NOTES FOR USERS OF SOFTWARE

FOR THE CANADIAN GEOMAGNETIC REFERENCE FIELD

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INTRODUCTION

The Canadian Geomagnetic Reference Field is a mathematical model of the geomagnetic field over Canada produced by the Geophysics Division of the Geological Survey of Canada at regular intervals, normally every 2.5 years. The latest model is for epoch 1990 and is referred to as CGRF 1990. By using the CGRF a user can calculate values of magnetic declination (or any other element of the magnetic field) at any location in Canada and adjacent areas.

The CGRF actually consists of a set of spherical harmonic coefficients in conjunction with a set of spherical cap harmonic coefficients. The spherical harmonic coefficients are those of the global International Geomagnetic Reference Field 1985 (IGRF 1985) (Barraclough, 1985) and the spherical cap harmonic coefficients are those derived for the residual field relative to the IGRF 1985 evaluated at 1990. That is, the spherical cap coefficients give an estimate of the difference between the true field and the field given by the global model over the Canadian region. Mathematically, this can be expressed as follows:

$$F_{resid} = F_{obs} - F_{igrf}$$

and

$$F_{schm} = F_{resid} - F_{diff}$$

where F_{obs} is the observed field, F_{igrf} is that part of the field modelled by the IGRF, F_{resid} is the residual field relative to the IGRF, F_{schm} is that part of the residual

field modelled by the spherical cap harmonic model, and F_{diff} is the part of the residual field which cannot be calculated by the model. Adding the two fields F_{igrf} and F_{schm} gives the Canadian Geomagnetic Reference Field for 1990 (CGRF 1990):

$$F_{cgrf} = F_{igrf} + F_{schm}$$

and

$$F_{obs} = F_{cgrf} + F_{diff}$$

where F_{cgrf} is the field calculated from the Canadian Geomagnetic Reference Field.

The method of spherical cap harmonic analysis has been described by Haines (1985), and the development of the CGRF has been described by Haines and Newitt (1986) and Newitt and Haines (1989).

The IGRF coefficients are listed in Appendix 1 and the spherical cap harmonic coefficients are listed in Appendix 2. (The file of IGRF coefficients also contains coefficients for epochs back to 1945.)

DETAILS

The subroutines described in this section and listed in full in Appendix 3 use the CGRF 1990 coefficients to calculate values of magnetic declination for a given location and time. We will give only a brief description of how the different subroutines are used. A detailed description of the computer software developed for spherical cap harmonic analysis, including many of the subroutines listed here, is given by Haines (1988). We will give a

brief summary of those programs and subroutines which are necessary for the calculation of magnetic declination values.

Program DECPROG is a simple driver program which produces a list of declination and annual change values at 5 x 5 degree grid intervals over Canada. A sample output is given in the appendix so that the user may verify that his program is operating correctly. The declination values are returned by Subroutine CALDEC. Inputs to this subroutine are FLAT and FLON, the geodetic latitude and longitude in degrees; longitude is positive east and latitude is positive north. ALT is the altitude above sea level in kilometres and YEAR is the year. The valid time span of the CGRF is 1960 to 1995. If a year outside these limits is entered, the value of declination will contain extrapolation errors. The input parameter L provides the subroutine with information about the coefficients used in calculating the declination. It should be set equal to 1 for the CGRF 1990 coefficients.

The output parameters of CALDEC are D and DSV. D is the magnetic declination in degrees. DSV is the annual change in minutes per year. In both cases, a positive value is easterly, and a negative value is westerly.

Subroutine CALDEC in turn calls several other subroutines which perform the actual calculations. All these subroutines are listed in the appendix. The first calls to FIELD, SCHNEV and SPHIT (an entry point in

subroutine SPHNEWF) read the two sets of coefficients and also return FLATO, FLONO and THETA which define the pole of rotation and radius of the spherical cap. For the CGRF 1990 the pole of rotation is 65° N, 85° W, and THETA is 30°. Note that the subroutines expect to find the CGRF residual coefficients in a file named SCHCOEF.90, and the IGRF coefficients in a file named IGRF4585.BYYEAR. If the user wishes to use other names for these files, changes must be made to the OPEN statements in FIELD and SCHNEV.

Subroutine GEOCENF converts geodetic coordinates to geocentric coordinates, and SPHNEWF rotates the coordinates to a system centered on FLATO,FLONO.

FIELD calculates the north, east and vertical components of the magnetic field using the IGRF 1985 coefficients. This is a world model of the magnetic field. If the desired location is within the spherical cap for which the CGRF is valid, SCHNEV is called after the call to FIELD. SCHNEV calculates residual values of the magnetic field using the CGRF residual coefficients. These residual values are rotated back to a geographic coordinate system by subroutine SPHNEWF (entry point SPHOLDF). They are then added to the IGRF magnetic field values to produce a more detailed description of the magnetic field over Canada than can be produced by a world model alone. GEOCINV converts geocentric values back to geodetic values. Finally, declination is calculated from the north and east components of the magnetic field. Note that two calls to SCHNEV are

made, one using YEAR and the second using YEAR + DELT, where DELT=1, so that annual change values can be determined.

If the desired location is outside the valid area of the CGRF (more than THETA degrees from FLATO,FLONO), declination values are calculated using the IGRF alone.

Users who have occasion to use components of the magnetic field other than declination, such as horizontal intensity or total intensity, may obtain them by adding the necessary code and changing the output parameters in CALDEC. Contact the authors of this report for details.

The program and subroutines just described have been written in VAX FORTRAN and have been run successfully on a VAX 11/750 and on a MicroVAX II. Users of other systems may have to make software modifications appropriate to their systems.

POINTS TO REMEMBER

1) Latitude and longitude must be entered in degrees. East longitude is positive, west longitude is negative. Altitude must be in kilometers above sea level.
2) Outside the area for which the CGRF is valid (more than 30 degrees from 65° N, 85° W), the subroutine will return declination values calculated using the IGRF 1985.
3) The valid time span of the CGRF 1985 is from 1960 to 1995.
4) The program and subroutines have been written in VAX FORTRAN.

5) The files containing the CGRF and IGRF coefficients must be named SCHCOEF.90 and IGRF4585.BYYEAR respectively. If you received the software and coefficients on a floppy disk, the latter filename may have been truncated to IGRF4585.BYY by DOS. Either rename it when you transfer the program to your own computer, or change the OPEN statement in FIELD.

5) New versions of the CGRF will be available at least every five years and possibly more frequently. Users should check periodically on the availability of a new model.

6) For further information, or if problems are encountered, contact the authors at: Geophysics Division, Geological Survey of Canada, 1 Observatory Cres, Ottawa, Ont, K1A 0Y3;

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613-995-0754 (GVH).

REFERENCES

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APPENDIX 1

INTERNATIONAL REMAGNETIC REFERENCE FIELD COEFFICIENTS
1945 - 1985

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10 1985.00  6371.200  6378.160   298.250IGRF 1945 TO 1985 WITH 85 TIME TERMS
 1    0  -30634.0       0.0  -30571.0       0.0  -30507.0       0.0  -30411.0
0.0  -30334.0       0.0  -30220.0       0.0  -30100.0       0.0  -29992.0
0.0  -29877.0       0.0      23.2       0.0
 1    1   -2240.0    5806.0   -2241.0    5807.0   -2134.0    5796.0   -2162.0
5780.0   -2119.0    5776.0   -2068.0    5737.0   -2013.0    5675.0   -1956.0
5604.0   -1903.0    5497.0      10.0     -24.5
 2    0   -1215.0       0.0   -1330.0       0.0   -1432.0       0.0   -1546.0
0.0   -1662.0       0.0   -1781.0       0.0   -1902.0       0.0   -1997.0
0.0   -2073.0       0.0     -13.7       0.0
 2    1    2972.0   -1700.0    2978.0   -1813.0    2995.0   -1896.0    3007.0
-1948.0    2997.0   -2016.0    3000.0   -2047.0    3010.0   -2067.0    3027.0
-2129.0    3045.0   -2191.0       3.4     -11.5
 2    2    1588.0     497.0    1579.0     388.0    1567.0     263.0    1572.0
209.0    1594.0     114.0    1611.0      25.0    1632.0     -68.0    1663.0
-200.0    1691.0    -309.0       7.0     -20.2
 3    0    1274.0       0.0    1293.0       0.0    1308.0       0.0    1307.0
0.0    1297.0       0.0    1287.0       0.0    1276.0       0.0    1281.0
0.0    1300.0       0.0       5.1       0.0
 3    1   -1833.0    -512.0   -1878.0    -485.0   -1955.0    -487.0   -1987.0
-421.0   -2038.0    -404.0   -2091.0    -366.0   -2144.0    -333.0   -2180.0
-336.0   -2208.0    -312.0      -4.6       5.3
 3    2    1225.0     185.0    1271.0     228.0    1293.0     235.0    1288.0
230.0    1292.0     240.0    1278.0     251.0    1260.0     262.0    1251.0
271.0    1244.0     284.0      -0.6       2.3
 3    3     926.0      -5.0     890.0     -67.0     897.0     -73.0     879.0
-130.0     856.0    -165.0     838.0    -196.0     830.0    -223.0     833.0
-252.0     835.0    -296.0       0.1     -10.8
 4    0     980.0       0.0     975.0       0.0     964.0       0.0     962.0
0.0     957.0       0.0     952.0       0.0     946.0       0.0     938.0
0.0     937.0       0.0       0.1       0.0
 4    1     771.0     155.0     795.0     171.0     794.0     167.0     804.0
150.0     804.0     148.0     800.0     167.0     791.0     191.0     782.0
212.0     780.0     233.0      -0.6       3.8
 4    2     544.0    -280.0     532.0    -306.0     510.0    -275.0     492.0
-272.0     479.0    -269.0     461.0    -266.0     438.0    -265.0     398.0
-257.0     363.0    -250.0      -7.8       2.2
 4    3    -408.0     -68.0    -402.0     -51.0    -392.0     -44.0    -392.0
1.0    -390.0      13.0    -395.0      26.0    -405.0      39.0    -419.0
53.0    -426.0      68.0      -1.4       2.5
 4    4     300.0    -158.0     310.0    -184.0     292.0    -249.0     267.0
-254.0     252.0    -269.0     234.0    -279.0     216.0    -288.0     199.0
-297.0     169.0    -298.0      -6.8       0.9
 5    0    -286.0       0.0    -255.0       0.0    -232.0       0.0    -236.0
0.0    -219.0       0.0    -216.0       0.0    -218.0       0.0    -218.0
0.0    -215.0       0.0       1.3       0.0
 5    1     341.0     -14.0     355.0      -8.0     360.0      14.0     358.0
12.0     358.0      19.0     359.0      26.0     356.0      31.0     357.0
46.0     356.0      47.0       0.1       0.1
 5    2     207.0      80.0     201.0     101.0     237.0     111.0     229.0
121.0     254.0     128.0     262.0     139.0     264.0     148.0     261.0
150.0     253.0     148.0      -1.5      -0.2
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5	3	-25.0	-65.0	-3.0	-95.0	-13.0	-90.0	-34.0
-115.0	-31.0	-126.0	-42.0	-139.0	-59.0	-152.0	-74.0	
-151.0	-94.0	-155.0	-3.2	-0.1				
5	4	-156.0	-114.0	-160.0	-100.0	-176.0	-111.0	-153.0
-106.0	-157.0	-97.0	-160.0	-91.0	-159.0	-83.0	-162.0	
-78.0	-161.0	-75.0	0.1	0.6				
5	5	-88.0	83.0	-76.0	73.0	-68.0	77.0	-64.0
83.0	-62.0	81.0	-56.0	83.0	-49.0	88.0	-48.0	
92.0	-48.0	95.0	-0.1	0.0				
6	0	68.0	0.0	57.0	0.0	47.0	0.0	47.0
0.0	45.0	0.0	43.0	0.0	45.0	0.0	48.0	
0.0	52.0	0.0	1.4	0.0				
6	1	67.0	9.0	50.0	-1.0	57.0	-7.0	56.0
-13.0	61.0	-11.0	64.0	-12.0	66.0	-13.0	66.0	
-15.0	65.0	-16.0	-0.3	-0.4				
6	2	6.0	118.0	15.0	100.0	4.0	101.0	-3.0
106.0	8.0	100.0	15.0	100.0	28.0	99.0	42.0	
93.0	50.0	90.0	1.7	-1.1				
6	3	-244.0	18.0	-261.0	52.0	-250.0	46.0	-241.0
55.0	-228.0	68.0	-212.0	72.0	-198.0	75.0	-192.0	
71.0	-186.0	69.0	0.6	-0.8				
6	4	-12.0	-9.0	8.0	-7.0	12.0	-16.0	3.0
-26.0	4.0	-32.0	2.0	-37.0	1.0	-41.0	4.0	
-43.0	4.0	-50.0	0.0	-2.3				
6	5	14.0	-12.0	8.0	-17.0	13.0	-6.0	4.0
-10.0	1.0	-8.0	3.0	-6.0	6.0	-4.0	14.0	
-2.0	17.0	-4.0	0.9	-0.5				
6	6	-100.0	-42.0	-108.0	-21.0	-105.0	-21.0	-108.0
-16.0	-111.0	-7.0	-112.0	1.0	-111.0	11.0	-108.0	
17.0	-102.0	20.0	1.2	-0.1				
7	0	72.0	0.0	67.0	0.0	80.	0.0	72.0
0.0	75.0	0.0	72.0	0.0	71.0	0.0	72.0	
0.0	75.0	0.0	0.2	0.0				
7	1	-61.0	-42.0	-48.0	-44.0	-66.0	-52.0	-52.0
-53.0	-57.0	-61.0	-57.0	-70.0	-56.0	-77.0	-59.0	
-82.0	-61.0	-82.0	-0.6	0.2				
7	2	6.0	-39.0	-3.0	-18.0	2.0	-37.0	4.0
-25.0	4.0	-27.0	1.0	-27.0	1.0	-26.0	2.0	
-27.0	2.0	-26.0	-0.5	1.0				
7	3	6.0	2.0	16.0	-6.0	4.0	6.0	11.0
-8.0	13.0	-2.0	14.0	-4.0	16.0	-5.0	21.0	
-5.0	24.0	-1.0	0.8	1.1				
7	4	-44.0	-1.0	-38.0	-8.0	-46.0	-1.0	-20.0
3.0	-26.0	6.0	-22.0	8.0	-14.0	10.0	-12.0	
16.0	-6.0	23.0	1.0	1.9				
7	5	-2.0	25.0	1.0	32.0	-15.0	29.0	-4.0
28.0	-6.0	26.0	-2.0	23.0	0.0	22.0	1.0	
18.0	4.0	17.0	0.4	0.3				
7	6	18.0	-19.0	9.0	-18.0	8.0	-20.0	15.0
-16.0	13.0	-23.0	13.0	-23.0	12.0	-23.0	11.0	
-23.0	9.0	-21.0	-0.5	0.2				
7	7	27.0	-23.0	11.0	-22.0	14.0	-12.0	6.0
-18.0	1.0	-12.0	-2.0	-11.0	-5.0	-12.0	-2.0	
-10.0	0.0	-6.0	-0.1	0.9				

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 8    0      15.0       0.0      16.0       0.0       5.0       0.0       6.0
0.0      13.0       0.0      14.0       0.0      14.0       0.0      18.0
0.0      21.0       0.0       0.7       0.0
 8    1       5.0      -7.0       4.0       2.0      17.0      12.0       4.0
7.0       5.0       7.0       6.0       7.0       6.0       6.0       6.0
7.0       6.0       7.0       0.0       0.1
 8    2     -12.0       9.0      -8.0      -2.0      -3.0       1.0      -3.0
-16.0      -4.0     -12.0      -2.0     -15.0      -1.0     -16.0       0.0
-18.0       0.0     -21.0       0.3      -1.0
 8    3     -21.0       0.0     -31.0      -3.0     -30.0      10.0     -13.0
5.0     -14.0       9.0     -13.0       6.0     -12.0       4.0     -11.0
4.0     -11.0       5.0       0.4       0.1
 8    4      18.0     -13.0      15.0      -7.0      14.0     -20.0      -5.0
-19.0       0.0     -16.0      -3.0     -17.0      -8.0     -19.0      -7.0
-22.0      -9.0     -25.0      -0.3      -0.8
 8    5      16.0       5.0       8.0       6.0      27.0       5.0      10.0
5.0       8.0       4.0       5.0       6.0       4.0       6.0       4.0
9.0       2.0      11.0      -0.3       0.2
 8    6     -14.0      26.0     -17.0      27.0     -15.0      34.0      -6.0
23.0      -1.0      24.0       0.0      21.0       0.0      18.0       3.0
16.0       4.0      12.0       0.1      -0.8
 8    7       1.0       1.0       7.0      -6.0       1.0       4.0      15.0
-2.0      11.0      -3.0      11.0      -6.0      10.0     -10.0       6.0
-13.0       4.0     -16.0      -0.5      -0.1
 8    8      10.0     -19.0      13.0     -22.0      12.0     -19.0       5.0
-18.0       4.0     -17.0       3.0     -16.0       1.0     -17.0      -1.0
-15.0      -6.0     -10.0      -0.8       1.3
 9    0       0.0       0.0       0.0       0.0       0.0       0.0      13.0
0.0       8.0       0.0       8.0       0.0       7.0       0.0       5.0
0.0       5.0       0.0       0.0       0.0
 9    1       0.0       0.0       0.0       0.0       0.0       0.0       5.0
-22.0      10.0     -22.0      10.0     -21.0      10.0     -21.0      10.0
-21.0      10.0     -21.0       0.0       0.0
 9    2       0.0       0.0       0.0       0.0       0.0       0.0       4.0
14.0       2.0      15.0       2.0      16.0       2.0      16.0       1.0
16.0       1.0      16.0       0.0       0.0
 9    3       0.0       0.0       0.0       0.0       0.0       0.0     -12.0
5.0     -13.0       7.0     -12.0       6.0     -12.0       7.0     -12.0
9.0     -12.0       9.0       0.0       0.0
 9    4       0.0       0.0       0.0       0.0       0.0       0.0      14.0
-5.0      10.0      -4.0      10.0      -4.0      10.0      -4.0       9.0
-5.0       9.0      -5.0       0.0       0.0
 9    5       0.0       0.0       0.0       0.0       0.0       0.0       5.0
0.0      -1.0      -5.0      -1.0      -5.0      -1.0      -5.0      -3.0
-6.0      -3.0      -6.0       0.0       0.0
 9    6       0.0       0.0       0.0       0.0       0.0       0.0      -2.0
11.0      -1.0      10.0       0.0      10.0      -1.0      10.0      -1.0
9.0      -1.0       9.0       0.0       0.0
 9    7       0.0       0.0       0.0       0.0       0.0       0.0       0.0
10.0       5.0      10.0       3.0      11.0       4.0      11.0       7.0
10.0       7.0      10.0       0.0       0.0
 9    8       0.0       0.0       0.0       0.0       0.0       0.0       0.0
2.0       1.0      -4.0       1.0      -2.0       1.0      -3.0       2.0
-6.0       2.0      -6.0       0.0       0.0
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 9    9        0.0        0.0        0.0        0.0        0.0        0.0       -1.0
-2.0       -2.0        1.0       -1.0        1.0       -2.0        1.0       -5.0
2.0       -5.0        2.0        0.0        0.0
10    0        0.0        0.0        0.0        0.0        0.0        0.0       -5.0
0.0       -2.0        0.0       -3.0        0.0       -3.0        0.0       -4.0
0.0       -4.0        0.0        0.0        0.0
10    1        0.0        0.0        0.0        0.0        0.0        0.0       -2.0
3.0       -3.0        2.0       -3.0        1.0       -3.0        1.0       -4.0
1.0       -4.0        1.0        0.0        0.0
10    2        0.0        0.0        0.0        0.0        0.0        0.0        0.0
0.0        2.0        1.0        2.0        1.0        2.0        1.0        2.0
0.0        2.0        0.0        0.0        0.0
10    3        0.0        0.0        0.0        0.0        0.0        0.0       -5.0
4.0       -5.0        2.0       -5.0        3.0       -5.0        3.0       -5.0
3.0       -5.0        3.0        0.0        0.0
10    4        0.0        0.0        0.0        0.0        0.0        0.0       -2.0
3.0       -2.0        6.0       -1.0        4.0       -2.0        4.0       -2.0
6.0       -2.0        6.0        0.0        0.0
10    5        0.0        0.0        0.0        0.0        0.0        0.0        8.0
-4.0        4.0       -4.0        6.0       -4.0        5.0       -4.0        5.0
-4.0        5.0       -4.0        0.0        0.0
10    6        0.0        0.0        0.0        0.0        0.0        0.0        3.0
-2.0        4.0        0.0        4.0        0.0        4.0       -1.0        3.0
0.0        3.0        0.0        0.0        0.0
10    7        0.0        0.0        0.0        0.0        0.0        0.0        0.0
-3.0        0.0       -2.0        1.0       -1.0        1.0       -1.0        1.0
-1.0        1.0       -1.0        0.0        0.0
10    8        0.0        0.0        0.0        0.0        0.0        0.0        1.0
5.0        2.0        3.0        0.0        3.0        0.0        3.0        2.0
4.0        2.0        4.0        0.0        0.0
10    9        0.0        0.0        0.0        0.0        0.0        0.0        0.0
3.0        2.0        0.0        3.0        1.0        3.0        1.0        3.0
0.0        3.0        0.0        0.0        0.0
10   10        0.0        0.0        0.0        0.0        0.0        0.0       -1.0
-3.0        0.0       -6.0       -1.0       -4.0       -1.0       -5.0        0.0
-6.0        0.0       -6.0        0.0        0.0
-1
```

APPENDIX 2

SPHERICAL CAP HARMONIC COEFFICIENTS USED FOR THE CANADIAN GEOMAGNETIC REFERENCE FIELD 1990

```
  65.00   -85.00  30.00  6371.2   66.3333
   1    0    0    2   16    4    0   -1
I  0  0   0.0000   0.100000E+01   0.000000E+00   0.000000E+00
  0.805212E+03   0.000000E+00  -0.213366E+04   0.000000E+00
  -0.442117E+04   0.000000E+00  -0.231748E+04   0.000000E+00
I  1  0   4.0837   0.100000E+01   0.393952E+01   0.000000E+00
  0.288157E+03   0.000000E+00   0.276897E+03   0.000000E+00
  -0.643388E+03   0.000000E+00  -0.480977E+03   0.000000E+00
I  1  1   3.1196   0.253621E+01  -0.152553E+03  -0.350967E+02
  0.658761E+03   0.333090E+03  -0.169371E+03  -0.304683E+03
  0.000000E+00  -0.493076E+03   0.136406E+03  -0.159062E+03
I  2  0   6.8354   0.100000E+01   0.000000E+00   0.000000E+00
  -0.124345E+03   0.000000E+00  -0.223119E+03   0.000000E+00
  -0.208055E+03   0.000000E+00  -0.122209E+03   0.000000E+00
I  2  1   6.8354   0.517746E+01   0.452437E+03   0.507498E+02
  -0.291487E+03  -0.382857E+03   0.000000E+00  -0.486984E+02
  0.000000E+00  -0.133601E+03   0.123905E+02  -0.741942E+02
I  2  2   5.4928   0.612537E+01   0.132779E+02  -0.188386E+03
  0.142083E+03   0.282898E+03   0.000000E+00  -0.175786E+03
  -0.590835E+02   0.000000E+00   0.000000E+00   0.956235E+02
I  3  0  10.0385   0.100000E+01   0.000000E+00   0.000000E+00
  0.293542E+02   0.000000E+00   0.470950E+02   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I  3  1   9.7121   0.721601E+01  -0.768652E+03  -0.774457E+02
  0.256738E+03   0.366483E+03   0.000000E+00   0.000000E+00
  -0.106881E+03   0.000000E+00  -0.783833E+02   0.000000E+00
I  3  2   9.3733   0.170110E+02  -0.171574E+02   0.569208E+03
  0.000000E+00  -0.244150E+03   0.000000E+00   0.724967E+02
  0.000000E+00  -0.661285E+02  -0.340082E+01  -0.395611E+02
I  3  3   7.7524   0.154891E+02   0.170846E+02  -0.333048E+01
  -0.187627E+03   0.749742E+02  -0.887667E+02   0.729314E+01
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I  4  0  12.9083   0.100000E+01   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.144852E+02   0.000000E+00   0.000000E+00   0.000000E+00
I  4  1  12.9083   0.947928E+01   0.995386E+03   0.636325E+02
  -0.154933E+03  -0.291324E+03   0.000000E+00   0.000000E+00
  0.963486E+01   0.000000E+00   0.000000E+00   0.000000E+00
I  4  2  12.3720   0.290691E+02   0.830277E+01  -0.113427E+04
  0.000000E+00   0.248416E+03   0.000000E+00  -0.378451E+02
  0.000000E+00   0.000000E+00   0.000000E+00   0.122722E+02
I  4  3  11.8074   0.533354E+02  -0.234119E+02   0.000000E+00
  0.122009E+03  -0.380616E+02   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.323442E+02   0.000000E+00
I  4  4   9.9589   0.398615E+02   0.000000E+00  -0.558992E+01
  -0.136597E+02   0.276629E+02   0.178351E+02   0.000000E+00
  0.000000E+00  -0.671208E+01   0.000000E+00   0.000000E+00
I  5  0  16.0248   0.100000E+01   0.102724E+01   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I  5  1  15.8215   0.115415E+02  -0.101329E+04  -0.382369E+02
  0.750231E+02   0.191267E+03   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
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I  5  2  15.6154   0.456895E+02   0.000000E+00   0.177861E+04
  0.000000E+00  -0.187180E+03   0.000000E+00   0.000000E+00
  0.115898E+02   0.000000E+00   0.137648E+02   0.000000E+00
I  5  3  14.9180   0.105995E+03   0.135495E+02   0.000000E+00
  -0.104855E+03   0.235087E+02   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00  -0.260955E+02   0.000000E+00
I  5  4  14.1778   0.162625E+03   0.000000E+00   0.000000E+00
  0.247057E+02  -0.457641E+01   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I  5  5  12.1334   0.103486E+03  -0.200459E+01   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I  6  1  18.9364   0.137460E+02   0.779207E+03   0.123826E+02
  -0.224413E+02  -0.857139E+02   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I  6  2  18.5830   0.641554E+02   0.000000E+00  -0.217468E+04
  0.000000E+00   0.994581E+02   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I  6  3  18.2219   0.190927E+03  -0.410011E+01  -0.371005E+01
  0.642951E+02  -0.944535E+01   0.000000E+00   0.000000E+00
  -0.182973E+02   0.000000E+00   0.000000E+00   0.000000E+00
I  6  4  17.3910   0.364976E+03   0.253005E+01   0.000000E+00
  -0.188470E+02   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I  6  5  16.5041   0.486587E+03   0.000000E+00   0.000000E+00
  0.000000E+00   0.267181E+01   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I  6  6  14.2861   0.270001E+03   0.000000E+00  -0.466811E+01
  0.000000E+00  -0.409800E+01   0.391241E+01   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00  -0.526934E+01
I  7  1  21.8702   0.158221E+02  -0.464803E+03   0.000000E+00
  0.000000E+00   0.258820E+02   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I  7  2  21.7210   0.870680E+02   0.000000E+00   0.211087E+04
  0.000000E+00  -0.305952E+02   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I  7  3  21.2461   0.300181E+03   0.000000E+00   0.000000E+00
  -0.247740E+02   0.000000E+00  -0.732047E+01   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I  7  4  20.7588   0.734755E+03   0.000000E+00   0.000000E+00
  0.981816E+01   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I  7  5  19.8121   0.121018E+04   0.000000E+00   0.281860E+01
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I  7  6  18.7979   0.143591E+04  -0.456082E+01   0.236503E+01
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I  8  1  24.9514   0.180025E+02   0.182408E+03   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I  8  2  24.6858   0.111915E+03   0.000000E+00  -0.165732E+04
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
```

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I  8  4  23.8390   0.126951E+04   0.000000E+00   0.663180E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I  8  7  21.0663   0.419235E+04  -0.134438E+01   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I  8  8  18.5472   0.185281E+04   0.000000E+00  -0.207342E+01
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I  9  1  27.8979   0.200874E+02  -0.408884E+02   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I  9  2  27.7807   0.141168E+03   0.000000E+00   0.988606E+03
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I  9  4  27.0470   0.209140E+04   0.401427E+01   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I  9  5  26.3784   0.501966E+04   0.000000E+00  -0.143431E+01
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I 10  2  30.7474   0.172387E+03   0.000000E+00  -0.455496E+03
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I 10  3  30.5325   0.876491E+03   0.000000E+00  -0.757373E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I 10  4  30.0829   0.318566E+04  -0.259024E+01   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I 10  8  26.8711   0.384162E+05   0.155144E+01   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I 10 10  22.7683   0.127842E+05   0.000000E+00  -0.229285E+01
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I 11  0  34.0120   0.100000E+01   0.123425E+01   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I 11  2  33.8193   0.207993E+03   0.564711E+00   0.137241E+03
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I 11  4  33.2235   0.471946E+04   0.000000E+00  -0.416833E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I 11  9  29.1761   0.117952E+06   0.000000E+00   0.158920E+01
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I 11 10  27.7627   0.996787E+05   0.134952E+01   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I 12  1  36.9669   0.265041E+02   0.276942E+01   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
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I 12  2  36.7886   0.245582E+03   0.000000E+00  -0.218306E+02
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I 12  6  35.2710   0.625103E+05   0.171012E+01   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I 12  8  33.7718   0.242271E+06   0.000000E+00   0.795277E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I 12 12  26.9619   0.884337E+05   0.000000E+00  -0.310819E+01
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I 13  0  40.0102   0.100000E+01  -0.531003E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I 13  4  39.3438   0.922032E+04   0.428681E+01   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I 13  6  38.4664   0.104918E+06  -0.684041E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I 13  9  36.1810   0.834895E+06  -0.587816E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I 13 12  32.1619   0.802105E+06   0.444168E+01   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I 14  1  42.9715   0.307525E+02  -0.102928E+01  -0.400819E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I 14  3  42.6643   0.236389E+04   0.000000E+00  -0.779218E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I 14  4  42.3494   0.123446E+05  -0.972112E+01   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I 14  5  42.0320   0.506746E+05  -0.409944E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I 14  6  41.5359   0.165915E+06   0.000000E+00   0.102912E+01
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I 14  8  40.3169   0.100244E+07   0.000000E+00  -0.202692E+01
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I 14  9  39.5844   0.188373E+07   0.000000E+00   0.177718E+01
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I 14 12  35.9940   0.321758E+07  -0.888707E+01  -0.172721E+01
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I 14 13  34.3470   0.226154E+07  -0.104301E+01   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
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I 15  2  45.8662   0.379827E+03  -0.606618E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I 15  4  45.4313   0.163099E+05   0.992168E+01  -0.729867E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I 15  7  44.1294   0.751154E+06   0.527667E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I 15  8  43.5694   0.186492E+07   0.000000E+00   0.161684E+01
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I 15  9  42.7989   0.381372E+07   0.000000E+00  -0.384056E+01
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I 15 10  42.0100   0.667923E+07   0.000000E+00   0.395886E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I 15 11  40.9382   0.938057E+07   0.198927E+01   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I 15 12  39.8232   0.111063E+08   0.941816E+01   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I 15 13  38.2408   0.953823E+07   0.000000E+00  -0.178600E+01
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I 15 14  36.5239   0.635452E+07   0.000000E+00  -0.582115E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I 15 15  33.2160   0.161204E+07   0.000000E+00  -0.919449E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I 16  0  48.9749   0.100000E+01   0.307120E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I 16  1  48.9749   0.350000E+02   0.000000E+00   0.598322E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I 16  3  48.7056   0.350375E+04   0.000000E+00  -0.391360E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I 16  4  48.4311   0.210193E+05  -0.452871E+01   0.121919E+01
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I 16  5  48.1549   0.995458E+05   0.000000E+00   0.279807E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I 16  6  47.7278   0.380260E+06   0.000000E+00   0.281341E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I 16  7  47.2962   0.121828E+07   0.000000E+00   0.964958E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
```

```
I 16  9  46.0801   0.742617E+07   0.000000E+00   0.269312E+01
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I 16 11  44.4162   0.232234E+08  -0.149749E+01   0.798591E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I 16 12  43.2911   0.307483E+08  -0.529923E+01   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I 16 13  42.1198   0.345010E+08   0.000000E+00   0.185191E+01
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I 16 14  40.4771   0.281031E+08   0.924275E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
I 16 15  38.6935   0.178002E+08  -0.107275E+01   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
  0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00
```

APPENDIX 3

PROGRAM DECPROG

SUBROUTINE CALDEC

SUBROUTINE GEOCENF

SUBROUTINE SCHNEV

SUBROUTINE LEGFUN

SUBROUTINE FIELD

SUBROUTINE SPHENWF

```
      PROGRAM DECPROG
C
C  THIS PROGRAM IS A SIMPLE DRIVER PROGRAM TO CALCULATE AND LIST
C  MAGNETIC FIELD VALUES
C  IN ITS MOST BASIC FORM THE PROGRAM AND ITS ASSOCIATED SUBROUTINES
C  FORM THE BASIC SOFTWARE WHICH IS PASSED ON TO OUTSIDE AGENCIES
C
C  L.R. NEWITT FEB 23, 1989
C
C  REVISED TO USE THE CGRF90 FEB 26, 1990
C
      L=1
      ALT=0.0
      YEAR=1990.
      DO 10 FLAT=40.,85,5
      DO 10 FLON=-50.,-145.,-5.
      CALL CALDEC(FLAT,FLON,ALT,YEAR,L,D,DSV)
   10 PRINT 1, FLAT,FLON,YEAR,D,DSV
    1 FORMAT(1H ,3F10.1,F10.2,F8.1)
      STOP
      END
```

```
      SUBROUTINE CALDEC(FLAT,FLON,ALT,YEAR,L,D,DSV)
      DATA IENTER /0/
      DELT=1.
      RF=6371.2
      NMAX=10
      IF(IENTER.NE.0)GO TO 10
      IENTER=1
      LF=1
      CALL FIELD(DUM,DUM,DUM,DUM,NMAX,LF,DUM,DUM,DUM)
      CALL SCHNEV(DUM,DUM,DUM,DUM,0,FLATO,FLONO,THETA)
      CALL SPHITF(FLATO,FLONO,DUM,DUM,DUM,DUM,DUM,DUM)
      TCGRF=1990.
      CAPLAT=90.-THETA
10    CONTINUE
      CALL GEOCENF(FLAT,ALT,DUM,DUM,GCLAT,R,DUM,DUM)
      CALL SPHNEWF(GCLAT,FLON,DUM,DUM,FLATR,FLONR,DUM,DUM)
      IF(FLATR.LT.CAPLAT)THEN
      CALL FIELD(GCLAT,FLON,R-RF,YEAR+DELT,NMAX,LF,BN2,Y2,BV2)
      CALL FIELD(GCLAT,FLON,R-RF,YEAR,NMAX,LF,BN,Y,BV)
      PRINT 100
100   FORMAT(1H ,'FOLLOWING POINT OUTSIDE AREA OF CGRF; CALCULATED USING
     * IGRF')
      ELSE
      IF(YEAR.LT.1990.)THEN
      CALL FIELD(GCLAT,FLON,R-RF,TCGRF,NMAX,LF,XR,YR,ZR)
      CALL SCHNEV(FLATR,FLONR,R,(YEAR+DELT)/30.,L,BNR2,BER2,BV2)
      CALL SPHOLDF(DUM,DUM,BN2,BE2,DUM,DUM,BNR2,BER2)
      BN2=BN2+XR
      Y2=BE2+YR
      BV2=BV2+ZR
      CALL SCHNEV(FLATR,FLONR,R,YEAR/30.,L,BNR,BER,BV)
      CALL SPHOLDF(DUM,DUM,BN,BE,DUM,DUM,BNR,BER)
      BN=BN+XR
      Y=BE+YR
      BV=BV+ZR
      ELSE
      DELUP=YEAR-TCGRF
      CALL FIELD(GCLAT,FLON,R-RF,TCGRF,NMAX,LF,XR,YR,ZR)
      CALL SCHNEV(FLATR,FLONR,R,(TCGRF+DELT)/30.,L,BNR2,BER2,BV2)
      CALL SPHOLDF(DUM,DUM,BN2,BE2,DUM,DUM,BNR2,BER2)
      CALL SCHNEV(FLATR,FLONR,R,TCGRF/30.,L,BNR,BER,BV)
      CALL SPHOLDF(DUM,DUM,BN,BE,DUM,DUM,BNR,BER)
      BN=BN+XR
      Y=BE+YR
      BV=BV+ZR
      BN2=BN2+XR
      Y2=BE2+YR
      BV2=BV2+ZR
      DELBN=BN2-BN
      DELY=Y2-Y
      DELBV=BV2-BV
      BN=DELBN*DELUP+BN
```

```
Y=DELY*DELUP+Y
BV=DELBV*DELUP+BV
BN2=DELBN+BN
Y2=DELY+Y
BV2=DELBV+BV
ENDIF
END IF
CALL GEOCINV(DUM,DUM,X2,Z2,DUM,DUM,BN2,BV2)
CALL GEOCINV(DUM,DUM,X,Z,DUM,DUM,BN,BV)
H=SQRT(X*X+Y*Y)
H2=SQRT(X2*X2+Y2*Y2)
D=0.
IF(H.NE.0.)D=ATAN2D(Y,X)
D2=0.
IF(H2.NE.0.)D2=ATAN2D(Y2,X2)
DSV=D2-D
IF(DSV.GT.180.)DSV=DSV-180.
IF(DSV.LT.-180.)DSV=DSV+360.
DSV=DSV*60./DELT
RETURN
END
```

```
      SUBROUTINE GEOCENF (GDLAT,GDALT,X,Z,GCLAT,R,BN,BV)

C     CONVERT FROM GEODETIC TO GEOCENTRIC COORDINATES, AND
C     CONVERT GEODETIC COMPONENTS X,Z TO GEOCENTRIC COMPONENTS BN,BV.

C     KAULA 1964 ELLIPSOID, RECOMMENDED BY I.A.U., 1964
      DATA  A/6378.160/, ESQ/.00669454/

      SLAT = SIND(GDLAT)
      CLAT = COSD(GDLAT)
      FN = A/SQRT(1.-ESQ*SLAT**2)
      FNPH = FN + GDALT
      WC = FNPH*CLAT
      ZC = (FNPH-ESQ*FN)*SLAT
      R = SQRT(WC**2+ZC**2)
      IF(WC.LT.ABS(ZC))THEN
         GCLAT=ACOSD(WC/R)
         IF(ZC. LT .0.)GCLAT=-GCLAT
      ELSE
          GCLAT = ASIND(ZC/R)
          ENDIF
      D = GDLAT - GCLAT
      SD = SIND(D)
      CD = COSD(D)
      BN = X*CD - Z*SD
      BV = X*SD + Z*CD
      RETURN

C     CONVERT BACK FROM GEOCENTRIC BN,BV TO GEODETIC X,Z.
C     THIS CALL MUST FILLOW A CALL TO GEOCENF

      ENTRY GEOCINV
      X = BN*CD + BV*SD
      Z = BV*CD - BN*SD
      RETURN

      END
```

```
      SUBROUTINE SCHNEV (FLAT,FLON,R,T,L,BN,BE,BV)

C     WHEN L IS POSITIVE:
C     COMPUTES SPHERICAL CAP HARMONIC (GEOCENTRIC) FIELD COMPONENTS
C     HORIZONTAL NORTH BN,HORIZONTAL EAST BE,AND VERTICAL DOWNWARD BV.
C     WHEN L IS NEGATIVE:
C     COMPUTES GENERAL FUNCTION BV, ITS HORIZONTAL NORTH DERIVATIVE BN,
C     AND ITS HORIZONTAL EAST DERIVATIVE BE, ON SPHERICAL CAP SURFACE.
C     NOTE THAT THESE ARE METRICAL DERIVATIVES, AND BE IS THE
C     LONGITUDINAL DERIVATIVE DIVIDED BY SIN(COLATITUDE).

C     FLAT,FLON,R ARE GEOCENTRIC SPHERICAL CAP LATITUDE,LONGITUDE,RADIAL
C     DISTANCE; T IS TIME.

C     L =  0  ON FIRST CALL:  RETURNS SPHERICAL CAP POLE POSITION FLATO,FLONO
C             AND HALF-ANGLE THETA AS BN,BE, AND BV AFTER INITIALIZATION.
C             ON SUBSEQUENT CALLS:  ACTS AS L=1.
C          1  COMPUTES POTENTIAL FIELD COMPONENTS FROM INTERNAL COEFFICIENTS.
C          2  COMPUTES POTENTIAL FIELD COMPONENTS FROM EXTERNAL COEFFICIENTS.
C          3  COMPUTES FIELD FROM BOTH INTERNAL AND EXTERNAL COEFFICIENTS.
C         -1  COMPUTES GENERAL FUNCTION BV AND DERIVATIVES BN WITH RESPECT TO
C             LATITUDE AND BE WITH RESPECT TO LONGITUDE DIVIDED BY COS(LAT)
C             (R IS DUMMY VARIABLE IN THIS CASE).
C     NOTE:   SUBROUTINE IS INITIALIZED DURING FIRST CALL REGARDLESS OF L.

C     SUBPROGRAM USED:  LEGFUN

      PARAMETER   (KDIM=16,LDIM=16)                                    SET UP
      DIMENSION   FN(0:KDIM,0:KDIM), CONST(0:KDIM,0:KDIM)
      DIMENSION   CML(KDIM), SML(KDIM)
      DIMENSION   GNM(0:LDIM), HNM(0:LDIM)
      DIMENSION   DELT(0:LDIM)
      DIMENSION   BINT(0:KDIM,0:KDIM,0:LDIM), BEXT(0:KDIM,0:KDIM,0:LDIM)
      CHARACTER*1 IE
      DATA        IENTER /0/

      IF (IENTER .NE. 0)  GO TO 100

      IENTER = 1
C     READ COEFFICIENT FILE
      IT1 = 85
      OPEN (UNIT=IT1,FILE='SCHCOEF.90',STATUS='OLD')
      READ (IT1,240,END=999)  FLATO,FLONO,THETA,RE,TZERO
      READ(IT1,241,END=999)IFIT,ICEN,IREF,IB,KINT,LINT,KEXT,LEXT
  240 FORMAT (F8.2,F9.2,F7.2,F8.1,F10.4)
  241 FORMAT(8I5)
      KMAX = MAX(KINT,KEXT)
      IF (KMAX .GT. KDIM)  GO TO 999
      KT = MAX(LINT,LEXT)
      IF (KT .GT. LDIM)  GO TO 999
  247 READ (IT1,250,END=280) IE,N,M,FNN,CON,(GNM(J),HNM(J),J=0,KT)
  250 FORMAT (1X,A1,2I3,F9.4,E15.6,<KT+1>(E15.6,E15.6))
```

```
      IF (N .LT. 0)  GO TO 280
      IF (M .LT. 0)  GO TO 280
      IF (N .GT. KMAX)  GO TO 247
      IF (M .GT. KMAX)  GO TO 247
      IF (IE .EQ. 'I')  THEN
         IF (N .GT. KINT)  GO TO 247
         LJ = LINT
      ELSE
         IF (N .GT. KEXT)  GO TO 247
         LJ = LEXT
         END IF
      FN(N,M) = FNN
      CONST(N,M) = CON
      IF (M .GT. 0)  GO TO 300
      DO 301 J=0,LJ
      IF (IE .EQ. 'I')  THEN
         BINT(N,M,J)    = GNM(J)
      ELSE
         BEXT(N,M,J)    = GNM(J)
         END IF
  301 CONTINUE
      GO TO 247
  300 CONTINUE
      DO 302 J=0,LJ
      IF (IE .EQ. 'I')  THEN
         BINT(N,M,J)    = GNM(J)
         BINT(M-1,N,J) = HNM(J)
      ELSE
         BEXT(N,M,J)    = GNM(J)
         BEXT(M-1,N,J) = HNM(J)
         END IF
  302 CONTINUE
      GO TO 247
  280 CLOSE (UNIT=IT1,STATUS='KEEP')

      IF (L .NE. 0)  GO TO 100
      BN = FLATO
      BE = FLONO
      BV = THETA
      T = TZERO
      RETURN

  100 IF (L .GE. 0)  THEN
         IF (IFIT .LT. 0)  GO TO 999
         AOR = RE/R
         AR = AOR**2
         IF (L .GT. 1)  GO TO 107
      ELSE
         IF (IFIT .GE. 0)  GO TO 999
         AR = -1.
         END IF
      KT = LINT
      GO TO 109
```

```
107 IF (KEXT .GT. 0)  AOR3 = AOR*AR
    IF (L .GT. 2)  GO TO 108
    KT = LEXT
    GO TO 109
108 KT = MAX (LINT,LEXT)
109 DELT(0) = 1.
    IF (KT .LE. 0)  GO TO 103
    DEL = T - TZERO
    DO 102 I=1,KT
102 DELT(I) = DELT(I-1)*DEL
103 X = 0.
    Y = 0.
    Z = 0.
    IF (L .EQ. 2)  GO TO 106
    IF (KINT .LT. 0)  GO TO 106
    GTI = 0.
    DO 105 I=0,LINT
105 GTI = GTI + BINT(0,0,I)*DELT(I)
    Z = -AR*GTI
106 COLAT = 90. - FLAT
    DO 150 N=1,KMAX
    IF (N .GT. 1)  GO TO 115
    CL = COSD(FLON)
    SL = SIND(FLON)
    CML(1) = CL
    SML(1) = SL
    GO TO 120
115 SML(N) = SL*CML(N-1) + CL*SML(N-1)
    CML(N) = CL*CML(N-1) - SL*SML(N-1)
120 CONTINUE
    DO 150 M=0,N
    IF (IB .EQ. 2)  GO TO 121
    NMM = N - M
    IF ((NMM/2)*2 .NE. NMM)  GO TO 150
121 FFN = FN(N,M)
    CALL LEGFUN (M,FFN,CONST(N,M),COLAT,P,DP,PMS,0)
    IF (L .GE. 0)  THEN
       AR = AOR**(FFN+2.)
    ELSE
       AR = 1.
       FFN = -2.
       DP = -DP
       PMS = -PMS
       END IF
    IF (M .NE. 0)  GO TO 130
    BT1 = 0.
    BT3 = 0.
    BT  = 0.
    IF (L .EQ. 2)  GO TO 123
    IF (N .GT. KINT)  GO TO 123
    GTI = 0.
    DO 122 I=0,LINT
122 GTI  = GTI  + BINT(N,M,I)*DELT(I)
```

```
      BT1  = AR*GTI
      BT3  = BT1
  123 IF (L .LE. 1)  GO TO 125
      IF (N .GT. KEXT)  GO TO 125
      GTE = 0.
      DO 124 I=0,LEXT
  124 GTE = GTE + BEXT(N,M,I)*DELT(I)
      BT  = AOR3/AR*GTE
      BT1 = BT1 + BT
  125 X = X + BT1*DP
      Z = Z - (FFN*(BT3-BT)+BT3)*P
      GO TO 150
  130 BT1 = 0.
      BT2 = 0.
      BT3 = 0.
      BT  = 0.
      IF (L .EQ. 2)  GO TO 133
      IF (N .GT. KINT)  GO TO 133
      GTI = 0.
      HTI = 0.
      DO 132 I=0,LINT
      GTI = GTI + BINT(N,M,I)*DELT(I)
  132 HTI = HTI + BINT(M-1,N,I)*DELT(I)
      BT1 = AR*(GTI*CML(M) + HTI*SML(M))
      BT2 = AR*(GTI*SML(M) - HTI*CML(M))
      BT3 = BT1
  133 IF (L .LE.  1)  GO TO 135
      IF (N .GT. KEXT)  GO TO 135
      GTE = 0.
      HTE = 0.
      DO 134 I=0,LEXT
      GTE = GTE + BEXT(N,M,I)*DELT(I)
  134 HTE = HTE + BEXT(M-1,N,I)*DELT(I)
      RA = AOR3/AR
      BT = RA*(GTE*CML(M) + HTE*SML(M))
      BT1 = BT1 + BT
      BT2 = BT2 + RA*(GTE*SML(M) - HTE*CML(M))
  135 X = X + BT1*DP
      Y = Y + BT2*PMS
      Z = Z - (FFN*(BT3-BT)+BT3)*P
  150 CONTINUE
      BN = X
      BE = Y
      BV = Z
      RETURN

  999 STOP
      END
```

```
      SUBROUTINE LEGFUN (M,FN,CONST,COLAT,P,DP,PMS,IPRT)

C     SERIES FORM FOR ASSOCIATED LEGENDRE FUNCTION P, ITS DERIVATIVE DP,
C     AND THE FUNCTION PMS=P*M/SIN(COLAT), IN POWERS OF (1-COS(COLAT))/2.
C     INTEGRAL ORDER M, REAL DEGREE FN, NORMALIZING CONSTANT CONST.
C     COLATITUDE COLAT IN DEGREES.
C     IPRT = 0      NO PRINT-OUT
C            1      PRINT PARAMETERS AND P SERIES
C            2      PRINT PARAMETERS AND DP SERIES
C            3      PRINT PARAMETERS AND BOTH P AND DP SERIES
C           -1      PRINT PARAMETERS ONLY
C     INPUT M,FN,CONST,COLAT,IPRT.   OUTPUT P,DP,PMS.
      REAL*8  FNN,AL,DX,A,B,PNM,DPNM

      PARAMETER (JMAX=60)
      DIMENSION  AM(JMAX), BM(JMAX)

      IF (COLAT .LT. 60.)  THEN
          X = SIND(COLAT/2.)**2
          C = 1. - 2.*X
      ELSE
          C = COSD(COLAT)
          X = (1. - C)/2.
          END IF
      S = SIND(COLAT)
      FNN = FN*(FN+1.)
      IF (M .GT.1)  GO TO 20
      IF (M .LT. 0)  STOP
      AL = CONST
      GO TO 50
   20 AL = CONST*S**(M-1)

   50 PNM = AL
      DPNM = 0.
      DX = X
      J = 0

  100 J = J + 1
      JPM = J + M
      B = AL*((JPM-1)-FNN/JPM)
      DPNM = DPNM + B
      A = (B*DX)/J
      PNM = PNM + A
      AL = A

C     STORE P OR DP SERIES FOR PRINTOUT.
      IF (IPRT .LE. 0)  GO TO 150
      IF (IPRT .EQ. 2)  GO TO 145
      AM(J) = A
      IF (IPRT .EQ. 1)  GO TO 150
  145 BM(J) = B
```

```
C     CHECK FOR TERMINATION OF SERIES.
  150 ABSA = ABS(A)
      ABSB = ABS(B)
      IF (ABSB .GE. 1.E-7)  GO TO 160
      IF (ABSA .LT. 1.E-7)  GO TO 110
  160 IF (ABSB .GE. 1.E+26)  GO TO 105
      IF (ABSA .GE. 1.E+26)  GO TO 105
C     CHANGE CHECK LIMITS ACCORDING TO ACCURACY DESIRED AND ACCORDING
C     TO WORD SIZE OF COMPUTER.
C     FOR 32-BIT WORD, DOUBLE PRECISION, E-7 AND E+9 GIVE 7 DIGITS ACCURACY.
C     FOR 60-BIT WORD, DOUBLE PRECISION, E-7 AND E+22 GIVE 7 DIGITS ACCURACY.
C     FOR 60-BIT WORD, SINGLE PRECISION, E-7 AND E+7 GIVE 7 DIGITS ACCURACY.
C     (DOUBLE OR SINGLE PRECISION REFER TO FNN,AL,A,B,PNM,DPNM)
      IF (J .LT. JMAX)  GO TO 100
C     CONVERGENCE SLOW OR JMAX TOO SMALL
  105 CONTINUE
C     NUMERICAL ERROR UNACCEPTABLY LARGE DUE TO ADDING OF
C     LARGE AND SMALL NUMBERS.
      PRINT 108, M,FN,CONST,J,A,B
  108 FORMAT (//12H ** ERROR **/1X,I5,F10.5,E15.7,I5,2D15.7)
      STOP

C     SERIES TRUNCATED SUCCESSFULLY.
  110 PS = PNM
      DPS = DPNM
      IF (M .NE. 0)  GO TO 115
      PMS = 0.
      P = PS
      DP = DPS*S/2.
      GO TO 120
  115 PMS = PS*M
      P = PS*S
      DP = DPS*S*S/2. + C*PMS
  120 CONTINUE

C     PRINT TERMS OF SERIES
      IF (IPRT .EQ. 0)  RETURN
      PRINT 125,  M,FN,CONST,COLAT,P,DP,PMS,J
  125 FORMAT (/1X,I5,F10.5,E20.12,F10.2,3F25.14,I5)
      IF (IPRT .LT. 0)  RETURN
      IF (IPRT .EQ. 2)  GO TO 135
      PRINT 130, (AM(I),I=1,J)
  130 FORMAT (1X,16E8.1)
      IF (IPRT .EQ. 1)  RETURN
  135 PRINT 130, (BM(I),I=1,J)
      RETURN
      END
```

```
      SUBROUTINE FIELD (DLAT,DLONG,ALT,TM,NMAX,L,BN,BE,BV)

C     GEOMAGNETIC FIELD COMPONENTS X,Y,Z, IN GAMMAS.
C     USES ANY SET OF COEFFICIENTS.
C     L POSITIVE READS A NEW SET OF COEFFICIENTS.
C
C*********************************************************************
C  MODIFIED TO CALCULATE VALUES INTERPOLATING BETWEEN DGRF MODELS
C  FROM 1945 TO 1985
C  VALUES FROM 1985 TO 1995 ARE CALCULATED USING IGRF TIME TERMS
C*********************************************************************

      PARAMETER  (ND=11)                                          DEGREE10
      DIMENSION P(ND,ND),G(ND,ND,9),H(ND,ND,9),DP(ND,ND),CONST(ND,ND),
     *   SP(ND),CP(ND),SHMIT(ND,ND),GT(ND,ND),HT(ND,ND),
     *   GTT(ND,ND),HTT(ND,ND),TG(ND,ND),TH(ND,ND),FM(ND),FN(ND)
      DIMENSION  AID(4), GGNM(9), HHNM(9)
      DATA  P(1,1)/0./

      IF (P(1,1) .EQ. 1.)  GO TO 9
      P(1,1)=1.
      IT = 75                                                     TAPE 75
      NDIM = ND
      DP(1,1)=0.
      SP(1)=0.
      CP(1)=1.
      RAD=57.295779513
      SHMIT(1,1)=-1.
      FM(1) = 0.
      DO 20 N=2,NDIM
      SHMIT(N,1)=SHMIT(N-1,1)*FLOAT (2*N-3)/FLOAT (N-1)
      FN(N)=N
      FM(N) = N - 1
      J=2
      DO 20 M=2,N
      SHMIT(N,M)=SHMIT(N,M-1)*SQRT (FLOAT ((N-M+1)*J)/FLOAT (N+M-2))
   20 J=1
      DO 4 N=3,NDIM
      NM2 = N-2
      DO 4 M=1,NM2
    4 CONST(N,M)=FLOAT ((N-2)**2-(M-1)**2)/FLOAT ((2*N-3)*(2*N-5))

    9 IF (L .EQ. 0)  GO TO 15
      IF (L .LT. 0)  GO TO 33
C  COEFFICIENTS ARE FOR GEOCENTRIC COORDINATES
      OPEN(UNIT=IT,FILE='IGRF4585.BYYEAR',STATUS='OLD')
      READ (IT,27) J,K,TZERO,RE,A,FLAT,(AID(I),I=1,4)             TAPE 75
   27 FORMAT (2I1,F8.2,3F10.3,4A10)

C        J       - ZERO IF COEFFICIENTS ARE FOR OBLATE EARTH
C                - NON-ZERO IF COEFFICIENTS ARE FOR SPHERICAL EARTH.
C        K       - ZERO IF COEFFICIENTS ARE SCHMIDT NORMALIZED
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C                - NON-ZERO IF GAUSS NORMALIZED.
C        TZERO   - EPOCH YEAR OF COEFFICIENTS.
C        RE      - RADIUS OF EQUIVALENT SPHERICAL EARTH USED IN DERIVING
C                  THE COEFFICIENTS.
C        A       - SEMI-MAJOR AXIS OF GEODETIC ELLIPSOID.
C        FLAT    - FLATTENING OF ELLIPSOID.
C        AID     - IDENTIFICATION (MAXIMUM 40 CHARACTERS)

      MAXN=0
      TEMP=0.
      IF (J .NE. 0)  GO TO 25
      FLAT= 1.-1./FLAT
      A2=A**2
      A4=A**4
      B2=(A*FLAT)**2
      A2B2=A2*(1.-FLAT**2)
      A4B4=A4*(1.-FLAT**4)
   25 READ (IT,2)  N,M,((GGNM(I),HHNM(I)),I=1,9),GTNM,HTNM              TAPE 75
    2 FORMAT (2I5,20F10.1)
      IF (N .LE. 0)     GO TO 3
      IF (N .LT. NDIM)  GO TO 7
      GO TO 25
    7 N=N+1
      M=M+1
      MAXN=  MAX0 (N,MAXN)
      DO 47 JK=1,9
      G(N,M,JK)=GGNM(JK)
47    H(N,M,JK)=HHNM(JK)
      GT(N,M)=GTNM
      HT(N,M)=HTNM
      TEMP=AMAX1(TEMP,ABS (GTNM))
      GO TO 25
    3 CONTINUE
      IF (NMAX .LT. MAXN)  GO TO 17
      MAXNM1 = MAXN-1
      STOP
   17 IF (TEMP .NE. 0)  GO TO 29
      L = -L
      GO TO 30
   29 L=0
   30 IF (K .NE. 0)  GO TO 16
      DO 32 N=2,MAXN
      DO 32 M=1,N
      DO 232 KK=1,9
      G(N,M,KK)=G(N,M,KK)*SHMIT(N,M)
      H(N,M,KK)=H(N,M,KK) *SHMIT(N,M)
232   CONTINUE
      GT(N,M)=GT(N,M)*SHMIT(N,M)
  32  HT(N,M)=HT(N,M)*SHMIT(N,M)
   15 IF (TM .EQ. TLAST)  GO TO 33
   16 T=TM-TZERO
      IF(TM.GE.TZERO)THEN
      DO 22 N=2,MAXN
```

```
      DO 22 M=1,N
      TG(N,M)=G(N,M,9)+T *GT(N,M)
      TH(N,M)=H(N,M,9)+T *HT(N,M)
22    CONTINUE
      ELSE
      KT=T/5
      DELT=(T-KT*5.)/5.
      KKT=KT+9
      DO 222 N=2,MAXN
      DO 222 M=1,N
      TG(N,M)=G(N,M,KKT)+DELT*(G(N,M,KKT)-G(N,M,KKT-1))
222   TH(N,M)=H(N,M,KKT)+DELT*(H(N,M,KKT)-H(N,M,KKT-1))
      ENDIF
      TLAST=TM

   33 RLAT=DLAT/RAD
      SINLA=SIN (RLAT)
      RLONG=DLONG/RAD
      CP(2)=COS (RLONG)
      SP(2)=SIN (RLONG)
      NMAXP1=NMAX+1
      DO 10 M=3,NMAXP1
      SP(M)=SP(2)*CP(M-1)+CP(2)*SP(M-1)
   10 CP(M)=CP(2)*CP(M-1)-SP(2)*SP(M-1)
      IF (J .EQ. 0)  GO TO 59
      R = RE + ALT
      CT=SINLA
      GO TO 21
   59 SINLA2=SINLA*SINLA
      DEN2=A2-A2B2*SINLA2
      DEN=SQRT (DEN2)
      COSLA = SQRT(1.-SINLA2)
      IF (COSLA .NE. 0.)  GO TO 18
      THETA = 90./RAD
      IF (SINLA .LT. 0.)  THETA = -THETA
      GO TO 19
   18 ALTDEN = ALT*DEN
      THETA = ATAN((ALTDEN+B2)/(ALTDEN+A2)*SINLA/COSLA)
   19 R=SQRT (ALT*(ALT+2.*DEN)+(A4-A4B4*SINLA2)/DEN2)
      CT=SIN (THETA)
   21 STST = 1. - CT**2
      ST = SQRT(STST)
      CTST = CT*ST
      AOR = RE/R
      AR=AOR*AOR
      BN=0.
      BE=0.
      BV=0.
      DO 54 N=2,NMAXP1
      SUMN=0.
      SUME=0.
      SUMV=0.
      AR=AOR*AR
```

```
      IF (N .GE. 3)  GO TO 60
      P(2,2) = 1.
      DP(2,2) = CT
      GO TO 61
   60  P(N,N) = ST* P(N-1,N-1)
      DP(N,N) = ST*DP(N-1,N-1) +  CTST*P(N-1,N-1)
   61 FACT = ST
      DO 45 M=1,N
      TEMP = TG(N,M)*CP(M) + TH(N,M)*SP(M)
      IF (M .EQ. 2)  FACT = STST
      IF (M .LE. N-2)  GO TO 12
      IF (N .EQ. M)  GO TO 13
       P(N,M) = CT* P(N-1,M)
      DP(N,M) = CT*DP(N-1,M) - FACT*P(N-1,M)
      GO TO 13
   12  P(N,M) = CT* P(N-1,M) - CONST(N,M)* P(N-2,M)
      DP(N,M) = CT*DP(N-1,M) - CONST(N,M)*DP(N-2,M) - FACT*P(N-1,M)
   13 SUMN = SUMN - DP(N,M)*TEMP
      IF (M .EQ. 1)  GO TO 45
      SUME = SUME + P(N,M)*FM(M)*(-TG(N,M)*SP(M)+TH(N,M)*CP(M))
      TEMP = TEMP*ST
   45 SUMV = SUMV + P(N,M)*TEMP
      BN = BN + SUMN*AR
      BE = BE + SUME*AR
   54 BV = BV + SUMV*AR*FN(N)
      IF (J .NE. 0)  GO TO 23
C      TRANSFORMS FIELD TO GEODETIC DIRECTIONS
      SIND=SIN (RLAT-THETA  )
      COSD=SQRT (1.0-SIND*SIND)
      TN=BN
      BN=BN*COSD+BV*SIND
      BV=BV*COSD-TN*SIND
   23 RETURN
      END
```

```
      SUBROUTINE SPHNEWF (FLAT1,FLON1,X1,Y1,FLAT2,FLON2,X2,Y2)

C     SUBROUTINE FOR TRANSFORMING GEOGRAPHIC COORDINATES (FLAT1,FLON1)
C     TO SPHERICAL COORDINATES (FLAT2,FLON2) ABOUT A NEW POLE (FLAT0,FLON0).
C     FIELD COMPONENTS GEOGRAPHIC NORTH X1 AND EAST Y1 ARE ROTATED TO
C     NORTH X2 AND EAST Y2 IN THE NEW COORDINATE SYSTEM.
C     FLON2 = 0  IS THE MERIDIAN THROUGH THE SOUTH GEOGRAPHIC POLE.
C     ENTER NEW POLE BY CALLING EITHER SPHINF OR SPHITF.
      DATA   FLAT0/90./


      IF (FLAT0 .LT. 90.)  GO TO 100
      FLAT2 = FLAT1
      FLON2 = FLON1
      GO TO 105
  100 IF (FLAT0 .GT. -90.)  GO TO 101
      FLAT2 = -FLAT1
      FLON2 = -FLON1
      GO TO 107

  101 IF (FLAT1 .LT. 90.)  GO TO 102
  131 FLAT2 = FLAT0
      FLON2 = 180.
      ANG = FLON0-FLON1+180.
      GO TO 103
  102 IF (FLAT1 .GT. -90.)  GO TO 104
  132 FLAT2 = -FLAT0
      FLON2 = 0.
      ANG = FLON1-FLON0
  103 COSROT = COSD(ANG)
      SINROT = SIND(ANG)
      GO TO 225
  104 DFLAT1 = FLAT1
      SIN1 = SIND(DFLAT1)
      COS1 = COSD(DFLAT1)
      IF (COS1 .NE. 0.)  GO TO 133
      IF (SIN1 .GT. 0.)  GO TO 131
      GO TO 132
  133 FLOND1 = FLON1 - FLON0
      COSD1 = COSD(FLOND1)
      SIN2 = SIN0*SIN1 + COS0*COS1*COSD1
      IF (SIN2 .LT. 1.)  GO TO 106
  108 FLAT2 = 90.
      FLON2 = 0.
  105 X2 = X1
      Y2 = Y1
      COSROT = 1.
      SINROT = 0.
      RETURN
  106 IF (SIN2 .GT. -1.)  GO TO 110
  109 FLAT2 = -90.
      FLON2 = 0.
```

```
  107 X2 = -X1
      Y2 = -Y1
      COSROT = -1.
      SINROT =  0.
      RETURN
  110 DFLAT2 = ASIND(SIN2)
      FLAT2 = DFLAT2
      COS2 = COSD(DFLAT2)
      IF (COS2 .NE. 0.)  GO TO 111
      IF (SIN2 .GT. 0.)  GO TO 108
      GO TO 109

  111 PROD = SIN0*SIN2
      SIND1 = SIND(FLOND1)
      IF (SIN1 .NE. PROD)  GO TO 120
      IF (SIND1 .GT. 0.)  GO TO 115
  112 FLON2 = -90.
      SLON2 = -1.
      GO TO 200
  115 FLON2 =  90.
      SLON2 = 1.
      GO TO 200
  120 SLON2 = (SIND1*COS1)/COS2
      IF (SLON2 .LE. -1.)  GO TO 112
      IF (SLON2 .GE.  1.)  GO TO 115
      IF (SIN1 .LT. PROD)  GO TO 125
      FLON2 = 180. - ASIND(SLON2)
      IF (FLON2 .GT. 180.)  FLON2 = FLON2 - 360.
      GO TO 200
  125 FLON2 = ASIND(SLON2)

  200 COSROT = (SIN0-SIN1*SIN2)/COS1/COS2
      SINROT = COS0*SLON2/COS1
  225 X2 = X1*COSROT - Y1*SINROT
      Y2 = X1*SINROT + Y1*COSROT
      RETURN

C     TRANSFORM BACK FROM ROTATED COMPONENTS X2,Y2
C                      TO GEOGRAPHIC COMPONENTS X1,Y1.

      ENTRY SPHOLDF
      X1 = X2*COSROT + Y2*SINROT
      Y1 = Y2*COSROT - X2*SINROT
      RETURN

C     INPUT NEW POLE POSITION FLAT0,FLON0 IN GEOGRAPHIC COORDINATES.
C     RETURN FLAT0,FLON0 AS FLAT1,FLON1.

      ENTRY SPHINF
      READ 10,  FLAT0,FLON0                                          INPUT
   10 FORMAT (2F10.0)
      FLAT1 = FLAT0
      FLON1 = FLON0
```

```
      GO TO 20

C     DEFINE NEW POLE POSITION THROUGH CALL PARAMETERS FLAT1,FLON1.

      ENTRY SPHITF
      FLAT0 = FLAT1
      FLON0 = FLON1
20    CONTINUE
      DFLAT0 = FLAT0
      SIN0 = SIND(DFLAT0)
      COS0 = COSD(DFLAT0)
      RETURN

      END
```