DEPARTMENT OF THE INTERIOR

U. S. GEOLOGICAL SURVEY

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 ADDGRD, 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,

θ = geocentric colatitude,

ϕ = 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, where b 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, unitsy = :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.

Chapman, Sydney, and Bartels, Julius, 1940, Geomagnetism: New York, New York, Oxford University Press, pp. 610-612, 639.

Godson, R., and Mall, Margaret R., 1988, Potential-field geophysical programs for IBM compatable microcomputers, version 1.0: U. S. Geological Survey Open-File Report 89-197 A-F, 23 p., 5 diskettes.

International Astronomical Union, 1966, Proceedings of the 12th General Assembly, v. 12B, pp. 594-595.

U.S.G.S., 1989, Potential-field geophysical programs for VAX7xx computers: U. S. Geological Survey Open-File Report 89-115, A-D, 21 p., 3 diskettes.

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

```
c   USGS Computer Program "IGRFGRID"; version 1.000
c   Technical Contact:  Ron Sweeney
c
c   Program IGRFGRID creates an output grid in latitude-longitude
c     coordinates of International Geomagnetic Reference Field
c     (IGRF) total magnetic field values, representing the earth's
c     main magnetic field, for a user-specified area.  The user
c     has a choice of models:  IGRF1965, IGRF1975, or the Definitive
c     Geomagnetic Reference Field (DGRF) package of DGRF models,
c     starting with epoch 1945, ending with epoch 1980, and coupled
c     with the IGRF 1985 model of the latest spherical harmonic
c     coefficients and secular change terms for field prediction.
c     Input elevation may be either constant barometric, or supplied
c     as a grid of barometric elevations covering an area identical
c     to the output IGRF grid.  Grid locations must be in degrees or
c     seconds of latitude & longitude (negative west longitude).
c     The output file is in USGS standard grid format.  The original
c     IGRF subroutine concept was created for the Branch of Geophysics,
c     U. S. Geological Survey, for our airborn formats by Gerald I.
c     Evenden.  Computational techniques are based on "Computation of
c     the Main Geomagnetic Field from Spherical Harmonic Expansions"
c     by J. C. Cain, et. al., NASA Data Users Note, NSSDC 68-11, May,
c     1968.
c
c   The program IGRFGRID is designed for interactive use.
c
c   Questions asked of the user:
c
c     Output file name    :  Name of output grid of IGRF magnetic
c                                 field values.
c     Title               :  56 characters of descriptive information
c                                 stored in the output grid.
c     Date of computation :  Date, entered as year & day of year, for
c                                 computation of the main field.
c     Model desired       :  Select IGRF1965,
c                                   IGRF1975, or
c                                   DIGRF, which includes ALL the DIGRF
c                                          models from 1945 - 1980, AND
c                                          including IGRF 1985.
c     Input elevation grid?  Yes -- IGRFGRID will prompt the user for a
c                                   grid file name and use the contained
c                                   elevations in the field calculations.
c                                   The output IGRF grid will have dimen-
c                                   sions identical to the elevation grid.
c                                   IGRFGRID asks if the elevations are in
c                                   feet or meters, and if the locations
c                                   are in degrees or seconds of latitude
c                                   & longitude.
c                            No  -- Constant barometric elevation is assumed
c                                   for the entire grid, and the user is
c                                   prompted for a value.  The user is also
c                                   asked to identify the dimensions of the
```

```
c                                       output IGRF grid, and the grid spacing,
c                                       in either degrees or seconds of latitude
c                                       & longitude.
c
c                         Ronald E. Sweeney
c                         Branch of Geophysics
c                         U. S. Geological Survey
c                         MS 964; Box 25046
c                         Denver, CO 80225
c
c
      dimension data(2000),alts(2000)
      character*56 title,etitle
      character*56 iofil,elfile
      character*8 pgm,epgm
      character*7 resp
      character*5 model
      character*4 elunx,eluny,unitss,unitsd,units
      character*1 r,w
      logical*1 elgrid,feet,deg
      data unitss/'sec '/,unitsd/'deg '/
      data r/'r'/,w/'w'/
      pgm='igrfgrid'
      rad=1./57.29578
      sec2deg=1./3600.
      ft2met=.3048
      zero=0.0
c
      nz=1
c
c  Write the ID-Stamp to default output device.
c
      write(6,17)
   17 format(/,' USGS Computer Program "IGRFGRID"; version 1.000',/,
     1       ' Technical Contact:  Ron Sweeney',/)
c
c  Request user input.
c
      write(6,1)
    1 format('$ Enter output filename:  ')
      read(5,2) iofil
    2 format(a)
      write(6,3)
    3 format('  Enter 56 character title:  ')
      read(5,2) title
      write(6,9)
    9 format('$ Enter date for computation of total field ',
     1'(yyyyddd):  ')
      read(5,*) idate
   13 write(6,10)
   10 format('$ Enter ''1965'', ''1975'', or ''digrf'' for igrf model',
     1' 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.
c
      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=11,file=elfile,status='old',form='unformatted',
     1           readonly)
      read(11,end=200) etitle,epgm,ncol,nrow,nz,xo,dx,yo,dy
    6 write(6,7)
    7 format('$ Are the elevations in ''feet'' or ''meters''?  ')
      read(5,2) resp
      if(resp.ne.'feet'.and.resp.ne.'meters') go to 6
      feet=.false.
      if(resp.eq.'feet') feet=.true.
    8 write(6,12)
   12 format('$ Are the elevation locations in ''degrees'' or ',
     1'''seconds''?  ')
      read(5,2) resp
      if(resp.ne.'degrees'.and.resp.ne.'seconds') go to 8
c
      if(resp.eq.'degrees') then
         deg=.true.
         units=unitsd
      else
         deg=.false.
         units=unitss
      end if
c
      write(6,11) title,units,units,model,idate,ncol,nrow,nz,xo,dx,yo,
     1           dy
   11 format(/,2x,'title = :',a56,
     1/,2x,'unitsx = :',a4,', unitsy = :',a4,
     2/,2x,'model = ',a5,', epoch = ',i7,
     3/,2x,'ncol,nrow,nz,xo,dx,yo,dy = ',3i4,4f10.1,/)
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
c
```

```
      else
c
Here, read parameters concerning the constant barometric elevation.
c
   26 write(6,27)
   27 format('$ Do you wish to enter geographic area in ''degrees'' ',
     1       'or ''seconds''?  ')
      read(5,2) resp
      if(resp.ne.'degrees'.and.resp.ne.'seconds') go to 26
c
      if(resp.eq.'degrees') then
         deg=.true.
         units=unitsd
      else
         deg=.false.
         units=unitss
      end if
c
      write(6,23)
   23 format('  Enter min, max lat & min, max (neg. west) lon:  ')
      read(5,*) flat1,flat2,flon1,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.
c
      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,/)
c
c   Open the output IGRF grid file, & output the header record.
c
      open(10,file=iofil,status='new',form='unformatted')
      write(10) title,pgm,ncol,nrow,nz,xo,dx,yo,dy
c
      end if
c
      if(deg) go to 14
      xo=xo*sec2deg
      dx=dx*sec2deg
      yo=yo*sec2deg
```

```
      dy=dy*sec2deg
   14 if(model.ne.'1965') go to 100
c
c
  igrf 1965 here.
c
      flat=yo-dy
      do 20 lt=1,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=1,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
c   digrf here.
c
  125 flat=yo-dy
      do 130 lt=1,nrow
      flat=flat+dy
      flatr=flat*rad
      flon=xo-dx
      if(elgrid) call rdbin(11,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(11)
      stop
c
  200 write(6,201)
  201 format(2x,'Error--unexpected E-O-F in elevation file....')
      close(10)
      close(11)
      stop
c
      end
```

```
      subroutine igrf1965(lat,long,alt,idate,vec,icode)
      save
c
c IGRF1965 GENERATES MAIN GEOMAGNETIC FIELD COMPONENTS
c
c_________________________________________________________________________
c
c     PROGRAM BASED ON:
c      "COMPUTATION OF THE MAIN GEOMAGNETIC FIELD FROM
c       SPHERICAL HARMONIC EXPANSIONS"
c       BY: J. C. CAIN, ET. AL., NASA DATA USERS NOTE, NSSDC 68-11,
c       MAY,1968
c     PROGRAM MODIFIED BY:
c      GERALD I. EVENDEN
c      U. S. GEOLOGICAL SURVEY
c      DENVER FEDERAL CENTER
c      DENVER, COLORADO   80225
c
c_________________________________________________________________________
c
c     PARAMETER DESCRIPTION:
c       LAT,LONG : LATITUDE, LONGITUDE COORDINATES IN RADIANS
c                  POS. NORTH LATITUDE
c                  POS. EAST LONGITUDE
c       ALT      : ALTITUDE OF POINT ABOVE SEA LEVEL (METERS)
c       IDATE    : DATE IN YEAR*1000+DAY
c                  IE. 1972035.. YEAR 1972, DAY 35
c       VEC      : RESULTANT EARTH FIELD VECTOR(S)
c       ICODE    : RESULTANT VECTOR(S) STORED IN VEC
c             =1 : TOTAL FIELD              (GAMMAS)
c             =2 : E-W HORIZONTAL COMPONENT (GAMMAS)
c             =3 : N-S HORIZONTAL COMPONENT (GAMMAS)
c             =4 : VERTICAL COMPONENT       (GAMMAS)
c             =5 : ALL OF THE ABOVE STORED IN VEC(1) THRU VEC(4)
c                  RESPECTIVELY,... PLUS
c                  VEC(5)=INCLINATION (RADIANS)
c                  VEC(6)=DECLINATION (RADIANS)
c
c_________________________________________________________________________
c
       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),cosd,den2),
     &   (p(4),notall,den),
     &   (p(5),altk),
     &   (p(6),fac)
```

```
c
c IGRF-1965 COEFFICIENTS, GAUSS NORMALIZED.
c
c     FROM 10/68 WMSB MEETING
c
        data g0/
     & 0.0           , 3.0339000e 04, 2.1230000e 03, 2.4810000e 03,
     &-5.1857539e 03,-1.3570610e 03,-3.2425000e 03, 6.2339492e 03,
     &-2.4961367e 03,-6.6644946e 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,-1.6370560e 01, 9.3072395e 00, 7.5229507e 01,
     &-1.9036875e 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 h0/
     & 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          ,-8.2456348e 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,
     &-1.1114024e 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, 4.4491701e 00, 2.7460871e 00, 7.5204664e-01,
     &  1.8801165e-01  /
c
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,.24475524,.22377622,
     & .18881119,.13986014,.076923077,0.,-.090909091,.25128205,
     & .24615385,.23076923,.20512821,.16923077,.12307692,.066666667,
     & 0.,-.076923077  /
        data a2,a4,b2,a2b2,a4b4,lastdt,tzero/
     & 4.0680989e07,
     & 1.6549428e15,
     & 4.0408694e07,
     & 2.7229501e05,
     & 2.2080316e13,
     & -99999999,
     & 1965.  /
        data cp(1),sp(1),dp(1),p(1)/1.,0.,0.,1./
c
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=1,90
50      gh(n)=gh0(n)+t*ght(n)
c
c POSITION COMPUTATIONS
c
100
        sinla=sin(lat)
        sinla2=sinla**2
        cosla2=1.-sinla2
        den2=a2-a2b2*sinla2
        den=sqrt(den2)
        altk=alt*1e-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=3,9
        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.
          n1m=1
          n2m=1
          fn=2.
          nm=2
c
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(n1m)-const(nm)*p(n2m)
          dp(nm)=ct*dp(n1m)-st*p(n1m)-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
          n1m=n1m+1
          n2m=n2m+1
290       fm=fm+1.
          fn=fn+1.
          n1m=n1m-1
300       n2m=n2m-2
          bp=bp/st
c
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 igrf1975(lat,long,alt,idate,vec,icode)
      save
c
c IGRF1975 GENERATES MAIN GEOMAGNETIC FIELD COMPONENTS
c
c_______________________________________________________________________
c
c     PROGRAM BASED ON:
c      "COMPUTATION OF THE MAIN GEOMAGNETIC FIELD FROM
c       SPHERICAL HARMONIC EXPANSIONS"
c       BY: J. C. CAIN, ET. AL., NASA DATA USERS NOTE, NSSDC 68-11,
c       MAY,1968
c
c     PROGRAM MODIFIED BY:
c       GERALD I. EVENDEN
c       U. S. GEOLOGICAL SURVEY
c       DENVER FEDERAL CENTER
c       DENVER, COLORADO   80225
c
c     PROGRAM FURTHER MODIFIED BY:
c       RONALD E. SWEENEY
c       U. S. GEOLOGICAL SURVEY
c       DENVER FEDERAL CENTER
c       DENVER, COLORADO   80225
c
c       SO AS TO INCLUDE CURRENT EARTH ELLIPSOIDAL PARAMETERS:
c
c       A=6371.2
c       RE=6378.16
c       FLAT=1./298.25
c
c_______________________________________________________________________
c
c     PARAMETER DESCRIPTION:
c       LAT,LONG : LATITUDE, LONGITUDE COORDINATES IN RADIANS
c                  POS. NORTH LATITUDE
c                  POS. EAST LONGITUDE
c       ALT      : ALTITUDE OF POINT ABOVE SEA LEVEL (METERS)
c       IDATE    : DATE IN YEAR*1000+DAY
c                  IE. 1972035.. YEAR 1972, DAY 35
c       VEC      : RESULTANT EARTH FIELD VECTOR(S)
c       ICODE    : RESULTANT VECTOR(S) STORED IN VEC
c             =1 : TOTAL FIELD               (GAMMAS)
c             =2 : E-W HORIZONTAL COMPONENT (GAMMAS)
c             =3 : N-S HORIZONTAL COMPONENT (GAMMAS)
c             =4 : VERTICAL COMPONENT        (GAMMAS)
c             =5 : ALL OF THE ABOVE STORED IN VEC(1) THRU VEC(4)
c                  RESPECTIVELY,... PLUS
c                  VEC(5)=INCLINATION (RADIANS)
c                  VEC(6)=DECLINATION (RADIANS)
c
c_______________________________________________________________________
c
      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),cosd,den2),
     &   (p(4),notall,den),
     &   (p(5),altk),
     &   (p(6),fac)
c
c  IGRF-1975 COEFFICIENTS, GAUSS NORMALIZED.
c     data g0/
     &  0.0000000e+00, 3.0186000e+04, 2.0360000e+03, 2.8470000e+03,
     & -5.1909563e+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,-8.8983518e+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, 4.3477187e+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, 1.1067972e+01,
     &  1.5261164e+01, 4.3924651e+00, 2.2924809e+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,-2.0941325e+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,
     &  -4.8412292e+00, 3.9528471e+00, 0.0000000e+00,-2.7669930e+01,
     &  -3.1304952e+00,-3.5558051e+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+00,-1.1418786e+00,
     &   0.0000000e+00, 4.9657445e+01, 2.8960810e+00,-6.1435156e+00,
     &  -3.7046793e+00, 4.3221258e+00,-2.4218246e-01,-5.1780788e-01,
     &   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 /
c
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,.24475524,.22377622,
     & .18881119,.13986014,.076923077,0.,-.090909091,.25128205,
     & .24615385,.23076923,.20512821,.16923077,.12307692,.066666667,
     & 0.,-.076923077  /
       data a2,a4,b2,a2b2,a4b4,lastdt,tzero/
     & 4.0680925e07,
     & 1.65493766e15,
     & 4.04085822e07,
     & 2.72342737e05,
     & 2.20841384e13,
     & -99999999,
     & 1975.  /
       data cp(1),sp(1),dp(1),p(1)/1.,0.,0.,1./
c
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=1,90
50
       gh(n)=gh0(n)+t*ght(n)
c
c   POSITION COMPUTATIONS
c
100
       sinla=sin(lat)
       sinla2=sinla**2
       cosla2=1.-sinla2
       den2=a2-a2b2*sinla2
       den=sqrt(den2)
       altk=alt*1e-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=3,9
      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.
      n1m=1
      n2m=1
      fn=2.
      nm=2
c
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(n1m)-const(nm)*p(n2m)
      dp(nm)=ct*dp(n1m)-st*p(n1m)-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
      n1m=n1m+1
      n2m=n2m+1
290   fm=fm+1.
      fn=fn+1.
      n1m=n1m-1
300   n2m=n2m-2
      bp=bp/st
c
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
c
c DIGRF GENERATES MAIN GEOMAGNETIC FIELD COMPONENTS, USING THE
c DEFINITIVE IGRF 1945 - 1980, IGRF 1985, & THE IGRF 1985
c SECULAR CHANGE COEFFICIENTS.
c
c_______________________________________________________________________
c
c     PROGRAM BASED ON:
c      "COMPUTATION OF THE MAIN GEOMAGNETIC FIELD FROM
c       SPHERICAL HARMONIC EXPANSIONS"
c       BY: J. C. CAIN, ET. AL., NASA DATA USERS NOTE, NSSDC 68-11,
c       MAY,1968
c
c     PROGRAM MODIFIED BY:
c       GERALD I. EVENDEN
c       U. S. GEOLOGICAL SURVEY
c       DENVER FEDERAL CENTER
c       DENVER, COLORADO   80225
c
c     PROGRAM FURTHER MODIFIED BY:
c       RONALD E. SWEENEY
c       U. G. GEOLOGICAL SURVEY
c       DENVER FEDERAL CENTER
c       DENVER, COLORADO   80225
c
c       SO AS TO INCLUDE CURRENT EARTH ELLIPSOIDAL PARAMETERS:
c
c       A=6371.2
c       RE=6378.16
c       FLAT=1./298.25
c
c_______________________________________________________________________
c
c     PARAMETER DESCRIPTION:
c       LAT,LONG : LATITUDE, LONGITUDE COORDINATES IN RADIANS
c                  POS. NORTH LATITUDE
c                  POS. EAST LONGITUDE
c       ALT      : ALTITUDE OF POINT ABOVE SEA LEVEL (METERS)
c       IDATE    : DATE IN YEAR*1000+DAY
c                  IE. 1972035.. YEAR 1972, DAY 35
c       VEC      : RESULTANT EARTH FIELD VECTOR(S)
c       ICODE    : RESULTANT VECTOR(S) STORED IN VEC
c             =1 : TOTAL FIELD              (GAMMAS)
c             =2 : E-W HORIZONTAL COMPONENT (GAMMAS)
c             =3 : N-S HORIZONTAL COMPONENT (GAMMAS)
c             =4 : VERTICAL COMPONENT       (GAMMAS)
c             =5 : ALL OF THE ABOVE STORED IN VEC(1) THRU VEC(4)
c                  RESPECTIVELY,... PLUS
c                  VEC(5)=INCLINATION (RADIANS)
c                  VEC(6)=DECLINATION (RADIANS)
c_______________________________________________________________________
```

```
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),gt(1)),(ght(67),ht(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/
   &  0.0000000E+00, 3.0594000E+04, 2.2850000E+03, 1.8660000E+03,
   & -5.1788319E+03,-1.3665881E+03,-3.2050000E+03, 5.6154552E+03,
   & -2.4302970E+03,-7.2178988E+02,-4.1300000E+03,-4.2943731E+03,
   & -2.1287367E+03, 8.8058468E+02,-2.2481103E+02, 1.9923750E+03,
   & -3.5176371E+03,-1.4909313E+03, 9.4124253E+01, 3.1503125E+02,
   &  5.7527982E+01,-8.5181250E+02,-1.0774781E+03,-8.9665394E+01,
   &  2.4508541E+03, 1.3642155E+02,-4.8863090E+01, 6.9856102E+01,
   & -1.8768750E+03, 1.4187841E+03, 0.0000000E+00, 0.0000000E+00,
   &  3.5811900E+02, 6.1744654E+01,-3.6327369E+01,-1.8770536E+01,
   & -6.5355469E+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,
   &  3.0134100E+01, 7.7519332E+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/
   &  0.0000000E+00, 0.0000000E+00,-5.8100000E+03, 0.0000000E+00,
   &  2.9479505E+03,-4.1309412E+02, 0.0000000E+00, 1.5278692E+03,
   & -3.6018745E+02, 8.6962636E+00, 0.0000000E+00,-7.9689397E+02,
   &  1.0800208E+03, 1.1504075E+02, 1.3163278E+02, 0.0000000E+00,
   &  1.2199898E+02,-7.3009524E+02, 3.1531625E+02, 2.6400506E+02,
   & -5.7527982E+01, 0.0000000E+00,-1.1341875E+02,-1.4944232E+03,
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     & -1.5940514E+02, 4.9111759E+01, 3.7229021E+01, 2.6196038E+01,
     &  0.0000000E+00, 1.5961322E+03, 5.2129458E+02,-4.0956770E+01,
     & -7.4093585E+01,-1.7288503E+02, 4.1171018E+01, 1.4239717E+01,
     &  0.0000000E+00,-8.0437500E+02, 1.1777297E+03, 4.9703488E+02,
     &  1.8715354E+02,-2.9661173E+01,-1.2357409E+02,-7.5204799E+00,
     &  6.8937732E+00, 0.0000000E+00, 3.4398936E+03,-1.8470507E+03,
     & -2.4065024E+03, 5.0738165E+02,-1.3476379E+02,-1.5658138E+02,
     & -4.5201150E+01,-2.5839777E+00,-4.8723951E+00, 0.0000000E+00,
     & -1.2164304E+03,-2.1069192E+02, 3.3056068E+03, 1.1687085E+02,
     &  4.4349369E+02,-2.4792051E+02, 8.0172741E+01, 1.6365192E+01,
     &  0.0000000E+00, 1.1872558E+00 /
      data g50/
     &  0.0000000E+00, 3.0554000E+04, 2.2500000E+03, 2.0115000E+03,
     & -5.1926883E+03,-1.3648560E+03,-3.2425000E+03, 5.7838577E+03,
     & -2.4670904E+03,-7.0835020E+02,-4.1737500E+03,-4.3829168E+03,
     & -2.0661268E+03, 8.5339323E+02,-2.2407152E+02, 1.8900000E+03,
     & -3.5481369E+03,-1.6215800E+03, 9.4124253E+01, 3.2612390E+02,
     &  5.3318618E+01,-7.7962500E+02,-1.0774781E+03,-5.9776929E+01,
     &  2.4608169E+03, 8.7309793E+01,-2.7921766E+01, 7.0527795E+01,
     & -1.7428125E+03, 1.9508282E+03,-5.7921620E+01,-2.0478385E+01,
     &  4.9395723E+02, 4.3221258E+01,-1.2109123E+01,-1.2297937E+01,
     & -1.1060156E+03,-1.0054688E+03, 2.2432947E+02, 4.1419573E+01,
     & -2.9409842E+02,-2.2245879E+02, 8.9247957E+01,-1.2534133E+01,
     &  6.2670665E-01,-2.8488281E+02, 8.9182427E+02, 1.0865004E+02,
     &  2.0745710E+03,-5.6375738E+02,-1.6845474E+02, 8.6989653E+01,
     &  1.5067050E+01,-7.7519332E+00,-4.8723951E+00, 1.4434063E+03,
     & -9.7314430E+02, 2.1069192E+02,-2.1486444E+03, 4.6748340E+02,
     & -2.9566246E+02,-4.9584102E+02,-6.0129556E+01,-1.6365192E+01,
     & -2.6547848E+01,-1.7808838E+00 /
      data h50/
     &  0.0000000E+00, 0.0000000E+00,-5.8150000E+03, 0.0000000E+00,
     &  3.1350120E+03,-3.2995568E+02, 0.0000000E+00, 1.4574464E+03,
     & -3.9891728E+02, 3.6366193E+01, 0.0000000E+00,-7.5262208E+02,
     &  1.0878471E+03, 7.7391052E+01, 1.5529709E+02, 0.0000000E+00,
     & -3.0499744E+01,-7.9157695E+02, 4.0944050E+02, 2.7066065E+02,
     & -5.6124861E+01, 0.0000000E+00, 1.8903125E+01,-1.4794790E+03,
     & -3.2877311E+02, 6.5482345E+01, 2.7921766E+01, 2.0150799E+01,
     &  0.0000000E+00, 1.2414361E+03, 4.9233377E+02, 0.0000000E+00,
     &  1.2348931E+02,-2.2228076E+02, 4.3592843E+01, 1.0356158E+01,
     &  0.0000000E+00,-3.3515625E+02, 1.2338121E+03, 0.0000000E+00,
     &  5.6146061E+02, 1.1864469E+02,-1.1670887E+02, 1.0027306E+01,
     &  1.0654013E+01, 0.0000000E+00, 3.0576832E+03,-2.0643508E+03,
     & -9.9579408E+02,-1.1275148E+02,-6.7381895E+01,-1.3918344E+02,
     & -6.0268199E+01, 2.8423755E+01, 4.2633457E+00, 0.0000000E+00,
     & -3.1627190E+03, 4.2138384E+02, 1.6528034E+03,-2.3374170E+02,
     &  2.2174685E+02,-2.4792051E+02, 6.0129556E+01,-4.9095577E+01,
     & -2.9202632E+01,-4.7490233E+00 /
      data g55/
     &  0.0000000E+00, 3.0500000E+04, 2.2150000E+03, 2.1600000E+03,
     & -5.2013486E+03,-1.3691862E+03,-3.2550000E+03, 5.9522601E+03,
     & -2.4942013E+03,-6.9728222E+02,-4.1912500E+03,-4.4050528E+03,
     & -1.9956907E+03, 8.3038508E+02,-2.1445789E+02, 1.8033750E+03,
     & -3.6599693E+03,-1.7675990E+03, 1.0824289E+02, 3.3721655E+02,
     &  4.8407692E+01,-6.7856250E+02,-1.0774781E+03,-4.4832697E+01,
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&   2.4608169E+03, 4.3654897E+01,-1.6287697E+01, 7.1871182E+01,
&  -1.7428125E+03, 1.9862978E+03,-5.7921620E+01,-2.0478385E+02,
&   3.9516579E+02, 6.7919120E+01,-2.1796421E+01,-1.1650677E+01,
&  -5.5300781E+02,-6.0328125E+02, 3.3649420E+02, 5.7987403E+02,
&  -1.6041732E+02,-1.4830586E+02, 4.8056592E+01,-1.5040960E+01,
&  -5.6403599E+00,-3.7984375E+02,-1.1466312E+03, 4.3460017E+02,
&   4.1491420E+02,-1.1275148E+02,-1.3476379E+02,-1.7397931E+01,
&  -1.5067050E+01,-5.1679555E+00,-3.0452470E+00, 5.4127734E+02,
&   1.2164304E+03, 2.1069192E+02,-3.3056068E+02, 3.5061255E+02,
&  -5.1740931E+02,-1.6528034E+02, 4.0086371E+01,-4.9095577E+01,
&   5.3095695E+00, 0.0000000E+00 /
 data h55/
&   0.0000000E+00, 0.0000000E+00,-5.8200000E+03, 0.0000000E+00,
&   3.2874324E+03,-2.5201339E+02, 0.0000000E+00, 1.4145803E+03,
&  -4.1828220E+02, 6.5617261E+01, 0.0000000E+00,-7.3602013E+02,
&   1.0721946E+03, 4.8107952E+01, 1.7008729E+02, 0.0000000E+00,
&  -1.5249872E+02,-8.4537344E+02, 4.6120884E+02, 2.6844212E+02,
&  -5.4721739E+01, 0.0000000E+00, 1.7012812E+02,-1.4346463E+03,
&  -4.7821543E+02, 8.7309793E+01, 2.7921766E+01, 1.6120639E+01,
&   0.0000000E+00, 1.7734802E+03, 6.9505944E+02, 8.1913541E+01,
&  -9.8791447E+01,-1.7288503E+02, 4.8436492E+01, 1.1650677E+01,
&   0.0000000E+00,-6.7031250E+02, 8.4123551E+02,-2.0709787E+02,
&   6.1493305E+02,-4.4491759E+01,-1.5790023E+02, 1.0027306E+01,
&   8.1471865E+00, 0.0000000E+00, 1.4014381E+03,-1.3038005E+03,
&  -5.8087988E+02,-3.3825443E+02, 6.7381895E+01,-1.7397931E+02,
&  -5.2734674E+01, 1.5503866E+01,-3.0452470E+00, 0.0000000E+00,
&   9.7314430E+02, 0.0000000E+00, 1.3222427E+03, 2.3374170E+02,
&   2.9566246E+02,-4.1320085E+01, 6.0129556E+01,-5.7278173E+01,
&   2.6547848E+00, 1.7808838E+00 /
 data g60/
&   0.0000000E+00, 3.0421000E+04, 2.1690000E+03, 2.3325000E+03,
&  -5.1996165E+03,-1.3769804E+03,-3.2550000E+03, 6.0992295E+03,
&  -2.4961378E+03,-6.9411995E+02,-4.1868750E+03,-4.4271887E+03,
&  -1.9722120E+03, 8.2411013E+02,-1.9892818E+02, 1.7482500E+03,
&  -3.6803024E+03,-1.8598216E+03, 1.2236153E+02, 3.4609067E+02,
&   4.4198328E+01,-6.6412500E+02,-1.0963812E+03,-1.4944232E+01,
&   2.3611887E+03, 5.4568621E+00, 4.6536276E+00, 7.5901342E+01,
&  -1.7964375E+03, 1.9862978E+03,-1.4480405E+02,-3.0717578E+02,
&   3.9516579E+02, 4.3221258E+01,-4.1171018E+01,-5.1780788E+00,
&  -7.5410156E+02,-4.0218750E+02, 2.2432947E+02, 4.5561531E+02,
&  -5.3472439E+01,-1.4830586E+02, 3.4326137E+01,-2.5068266E+01,
&  -5.0136532E+00,-3.7984375E+02,-7.6442080E+02, 0.0000000E+00,
&   7.4684556E+02,-5.6375738E+01,-1.3476379E+02, 1.7397931E+01,
&   1.5067050E+01,-7.7519332E+00, 6.0904939E-01,-1.8042578E+02,
&   7.2985822E+02,-8.4276768E+02, 0.0000000E+00, 1.1687085E+02,
&  -2.9566246E+02,-2.4792051E+02,-2.0043185E+01, 8.1825962E+00,
&  -5.3095695E+00, 0.0000000E+00 /
 data h60/
&   0.0000000E+00, 0.0000000E+00,-5.7910000E+03, 0.0000000E+00,
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&  -4.3377413E+02, 1.0277402E+02, 0.0000000E+00,-7.4708810E+02,
&   1.0878471E+03,-6.2749502E+00, 1.8857504E+02, 0.0000000E+00,
&  -1.6266530E+02,-9.6065163E+02, 5.5062688E+02, 2.5291241E+02,
&  -5.6826422E+01, 0.0000000E+00, 1.8903125E+02,-1.4794790E+03,
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&  -5.9776929E+02, 1.0913724E+02, 2.5594952E+01, 1.1418786E+01,
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&  -8.6442516E+01,-1.4201271E+02, 4.3592843E+01, 1.1003417E+01,
&   0.0000000E+00,-7.3734375E+02, 7.8515314E+02,-2.8993701E+02,
&   4.8125195E+02,-5.9322345E+01,-1.5790023E+02,-2.5068266E+00,
&   1.2534133E+01, 0.0000000E+00, 2.2932624E+03,-1.3038005E+03,
&  -1.6596568E+02, 0.0000000E+00, 1.0107284E+02,-1.5658138E+02,
&  -6.0268199E+01, 0.0000000E+00,-3.0452470E+00, 0.0000000E+00,
&  -9.7314430E+02,-2.1069192E+02, 0.0000000E+00,-2.3374170E+02,
&   3.6957808E+02,-4.1320085E+01, 2.0043185E+01,-4.9095577E+01,
&   0.0000000E+00, 4.1553954E+00 /
 data g65/
&   0.0000000E+00, 3.0334000E+04, 2.1190000E+03, 2.4930000E+03,
&  -5.1909563E+03,-1.3804445E+03,-3.2425000E+03, 6.2400751E+03,
&  -2.5019472E+03,-6.7672742E+02,-4.1868750E+03,-4.4493247E+03,
&  -1.8743840E+03, 8.1574353E+02,-1.8635651E+02, 1.7246250E+03,
&  -3.6396361E+03,-1.9520441E+03, 1.4589259E+02, 3.4830920E+02,
&   4.3496767E+01,-6.4968750E+02,-1.1530906E+03,-1.1955386E+02,
&   2.2715233E+03,-2.1827448E+01,-2.3268138E+00, 7.4557955E+01,
&  -2.0109375E+03, 2.0217674E+03,-1.1584324E+02,-2.6621901E+02,
&   3.2107220E+02, 3.7046793E+01,-3.1483720E+01,-6.4725985E-01,
&  -6.5355469E+02,-3.3515625E+02, 2.2432947E+02, 5.7987403E+02,
&   0.0000000E+00,-1.1864469E+02, 6.8652274E+00,-2.7575093E+01,
&  -2.5068266E+00,-7.5968750E+02,-1.2740347E+03,-2.1730008E+02,
&   1.0787769E+03,-5.6375738E+02, 3.3690948E+01, 1.7397931E+01,
&  -3.7667625E+01,-2.5839777E+00, 1.2180988E+00, 3.6085156E+02,
&   7.2985822E+02,-4.2138384E+02, 8.2640170E+02, 2.3374170E+02,
&  -2.9566246E+02,-1.6528034E+02, 0.0000000E+00,-1.6365192E+01,
&  -5.3095695E+00, 0.0000000E+00 /
 data h65/
&   0.0000000E+00, 0.0000000E+00,-5.7760000E+03, 0.0000000E+00,
&   3.4918144E+03,-9.8726896E+01, 0.0000000E+00, 1.2369923E+03,
&  -4.6475800E+02, 1.3044395E+02, 0.0000000E+00,-8.1902991E+02,
&   1.0526290E+03,-2.7191451E+01, 1.9892818E+02, 0.0000000E+00,
&  -1.9316504E+02,-9.8370727E+02, 5.9298279E+02, 2.1519740E+02,
&  -5.6826422E+01, 0.0000000E+00, 2.0793437E+02,-1.4944232E+03,
&  -6.7747186E+02, 1.7461959E+02, 1.8614510E+01, 4.7018530E+00,
&   0.0000000E+00, 2.1636458E+03, 7.8194187E+02, 4.0956770E+01,
&  -7.4093585E+01,-1.6053610E+02, 5.5701966E+01, 7.7671182E+00,
&   0.0000000E+00,-4.6921875E+02, 6.7298841E+02,-3.7277616E+02,
&   4.2777951E+02,-5.9322345E+01,-1.6476546E+02, 7.5204799E+00,
&   1.0654013E+01, 0.0000000E+00, 2.8028763E+03,-1.6297506E+03,
&  -5.8087988E+02, 2.2550295E+02, 1.6845474E+02,-1.7397931E+02,
&  -7.5335249E+01, 1.0335911E+01,-6.0904939E-01, 0.0000000E+00,
&  -4.8657215E+02,-2.1069192E+02,-3.3056068E+02,-7.0122510E+02,
&   2.9566246E+02, 0.0000000E+00, 4.0086371E+01,-2.4547788E+01,
&   0.0000000E+00, 3.5617675E+00 /
 data g70/
&   0.0000000E+00, 3.0220000E+04, 2.0680000E+03, 2.6715000E+03,
&  -5.1961524E+03,-1.3951669E+03,-3.2175000E+03, 6.4023538E+03,
&  -2.4748364E+03,-6.6249717E+02,-4.1650000E+03,-4.4271887E+03,
&  -1.8039478E+03, 8.2620178E+02,-1.7304533E+02, 1.7010000E+03,
&  -3.6498027E+03,-2.0135258E+03, 1.9766093E+02, 3.5496479E+02,
&   3.9287403E+01,-6.2081250E+02,-1.2098000E+03,-2.2416348E+02,
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&   2.1121182E+03,-1.0913724E+01,-6.9804414E+00, 7.5229648E+01,
&  -1.9305000E+03, 2.0217674E+03,-2.8960810E+01,-2.8669739E+02,
&   2.7167648E+02, 1.2348931E+01,-3.1483720E+01, 1.2945197E+00,
&  -7.0382813E+02,-4.0218750E+02, 1.1216473E+02, 5.3845445E+02,
&   8.0208659E+01,-7.4152931E+01, 0.0000000E+00,-2.7575093E+01,
&  -1.8801200E+00,-7.5968750E+02,-1.2740347E+03,-2.1730008E+02,
&   9.9579408E+02,-5.6375738E+02, 3.3690948E+01, 0.0000000E+00,
&  -2.2600575E+01,-2.5839777E+00, 6.0904939E-01, 5.4127734E+02,
&   7.2985822E+02,-4.2138384E+02, 8.2640170E+02, 1.1687085E+02,
&  -4.4349369E+02,-1.6528034E+02,-2.0043185E+01, 0.0000000E+00,
&  -7.9643543E+00, 5.9362792E-01 /
 data h70/
&   0.0000000E+00, 0.0000000E+00,-5.7370000E+03, 0.0000000E+00,
&   3.5455080E+03,-2.1650635E+01, 0.0000000E+00, 1.1206416E+03,
&  -4.8605941E+02, 1.5495161E+02, 0.0000000E+00,-9.2417565E+02,
&   1.0408896E+03,-5.4382902E+01, 2.0632328E+02, 0.0000000E+00,
&  -2.6433111E+02,-1.0682446E+03, 6.5416356E+02, 2.0188622E+02,
&  -5.8229543E+01, 0.0000000E+00, 2.2683750E+02,-1.4944232E+03,
&  -7.1732315E+02, 2.0190390E+02, 1.3960883E+01,-6.7169329E-01,
&   0.0000000E+00, 2.4828722E+03, 7.8194187E+02, 8.1913541E+01,
&  -9.8791447E+01,-1.4201271E+02, 5.5701966E+01, 7.1198583E+00,
&   0.0000000E+00,-4.6921875E+02, 8.4123551E+02,-2.4851744E+02,
&   4.5451573E+02,-8.8983518E+01,-1.4416978E+02, 1.5040960E+01,
&   1.0027306E+01, 0.0000000E+00, 2.6754728E+03,-1.7384007E+03,
&  -4.9789704E+02, 2.2550295E+02, 1.6845474E+02,-1.7397931E+02,
&  -8.2868774E+01, 5.1679555E+00,-6.0904939E-01, 0.0000000E+00,
&  -2.4328607E+02,-2.1069192E+02,-4.9584102E+02,-4.6748340E+02,
&   2.9566246E+02, 0.0000000E+00, 2.0043185E+01,-2.4547788E+01,
&  -2.6547848E+00, 2.3745117E+00 /
 data g75/
&   0.0000000E+00, 3.0100000E+04, 2.0130000E+03, 2.8530000E+03,
&  -5.2134729E+03,-1.4133535E+03,-3.1900000E+03, 6.5646325E+03,
&  -2.4399795E+03,-6.5617261E+02,-4.1387500E+03,-4.3773829E+03,
&  -1.7139461E+03, 8.4711828E+02,-1.5973415E+02, 1.7167500E+03,
&  -3.6193029E+03,-2.0288963E+03, 2.7766655E+02, 3.5274626E+02,
&   3.4376477E+01,-6.4968750E+02,-1.2476062E+03,-4.1843850E+02,
&   1.9726387E+03,-5.4568621E+00,-1.3960883E+01, 7.4557955E+01,
&  -1.9036875E+03, 1.9862978E+03,-2.8960810E+01,-3.2765416E+02,
&   1.7288503E+02, 0.0000000E+00,-2.9061895E+01, 3.2362992E+00,
&  -7.0382813E+02,-4.0218750E+02, 5.6082367E+01, 4.9703488E+02,
&   2.1388976E+02,-5.9322345E+01, 0.0000000E+00,-2.5068266E+01,
&  -6.2670665E-01,-6.6472656E+02,-1.2740347E+03,-2.1730008E+02,
&   9.9579408E+02,-5.6375738E+02, 3.3690948E+01, 1.7397931E+01,
&  -3.0134100E+01,-2.5839777E+00, 1.2180988E+00, 5.4127734E+02,
&   7.2985822E+02,-4.2138384E+02, 8.2640170E+02, 2.3374170E+02,
&  -3.6957808E+02,-1.6528034E+02,-2.0043185E+01, 0.0000000E+00,
&  -7.9643543E+00, 5.9362792E-01 /
 data h75/
&   0.0000000E+00, 0.0000000E+00,-5.6750000E+03, 0.0000000E+00,
&   3.5801490E+03, 5.8889727E+01, 0.0000000E+00, 1.0196001E+03,
&  -5.0736082E+02, 1.7629698E+02, 0.0000000E+00,-1.0569913E+03,
&   1.0369765E+03,-8.1574353E+01, 2.1297887E+02, 0.0000000E+00,
&  -3.1516402E+02,-1.1374115E+03, 7.1534432E+02, 1.8413798E+02,
&  -6.1737347E+01, 0.0000000E+00, 2.4574062E+02,-1.4794790E+03,
```

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&  -7.4721161E+02, 2.2373135E+02, 9.3072552E+00,-7.3886262E+00,
&   0.0000000E+00, 2.7311595E+03, 7.5298106E+02, 1.0239193E+02,
&  -1.2348931E+02,-1.3583824E+02, 5.5701966E+01, 7.7671182E+00,
&   0.0000000E+00,-4.0218750E+02, 8.9731788E+02,-1.6567829E+02,
&   5.0798817E+02,-8.8983518E+01,-1.2357409E+02, 2.5068266E+01,
&   1.0654013E+01, 0.0000000E+00, 2.6754728E+03,-1.7384007E+03,
&  -5.8087988E+02, 2.2550295E+02, 1.6845474E+02,-1.7397931E+02,
&  -8.2868774E+01, 7.7519332E+00,-6.0904939E-01, 0.0000000E+00,
&  -2.4328607E+02,-2.1069192E+02,-4.9584102E+02,-4.6748340E+02,
&   2.9566246E+02, 4.1320085E+01, 2.0043185E+01,-2.4547788E+01,
&  -2.6547848E+00, 2.9681396E+00 /
 data g80/
&   0.0000000E+00, 2.9992000E+04, 1.9560000E+03, 2.9955000E+03,
&  -5.2429178E+03,-1.4402002E+03,-3.2025000E+03, 6.6748595E+03,
&  -2.4225511E+03,-6.5854432E+02,-4.1037500E+03,-4.3275770E+03,
&  -1.5574213E+03, 8.7640138E+02,-1.4716248E+02, 1.7167500E+03,
&  -3.6294695E+03,-2.0058406E+03, 3.4825974E+02, 3.5940185E+02,
&   3.3674916E+01,-6.9300000E+02,-1.2476062E+03,-6.2765776E+02,
&   1.9128617E+03,-2.1827448E+01,-3.2575393E+01, 7.2542875E+01,
&  -1.9305000E+03, 2.0927066E+03,-5.7921620E+01,-4.3004609E+02,
&   1.4818717E+02,-6.1744654E+00,-2.6640071E+01, 1.2945197E+00,
&  -9.0492188E+02,-4.0218750E+02, 0.0000000E+00, 4.5561531E+02,
&   1.8715354E+02,-5.9322345E+01,-2.0595682E+01,-1.5040960E+01,
&   6.2670665E-01,-4.7480469E+02,-1.2740347E+03,-1.0865004E+02,
&   9.9579408E+02,-5.0738165E+02, 1.0107284E+02, 1.7397931E+01,
&  -5.2734674E+01,-5.1679555E+00, 3.0452470E+00, 7.2170313E+02,
&   9.7314430E+02,-4.2138384E+02, 8.2640170E+02, 2.3374170E+02,
&  -3.6957808E+02,-1.2396026E+02,-2.0043185E+01,-1.6365192E+01,
&  -7.9643543E+00, 0.0000000E+00 /
 data h80/
&   0.0000000E+00, 0.0000000E+00,-5.6040000E+03, 0.0000000E+00,
&   3.6875362E+03, 1.7320508E+02, 0.0000000E+00, 1.0287857E+03,
&  -5.2478924E+02, 1.9922349E+02, 0.0000000E+00,-1.1732050E+03,
&   1.0056716E+03,-1.1085745E+02, 2.1963446E+02, 0.0000000E+00,
&  -4.6766274E+02,-1.1527820E+03, 7.1063811E+02, 1.7304533E+02,
&  -6.4543590E+01, 0.0000000E+00, 2.8354687E+02,-1.3898136E+03,
&  -7.0736033E+02, 2.3464507E+02, 4.6536276E+00,-1.1418786E+01,
&   0.0000000E+00, 2.9085075E+03, 7.8194187E+02, 1.0239193E+02,
&  -1.9758289E+02,-1.1114038E+02, 5.5701966E+01, 6.4725985E+00,
&   0.0000000E+00,-4.6921875E+02, 1.0094826E+03,-1.6567829E+02,
&   5.8819683E+02,-1.3347528E+02,-1.0984364E+02, 3.2588746E+01,
&   9.4005998E+00, 0.0000000E+00, 2.6754728E+03,-1.7384007E+03,
&  -7.4684556E+02, 2.8187869E+02, 2.0214569E+02,-1.5658138E+02,
&  -7.5335249E+01, 1.5503866E+01,-1.2180988E+00, 0.0000000E+00,
&  -2.4328607E+02, 0.0000000E+00,-4.9584102E+02,-7.0122510E+02,
&   2.9566246E+02, 0.0000000E+00, 2.0043185E+01,-3.2730385E+01,
&   0.0000000E+00, 3.5617675E+00 /
 data g85/
&   0.0000000E+00, 2.9877000E+04, 1.9030000E+03, 3.1095000E+03,
&  -5.2740947E+03,-1.4644490E+03,-3.2500000E+03, 6.7605917E+03,
&  -2.4089956E+03,-6.6012546E+02,-4.0993750E+03,-4.3165090E+03,
&  -1.4204622E+03, 8.9104293E+02,-1.2497719E+02, 1.6931250E+03,
&  -3.6193029E+03,-1.9443589E+03, 4.4238399E+02, 3.5718332E+02,
&   3.3674916E+01,-7.5075000E+02,-1.2287031E+03,-7.4721161E+02,
```

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&   1.8530848E+03,-2.1827448E+01,-3.9555835E+01, 6.8512716E+01,
&  -2.0109375E+03, 2.1636458E+03,-5.7921620E+01,-4.9148124E+02,
&   7.4093585E+01,-2.4697862E+01,-2.1796421E+01, 0.0000000E+00,
&  -1.0557422E+03,-4.0218750E+02, 0.0000000E+00, 4.5561531E+02,
&   2.4062598E+02,-2.9661173E+01,-2.7460910E+01,-1.0027306E+01,
&   3.7602399E+00,-4.7480469E+02,-1.2740347E+03,-1.0865004E+02,
&   9.9579408E+02,-5.0738165E+02, 1.0107284E+02, 1.7397931E+01,
&  -5.2734674E+01,-5.1679555E+00, 3.0452470E+00, 7.2170313E+02,
&   9.7314430E+02,-4.2138384E+02, 8.2640170E+02, 2.3374170E+02,
&  -3.6957808E+02,-1.2396026E+02,-2.0043185E+01,-1.6365192E+01,
&  -7.9643543E+00, 0.0000000E+00 /
 data h85/
&   0.0000000E+00, 0.0000000E+00,-5.4970000E+03, 0.0000000E+00,
&   3.7949233E+03, 2.6760185E+02, 0.0000000E+00, 9.5530100E+02,
&  -5.4996364E+02, 2.3400855E+02, 0.0000000E+00,-1.2894187E+03,
&   9.7827974E+02,-1.4223220E+02, 2.2037397E+02, 0.0000000E+00,
&  -4.7782932E+02,-1.1374115E+03, 7.2946296E+02, 1.6638974E+02,
&  -6.6648272E+01, 0.0000000E+00, 3.0245000E+02,-1.3449809E+03,
&  -6.8743468E+02, 2.7284310E+02, 9.3072552E+00,-1.3433866E+01,
&   0.0000000E+00, 2.9085075E+03, 7.5298106E+02, 2.0478385E+01,
&  -2.8402541E+02,-1.0496591E+02, 5.0858317E+01, 3.8835591E+00,
&   0.0000000E+00,-4.6921875E+02, 1.1777297E+03,-2.0709787E+02,
&   6.6840549E+02,-1.6313645E+02,-8.2382729E+01, 4.0109226E+01,
&   6.2670665E+00, 0.0000000E+00, 2.6754728E+03,-1.7384007E+03,
&  -7.4684556E+02, 2.8187869E+02, 2.0214569E+02,-1.5658138E+02,
&  -7.5335249E+01, 1.5503866E+01,-1.2180988E+00, 0.0000000E+00,
&  -2.4328607E+02, 0.0000000E+00,-4.9584102E+02,-7.0122510E+02,
&   2.9566246E+02, 0.0000000E+00, 2.0043185E+01,-3.2730385E+01,
&   0.0000000E+00, 3.5617675E+00 /
 data gt/
&   0.0000000E+00,-2.3200001E+01,-1.0000000E+01, 2.0550000E+01,
&  -5.8889729E+00,-6.0621778E+00,-1.2750000E+01, 1.4084566E+01,
&   1.1618951E+00,-7.9056943E-02,-4.3750001E-01, 3.3203917E+00,
&   3.0522329E+01, 2.9283100E+00, 5.0286680E+00,-1.0237500E+01,
&  -1.0166581E+00, 1.1527820E+01, 1.5059881E+01,-2.2185300E-01,
&   7.0156077E-02,-2.0212500E+01, 5.6709376E+00,-2.5405196E+01,
&  -5.9776931E+00, 0.0000000E+00,-2.0941324E+00,-8.0603198E-01,
&  -5.3625001E+00, 2.1281763E+01, 1.4480405E+01,-1.6382708E+01,
&  -1.2348931E+01,-2.4697862E+00, 1.2109123E+00, 6.4725986E-02,
&  -3.5191406E+01, 0.0000000E+00,-1.6824711E+01,-1.6567830E+01,
&   8.0208662E+00, 4.4491761E+00,-6.8652275E-01, 1.2534133E+00,
&   5.0136533E-01, 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, 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, 0.0000000E+00 /
 data ht/
&   0.0000000E+00, 0.0000000E+00, 2.4500000E+01, 0.0000000E+00,
&   1.9918584E+01, 1.7493714E+01, 0.0000000E+00,-1.6227870E+01,
&  -4.4539308E+00, 8.5381498E+00, 0.0000000E+00,-2.1029146E+01,
&  -8.6088619E+00,-5.2291252E+00,-6.6555896E-01, 0.0000000E+00,
&  -1.0166581E+00, 1.5370426E+00, 4.7062127E-01,-1.3311180E+00,
&   0.0000000E+00, 0.0000000E+00, 7.5612500E+00, 1.6438656E+01,
```

```
     &   7.9702573E+00, 1.2550783E+01, 1.1634069E+00, 6.7169330E-02,
     &   0.0000000E+00,-7.0939208E+00,-2.8960810E+01,-2.2526224E+01,
     &  -2.3462968E+01,-1.8523397E+00,-4.8436493E-01,-5.8253385E-01,
     &   0.0000000E+00,-6.7031251E+00, 5.6082367E+01,-4.1419574E+00,
     &   2.1388976E+01,-2.9661173E+00, 5.4921820E+00, 2.5068267E-01,
     &  -8.1471862E-01, 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, 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, 0.0000000E+00 /
c
c                        COMPUTATIONAL COEFFICIENTS
c
       data const/
     &   0.0000000E+00, 0.0000000E+00, 1.0000000E+00, 3.3333333E-01,
     &   0.0000000E+00,-1.0000000E+00, 2.6666667E-01, 2.0000000E-01,
     &   0.0000000E+00,-3.3333333E-01, 2.5714286E-01, 2.2857143E-01,
     &   1.4285714E-01, 0.0000000E+00,-2.0000000E-01, 2.5396825E-01,
     &   2.3809524E-01, 1.9047619E-01, 1.1111111E-01, 0.0000000E+00,
     &  -1.4285714E-01, 2.5252525E-01, 2.4242424E-01, 2.1212121E-01,
     &   1.6161616E-01, 9.0909091E-02, 0.0000000E+00,-1.1111111E-01,
     &   2.5174825E-01, 2.4475524E-01, 2.2377622E-01, 1.8881119E-01,
     &   1.3986014E-01, 7.6923077E-02, 0.0000000E+00,-9.0909091E-02,
     &   2.5128205E-01, 2.4615385E-01, 2.3076923E-01, 2.0512821E-01,
     &   1.6923077E-01, 1.2307692E-01, 6.6666667E-02, 0.0000000E+00,
     &  -7.6923077E-02, 2.5098039E-01, 2.4705882E-01, 2.3529412E-01,
     &   2.1568627E-01, 1.8823529E-01, 1.5294118E-01, 1.0980392E-01,
     &   5.8823529E-02, 0.0000000E+00,-6.6666667E-02, 2.5077399E-01,
     &   2.4767802E-01, 2.3839009E-01, 2.2291022E-01, 2.0123839E-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,
     &   1.65493766e15,
     &   4.04085822e07,
     &   2.72342737e05,
     &   2.20841384e13,
     &  -99999999,
     &   1945.  /
        data cp(1),sp(1),dp(1),p(1)/1.,0.,0.,1./
c
c  TIME CORRECTION
c
        if (idate.eq.lastdt) go to 100
        t=float(idate/1000)+float(mod(idate,1000))/365. - tzero
        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
c
```

```
c   Here use 1985 coefficients & time terms.
c
      t=t-40.
      do 30 n=1,132
   30 gh(n)=gh0(n,9)+t*ght(n)
      go to 100
c
c   Here interpolate between the 1945 thru 1985 coefficients.
c
   40 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))
c
c  POSITION COMPUTATIONS
c
100       sinla=sin(lat)
          sinla2=sinla**2
          cosla2=1.-sinla2
          den2=a2-a2b2*sinla2
          den=sqrt(den2)
          altk=alt*1e-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.
          n1m=1
          n2m=1
          fn=2.
          nm=2
c
c  POLYNOMIAL EVALUATION LOOP
c
          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)
```

```
        go to 250
240     p(nm)=ct*p(n1m)-const(nm)*p(n2m)
        dp(nm)=ct*dp(n1m)-st*p(n1m)-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
        n1m=n1m+1
        n2m=n2m+1
290     fm=fm+1.
        fn=fn+1.
        n1m=n1m-1
300     n2m=n2m-2
        bp=bp/st
c
c   TRANSFORM, IF REQUIRED
c
        notall=icode.lt.5
        if (icode.eq.1) go to 411
        sind=sin1a*st-sqrt(cos1a2)*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
end
```

```
      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
```