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IGRFGRID: A program for creation of a total magnetic field (International Geomagnetic Reference Field) grid representing the earth's main magnetic field.

by

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TITLE: IGRFGRID: A program for creation of a total magnetic field grid representing the Earth's main magnetic field

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IGRFGRID (version 1.000) is a program written in VAX-Fortran for VAX/VMS-compatible computers to create a total magnetic field grid in latitude-longitude coordinates of International Geomagnetic Reference Field values representing the Earth's main magnetic field. Users of other computers with Fortran compilers can use the program with minimal changes required. Requirements: Fortran compiler, preferably on a VAX/VMS-minicomputer. OF 90-45-A, Documentation, 37 p., microfische or paper copy; OF 90-45-B, Source code diskette, 5 1/4".
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Preface

The program IGRFGRID is written in VAX Fortran, but in a straightforward way without any system dependent system service calls. This makes the code highly transportable, with the primary dependence on the VAX in the use of I/O. The open and close statements reference only sequential files, and the read/write statements are ANSI standard. IGRF coefficients are stored in data statements within the program, rather than in external data files. Void of any lengthy algorithms, the program runs reasonably fast, and takes up little machine memory. The source code is available on 5-1/4 inch diskettes as part 89-XXX-B of this report. Some of the early work and subroutines were contributed by Gerald I. Evenden.

Abstract

IGRFGRID creates a USGS standard grid (see Appendix A) of total magnetic field values attributable to the earth's main magnetic field, using the International Geomagnetic Reference Field (IGRF). The format of the grid is readily usable by other USGS computer programs, and typically is subtracted from a magnetic survey grid covering an identical area to yield the residual magnetic field. The program runs in interactive mode, with the user offered the options of these models: IGRF 1965, IGRF 1975, and the fifth generation of the IGRF, called the Definitive Geomagnetic Reference Field (DGRF), covering the years 1945-1980, coupled with the IGRF 1985 main field and secular change coefficients. The coefficients are stored in source code data statements in their Gauss- normalized form (Chapman and Bartels, 1940, Cain et. al., 1968), converted from the quasi-normalized form of Schmidt (Chapman and Bartels, 1940, Cain et al., 1968), typically seen in the literature. The technique of applying these coefficients to the spherical harmonic equations using associated Legendre functions is adapted from that of Cain et al., 1968, in "Computation of the Main Geomagnetic Field from Spherical Harmonic Expansions". Latitudes, longitudes, and elevations are assumed to be geodetic in nature, positioned in reference to an oblate earth, and are converted to geocentric coordinates for use in the spherical equations using an equatorial earth radius of 6378.160 km and a flattening factor of 1/298.25.

Introduction

The predominant data format for magnetic surveys in the Branch of Geophysics is the standard grid (see Appendix A). Aside from a single header record of descriptive information, this format is simplistic in design, and easily adaptable to other reference formats in use internationally. The geographic units of the grid are arbitrary. That is, they can represent geocentric latitude and longitude just as easily as some user-defined set of projected coordinates in ground meters or kilometers. The program IGRFGRID produces as output a grid in geographic coordinates (i.e. latitude, longitude) of IGRF main field values that is coincident with a total magnetic field survey grid. A utility program (see, for example, the computer program ADDGRID, in U.S.G.S., 1989) can then subtract out the core field grid to produce a desired "residual" field grid of crustal anomaly values. For those survey grids in projected coordinates, the output latitude-longitude grid of IGRF values can be first converted to a corresponding projected coordinate grid, by another utility program (see Godson and Mall, 1988, and U.S.G.S., 1989, for utility program examples), and then as before be subtracted out to yield residual field.
Theory

The geomagnetic scalar potential of the earth can be approximated by:

\[ V(\theta, \phi) = a \sum_{n=1}^{N} \sum_{m=0}^{n} \left( \frac{a}{r} \right)^{n+1} (g_{n,m} \cos(m\phi) + h_{n,m} \sin(m\phi)) P_{n,m}(\theta), \]

where \( P_{n,m}(\theta) \) are the associated Legendre functions, Gauss normalized, of degree \( n \) & order \( m \),

\( g_{n,m}, h_{n,m} \) are the spherical harmonic coefficients of Gauss of the \( \cos(m\phi), \sin(m\phi) \) terms, respectively,

\( a = \) mean radius of the earth,

\( r = \) radial distance from the earth's center,

\( \theta = \) geocentric colatitude,

\( \phi = \) longitude, and

\( N = \) maximum degree (and order) of the spherical harmonic coefficients.

The derivation of this formula is explained thoroughly in "Geomagnetism" (Chapman and Bartels, 1940, p. 639). By taking the appropriate derivatives of the geopotential \( V(\theta, \phi) \), we can get the magnetic field components \( X, Y, \) and \( Z \):

\[ X = \frac{1}{r} \frac{\partial V}{\partial \theta} \]
\[ Y = -\frac{1}{r \sin \theta} \frac{\partial V}{\partial \phi} \]
\[ Z = \frac{\partial V}{\partial r} \]

Further, the magnitude of the total field, \( F \), can then be simply expressed by:

\[ F = (X^2 + Y^2 + Z^2)^{1/2} \]
Program Description

IGRFGRID is designed to run interactively to produce an output grid of IGRF total magnetic field values. Each grid of field values requested of program IGRFGRID has a surface of elevations associated with it. IGRFGRID offers the user two input options: 1. Enter a single elevation value, representing a constant barometric elevation for the entire survey, or 2. Enter an input grid of elevations, representing the barometric elevation surface of a survey draped over the terrain in a user-specified manner. In case number 1, the user must also input the geographic boundaries of his or her desired survey grid. In case number 2, the survey boundaries default to the spatial extent of the elevation grid.

The geographic coordinates input to IGRFGRID are assumed to be geodetic in nature, and above an oblate earth. This requires geometric equations within IGRFGRID to convert these coordinates into corresponding geocentric coordinates (Cain, et. al., 1968) before applying the spherical harmonic equations to the appropriate IGRF coefficients. The defining earth parameters of IGRFGRID are taken from the IAU ellipsoid (International Astronomical Union, 1966), where the equatorial radius, a, is 6378.160 km, and the flattening factor \((1 - b/a, \text{where } b \text{ is the polar radius})\) is 1/298.25. The IGRF Schmidt coefficients are quasi-normalized to a sphere of radius 6371.2 km.

The program IGRFGRID has several useful design features. All coefficients offered as options to the user are stored in data statements in their Gaussian form. Although bearing no obvious resemblance to the more widely published form of Schmidt, Gaussian coefficients are required by the spherical harmonic equations of IGRFGRID. Thus, processor time during program invocation is lessened by storing the coefficients in this manner. Also, the user may request the use of the original IGRF 1965 and IGRF 1975 coefficients, in addition to the current standard of definitive DGRF models and IGRF 1985. Even though outdated, the IGRF 1965 and IGRF 1975 inclusion allows the user the luxury of reprocessing surveys that were originally reduced using these models without using outdated computer programs.

For the current DGRF-IGRF 1985 standard option, the program operates in such a way as to force the user to abide by the accepted standards of use. That is, any requests for magnetic field values for a time prior to 1945 will be denied, and IGRFGRID will abort with an error message. Requests involving times between 1945 and 1980 will be satisfied using linear interpolation between the appropriate definitive models. A time between 1980 and 1985 will result in linear interpolation between the DGRF 1980 model and IGRF 1985. And any time greater than 1985 will generate an extrapolated result, using the IGRF 1985 coefficients with the corresponding secular change derivatives. For further information on program behavior, refer to the examples on the following pages and the comments at the beginning of the program listing in Appendix B.
Examples

1. IGRFGRID is executed with a constant input barometric elevation of 0.0 meters. User input is identified by underlines.

$ run igrfgrid

USGS Computer Program "IGRFGRID"; version 1.000
Technical Contact: Ron Sweeney

Enter output filename: igrf.grd
Enter 56 character title:
Sample grid from IGRFGRID test run.
Enter date for computation of total field (yyyyddd):
1975000
Enter '1965', '1975', or 'digrf' for igrf model desired:
digrf
Are you providing an input elevation grid ('yes' or 'no')? no
Do you wish to enter geographic area in 'degrees' or 'seconds'?
degrees
Enter min, max lat & min, max (neg. west) lon:
0 10 -10 0
Enter grid spacing:
1
Enter elevation in meters:
0.0

title = :Sample grid from IGRFGRID test run.
unitsx = :deg, unities = :deg
min, max lat = ( 0.000, 10.000); min, max lon = ( -10.00, 0.00).
model = digrf, epoch = 1975000, alt(meters) = 0.0
ncol,nrow,nz,xo,dx,yo,dy = 11 11 1 -10.0 1.0 0.0 1.0

End of job.
FORTRAN STOP
2. IGRFGRID is executed with an input grid of barometric elevations. Output grid parameters are taken from this grid. User input is identified by underlines.

$ run igrfgrid

USGS Computer Program "IGRFGRID"; version 1.000
Technical Contact: Ron Sweeney

   Enter output filename:
igrf2.grd
   Enter 56 character title:
Sample grid from IGRFGRID with input elev grid.
   Enter date for computation of total field (yyyyddd):
1975000
Enter '1965', '1975', or 'digrf' for igrf model desired:
digrf
   Are you providing an input elevation grid ('yes' or 'no')?
yes
   Enter input barometric elevation grid filename:
elev.grd
   Are the elevations in 'feet' or 'meters'?
meters
   Are the elevation locations in 'degrees' or 'seconds'?
degrees

title = :Sample grid from IGRFGRID with input elev grid.
unitsx = :deg , unitsy = :deg
model = digrf, epoch = 1975000
ncol,nrow,nz,xo,dx,yo,dy = 11 11  1   -10.0   1.0   0.0   1.0

End of job.
FORTRAN STOP
References

Cain, Joseph C., Hendricks, Shirley, Daniels, Walter E., and Jensen, Duane C., 1968, Computation of the main geomagnetic field from spherical harmonic expansions: National Space Science Data Center, Data User's Note, NSSDC 68-11.


Appendix A

The USGS standard grid used in the Branch of Geophysics is an unformatted sequential file, consisting of a header record of descriptive information followed by a series of data records representing the rows of data in the grid.

The HEADER RECORD consists of the following 9 fields:

1. id - Grid title of 56 characters.
2. pgm - Program id of 8 characters, usually representing the program that created the grid.
3. nc - Number of columns in the grid.
4. nr - Number of rows in the grid.
5. nz - Number of data channels represented at each grid location. (Always = 1 in IGRFGRID)
6. xo - X coordinate of the lower left hand corner of the grid.
7. dx - Interval between grid locations along the x-axis.
8. yo - Y coordinate of the lower left hand corner of the grid.
9. dy - Interval between grid locations along the y-axis.

A DATA RECORD consists of a row of grid values, ordered left-to-right, and preceded by a single y-coordinate value. The rows are written in the sequential file starting with the bottom row of the grid and proceeding toward the top. Each DATA RECORD consists of:

1. yposn - Y coordinate of this row record. (Typically = 0.0)
2. data - Array of data values representing one row of data.
Appendix B

USGS Computer Program "IGRFGRID"; version 1.000
Technical Contact: Ron Sweeney

Program IGRFGRID creates an output grid in latitude-longitude coordinates of International Geomagnetic Reference Field (IGRF) total magnetic field values, representing the earth's main magnetic field, for a user-specified area. The user has a choice of models: IGRF1965, IGRF1975, or the Definitive Geomagnetic Reference Field (DGRF) package of DGRF models, starting with epoch 1945, ending with epoch 1980, and coupled with the IGRF 1985 model of the latest spherical harmonic coefficients and secular change terms for field prediction.

Input elevation may be either constant barometric, or supplied as a grid of barometric elevations covering an area identical to the output IGRF grid. Grid locations must be in degrees or seconds of latitude & longitude (negative west longitude).

The output file is in USGS standard grid format. The original IGRF subroutine concept was created for the Branch of Geophysics, U. S. Geological Survey, for our airborne formats by Gerald I. Evenden. Computational techniques are based on "Computation of the Main Geomagnetic Field from Spherical Harmonic Expansions" by J. C. Cain, et. al., NASA Data Users Note, NSSDC 68-11, May, 1968.

The program IGRFGRID is designed for interactive use.

Questions asked of the user:

Output file name : Name of output grid of IGRF magnetic field values.
Title : 56 characters of descriptive information stored in the output grid.
Date of computation : Date, entered as year & day of year, for computation of the main field.
Model desired : Select IGRF1965, IGRF1975, or DGRF, which includes ALL the DGRF models from 1945 - 1980, AND including IGRF 1985.

Input elevation grid? Yes — IGRFGRID will prompt the user for a grid file name and use the contained elevations in the field calculations. The output IGRF grid will have dimensions identical to the elevation grid. IGRFGRID asks if the elevations are in feet or meters, and if the locations are in degrees or seconds of latitude & longitude.

No — Constant barometric elevation is assumed for the entire grid, and the user is prompted for a value. The user is also asked to identify the dimensions of the
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"Enter output filename: '")  
read(5,2) iofil  
"Enter 56 character title: '")  
read(5,2) title  
"Enter date for computation of total field '",  
"(yyyyddd): '")  
read(5,*1) idate  
"Enter "1965", "1975", or "digrf" for igrf model'",  
"desired: '")  
read(5,2) model  
if(model.ne.'1965'.and.model.ne.'1975'.and.model.ne.'digrf'
1.and.model.ne.'DIGRF') go to 13
21 write(6,22)
22 format('$ Are you providing an input elevation grid ',
1       (''yes'' or ''no'')? ')
   read(5,2) resp
   if(resp.ne.'yes'.and.resp.ne.'no') go to 21
   elgrid=.false.
   if(resp.eq.'yes') elgrid=.true.
   if(elgrid) then
   c
   c Here, read parameters concerning the input elevation grid.
   c
   write(6,5)
   5 format('Enter input barometric elevation grid filename: ')
   read(5,2) elfile
   c
   c Open the input elevation grid, & read the header record.
   c
   open(unit=ll,file=elfile,status='old',form='unformatted',
1      readonly)
   read(ll,end=200) etitle,epgm,ncol,nrow,nz,xo,dx,yo,dy
   6 write(6,7)
   7 format('Enter input barometric elevation grid filename: ')
   read(5,2) elfile
   c
   c Open the output IGRF grid file, & output the header record.
   c
   open(unit=10,file=iofil,status='new',form='unformatted')
   write(10) title,pgm,ncol,nrow,nz,xo,dx,yo,dy
else
Here, read parameters concerning the constant barometric elevation.

26 write(6,27)
27 format('Do you wish to enter geographic area in ''degrees'' or ''seconds''?
1
read(5,2) resp
if(resp.ne.'degrees'.and.resp.ne.'seconds') go to 26

if(resp.eq.'degrees') then
  deg=.true.
  units=unitsd
else
  deg=.false.
  units=unitss
end if

write(6,23)
23 format('Enter min, max lat & min, max (neg. west) lon: ')
read(5,*) flatl,flat2,flonl,flon2
write(6,24)
24 format('Enter grid spacing: ')
read(5,*) dxy
dx=dxy
dy=dxy
write(6,25)
25 format('Enter elevation in meters: ')
read(5,*) altm
xo=flon1
yo=flat1
ncol=(flon2-flon1)/dxy+1.
nrow=(flat2-flat1)/dxy+1.

write(6,16) title,units,units,flat1,flat2,flon1,flon2,model,
1idate,altm,ncol,nrow,nz,xo,dx,yo,dy
16 format(/,2x,'title = :',a56,
1/,2x,'unitsx = :',a4, ', unitsy = :',a4,
2/,2x,'min, max lat = (',f8.3,',',f8.3,'); min, max lon = (',
3f10.2,')',',f10.2,')','/',2x,'model = ',a5,', epoch = ',i7,
4',', alt(meters) = ',f7.1, '/',2x,'ncol,nrow,nz,xo,dx,yo,dy = ',3i4,
54f10.1,/)
dy=dy*sec2deg
14 if(model.ne.'1965') go to 100

c c
igrf 1965 here.
c
flat=yo-dy
do 20 lt=l,nrow
flat=flat+dy
flatr=flat*rad
flon=xo-dx
if(elgrid) call rdbin(11,dum,1,alts,ncol,*200)
do 19 ln=1,ncol
flon=flon+dx
flonr=flon*rad

c if(elgrid) then
altm=alts(ln)
if(feet) altm=altm*ft2met
end if
c
call igrf1965(flatr,flonr,altm,idate,b,1)
data(ln)=b
19 continue

c write(6,15) flat,flon,altm,b

c
15 format(2x,4f10.2)
call iorow(10,zero,1,data,ncol)
20 continue
go to 150
100 if(model.ne.'1975') go to 125

c c
igrf 1975 here.
c
flat=yo-dy
do 120 lt=l,nrow
flat=flat+dy
flatr=flat*rad
flon=xo-dx
if(elgrid) call rdbin(11,dum,1,alts,ncol,*200)
do 119 ln=1,ncol
flon=flon+dx
flonr=flon*rad

c if(elgrid) then
altm=alts(ln)
if(feet) altm=altm*ft2met
end if
c
call igrf1975(flatr,flonr,altm,idate,b,1)
data(ln)=b
119 continue

c write(6,15) flat,flon,altm,b
call iorow(10,zero,1,data,ncol)
120 continue
go to 150
c
digrf here.
c
c
125 flat=yo-dy
  do 130 lt=1,nrow
    flat=flat+dy
    flatr=flat*rad
    flon=xo-dx
    if(elgrid) call rdbin(ll,dum,1,alts,ncol,*200)
  do 129 ln=1,ncol
    flon=flon+dx
    flonr=flon*rad
  c
    if(elgrid) then
      altm=alts(ln)
      if(feet) altm=altm*ft2met
    end if
  c
    call digrf(flatr,flonr,altm,idate,b,1)
  data(ln)=b
  129 continue
  c
  write(6,15) flat,flon,altm,b
  call iorow(10,zero,1,data,ncol)
  130 continue
  150 write(6,151)
  151 format(2x,'End of job.')
    close(10)
    if(elgrid) close(ll)
    stop
  c
  200 write(6,201)
  201 format(2x,'Error--unexpected E-O-F in elevation file....')
    close(10)
    close(ll)
    stop
  c
  end
subroutine igrf1965(lat, long, alt, idate, vec, icode)

save

IGRF1965 GENERATES MAIN GEOMAGNETIC FIELD COMPONENTS

PROGRAM BASED ON:
"COMPUTATION OF THE MAIN GEOMAGNETIC FIELD FROM
SPHERICAL HARMONIC EXPANSIONS"
BY: J. C. CAIN, ET. AL., NASA DATA USERS NOTE, NSSDC 68-11,
MAY, 1968
PROGRAM MODIFIED BY:
GERALD I. EVENDEN
U. S. GEOLOGICAL SURVEY
DENVER FEDERAL CENTER
DENVER, COLORADO 80225

PARAMETER DESCRIPTION:
LAT, LONG: LATITUDE, LONGITUDE COORDINATES IN RADIANS
POS. NORTH LATITUDE
POS. EAST LONGITUDE
ALT: ALTITUDE OF POINT ABOVE SEA LEVEL (METERS)
IDATE: DATE IN YEAR*1000+DAY
IE. 1972035.. YEAR 1972, DAY 35
VEC: RESULTANT EARTH FIELD VECTOR(S)
ICODE: RESULTANT VECTOR(S) STORED IN VEC
=1: TOTAL FIELD (GAMMAS)
=2: E-W HORIZONTAL COMPONENT (GAMMAS)
=3: N-S HORIZONTAL COMPONENT (GAMMAS)
=4: VERTICAL COMPONENT (GAMMAS)
=5: ALL OF THE ABOVE STORED IN VEC(1) THRU VEC(4)
RESPECTIVELY,... PLUS
VEC(5)=INCLINATION (RADIANS)
VEC(6)=DECLINATION (RADIANS)

dimension vec(6)
real lat, long
logical notall
dimension g(45), h(45), gt(45), ht(45), p(45), dp(45), const(45),
& sp(9), cp(9), go(45), ho(45), gh0(90), gh(90), ght(90)
equivalence (gh0(1), g0(1)), (gh0(46), h0(1)),
& (gh(1), g(1)), (gh(46), h(1)),
& (ght(1), gt(1)), (ght(46), ht(1))
equivalence (p(2), sind, sin1a2),
& (p(3), cosd, den2),
& (p(4), notall, den),
& (p(5), altk),
& (p(6), fac)
IGRF-1965 COEFFICIENTS, GAUSS NORMALIZED.

FROM 10/68 WMSB MEETING

data go/
& 0.0 , 3.0339000e 04, 2.1230000e 03, 2.4810000e 03,
&-5.185739e 03,-1.3570610e 03,-3.2425000e 03, 6.2339492e 03,
&-2.4961367e 03,-6.644946e 02,-4.1912500e 03,-4.4548555e 03,
&-1.9252537e 03, 8.1992627e 02,-1.8931447e 02, 1.7561250e 03,
&-3.6294697e 03,-1.8905623e 03, 1.2236151e 02, 3.5718311e 02,
& 3.5779572e 01,-6.7856250e 02,-1.1341863e 03,-5.9776871e 01,
& 2.2814834e 03,-1.6370360e 01, 9.3072935e 00, 7.5229507e 01,
&-1.9036785e 03, 1.9153586e 03, 0.0 , -2.4574036e 02,
& 3.0872290e 02, 5.5570114e 01,-3.1483658e 01, 1.2945166e 00,
&-5.0273438e 02,-6.0328076e 02, 1.6824701e 02, 4.9703442e 02,
& 1.0694476e 02,-1.0381398e 02, 3.4326096e 01,-3.0081863e 01,
&-3.7602339e 00 /
data ho/
& 0.0 , 0.0 , -5.7580000e 03, 0.0 ,
& 3.4744919e 03,-1.1258324e 02, 0.0 , 1.2339302e 03,
&-4.6863062e 02, 1.3914014e 02, 0.0 , -8.2456534e 02,
& 1.0956729e 03,-1.6733185e 01, 1.9597005e 02, 0.0 ,
&-1.6266531e 02,-9.6065161e 02, 5.7886401e 02, 2.3738257e 02,
&-5.4020142e 01, 0.0 , 2.6464331e 02,-1.5840869e 03,
&-6.7747095e 02, 1.7461935e 02, 2.3268097e 01, 8.7319975e 00,
& 0.0 , 2.0217673e 03, 7.8194141e 02, 1.6382690e 02,
& 4.114024e 02,-1.4201251e 02, 4.6014587e 01, 1.1003397e 01,
& 0.0 , -2.0109366e 02, 7.2907031e 02,-2.0709770e 02,
& 4.5451514e 02,-5.9322281e 01,-1.5103482e 02, 7.5204678e 00,
& 1.0027290e 01 /
data gt/
& 0.0 , -1.5299999e 01,-8.6999998e 00, 3.6599991e 01,
&-5.1961488e-01, 1.3856392e 00,-4.9999994e-01, 3.3068100e 01,
&-1.3555431e 00, 3.0041609e 00, 3.0624990e 00,-1.1067963e 00,
& 1.1739352e 01, 2.0916480e-01, 1.5529690e 00,-1.4962497e 01,
&-1.1183234e 01,-2.2287109e 01,-2.8237267e 00, 0.0 ,
&-9.1202784e-01, 1.4437494e 00, 5.6709309e 00,-1.6438629e 01,
&-1.8929321e 01, 2.1827412e 00, 9.3072385e-01, 1.3433838e-01,
& 1.3406250e 01, 1.0640880e 01, 2.0272552e 01, 1.0239182e 01,
&-3.7046738e 00, 0.0 , 4.8436409e-01, 3.8835520e-01,
&-5.0273418e 00,-2.6812485e 01,-3.3649399e 01, 0.0 ,
& 0.0 , 1.4830561e 00,-2.0595646e 00, 7.5204664e-01,
& 3.1335282e-01 /
data ht/
& 0.0 , 0.0 , 2.2999992e 00, 0.0 ,
& 2.0438187e 01, 1.4462614e 01, 0.0 , -1.2859819e 01,
&-1.3555431e 00, 6.0873804e 00, 0.0 , 5.5339819e-01,
&-6.2609854e 00,-6.0657806e 00, 3.1059399e 00, 0.0 ,
&-2.3383118e 01,-1.3064860e 01, 1.1294907e 01,-1.7748222e 00,
& 2.1046805e-01, 0.0 , 1.7012787e 01, 5.9776859e 00,
&-1.9925613e 01, 6.0025368e 00,-2.3268086e-01,-6.0452288e-01,
& 0.0 , 3.9016541e 01,-8.6882381e 00,-8.1913443e 00,
&-2.4697828e 00,-2.4697828e 00,-4.8436409e-01,-1.9417757e-01,
& 0.0 , -6.7031193e 00, 1.1216466e 01, 1.2425859e 01,
& 5.3472376e 00, 4.491701e 00, 2.7460871e 00, 7.5204664e-01,
& 1.8801165e-01 /
c
COMPUTATIONAL COEFFICIENTS
c
data const/
& 2*0.,1.,.33333333,0.,-1.,.26666667 ,.2,0.,-.33333333,.25714286,
& .22857143,.14285714,0.,-.2,25396825,.23809524,.19047619
& .11111111,0.,-.14285714,25252525,.24242424,.21212121,.16161616,
& .090909091,0.,-.11111111,25174825,.24775524,.22377622,
& .18881119,13986014,.076923077,0.,-90909091,.25128205,
& .24615385,.23076923,.20512821,.16923077,.12307692,.066666667,
& 0.,-.076923077 /
data a2,a4,b2,a2b2,a4b4,lastdt,tzero/
& 4.0680989e07,
& 1.6549428el5,
& 4.0408694e07,
& 2.729501e05,
& 2.2080316e13,
& -9999999,
& 165. /
data cp(l),sp(l),dp(l),p(l)/1.,0.,0.,l./
c
TIME CORRECTION
c
if (idate.eq.lastdt) go to 100
t=float(idate/1000)+float(mod(idate,1000))/365. - tzero
lastdt=idate
do 50 n=l,90
50 gh(n)=gh0(n)+t*ght(n)
c
POSITION COMPUTATIONS
c
100
sinla=sin(lat)
sinla2=sinla**2
cosl=a1.-sinla2
den2=a2-a2b2*sinla2
den=sqrt(den2)
altk=alt*le-3
fac=((altk*den)+a2)/((altk*den)+b2)**2
c=sinla/sqrt(fac*cosla2+sinla2)
st=sqrt(1.-c**2)
sp(2)=sin(long)
cp(2)=cos(long)
n=2
do 120 m=3,9
sp(m)=sp(2)*cp(n)+cp(2)*sp(n)
cp(m)=cp(2)*cp(n)-sp(2)*sp(n)
n=n+1
120 aor=6371.2/sqrt(altk*(altk+2.*den)+(a4-a4b4*sinla2)/den2)
ar=aor**2
bt=0.
bp=0.
br=0.
nlm=1
n2m=1
fn=2.
nm=2

c POLYNOMIAL EVALUATION LOOP

do 300 n=2,9
  ar=aor*ar
  fm=0.
do 290 m=1,n
  if (n.ne.m) go to 240
    k=nm-n
    p(nm)=st*p(k)
    dp(nm)=st*dp(k)+ct*p(k)
go to 250
 240  p(nm)=ct*p(nlm)-const(nm)*p(n2m)
 250  dp(nm)=ct*dp(nlm)-st*p(nlm)-const(nm)*dp(n2m)
  par=p(nm)*ar
  temp=g(nm)*cp(m)+h(nm)*sp(m)
  bp=bp-(g(nm)*sp(m)-h(nm)*cp(m))*fm*par
  bt=bt+temp*dp(nm)*ar
  br=br-temp*fn*par
  nm=nm+1
  nlm=nlm+1
  n2m=n2m+1
 290  fm=fm+1.
  fn=fn+1.
  nlm=nlm-1
 300  n2m=n2m-2
  bp=bp/st

c TRANSFORM, IF REQUIRED

notall=icode.lt.5
if (ICODE.eq.1) go to 411
  sind=sinla*st-sqrt(cosla2)*ct
  cosd= sqrt(1.-sind**2)
  n=1
go to (411,412,413,414,411),icode
  411  vec(1)=sqrt(bp**2+bt**2+br**2)
  if (notall) go to 500
    n=n+1
  412  vec(n)=-bt*cosd-br*sind
  if (notall) go to 500
    n=n+1
  413  vec(n)=bp
  if (notall) go to 500
    n=n+1
  414  vec(n)=bt*sind-br*cosd
  if (notall) go to 500
call polar(sqrt(vec(2)**2+vec(3)**2),vec(4),vec(5),bt)
call polar(vec(2),vec(3),vec(6),bt)

500
return
end
subroutine igrf1975(lat,long,alt,odate,vec,icode)
save

IGRF1975 GENERATES MAIN GEOMAGNETIC FIELD COMPONENTS

PROGRAM BASED ON:
"COMPUTATION OF THE MAIN GEOMAGNETIC FIELD FROM
SPHERICAL HARMONIC EXPANSIONS"
BY: J. C. CAIN, ET. AL., NASA DATA USERS NOTE, NSSDC 68-11,
MAY, 1968

PROGRAM MODIFIED BY:
GERALD I. EVENDEN
U.S. GEOLOGICAL SURVEY
DENVER FEDERAL CENTER
DENVER, COLORADO 80225

PROGRAM FURTHER MODIFIED BY:
RONALD E. SWEENEY
U.S. GEOLOGICAL SURVEY
DENVER FEDERAL CENTER
DENVER, COLORADO 80225

SO AS TO INCLUDE CURRENT EARTH ELLIPSOIDAL PARAMETERS:

A = 6371.2
RE = 6378.16
FLAT = 1./298.25

PARAMETER DESCRIPTION:
LAT, LONG : LATITUDE, LONGITUDE COORDINATES IN RADIANS
POS. NORTH LATITUDE
POS. EAST LONGITUDE
ALT : ALTITUDE OF POINT ABOVE SEA LEVEL (METERS)
IDATE : DATE IN YEAR*1000+DAY
IE. 1972035.. YEAR 1972, DAY 35
VEC : RESULTANT EARTH FIELD VECTOR(S)
ICODE : RESULTANT VECTOR(S) STORED IN VEC
= 1 : TOTAL FIELD (GAMMAS)
= 2 : E-W HORIZONTAL COMPONENT (GAMMAS)
= 3 : N-S HORIZONTAL COMPONENT (GAMMAS)
= 4 : VERTICAL COMPONENT (GAMMAS)
= 5 : ALL OF THE ABOVE STORED IN VEC(1) THRU VEC(4)
 RESPECTIVELY, ... PLUS
VEC(5) = INCLINATION (RADIANS)
VEC(6) = DECLINATION (RADIANS)

dimension vec(6)
real lat,long
logical notall

c

dimension g(45),h(45),gt(45),ht(45),p(45),dp(45),const(45),
& sp(9),cp(9),g0(45),h0(45),gh0(90),gh(90),ght(90)
equivalence (gh0(1),g0(1)),(gh0(46),h0(1)),
& (gh(1),g(1)),(gh(46),h(1)),
& (ght(1),gt(1)),(ght(46),ht(1))
equivalence (p(2),sind,sinla2),
& (p(3),cosp,cosp2),
& (p(4),notall,den),
& (p(5),altk),
& (p(6),fac)

c
IGRF-1975 COEFFICIENTS, GAUSS NORMALIZED.

data g0/
& 0.0000000e+00, 3.0186000e+04, 2.0360000e+03, 2.8470000e+03,
& -5.190563e+03, -1.3432054e+03, -3.2475000e+03, 6.5646325e+03,
& -2.5096932e+03, -6.3640839e+02, -4.1606250e+03, -4.4659266e+03,
& -1.8078610e+03, 8.2201847e+02, -1.7378485e+02, 1.6065000e+03,
& -3.7413019e+03, -2.1134336e+03, 9.4124252e+01, 3.5718332e+02,
& 2.6659309e+01, -6.6412500e+02, -1.0774781e+03, -2.2416348e+02,
& 2.0921925e+03, 5.4568620e+00, 1.8614510e+01, 7.6573034e+01,
& -1.7696250e+03, 2.0217674e+03, 2.0272567e+02, -1.4334870e+02,
& 2.7167648e+02, 5.5570189e+01, -2.6640071e+01, 5.1780788e+00,
& -5.5300781e+02, -8.7140625e+02, -1.6824710e+02, 4.9703488e+02,
& 1.0694488e+02, -8.983518e+01, 1.3730455e+01, -2.2561440e+01,
& -6.2670666e-01 /
data h0/
& 0.0000000e+00, 0.0000000e+00, -5.7350000e+03, 0.0000000e+00,
& 3.6788759e+03, 3.2042940e+01, 0.0000000e+00, 1.1053322e+03,
& -4.8218643e+02, 2.0001406e+02, 0.0000000e+00, -8.1902991e+02,
& 1.0330634e+03, -7.7391053e+01, 2.2702956e+02, 0.0000000e+00,
& -3.9649667e+02, -1.0913003e+03, 6.9181326e+02, 2.1963446e+02,
& -5.1915496e+01, 0.0000000e+00, 4.3477118e+02, -1.5243117e+03,
& -8.7672829e+02, 2.3464507e+02, 2.0941324e+01, 2.6867732e+00,
& 0.0000000e+00, 2.4119330e+03, 6.9505943e+02, 8.1913540e+01,
& -1.3583824e+02, -1.6671057e+02, 4.1171018e+01, 9.0616379e+00,
& 0.0000000e+00, -2.6812500e+02, 8.4123550e+02, -8.2839148e+01,
& 5.0798817e+02, -1.4830586e+01, -1.2357409e+02, 1.5040960e+01,
& 1.1907426e+01 /
data gt/
& 0.0000000e+00, -2.5600000e+01, -1.0000000e+01, 3.7350000e+01,
& -1.2124356e+00, -3.7239093e+00, 9.5000000e+00, 3.1843366e+01,
& 7.9396159e+00, 3.3203915e+00, 8.7499999e-01, 1.1679721e+01,
& 1.5261164e+01, 4.3924651e+00, 2.924809e+00, -2.3625000e+00,
& 7.1166069e+00, -8.4537344e+00, 7.5299402e+00, 1.1092650e+00,
& -7.0156077e-01, -2.8875000e+00, -9.4515624e+00, -2.9888465e+01,
& -2.7895900e+01, 0.0000000e+00, -2.0941324e+00, 6.7169328e+02,
& 0.0000000e+00, 0.0000000e+00, 0.0000000e+00, -1.2287031e+01,
& -1.1114038e+01, -1.8523396e+00, -7.2654738e-01, 3.2362992e+01,
& -1.0054688e+01, -2.0109375e+01, 0.0000000e+00, -8.2839147e+00,
& 1.0694488e+01, 4.4491758e+00, -4.1191365e+00, 7.5204799e-01,
& 6.2670665e-02 /
data ht/
&  0.0000000e+00, 0.0000000e+00, 1.0200000e+01, 0.0000000e+00,
&  5.1961524e+00, 1.6367880e+01, 0.0000000e+00,-2.1126849e+01,
& -4.8142922e+00, 3.9528471e+00, 0.0000000e+00,-2.7669930e+01,
& -3.1304952e+00,-5.558051e+00, 7.3950997e-01, 0.0000000e+00,
& -1.2199898e+01,-1.7675990e+01, 9.4124253e+00,-2.8840889e+00,
& -7.7171683e+01, 0.0000000e+00, 9.4515623e+00, 1.4944232e+00,
& 1.9925643e+00, 7.0939206e+00,-1.6287697e+01,-1.1418786e+00,
& 0.0000000e+00, 4.9657445e+00, 2.8960810e+00, 1.1435156e+00,
& -3.7046793e+00, 4.3221258e+00,-5.1780788e-01, 9.4124253e+00,
& 0.0000000e+00, 1.3406250e+01, 2.2432947e+01, 8.2839146e+00,
& 8.0208658e+00,-5.9322345e+00, 2.0595682e+00, 1.5040960e+00,
& -1.8801200e+01 /

COMPUTATIONAL COEFFICIENTS

data const/
& 2*0.,1.,.33333333,0.,-1.,.26666667,.2,0.,-.33333333,.25714286,
& .22857143,.14285714,0.,-2.,25396825,.23809524,.19047619,
& .11111111,0.,-14285714,25252525,.24242424,.21212121,.16161616,
& .090909091,0.,-11111111,.25174825,.24475524,.22377622,
& .18881119,.13986014,.076923077,.090909091,.25128205,
& .24615385,.23076923,.20512821,.16923077,.066666667,
& 0.,-0.76923077 /

data a2,a4,b2,a2b2,a4b4,lastdt,tzero/
& 4.0680925e07,
& 1.65493766e15,
& 4.04085822e07,
& 2.72342737e05,
& 2.20841384e13,
& -99999999,
& 1975. /

data cp(l),sp(l),dp(l),p(l)/1.,0.,0.,1./

TIME CORRECTION

c if (idate.eq.lastdt) go to 100
    t=float(idate/1000)+float(mod(idate,1000))/365. - tzero
    lastdt=idate
    do 50 n=1,90
        gh(n)=gh0(n)+t*ght(n)
    50

POSITION COMPUTATIONS

c sinla=sin(lat)
sinla2=sinla**2
cosla2=1.-sinla2
den2=a2-a2b2*sinla2
den=sqrt(den2)
altk=alt*le-3
fac=((((altk*den)+a2)/((altk*den)+b2))**2
ct=sinla/sqrt(fac*cosla2+sinla2)
st = sqrt(1 - ct**2)
sp(2) = sin(long)
sp(2) = cos(long)
n = 2
do 120 m = 3, 9
sp(m) = sp(2) * cp(n) + cp(2) * sp(n)
cp(m) = cp(2) * cp(n) - sp(2) * sp(n)
120 n = n + 1
aor = 6371.2 / sqrt(altk * (altk + 2. * den) + (a4 - a4b4 * sinla2) / den2)
ar = aor**2
bt = 0.
bp = 0.
br = 0.
nlm = l
n2m = l
fn = 2.
nm = 2

c POLYNOMIAL EVALUATION LOOP
c
do 300 n = 2, 9
ar = aor * ar
fm = 0.
do 290 m = 1, n
if (n .ne. m) go to 240
k = nm - n
p(nm) = st * p(k)
dp(nm) = st * dp(k) + ct * p(k)
go to 250
240 p(nm) = ct * p(nlm) - const(nm) * p(n2m)
dp(nm) = ct * dp(nlm) - st * p(nlm) - const(nm) * dp(n2m)
250 par = p(nm) * ar
temp = g(nm) * cp(m) + h(nm) * sp(m)
bp = bp - (g(nm) * sp(m) - h(nm) * cp(m)) * fm * par
bt = bt + temp * dp(nm) * ar
br = br - temp * fn * par
nm = nm + 1
nlm = nlm + 1
n2m = n2m + 1
290 fm = fm + 1.
fn = fn + 1.
nlm = nlm - 1
300 n2m = n2m - 2
bp = bp / st

c TRANSFORM, IF REQUIRED
c
notall = icode .lt. 5
if (icode .eq. 1) go to 411
sind = sinla * st - sqrt(cosla2) * ct
cosd = sqrt(1 - sind**2)
n = 1
go to (411, 412, 413, 414, 411), icode
411 vec(1) = sqrt(bp**2 + bt**2 + br**2)
if (notall) go to 500
n=n+1

412 vec(n)=-bt*cosd-br*sind
if (notall) go to 500
n=n+1

413 vec(n)=bp
if (notall) go to 500
n=n+1

414 vec(n)=bt*sind-br*cosd
if (notall) go to 500
call polar(sqrt(vec(2)**2+vec(3)**2),vec(4),vec(5),bt)
call polar(vec(2),vec(3),vec(6),bt)

500 return
end
subroutine digrf(lat, long, alt, idate, vec, icode)
save

DIGRF GENERATES MAIN GEOMAGNETIC FIELD COMPONENTS, USING THE
SECULAR CHANGE COEFFICIENTS.

PROGRAM BASED ON:
"COMPUTATION OF THE MAIN GEOMAGNETIC FIELD FROM
SPHERICAL HARMONIC EXPANSIONS"
BY: J. C. CAIN, ET. AL., NASA DATA USERS NOTE, NSSDC 68-11,
MAY, 1968

PROGRAM MODIFIED BY:
GERALD I. EVENDEN
U. S. GEOLOGICAL SURVEY
DENVER FEDERAL CENTER
DENVER, COLORADO 80225

PROGRAM FURTHER MODIFIED BY:
RONALD E. SWEENEY
U. S. GEOLOGICAL SURVEY
DENVER FEDERAL CENTER
DENVER, COLORADO 80225

SO AS TO INCLUDE CURRENT EARTH ELLIPSOIDAL PARAMETERS:

A=6371.2
RE=6378.16
FLAT=1./298.25

PARAMETER DESCRIPTION:

LAT, LONG : LATITUDE, LONGITUDE COORDINATES IN RADIANS
POS. NORTH LATITUDE
POS. EAST LONGITUDE

ALT : ALTITUDE OF POINT ABOVE SEA LEVEL (METERS)

IDATE : DATE IN YEAR*1000+DAY
IE. 1972035.. YEAR 1972, DAY 35

VEC : RESULTANT EARTH FIELD VECTOR(S)

ICODE : RESULTANT VECTOR(S) STORED IN VEC
= 1 : TOTAL FIELD
(GAMMAS)
= 2 : E-W HORIZONTAL COMPONENT
(GAMMAS)
= 3 : N-S HORIZONTAL COMPONENT
(GAMMAS)
= 4 : VERTICAL COMPONENT
(GAMMAS)
= 5 : ALL OF THE ABOVE STORED IN VEC(1) THRU VEC(4)
RESPECTIVELY,... PLUS
VEC(5)=INCLINATION (RADIANS)
VEC(6)=DECLINATION (RADIANS)
c
dimension vec(6)
real lat, long
logical notall
c
dimension g(66), h(66), gt(66), ht(66), p(66), dp(66), const(66),
  & sp(11), cp(11), g45(66), h45(66), g50(66), h50(66),
  & g55(66), h55(66), g60(66), h60(66), g65(66), h65(66),
  & g70(66), h70(66), g75(66), h75(66), g80(66), h80(66),
  & g85(66), h85(66), gh0(132, 9), gh(132), ght(132)
equivalence (gh0(1, 1), g45(1)), (gh0(67, 1), h45(1)),
  & (gh0(1, 2), g50(1)), (gh0(67, 2), h50(1)),
  & (gh0(1, 3), g55(1)), (gh0(67, 3), h55(1)),
  & (gh0(1, 4), g60(1)), (gh0(67, 4), h60(1)),
  & (gh0(1, 5), g65(1)), (gh0(67, 5), h65(1)),
  & (gh0(1, 6), g70(1)), (gh0(67, 6), h70(1)),
  & (gh0(1, 7), g75(1)), (gh0(67, 7), h75(1)),
  & (gh0(1, 8), g80(1)), (gh0(67, 8), h80(1)),
  & (gh0(1, 9), g85(1)), (gh0(67, 9), h85(1)),
  & (gh(1), g(1)), (gh(67), h(1)),
  & (ght(1), ght(1))
equivalence (p(2), sind, sinla2),
  & (p(3), cosd, den2),
  & (p(4), notall, den),
  & (p(5), altk),
  & (p(6), fac)
c
c DIGRF COEFFICIENTS, GAUSS NORMALIZED.
c
data g45/
  & 0.00000000E+00, 3.05940000E+04, 2.28500000E+03, 1.86600000E+03,
  & -5.1788319E+03, -1.3675814E+03, -3.2050000E+03, 5.6154552E+03,
  & -2.4302970E+03, -7.2189382E+03, -1.3050000E+03, -4.2943731E+03,
  & -2.1287367E+03, 8.0058468E+02, -2.6681033E+02, 1.9923750E+03,
  & -3.5167317E+03, -1.4909314E+03, 9.4124253E+01, 3.1503125E+02,
  & 5.7527982E+01, -8.5181250E+02, -1.0774781E+03, -8.9665394E+01,
  & 2.4505854E+03, 1.3642155E+02, -4.8863909E+01, 6.9856102E+01,
  & -1.8768750E+03, 1.4187841E+02, 0.00000000E+00, 0.00000000E+00,
  & 3.5811900E+02, 6.1744654E+01, -3.6327369E+01, -1.8770536E+01,
  & -6.5354699E+02, -4.6921875E+02, 4.4865894E+02, 2.0709787E+02,
  & -2.4062598E+02, -1.0381410E+02, 6.8652274E+01, -1.7547786E+01,
  & -1.2534133E+00, -4.7480469E+02, 2.6754728E+03, -1.0865004E+02,
  & 9.1281124E+02, -1.6912722E+02, -5.3905516E+02, 5.2193792E+01,
  & 3.0134010E+01, 7.5519332E+00, 2.4361976E+00, 5.4127734E+02,
  & -2.6761468E+03, -2.1069192E+02, -3.3056068E+02, 5.8435425E+02,
  & 7.3915615E+01, -3.3056068E+02, 2.0043185E+01, 2.4547788E+01,
  & -1.3273924E+01, 1.1872558E+00 /
data h45/
  & 0.00000000E+00, 0.00000000E+00, -5.81000000E+03, 0.00000000E+00,
  & 2.9479505E+03, -4.1309412E+02, 0.00000000E+00, 1.5278692E+03,
  & -3.6018745E+02, 8.6962636E+00, 0.00000000E+00, -7.9689397E+02,
  & 1.0800208E+03, -1.1504075E+02, 1.3163278E+02, 0.00000000E+00,
  & 1.2199898E+02, -7.3009524E+02, 3.1531625E+02, 2.6405060E+02,
  & -5.7527982E+01, 0.00000000E+00, -1.1341875E+02, -1.4944232E+03,
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### Note
- The table above contains numerical data extracted from the document. Each entry represents a dataset, and the format varies depending on the specific dataset (g50, h50, g55). The data includes various numerical values, some of which are in scientific notation, indicating a range of magnitudes from very small to very large numbers. This kind of data is often used in scientific, mathematical, or engineering contexts. The exact interpretation of the data would depend on the specific field or application it is associated with. For example, if these are financial figures, they might represent stock market values, exchange rates, or economic indicators. If they are related to scientific experiments or measurements, they could represent experimental results, parameters, or constants in a research project. Without additional context, the precise meaning of each entry cannot be determined. However, the structure of the data suggests it is designed to be analyzed or compared, possibly as part of a larger dataset or report.
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& 0.0000000E+00, 0.0000000E+00, 0.0000000E+00, 0.0000000E+00,
& 0.0000000E+00, 0.0000000E+00, 0.0000000E+00, 0.0000000E+00,
& 0.0000000E+00, 0.0000000E+00

COMPUTATIONAL COEFFICIENTS

data const/
& 0.000000E+00, 0.000000E+00, 1.000000E+00, 3.333333E-01,
& 0.000000E+00,-1.000000E+00, 2.666667E-01, 2.000000E-01,
& 0.000000E+00,-3.333333E-01, 2.5714286E-01, 2.2857143E-01,
& 1.4285714E-01, 0.000000E+00,-2.000000E-01, 2.5396825E-01,
& 2.3809524E-01, 1.9047619E-01, 1.1111111E-01, 0.000000E+00,
& -1.4285714E-01, 2.5252525E-01, 2.4242424E-01, 2.1212121E-01,
& 1.6161616E-01, 9.090909E-02, 0.000000E+00,-1.1111111E-01,
& 2.5174825E-01, 2.4475524E-01, 2.2377622E-01, 1.8881119E-01,
& 1.3986014E-01, 7.6923077E-02, 0.000000E+00,-9.090909E-02,
& 2.5128205E-01, 2.4615385E-01, 2.3076923E-01, 2.0512821E-01,
& 1.6923077E-01, 1.2307692E-01, 6.6666667E-02, 0.000000E+00,
& -7.6923077E-02, 2.5098039E-01, 2.4703882E-01, 2.3529412E-01,
& 2.1568627E-01, 1.8823529E-01, 1.5294118E-01, 1.0980392E-01,
& 5.8823529E-02, 0.000000E+00,-6.6666667E-02, 2.5077399E-01,
& 2.4767802E-01, 2.3839090E-01, 2.2291022E-01, 2.0128393E-01,
& 1.7337461E-01, 1.3931889E-01, 9.9071207E-02, 5.2631579E-02,
& 0.0000000E+00,-5.8823529E-02 /
& data a2,a4,b2,a2b2,a4b4,lastdt,tzero/
& 4.0680925e07,
& 1.6549376615,
& 4.04085822e07,
& 2.72342737e05,
& 2.20841384e13,
& -99999999,
& 1945. /
& data cp(1),sp(1),dp(1),p(1)/1.,0.,0.,1./

TIME CORRECTION

if (idate.eq.lastdt) go to 100
(t=30.0)
lastdt=idate

if(t.ge.0.0) go to 20
write(6,10) idate
10 format(2x,'Error--DIGRF called with IDATE = ',i7,/,
&9x,'For any IDATE < 1945000, DIGRF invalid!!')
stop
20 if(t.lt.40.) go to 40
Here use 1985 coefficients & time terms.

t=t-40.
do 30 n=1,132
30 gh(n)=gh0(n,9)+t*ght(n)
go to 100

Here interpolate between the 1945 thru 1985 coefficients.

frac=t/5.+1.
ncoef1=frac
frac=amod(frac,1.0)
ncoef2=ncoef1+1

do 50 n=1,132
50 gh(n)=gh0(n,ncoef1)+frac*(gh0(n,ncoef2)-gh0(n,ncoef1))

POSITION COMPUTATIONS

100 sinla=sin(lat)
sinla2=sinla**2
cosla2=1.-sinla2
den2=a2-a2b2*sinla2
den=sqrt(den2)
altk=alt*le-3
fac=((altk*den)+a2)/((altk*den)+b2)**2
ct=sinla/sqrt(fac*cosla2+sinla2)
st=sqrt(1.-ct**2)
sp(2)=sin(long)
cp(2)=cos(long)
n=2
do 120 m=3,11
sp(m)=sp(2)*cp(n)+cp(2)*sp(n)
cp(m)=cp(2)*cp(n)-sp(2)*sp(n)
120 n=n+1
aor=6371.2/sqrt(altk*(altk+2.*den)+(a4-a4b4*sinla2)/den2)
ar=aor**2
bt=0.
bp=0.
br=0.
nlm=1
n2m=1
fn=2.
mm=2

POLYNOMIAL EVALUATION LOOP

do 300 n=2,11
ar=aor*ar
fm=0.
do 290 m=1,n
if (n.ne.m) go to 240
k=nm-n
p(nm)=st*p(k)
dp(nm)=st*dp(k)+ct*p(k)
p(nm)=ct*p(nlm)-const(nm)*p(n2m)
dp(nm)=ct*dp(nlm)-st*p(nlm)-const(nm)*dp(n2m)
par=p(nm)*ar
temp=g(nm)*cp(m)+h(nm)*sp(m)
bp=bp-(g(nm)*sp(m)-h(nm)*cp(m))*fm*par
bt=bt+temp*dp(nm)*ar
br=br-temp*fn*par
nm=nm+1
nlm=nlm+1
n2m=n2m+1
fm=fm+1.
fn=fn+1.
nlm=nlm-1
300 n2m=n2m-2
bp=bp/st

TRANSFORM, IF REQUIRED

notall=icode.lt.5
if (icode.eq.1) go to 411
sind=sinla*st-sqrt(cosla2)*ct
cosd= sqrt(1.-sind**2)
n=1
go to (411,412,413,414,411),icode
411 vec(1)=sqrt(bp**2+bt**2+br**2)
if (notall) go to 500
n=n+1
412 vec(n)=-bt*cosd-br*sind
if (notall) go to 500
n=n+1
413 vec(n)=bp
if (notall) go to 500
n=n+1
414 vec(n)=bt*sind-br*cosd
if (notall) go to 500
call polar(sqrt(vec(2)**2+vec(3)**2),vec(4),vec(5),bt)
call polar(vec(2),vec(3),vec(6),bt)
500 return
end
subroutine iorow(io, dat1, n1, dat2, n2)
dimension dat1(n1), dat2(n2)
write(io) dat1, dat2
return
dat1, dat2
subroutine rdbin(iu,dum,i1,data,i2,*

dimension dum(i1),data(i2)
read(iu,end=100) dum,data
return
100 return 1
end
subroutine polar(zr,zi,rad,amp)
   c    PARMS  ZR = GIVEN REAL(Z) OR X-COORD.
   c    ZI = GIVEN IMAG(Z) OR Y-COORD.
   c    RAD= COMPUTED PHASE IN RADIANS (0,2PI)
   c    AMP= COMPUTED AMPLITUDE.
   c    data pi,pi2/3.1415927,6.2831853/ 
   if(zr.eq.0.and.zi.eq.0) go to 9
      pv=atan2(abs(zi),abs(zr))
   if(zi.ge.0.and.zr.ge.0) go to 10
   if(zi.ge.0.and.zr.lt.0) go to 20
   if(zi.lt.0.and.zr.le.0) go to 30
   rad=pi2-pv
   go to 40
9      rad=0.
      amp=0.
      return
10     rad=pv
      go to 40
20     rad=pi-pv
      go to 40
30     rad=pi+pv
40     amp=sqrt(zr*zr+zi*zi)
      return
end