.66 |
| LAUDER | -45.05 | 169.67 | -52.61 | 184.38 |
| DUNEDIN | -45.90 | 170.60 | -53.29 | 185.93 |
| INVERCARGILL | -46.40 | 168.30 | -54.26 | 183.51 |
| SLOPE POINT | -46.67 | 169.02 | -54.40 | 184.51 |
| MARION ISLAND | -46.85 | 37.87 | -51.66 | 21.30 |
| KERGUELEN | -49.30 | 70.50 | -58.25 | 50.74 |
| KERGUELEN | -49.35 | 70.20 | -58.24 | 50.37 |
| KERGUELEN | -49.40 | 70.30 | -58.30 | 50.59 |
| CAMPBELL ISLAND | -52.50 | 169.20 | -60.30 | 188.68 |
| CAMPBELL ISLAND | -52.55 | 169.15 | -60.36 | 188.66 |
| CAMPBELL ISLAND | -52.55 | 169.25 | -60.34 | 188.78 |
| SOUTH GEORGIA | -54.28 | 323.50 | -42.91 | 316.60 |
| MACQUARIE ISLAND | -54.50 | 158.95 | -64.47 | 177.67 |
| MACQUARIE ISLAND | -54.50 | 158.90 | -64.48 | 177.61 |
| MACQUARIE ISLAND | -54.50 | 159.00 | -64.46 | 177.74 |
| USHUAIA | -54.80 | 291.70 | -40.22 | 297.96 |
| ARGENTINE ISLAND | -65.20 | 295.70 | -49.79 | 301.38 |
| CASEY | -66.17 | 110.32 | -80.60 | 85.31 |
| FIELD SITE / CASEY | -66.17 | 110.32 | -80.60 | 85.31 |
| CASEY | -66.20 | 110.35 | -80.64 | 85.29 |
| TERRE ADELIE | -66.40 | 140.01 | -80.34 | 164.12 |
| TERRE ADELIE | -66.70 | 140.00 | -80.68 | 164.86 |
| MAWSON | -67.60 | 62.80 | -70.09 | 19.55 |
| MAWSON | -67.60 | 62.88 | -70.11 | 19.61 |
| MAWSON | -67.60 | 62.90 | -70.11 | 19.63 |
| DAVIS | -68.60 | 78.00 | -74.48 | 29.60 |
| SYOWA BASE | -69.00 | 39.35 | -65.94 | 1.07 |
| SYOWA BASE | -69.00 | 39.58 | -65.98 | 1.22 |
| SYOWA BASE | -69.00 | 39.60 | -65.99 | 1.23 |
| SANAE | -70.30 | 357.60 | -59.91 | 334.35 |
| SANAE | -70.30 | 357.65 | -59.91 | 334.38 |
| SANAE | -70.31 | 357.64 | -59.92 | 334.37 |
| HALLEY BAY | -75.50 | 333.40 | -61.04 | 319.65 |
| SIPLE | -76.00 | 276.00 | -61.10 | 294.94 |
| BELGRANO | -77.80 | 321.75 | -62.33 | 314.12 |
| MCMURDO | -77.85 | 166.70 | -80.06 | 257.98 |
| SCOTT BASE | -77.85 | 166.78 | -80.04 | 257.98 |
| SCOTT BASE | -77.90 | 166.80 | -80.04 | 258.29 |
| BELGRANO | -77.97 | 321.20 | -62.46 | 313.88 |
| VOSTOK | -78.45 | 106.87 | -83.37 | 344.72 |

APPENDIX F.

FILE LAT250

| | | | |
|---|---|---|---|
| 1 | 1 | 0.182 | 0.000 |
| 1 | 2 | -0.736 | 0.000 |
| 2 | 2 | 0.673 | -0.318 |
| 1 | 3 | -0.028 | 0.000 |
| 2 | 3 | -0.996 | -0.158 |
| 3 | 3 | 0.610 | 0.220 |
| 1 | 4 | 0.050 | 0.000 |
| 2 | 4 | 0.765 | -0.604 |
| 3 | 4 | 0.356 | -0.219 |
| 4 | 4 | 0.245 | -0.082 |
| 1 | 5 | -0.540 | 0.000 |
| 2 | 5 | -0.270 | -0.593 |
| 3 | 5 | 1.247 | 0.461 |
| 4 | 5 | -0.021 | -0.108 |
| 5 | 5 | 0.067 | -0.074 |
| 1 | 6 | 0.317 | 0.000 |
| 2 | 6 | -0.583 | -0.215 |
| 3 | 6 | 0.548 | -0.188 |
| 4 | 6 | 0.445 | -0.200 |
| 5 | 6 | -0.032 | -0.076 |
| 6 | 6 | -0.001 | 0.020 |
| 1 | 7 | 0.040 | 0.000 |
| 2 | 7 | 0.425 | -0.346 |
| 3 | 7 | 0.457 | 0.159 |
| 4 | 7 | -0.140 | -0.070 |
| 5 | 7 | 0.116 | -0.149 |
| 6 | 7 | -0.014 | -0.003 |
| 7 | 7 | -0.017 | 0.000 |
| 1 | 8 | -0.127 | 0.000 |
| 2 | 8 | -0.135 | -0.234 |
| 3 | 8 | 0.294 | 0.018 |
| 4 | 8 | 0.084 | -0.162 |
| 5 | 8 | -0.086 | -0.068 |
| 6 | 8 | -0.013 | 0.040 |
| 7 | 8 | -0.013 | 0.005 |
| 8 | 8 | -0.002 | -0.002 |
| 1 | 9 | 0.023 | 0.000 |
| 2 | 9 | 0.024 | 0.036 |
| 3 | 9 | 0.143 | 0.001 |
| 4 | 9 | -0.115 | -0.001 |
| 5 | 9 | 0.003 | -0.044 |
| 6 | 9 | -0.007 | 0.006 |
| 7 | 9 | -0.029 | 0.001 |
| 8 | 9 | -0.005 | 0.003 |
| 9 | 9 | -0.002 | -0.002 |
| 1 | 10 | 0.026 | 0.000 |
| 2 | 10 | 0.017 | -0.165 |
| 3 | 10 | 0.060 | 0.045 |
| 4 | 10 | 0.009 | -0.123 |
| 5 | 10 | -0.088 | -0.015 |
| 6 | 10 | -0.027 | 0.016 |
| 7 | 10 | -0.004 | 0.005 |
| 8 | 10 | -0.003 | -0.006 |
| 9 | 10 | -0.000 | 0.001 |
| 10 | 10 | -0.001 | 0.002 |

| | | | |
|---|---|---|---|
| 1 | 11 | -0.071 | 0.000 |
| 2 | 11 | 0.065 | -0.126 |
| 3 | 11 | 0.098 | 0.001 |
| 4 | 11 | 0.025 | -0.037 |
| 5 | 11 | -0.025 | 0.006 |
| 6 | 11 | 0.007 | 0.017 |
| 7 | 11 | -0.000 | 0.001 |
| 8 | 11 | -0.003 | 0.001 |
| 9 | 11 | -0.003 | -0.005 |
| 10 | 11 | -0.000 | 0.001 |
| 11 | 11 | 0.001 | -0.000 |
| 1 | 12 | -0.012 | 0.000 |
| 2 | 12 | -0.079 | -0.069 |
| 3 | 12 | 0.031 | 0.010 |
| 4 | 12 | 0.027 | -0.062 |
| 5 | 12 | -0.042 | -0.029 |
| 6 | 12 | -0.021 | 0.012 |
| 7 | 12 | 0.014 | 0.005 |
| 8 | 12 | 0.002 | -0.004 |
| 9 | 12 | 0.001 | -0.001 |
| 10 | 12 | -0.002 | 0.003 |
| 11 | 12 | 0.000 | -0.001 |
| 12 | 12 | 0.001 | 0.001 |
| 1 | 13 | -0.013 | 0.000 |
| 2 | 13 | 0.031 | -0.084 |
| 3 | 13 | 0.058 | 0.010 |
| 4 | 13 | 0.015 | -0.030 |
| 5 | 13 | -0.016 | -0.002 |
| 6 | 13 | 0.001 | 0.009 |
| 7 | 13 | 0.002 | 0.002 |
| 8 | 13 | 0.004 | -0.003 |
| 9 | 13 | 0.002 | -0.002 |
| 10 | 13 | -0.002 | 0.002 |
| 11 | 13 | 0.001 | -0.002 |
| 12 | 13 | 0.001 | 0.001 |
| 13 | 13 | 0.001 | 0.000 |
| 1 | 14 | -0.050 | 0.000 |
| 2 | 14 | 0.020 | -0.048 |
| 3 | 14 | 0.014 | 0.002 |
| 4 | 14 | 0.000 | -0.022 |
| 5 | 14 | -0.025 | -0.027 |
| 6 | 14 | -0.015 | 0.020 |
| 7 | 14 | 0.006 | 0.013 |
| 8 | 14 | 0.005 | 0.003 |
| 9 | 14 | 0.001 | -0.003 |
| 10 | 14 | -0.000 | -0.001 |
| 11 | 14 | 0.001 | -0.000 |
| 12 | 14 | 0.001 | 0.003 |
| 13 | 14 | -0.000 | -0.001 |
| 14 | 14 | 0.001 | -0.001 |
| 1 | 15 | -0.050 | 0.000 |
| 2 | 15 | -0.051 | 0.045 |
| 3 | 15 | 0.043 | -0.003 |
| 4 | 15 | -0.014 | -0.028 |
| 5 | 15 | -0.021 | -0.007 |

| | | | |
|---|---|---|---|
| 6 | 15 | -0.002 | -0.001 |
| 7 | 15 | 0.001 | -0.001 |
| 8 | 15 | 0.002 | -0.003 |
| 9 | 15 | -0.000 | 0.000 |
| 10 | 15 | -0.001 | 0.001 |
| 11 | 15 | -0.001 | -0.003 |
| 12 | 15 | 0.002 | 0.001 |
| 13 | 15 | 0.003 | -0.000 |
| 14 | 15 | 0.000 | 0.001 |
| 15 | 15 | 0.002 | 0.001 |

APPENDIX G.    FILE LNG250

| | | | | | |
|---|---|---|---|---|---|
| 1 | 1 | -0.0113 | 0.0000 | 0.0239 | 0.0000 |
| 1 | 2 | 0.1270 | 0.0000 | -0.0522 | 0.0000 |
| 2 | 2 | 0.0259 | 0.9537 | 0.9805 | -0.0143 |
| 1 | 3 | -0.0209 | 0.0000 | 0.0184 | 0.0000 |
| 2 | 3 | 0.0076 | -0.0113 | 0.0620 | 0.0153 |
| 3 | 3 | -0.0318 | -0.0560 | -0.0504 | 0.0204 |
| 1 | 4 | -0.0010 | 0.0000 | -0.0215 | 0.0000 |
| 2 | 4 | -0.0080 | -0.0259 | 0.0098 | -0.0012 |
| 3 | 4 | -0.0034 | -0.0078 | 0.0309 | -0.0033 |
| 4 | 4 | -0.0073 | -0.0042 | -0.0087 | -0.0078 |
| 1 | 5 | 0.0048 | 0.0000 | 0.0084 | 0.0000 |
| 2 | 5 | -0.0003 | -0.0085 | -0.0092 | -0.0046 |
| 3 | 5 | -0.0030 | 0.0021 | -0.0132 | 0.0025 |
| 4 | 5 | -0.0066 | -0.0137 | 0.0009 | -0.0086 |
| 5 | 5 | -0.0063 | 0.0085 | -0.0016 | -0.0024 |
| 1 | 6 | -0.0025 | 0.0000 | 0.0048 | 0.0000 |
| 2 | 6 | 0.0061 | -0.0009 | 0.0022 | 0.0017 |
| 3 | 6 | -0.0029 | 0.0044 | -0.0001 | -0.0005 |
| 4 | 6 | 0.0008 | -0.0037 | -0.0078 | 0.0006 |
| 5 | 6 | -0.0005 | -0.0037 | -0.0031 | 0.0027 |
| 6 | 6 | -0.0018 | 0.0072 | 0.0000 | 0.0029 |
| 1 | 7 | 0.0008 | 0.0000 | 0.0002 | 0.0000 |
| 2 | 7 | -0.0002 | -0.0020 | -0.0020 | 0.0008 |
| 3 | 7 | 0.0015 | 0.0006 | -0.0028 | 0.0024 |
| 4 | 7 | 0.0013 | -0.0023 | -0.0028 | -0.0010 |
| 5 | 7 | 0.0028 | 0.0021 | 0.0036 | 0.0012 |
| 6 | 7 | -0.0016 | 0.0007 | -0.0027 | 0.0007 |
| 7 | 7 | 0.0020 | 0.0047 | 0.0016 | 0.0026 |
| 1 | 8 | 0.0011 | 0.0000 | -0.0004 | 0.0000 |
| 2 | 8 | -0.0010 | 0.0009 | -0.0005 | -0.0004 |
| 3 | 8 | 0.0005 | 0.0001 | -0.0005 | 0.0005 |
| 4 | 8 | 0.0008 | 0.0001 | -0.0003 | 0.0010 |
| 5 | 8 | 0.0003 | 0.0006 | -0.0001 | -0.0005 |
| 6 | 8 | -0.0014 | -0.0002 | 0.0013 | 0.0002 |
| 7 | 8 | 0.0006 | 0.0012 | 0.0004 | -0.0016 |
| 8 | 8 | 0.0015 | 0.0009 | 0.0017 | 0.0010 |
| 1 | 9 | -0.0002 | 0.0000 | 0.0002 | 0.0000 |
| 2 | 9 | -0.0008 | 0.0018 | 0.0002 | -0.0009 |
| 3 | 9 | -0.0006 | -0.0005 | 0.0001 | 0.0000 |
| 4 | 9 | -0.0007 | 0.0008 | 0.0005 | 0.0002 |
| 5 | 9 | -0.0005 | -0.0001 | 0.0001 | -0.0002 |
| 6 | 9 | -0.0011 | -0.0002 | 0.0003 | 0.0009 |
| 7 | 9 | -0.0002 | -0.0002 | 0.0001 | -0.0007 |
| 8 | 9 | -0.0007 | 0.0006 | 0.0002 | -0.0009 |
| 9 | 9 | 0.0013 | -0.0005 | 0.0008 | -0.0005 |
| 1 | 10 | -0.0015 | 0.0000 | 0.0001 | 0.0000 |
| 2 | 10 | -0.0002 | -0.0005 | 0.0003 | 0.0002 |
| 3 | 10 | -0.0015 | -0.0005 | 0.0004 | 0.0001 |
| 4 | 10 | 0.0003 | -0.0001 | -0.0003 | -0.0002 |
| 5 | 10 | -0.0014 | -0.0008 | -0.0002 | 0.0006 |
| 6 | 10 | 0.0003 | -0.0001 | -0.0000 | -0.0004 |
| 7 | 10 | 0.0003 | 0.0001 | -0.0003 | 0.0003 |
| 8 | 10 | -0.0010 | -0.0000 | -0.0000 | -0.0002 |
| 9 | 10 | -0.0003 | 0.0007 | -0.0005 | 0.0001 |
| 10 | 10 | -0.0005 | -0.0009 | -0.0000 | -0.0005 |

| | | | | | |
|---|---|---|---|---|---|
| 1 | 11 | 0.0000 | 0.0000 | -0.0002 | 0.0000 |
| 2 | 11 | 0.0005 | -0.0018 | -0.0002 | 0.0006 |
| 3 | 11 | -0.0000 | 0.0001 | 0.0001 | 0.0001 |
| 4 | 11 | 0.0012 | -0.0010 | -0.0006 | -0.0004 |
| 5 | 11 | 0.0003 | -0.0002 | -0.0000 | -0.0001 |
| 6 | 11 | 0.0004 | 0.0000 | 0.0001 | -0.0006 |
| 7 | 11 | 0.0001 | 0.0001 | 0.0000 | -0.0001 |
| 8 | 11 | -0.0003 | -0.0003 | 0.0001 | 0.0003 |
| 9 | 11 | 0.0002 | 0.0003 | -0.0001 | 0.0001 |
| 10 | 11 | -0.0003 | -0.0006 | -0.0004 | 0.0003 |
| 11 | 11 | 0.0002 | -0.0006 | -0.0003 | -0.0005 |
| 1 | 12 | 0.0008 | 0.0000 | 0.0000 | 0.0000 |
| 2 | 12 | 0.0001 | 0.0004 | 0.0004 | 0.0001 |
| 3 | 12 | 0.0021 | 0.0007 | -0.0003 | -0.0001 |
| 4 | 12 | -0.0001 | -0.0004 | 0.0003 | -0.0000 |
| 5 | 12 | 0.0009 | 0.0006 | 0.0003 | -0.0008 |
| 6 | 12 | 0.0003 | -0.0001 | -0.0001 | 0.0001 |
| 7 | 12 | -0.0001 | -0.0000 | 0.0004 | -0.0002 |
| 8 | 12 | 0.0001 | -0.0005 | 0.0000 | 0.0001 |
| 9 | 12 | 0.0007 | 0.0000 | 0.0001 | 0.0002 |
| 10 | 12 | -0.0001 | -0.0002 | -0.0000 | 0.0000 |
| 11 | 12 | 0.0003 | 0.0005 | -0.0001 | 0.0001 |
| 12 | 12 | -0.0007 | 0.0001 | -0.0002 | -0.0002 |
| 1 | 13 | 0.0001 | 0.0000 | -0.0004 | 0.0000 |
| 2 | 13 | 0.0001 | 0.0015 | 0.0002 | -0.0005 |
| 3 | 13 | 0.0009 | 0.0003 | 0.0000 | -0.0002 |
| 4 | 13 | -0.0014 | 0.0009 | 0.0008 | 0.0004 |
| 5 | 13 | -0.0002 | 0.0003 | 0.0001 | -0.0001 |
| 6 | 13 | 0.0001 | 0.0004 | -0.0000 | 0.0007 |
| 7 | 13 | -0.0000 | -0.0003 | 0.0001 | 0.0001 |
| 8 | 13 | -0.0000 | 0.0000 | 0.0001 | -0.0002 |
| 9 | 13 | 0.0001 | 0.0003 | 0.0000 | 0.0002 |
| 10 | 13 | -0.0004 | -0.0001 | 0.0003 | -0.0002 |
| 11 | 13 | 0.0006 | 0.0000 | -0.0000 | 0.0002 |
| 12 | 13 | -0.0001 | -0.0007 | 0.0002 | 0.0001 |
| 13 | 13 | 0.0004 | -0.0003 | -0.0003 | -0.0001 |
| 1 | 14 | -0.0014 | 0.0000 | 0.0011 | 0.0000 |
| 2 | 14 | 0.0001 | 0.0024 | 0.0025 | -0.0002 |
| 3 | 14 | -0.0018 | -0.0004 | -0.0001 | 0.0003 |
| 4 | 14 | -0.0007 | 0.0005 | 0.0002 | 0.0000 |
| 5 | 14 | -0.0002 | -0.0004 | -0.0003 | 0.0005 |
| 6 | 14 | 0.0001 | 0.0001 | 0.0001 | 0.0001 |
| 7 | 14 | -0.0002 | -0.0003 | -0.0004 | 0.0003 |
| 8 | 14 | -0.0001 | 0.0005 | -0.0000 | 0.0001 |
| 9 | 14 | -0.0001 | 0.0003 | -0.0000 | -0.0001 |
| 10 | 14 | -0.0001 | -0.0005 | 0.0000 | 0.0000 |
| 11 | 14 | 0.0004 | 0.0006 | 0.0001 | -0.0000 |
| 12 | 14 | -0.0002 | -0.0003 | 0.0001 | 0.0001 |
| 13 | 14 | 0.0001 | 0.0006 | 0.0001 | 0.0001 |
| 14 | 14 | -0.0005 | 0.0001 | -0.0002 | 0.0002 |
| 1 | 15 | 0.0008 | 0.0000 | -0.0003 | 0.0000 |
| 2 | 15 | -0.0001 | -0.0011 | 0.0011 | 0.0007 |
| 3 | 15 | -0.0016 | -0.0001 | -0.0002 | 0.0002 |
| 4 | 15 | 0.0011 | -0.0005 | -0.0005 | -0.0000 |
| 5 | 15 | 0.0002 | -0.0002 | -0.0002 | 0.0001 |

| | | | | | |
|---|---|---|---|---|---|
| 6 | 15 | -0.0007 | -0.0004 | -0.0001 | -0.0004 |
| 7 | 15 | -0.0006 | 0.0001 | -0.0002 | 0.0001 |
| 8 | 15 | 0.0005 | 0.0001 | -0.0000 | 0.0002 |
| 9 | 15 | 0.0001 | -0.0003 | -0.0001 | 0.0000 |
| 10 | 15 | -0.0004 | -0.0003 | -0.0003 | 0.0001 |
| 11 | 15 | -0.0001 | 0.0007 | -0.0001 | -0.0000 |
| 12 | 15 | -0.0002 | -0.0001 | -0.0001 | -0.0002 |
| 13 | 15 | 0.0004 | -0.0000 | 0.0002 | 0.0001 |
| 14 | 15 | -0.0004 | -0.0004 | 0.0000 | -0.0001 |
| 15 | 15 | -0.0001 | -0.0007 | -0.0002 | 0.0004 |

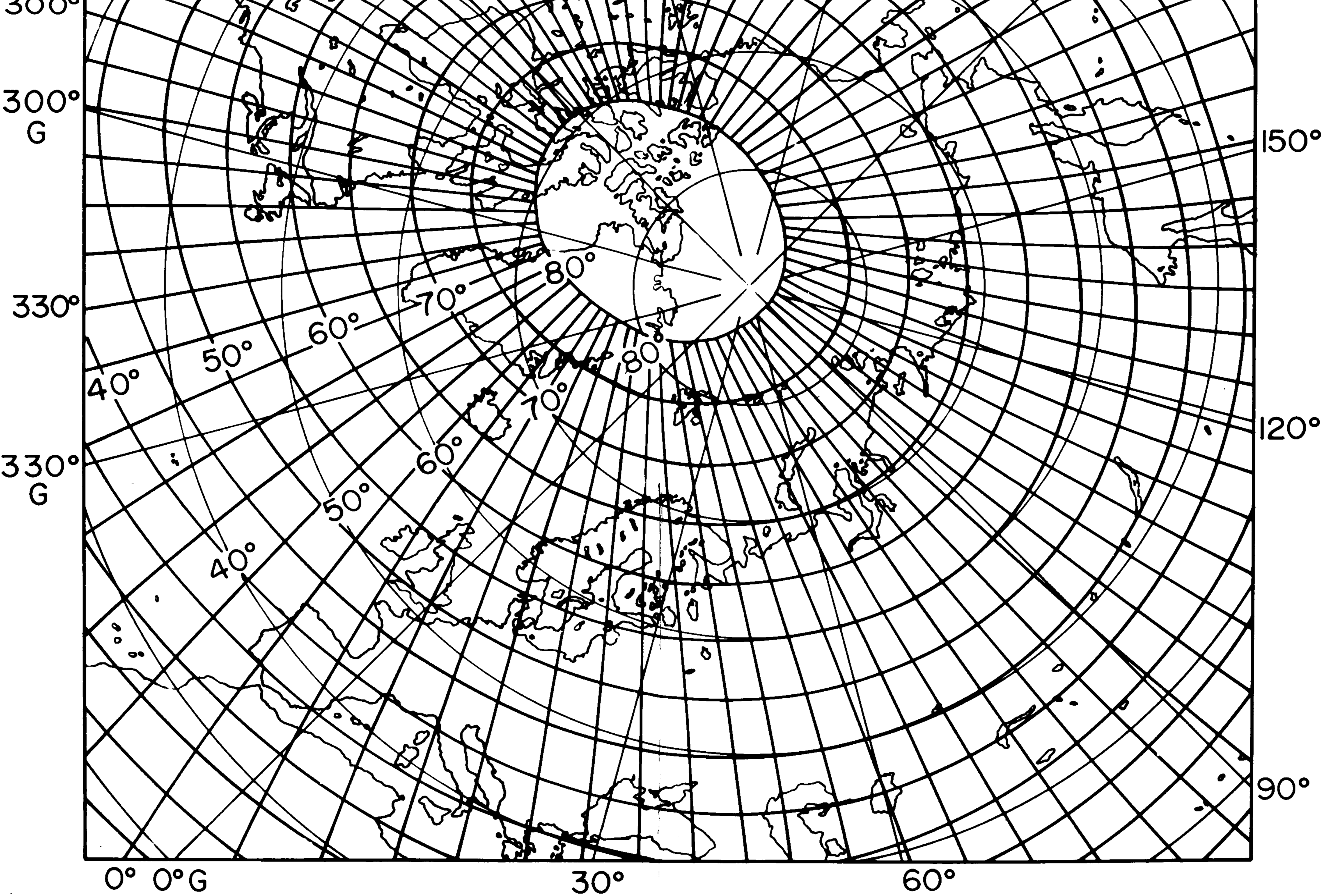



Figure 1. Invariant geomagnetic co-ordinates superimposed on an azimuthal equidistant geographic co-ordinate grid for the Northern Hemisphere. The letter G indicates lines of geographic longitude. (To accompany ANARE Research Note 19).

FIGURE 1.

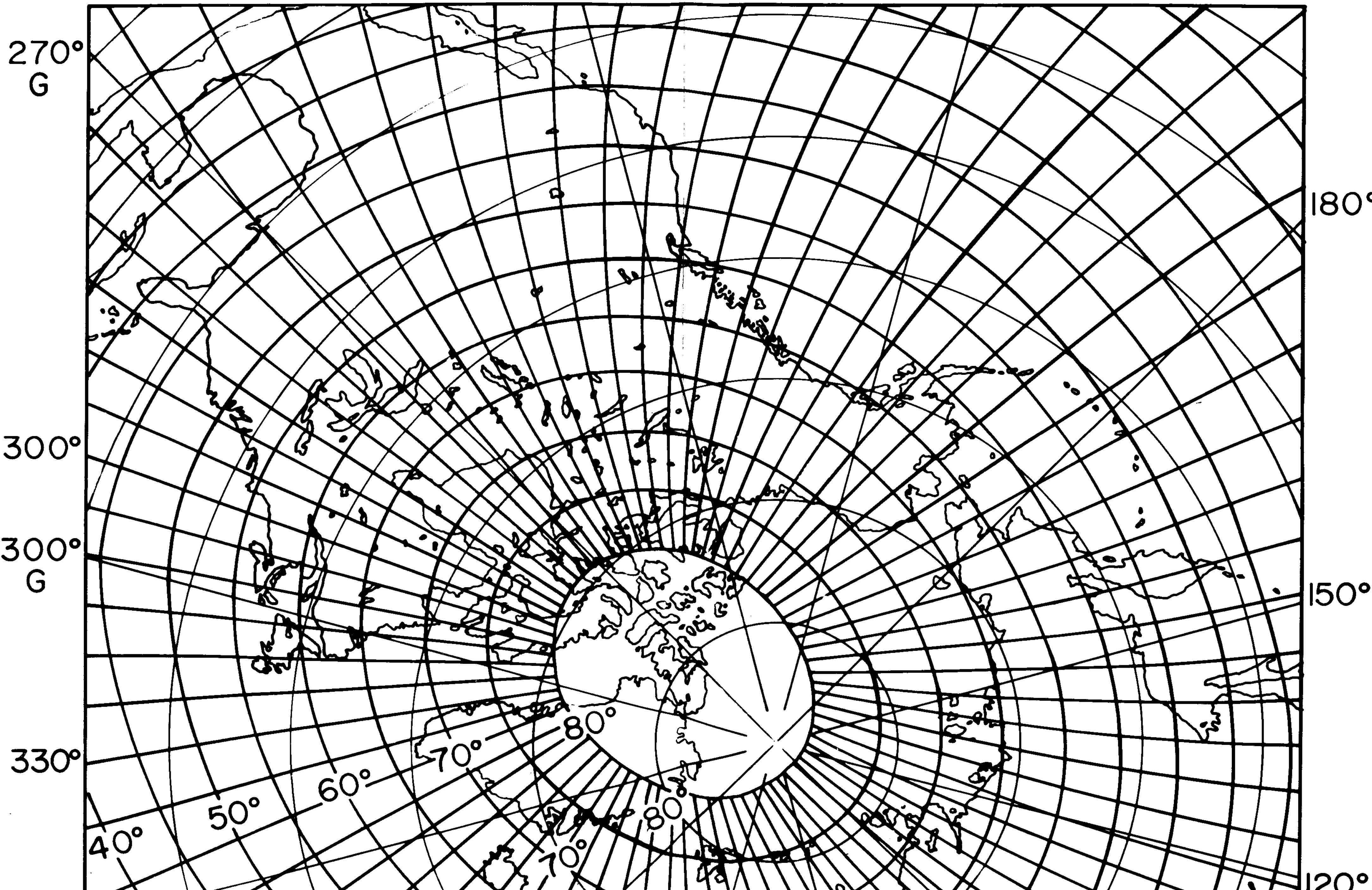
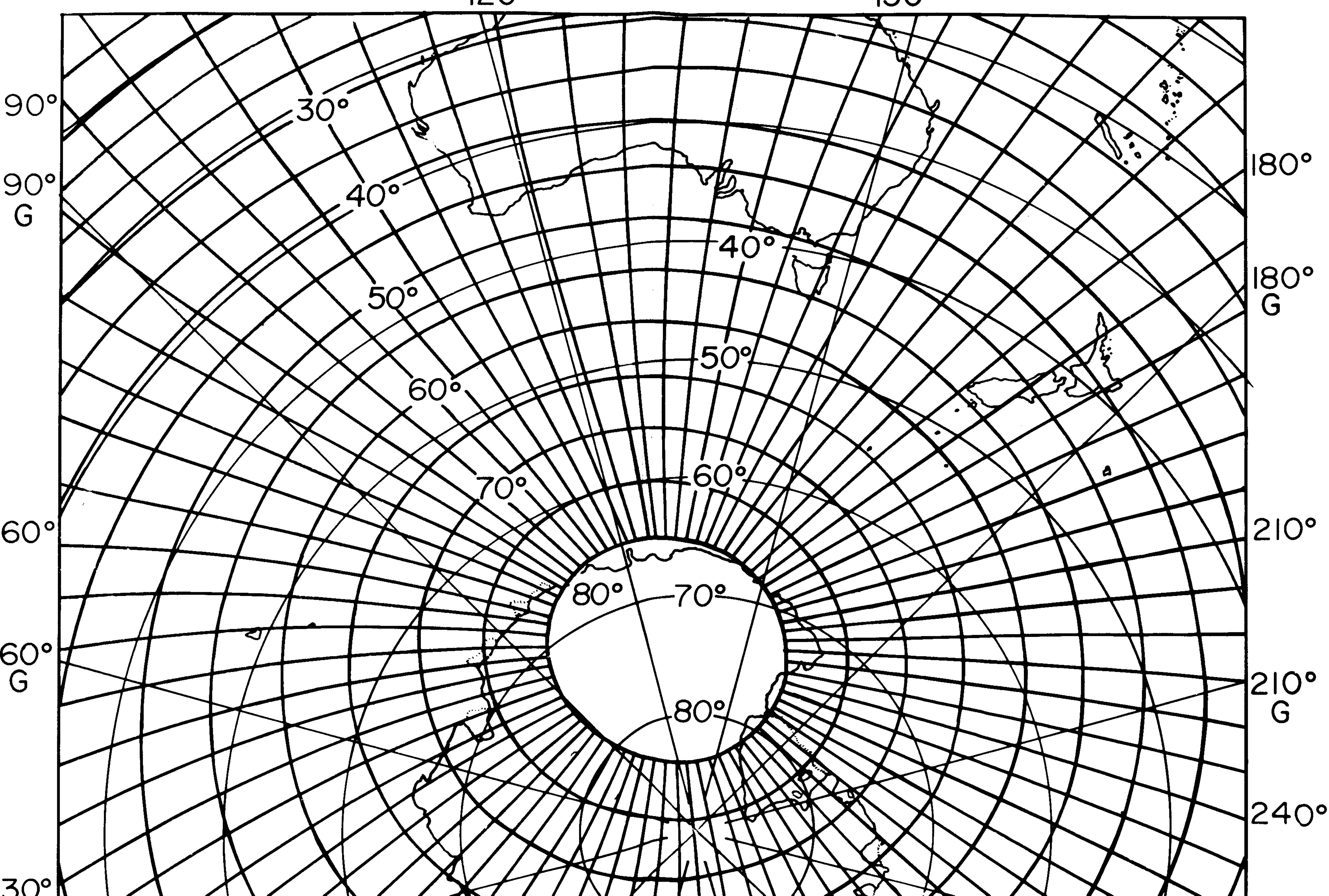


FIGURE 2.


120°
150°
90°
90°
G
180°
180°
G
30°
40°
50°
60°
70°
40°
50°
60°
80°
70°
80°
60°
60°
G
210°
210°
G
240°
30°

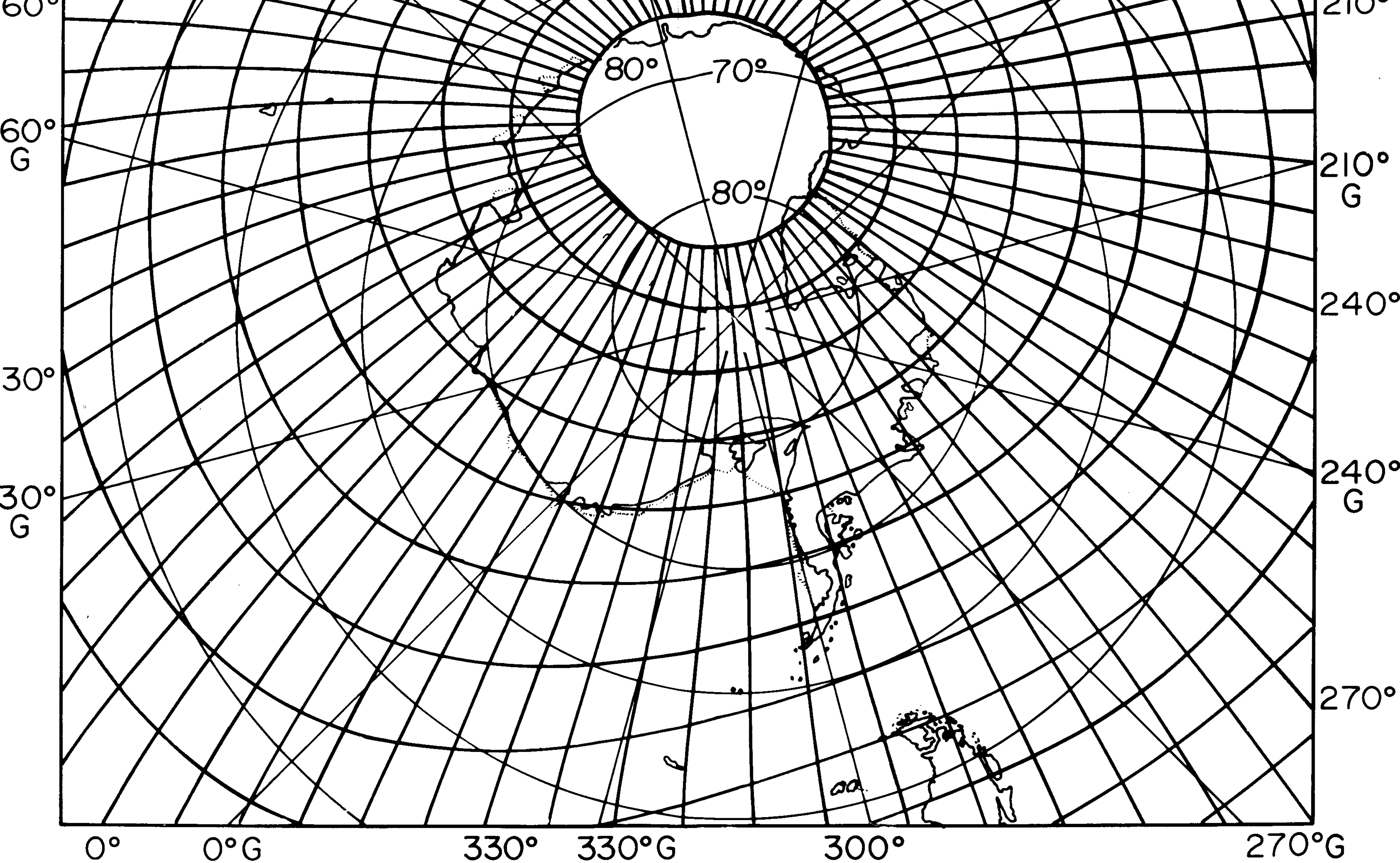
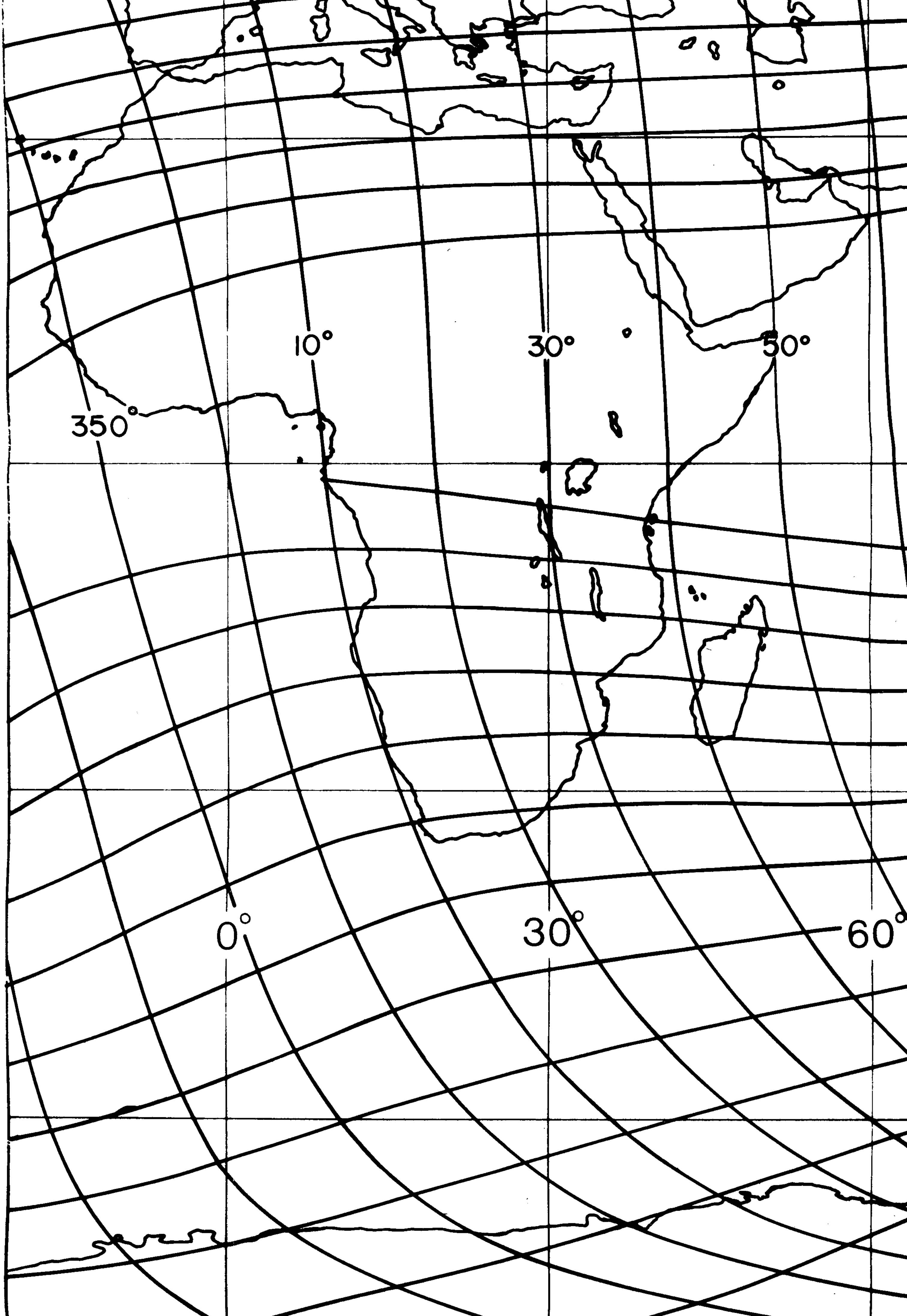
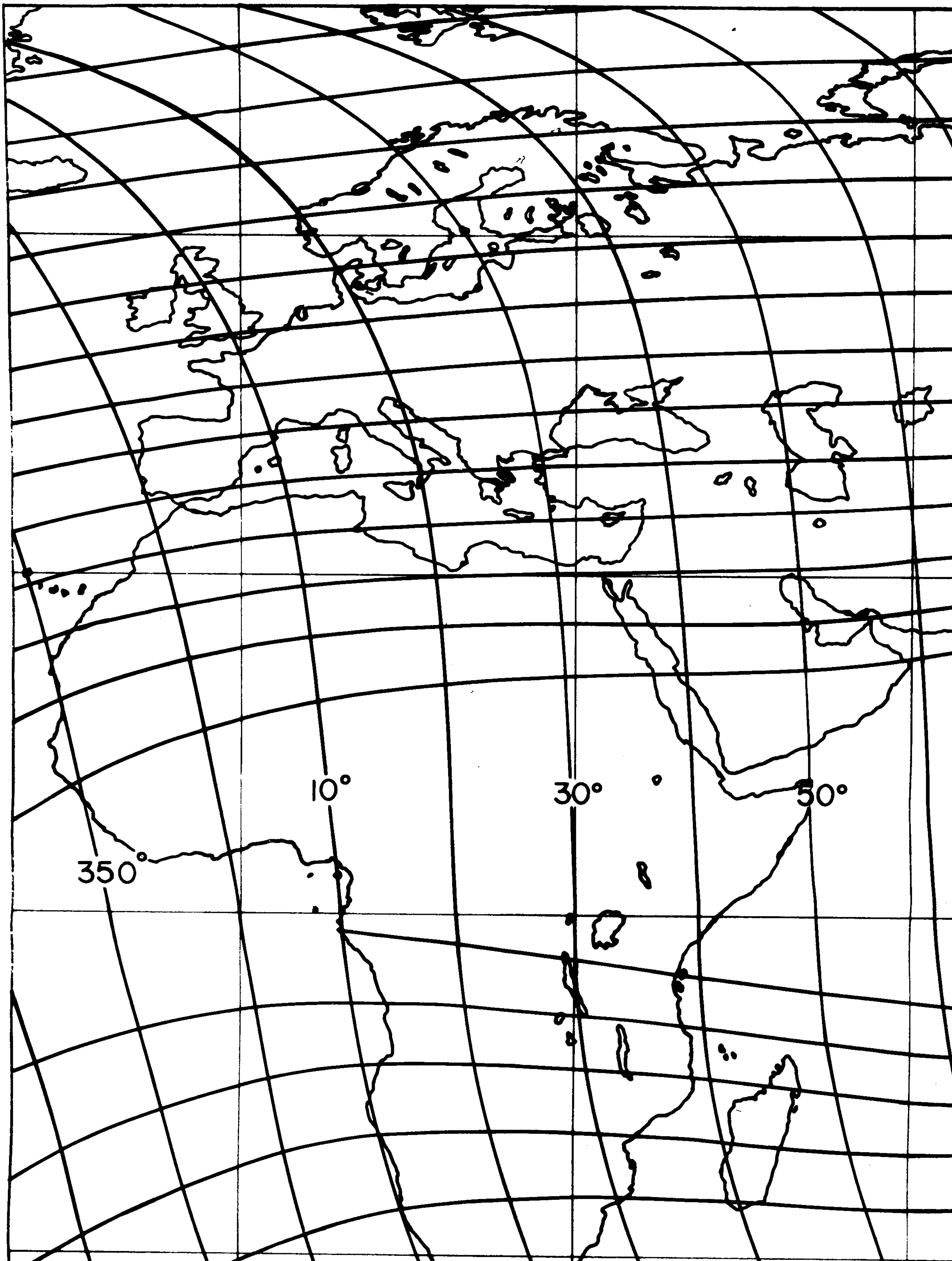
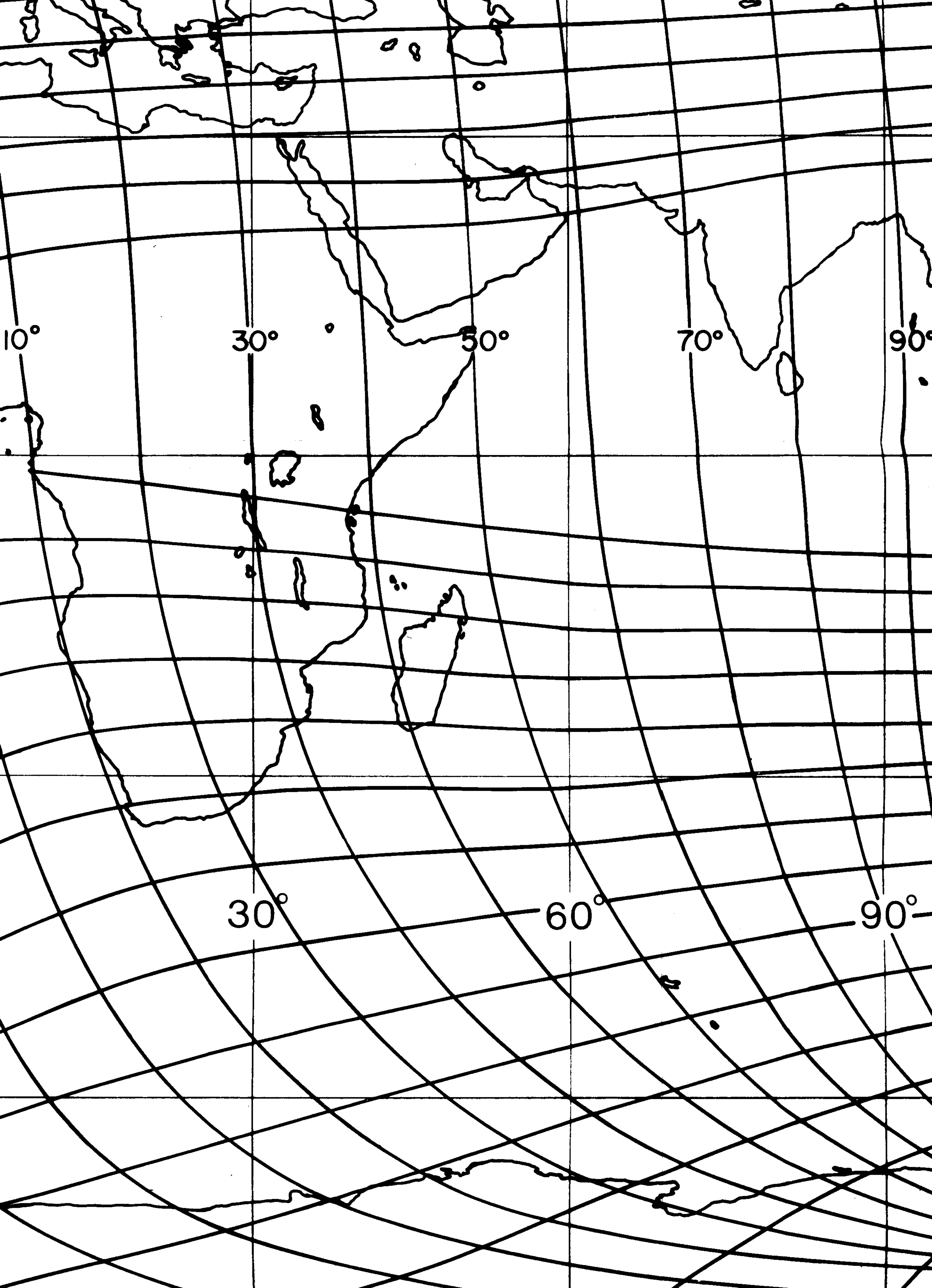


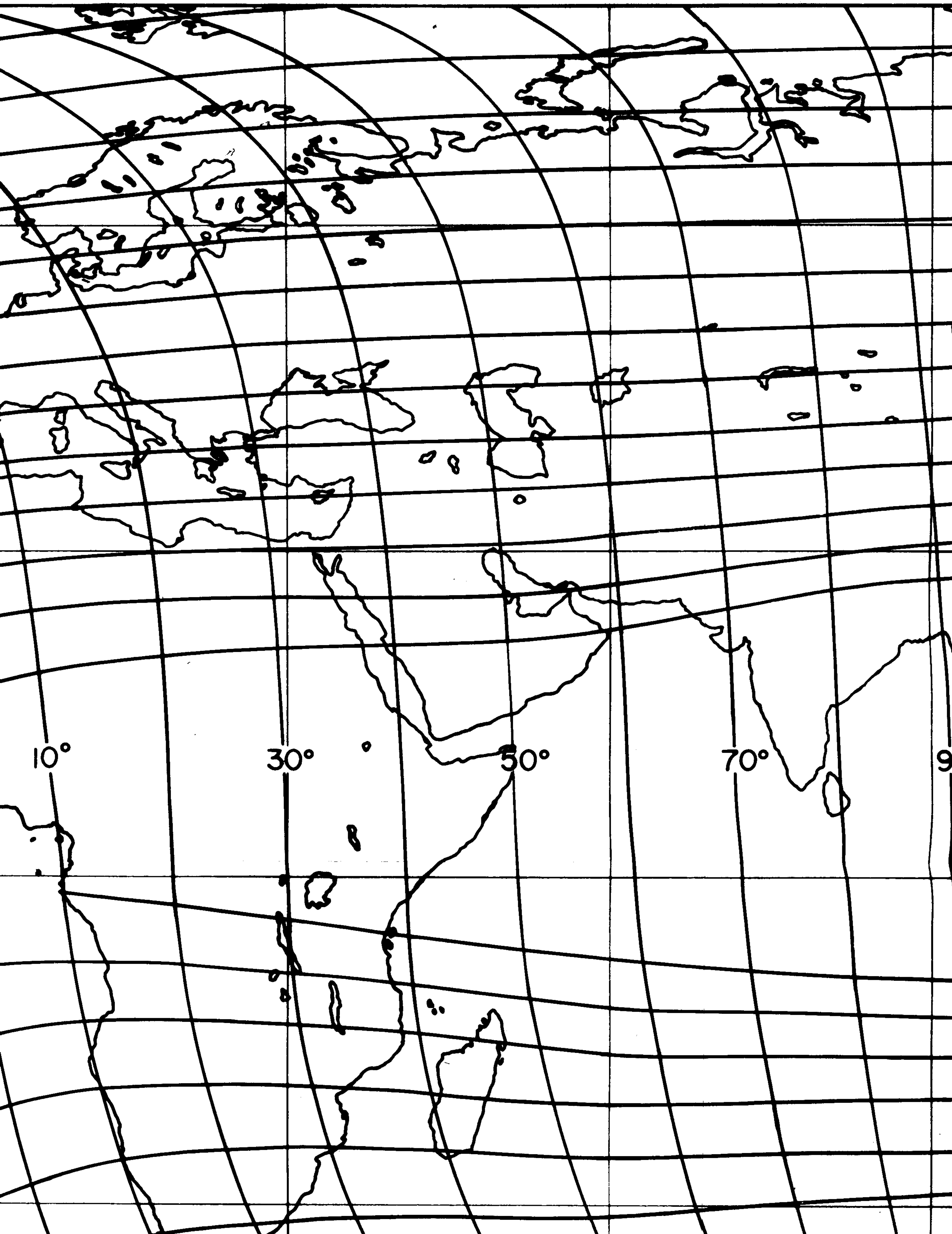

Figure 2. Invariant geomagnetic co-ordinates superimposed on an azimuthal equidistant geographic co-ordinate grid for the Southern Hemisphere. (To accompany ANARE Research Note 19).

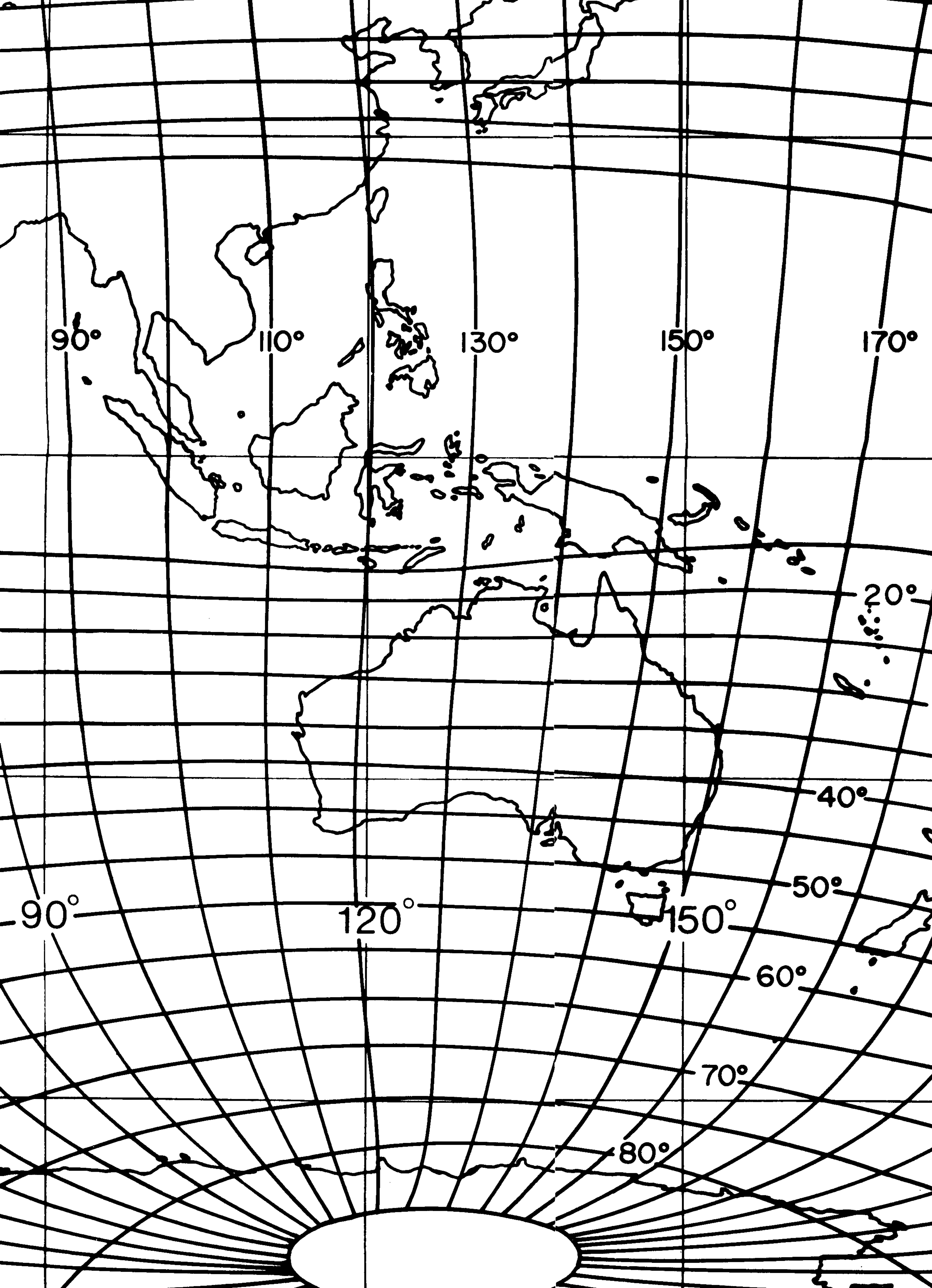


10°
30°
50°
350°
0°
30°
60°

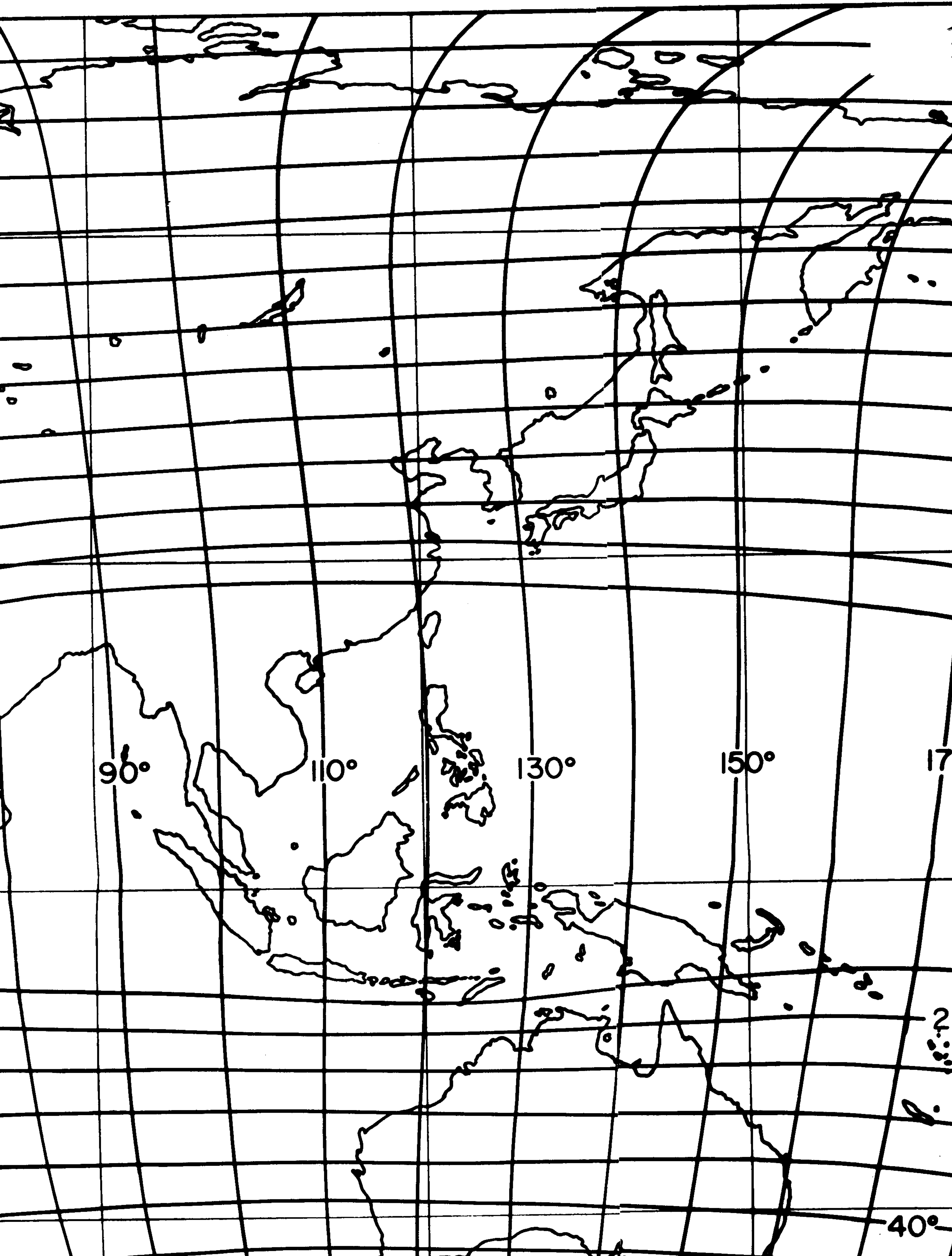

10°
30°
50°
350°

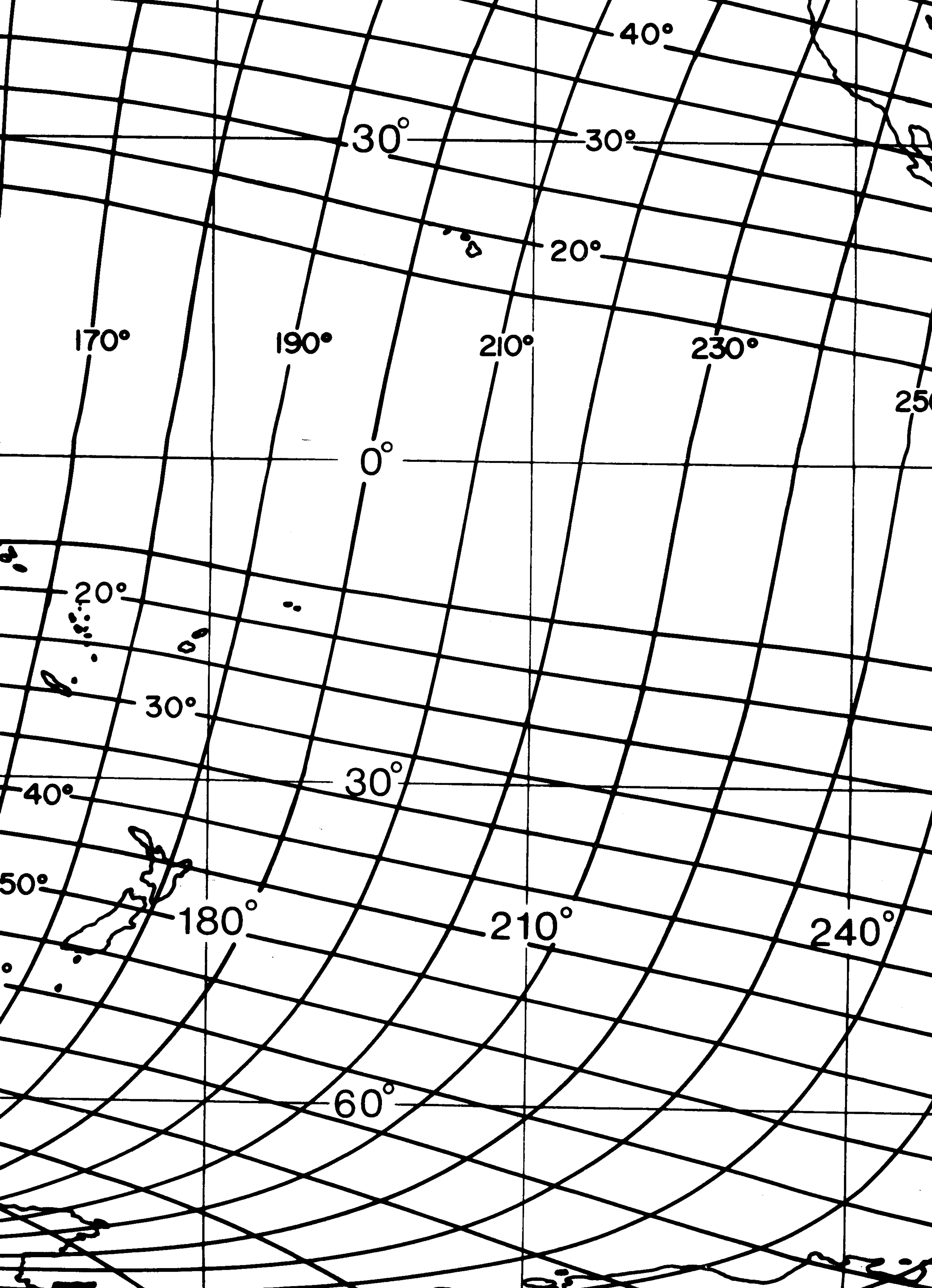

10°
30°
50°
70°
90°
30°
60°
90°


10°
30°
50°
70°
9



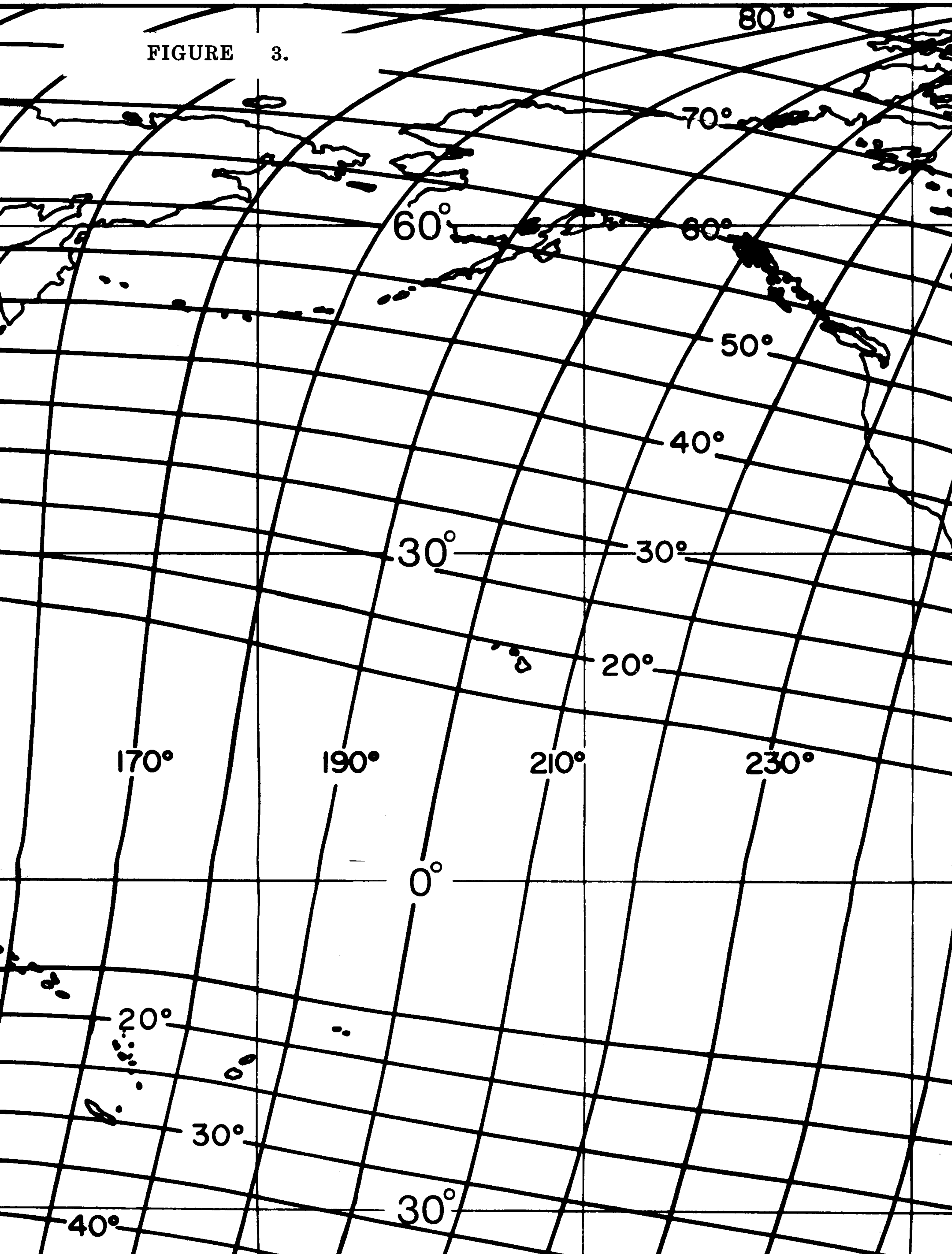
90°
110°
130°
150°
170°
20°
40°
50°
90°
120°
150°
60°
70°
80°

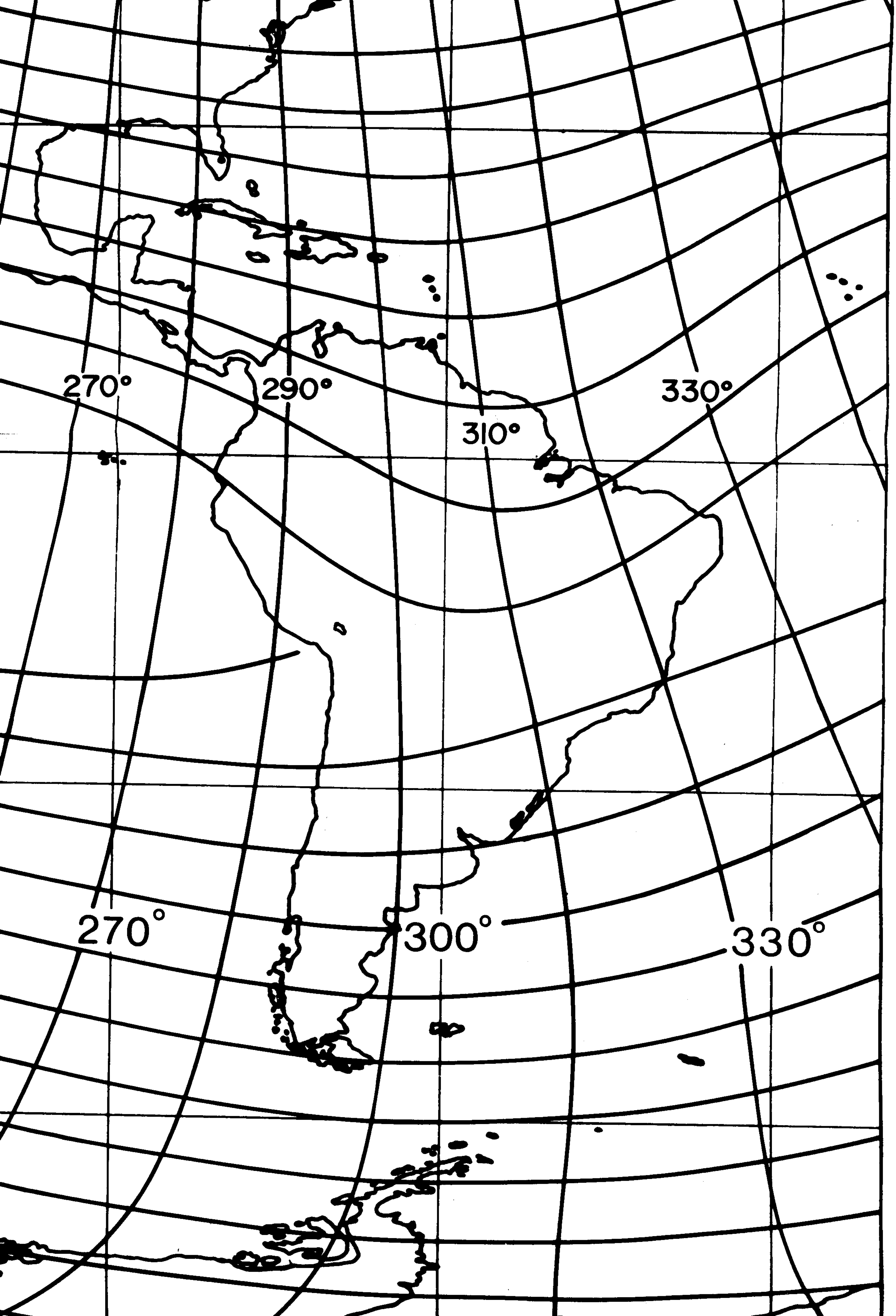

90°
110°
130°
150°
17
2
40°

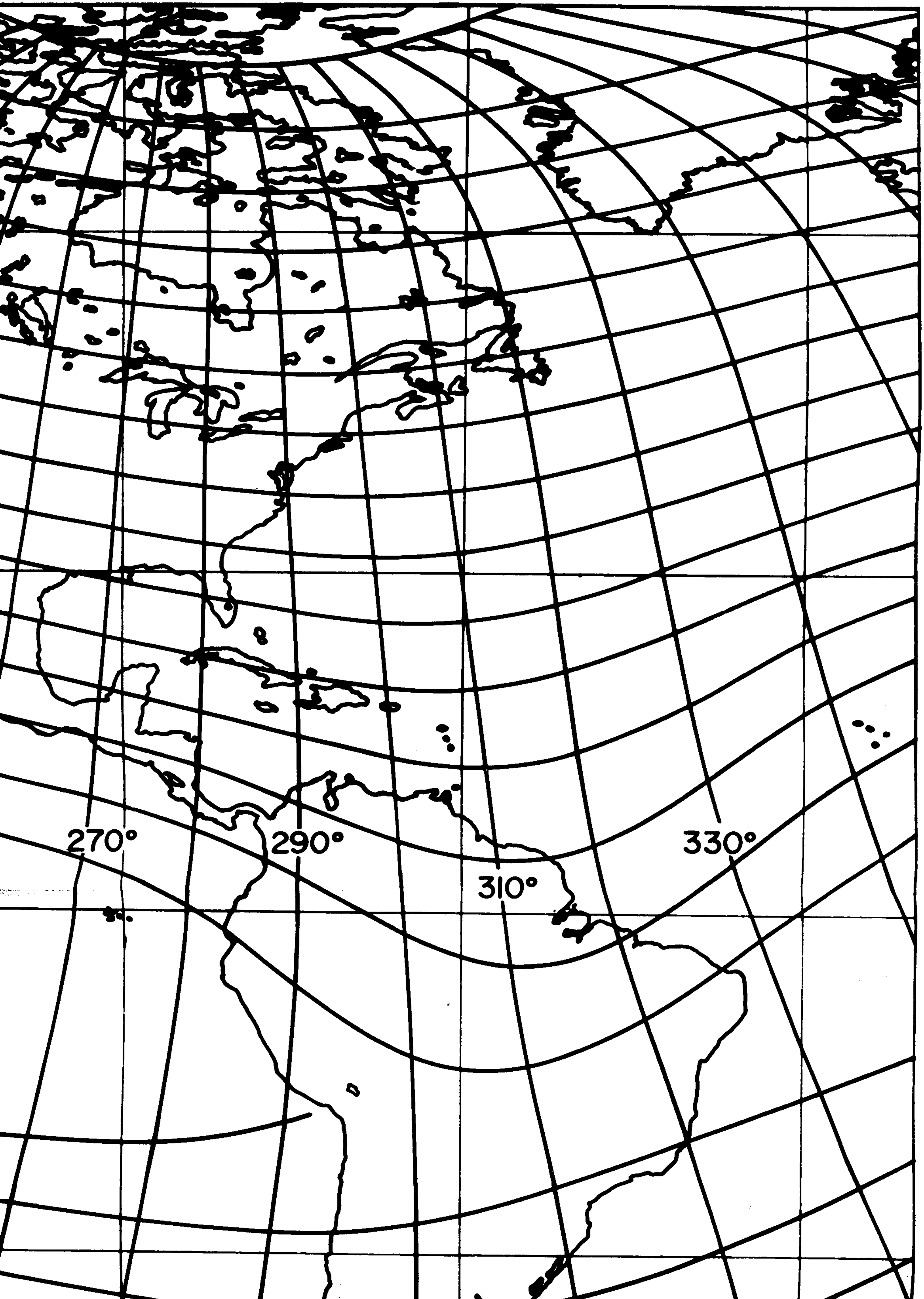


40°
30°
30°
20°
170°
190°
210°
230°
0°
20°
30°
30°
40°
50°
180°
210°
240°
60°

FIGURE 3.




270°
290°
310°
330°
270°
300°
330°


270°
290°
310°
330°

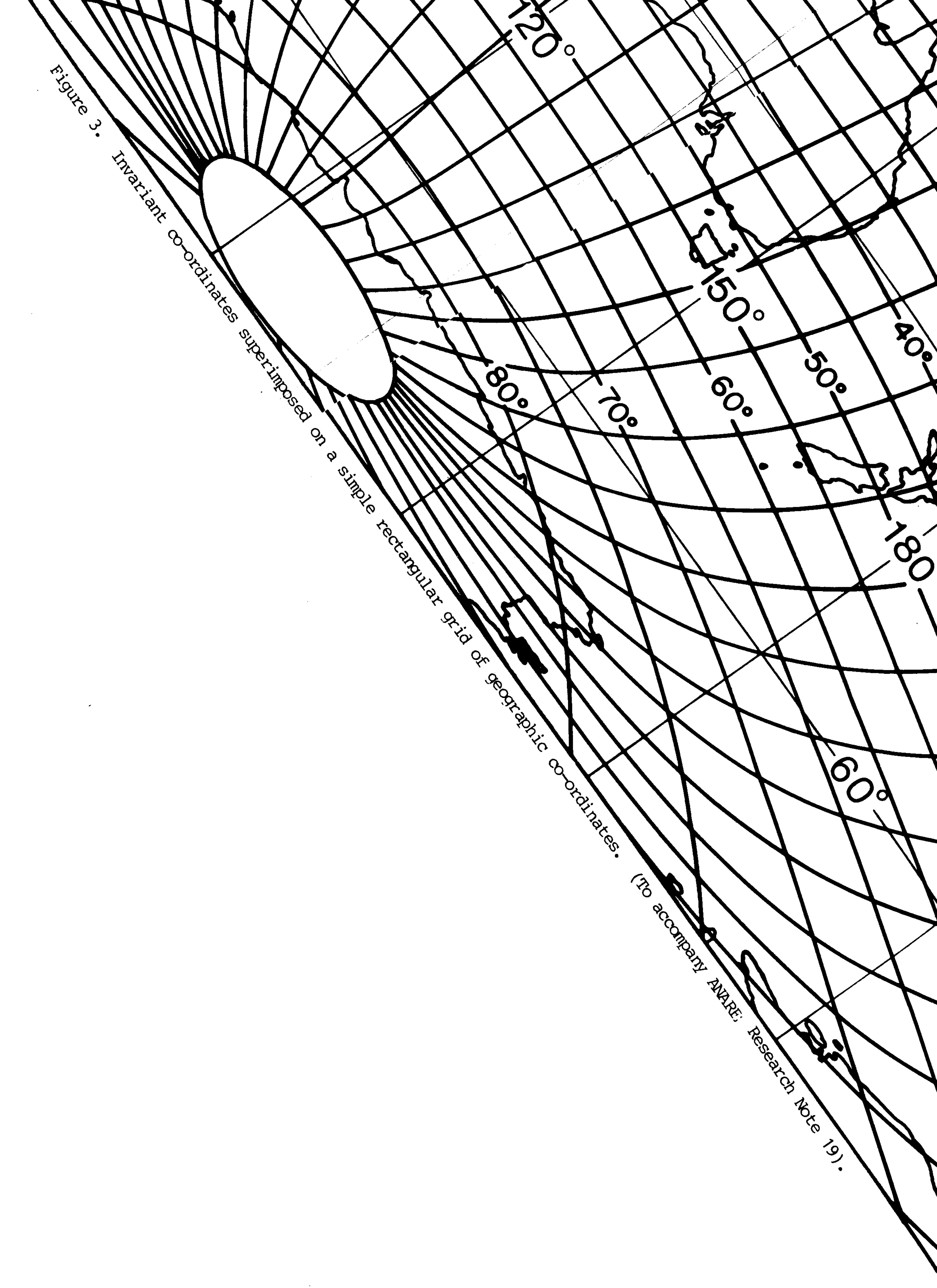



Figure 3. Invariant co-ordinates superimposed on a simple rectangular grid of geographic co-ordinates. (To accompany ANARE Research Note 19).