**GEOPACK-2008: A package of subroutines for magnetospheric**

**and solar-terrestrial studies**

**Abstract:** The new version (02/08/2008) of the GEOPACK library includes 20 FORTRAN subroutines, to be used in various studies that involve calculations of the geomagnetic field in the Earth’s magnetosphere using empirical models and/or spacecraft observations. The library includes subroutines for the current (IGRF) and past (DGRF) internal geomagnetic field models, a group of subroutines for transformations between various coordinate systems, a field line tracer, and two magnetopause model codes.

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**PREFATORY NOTES TO THIS RELEASE (FEBRUARY 08, 2008)**

To avoid inadvertent use of obsolete subroutines from earlier versions, a suffix 08 was added to the end of each subroutine’s name. With respect to their content, three essential changes/additions were made in this version, as follows below.

The first modification is the possibility to calculate components of a vector in the “Geocentric Solar-Wind” (GSW) coordinate system [*Hones et al.*, 1986], also known as GSWM [*Tsyganenko et al.*, 1998; *Tsyganenko and Fairfield*, 2004]. That system is analogous to the standard geocentric solar-magnetospheric (GSM), except that X-axis in the GSW coordinates is anti-parallel to the actual observed direction of the solar wind flow, which not only aberrates by ~4o from the strictly radial line due to Earth’s orbital motion around Sun, but also often significantly fluctuates around its average direction. Orientation of axes in the GSW system can be uniquely defined by specifying three Cartesian components of the solar wind velocity vector (VX, VY, VZ), included as additional input parameters in the new version of the subroutine RECALC\_08. In the absence of reliable data on the solar wind direction, one can either set Vx = −400.0 (or any other arbitrary negative value), and VY = VZ = 0.0 (in which case the GSW system becomes identical to the standard GSM) or set Vx= −430.0, VY = 29.8, VZ = 0.0, thus taking into account the 4° aberration effect.

The second modification allows users to have more control over the procedure of field line mapping using the subroutine TRACE\_08. To that end, three new input parameters were added in that subroutine, making it possible to set (i) an upper limit, DSMAX, on the automatically adjusted step size, (ii) a permissible step error, ERR, and (iii) maximal length, LMAX, of arrays XX,YY,ZZ, where field line point coordinates are stored. Minor changes in the tracing algorithm were also introduced, in order to (i) make it more compact and easier to

understand, and (ii) prevent the algorithm from making uncontrollable large number of multiple loops in some cases with plasmoid-like (spiraling) field structures.

Finally, one more subroutine named GEODGEO\_08 was added to the package, making it possible to convert geodetic coordinates of a point in space (altitude above the Earth's WGS84 ellipsoid and geodetic latitude) to geocentric radial distance and colatitude, and vice versa.

The users should be aware of the following changes and caveats:

1. Length of the common-block /GEOPACK1/ has been reduced in this version from 35 to 34.

2. Subroutine RECALC\_08: (a) three GSE components of the solar wind velocity have been added to the list of input formal arguments, (b) common block /GEOPACK1/ has been reduced to 34 elements (see #1 above), and (c) extensive changes were made in the body of the subroutine to include the calculation of elements of GSW-GSE transformation matrix. As already noted above, to convert vectors to and from the standard GSM system, it suffices to set VGSEX= −400.0, VGSEY = VGSEZ = 0.0.

3. Subroutine STEP\_08: (a) one more formal argument, DSMAX, was added, which sets the upper limit on the step size.

4. Subroutine TRACE\_08: (a) three more formal arguments were added, making it possible to explicitly specify a value of permissible step error ERR and set any desired upper limits on the step size along the field line, DSMAX, and on the maximal length LMAX of output arrays XX, YY, ZZ, where coordinates of field line points are stored; (b) as in many other subroutines, all vectors are now in the Geocentric Solar-Wind GSW system (reduces to standard GSM by setting VGSEX= −400.0, VGSEY = VGSEZ = 0.0 in RECALC\_08, as detailed in item 2 above).

5. Subroutines SHUETAL\_MGNP\_08 and T96\_MGNP\_08: no changes, but the position vectors (XGSM, YGSM, ZGSM) and (XMGNP,YMGNP,ZMGNP) can be interpreted as referring to the GSW system (assuming that the magnetopause orients itself along the solar wind flow direction).

6. Information on the solar wind direction (VGSEX, VGSEY, and VGSEZ) can be obtained from available online resources of interplanetary data, e.g., <http://cdaweb.gsfc.nasa.gov/cdaweb/sp_phys/> ,

or <http://omniweb.gsfc.nasa.gov/form/omni_min.html>. An important thing to keep in mind is that, in most cases, the observed values of VGSEY in those data are already reduced by 29.78 km/s, in order to take into account the aberration effect due to Earth’s orbital motion around Sun. In order to restore the actual orientation of the observed solar wind vector in the GSE coordinate system, the offset 29.78 km/s must be added back to VGSEY, before using it as an input argument of the subroutine RECALC\_08. Whether or not to do that, should be determined by consulting with the data originator, and/or by calculating average values of VGSEY in the data set over a sufficiently long (e.g., one-year) time period. If those averages are close to zero, then the 29.78 km/s correction must be added back to individual values of VGSEY; otherwise (if close to ~30 km/s) they should be left intact.

**PREFATORY NOTES TO THE RELEASE OF MAY 4, 2005**

In this version, the IGRF coefficients were updated according to the recently published table of IGRF-10 coefficients, so that the main field model now extends through 2010 (a linear extrapolation is used for 2005 - 2010, based on the table of secular velocities). For more details, see

<http://www.ngdc.noaa.gov/IAGA/vmod/igrf.html> (revision of 03/22/2005).

**FOREWORD TO THE RELEASE OF APRIL 22, 2003**

This collection of subroutines is a result of several upgrades of the original package, developed almost a quarter century ago [*Tsyganenko*, 1979]. It represents an in-depth revision of the previous release (January 5, 2001), with significant changes in the format of calling statements. Users should familiarize themselves with the new formats and rules, and accordingly adjust their source codes, as specified below.

The following changes were made to the previous release of GEOPACK:

(1) Subroutine IGRF, calculating the Earth's main field:

(a) Two versions of this subroutine are provided here. In the first one (IGRF\_GSM), both input (position) and output (field components) are in the Geocentric Solar-Magnetospheric Cartesian coordinates, while the second one (IGRF\_GEO) uses spherical geographical (geocentric) coordinates, as in the older releases.

(b) updating of all expansion coefficients is now made separately in the s/r RECALC, which also takes into account the secular change of the coefficients within a given year (at the Earth's surface, the rate of the change can reach 7 nT/month).

(c) the optimal length of the spherical harmonic expansions is now automatically set inside the code as a function of the radial distance, so that the deviation from the full-length approximation does not exceed 0.01 nT. (In all previous versions, the upper limit on the order of spherical harmonics had to be explicitly specified by users),

(2) Subroutine DIP, calculating the Earth's field in the dipole approximation:

(a) no longer accepts the tilt angle via the list of formal parameters. Instead, the sine SPS and cosine CPS of that angle are now implicitly forwarded into DIP via the first common block /GEOPACK1/. Accordingly, there are two options: (i) to implicitly calculate SPS and CPS by invoking RECALC before calling DIP, or (ii) to specify them explicitly. In the last case, the common block must be present in the calling module **and** SPS and CPS should be specified **after** the invocation of RECALC (otherwise they will be overridden by those returned by RECALC).

(b) the Earth's dipole moment is now calculated by RECALC, based on the table of the IGRF coef-ficients and their secular variation rates, for a given year and day of the year, and the obtained value of the moment is forwarded into DIP via the second common block /GEOPACK2/. (In all previous versions, only a single fixed value was provided for the geodipole moment, corresponding to the most

recent epoch).

(3) Subroutine RECALC: now consolidates in one module all calculations needed to initialize and up-date the values of coefficients and quantities that vary in time, either due to secular changes of the main geomagnetic field or as a result of Earth's diurnal rotation and orbital motion around Sun. That allowed us to simplify the codes and make them more compiler-independent.

(4) Subroutine GEOMAG: is now identical in its structure to other coordinate transformation subrou-tines. It no longer invokes RECALC from within GEOMAG, but uses pre-calculated values of the ro-tation matrix elements, obtained by a separate external invocation of RECALC. This eliminates possi-ble interference of the two subroutines in the old version of the package.

(5) Subroutine TRACE (and the subsidiary modules STEP and RHAND):

(a) no longer needs to specify the highest order of spherical harmonics in the main geomagnetic field expansion. Instead, it is now

calculated automatically inside the IGRF\_GSM (or IGRF\_GEO) subroutine.

(b) the internal field model can now be explicitly chosen by specifying the parameter INNAME (either as IGRF\_GSM or DIP).

(6) A new subroutine BCARSP was added. It converts Cartesian field components into spherical ones (an operation inverse to that performed by the subroutine BSPCAR).

(7) Two new subroutines were added, SHUETAL\_MGNP and T96\_MGNP, to calculate the position of the magnetopause, according to the model of *Shue et al.* [1998] and the one used in the T96 magnetospheric magnetic field model [*Tsyganenko*, 1995, 1996]. The model of *Shue et al.* provides better accuracy, since it takes into account both the solar wind ram pressure P and the IMF Bz component, while the T96 model magnetopause is driven only by P (it provides here a starting approximation boundary for the subroutine SHUETAL\_MGNP).

**GEOPACK-2008: A SET OF FORTRAN SUBROUTINES FOR COMPUTATIONS OF THE**

**GEOMAGNETIC FIELD IN THE EARTH'S MAGNETOSPHERE**

Version of February 08, 2008

(Previous releases: October 1979, March 1987, April 16, 1996, January 5, 2001, April 22, 2003, May 4, 2005)

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I. **INTRODUCTION**

Recent studies in the solar-terrestrial physics led to recognizing the role of the geomagnetic field as one of the most important characteristics of human environment. The Earth's magnetic field links the interplanetary medium with the upper atmosphere and ionosphere, guides energetic charged particles ejected during solar flares, channels the low-frequency electromagnetic waves and heat flux, confines the radiation belt and auroral plasma, and serves as a giant accumulator of the solar wind energy that eventually dissipates during the magnetic storms. Understanding these phenomena is crucial for forecasting conditions in the near-Earth geospace (“space weather”) that strongly affect modern space technologies.

In many applications one often needs numerical tools for evaluating the components of the geomagnetic field in a wide range of distances and tracing its force lines far away from the Earth's surface, calculate geomagnetically conjugate points, and map a spacecraft's position with respect to characteristic magnetospheric/ionospheric boundaries. This requires using quantitative models of the Earth's magnetic field, including its internal part due to the dynamo currents inside Earth, and the external part, produced by the magnetospheric and ionospheric electric current systems.

The present set of subroutines was conceived as a subsidiary software package for calculating the geomagnetic field components at any point of space from the Earth's surface up to the Moon's orbit. Upon specifying year, day of year, and universal time as input parameters, it calculates elements of the matrices of transformations between several most frequently used coordinate systems. It also updates coefficients of spherical harmonic expansions, approximating the Earth's internal magnetic field (the IGRF/DGRF models). That field can be computed either in a dipole approximation or by using a full-scale IGRF/DGRF model, in which the length of expansions is automatically controlled to maintain the needed precision. It also contains a field line mapping subroutine, tracing the geomagnetic field lines from any point of space, based on appropriate internal and external field models for a specified date/time and/or the geodipole tilt angle. Like in the previous versions, we did not include subroutines for calculating the external magnetic field, but chose to restrict this package to only a general-use set of codes, which is unlikely to significantly change in the future. In contrast, the external field models rapidly improve and supersede older versions; for that reason, it was considered reasonable to provide them separately.

A convenient way of using the GEOPACK-2008 subroutines is to separately compile them and consolidate the corresponding object modules into a dedicated library.

The GEOPACK subroutines were originally written in 1978; the present version emerged as a result of their many upgrades, various tests, and numerous helpful comments received from users since the first release of the package. Although it now appears as a quite robust tool, there should certainly exist room for further improvement. The author would greatly appreciate any comments on the performance of the package, reports on related problems, and any suggestions on how to make the GEOPACK subroutines simpler, faster, more versatile, and easier to understand.

Below a brief manual guide for using the subroutines, including a bibliography and two typical samples of a main program for tracing model field lines, aimed at helping users to compile and debug their own codes, avoiding common mistakes. The FORTRAN listings of the package subroutines are placed in a separate file GEOPACK-2008.FOR.

II. **DESCRIPTIONS OF INDIVIDUAL SUBROUTINES**

**1.** SUBROUTINE: **IGRF\_GSW\_08**

FUNCTION: Calculates three components of the main (internal) geomagnetic field in the

Geocentric Solar-Wind (GSW, also known as GSWM) coordinate system.

FORTRAN STATEMENT:

CALL IGRF\_GSW\_08 (XGSW,YGSW,ZGSW,BXGSW,BYGSW,BZGSW)

INPUT PARAMETERS: XGSW,YGSW,ZGSW - position of the observation point in Cartesian GSW

coordinates (in Earth's radii, RE=6371.2 km), at which the field vector is to

be evaluated. XGSW axis is directed antiparallel to the observed solar wind

flow vector, ZGSW axis points northward and lies in the plane defined by

XGSW and the Earth’s magnetic dipole axis, YGSW axis completes the right-

handed system. The GSW system reduces to the standard GSM in the case of

strictly radial solar wind flow.

OUTPUT PARAMETERS: BXGSW, BYGSW, BZGSW − Cartesian GSW components of the main

geomagnetic field in nanotesla.

COMMON BLOCKS: /GEOPACK2/.

OTHER SUBROUTINES INVOKED: GEOGSW\_08.

COMMENTS: The internal sources of the geomagnetic field are rigidly tied to rotating Earth, and hence

their position with respect to Sun varies with universal time and day of year. In addition,

the geomagnetic field slowly changes with time in the Earth's frame of reference (secular

variation). Because of that, when calculating the geomagnetic field in the GSW system,

one needs first to define a transformation matrix between the geographic coordinates and

GSW and initialize/update the IGRF model coefficients. This is done by first calling the

subroutine RECALC\_08 with properly specified universal time and date, and three GSE

components of the solar wind velocity before the first invocation of IGRF\_GSW\_08, and

then each time the time/date are changed. The subroutine RECALC\_08 calculates the

position of Sun and takes into account the secular variation of the internal field. It includes

the IGRF harmonic coefficients for 11 epochs: 1965.0, 1970.0, 1975.0, 1980.0, 1985.0,

1990.0, 1995.0, 2000.0, 2005.0, 2010.0, and 2015, so that their values for any date are

calculated by linearly interpolating between the nearest epochs. For the dates in the interval

2015<IYEAR<2020, the subroutine uses extrapolated coefficients, based on the secular

velocities through the order 8. If IYEAR<1965 or IYEAR>2020, the coefficients are

assumed equal to those for 1965 or 2015, respectively. The subroutine RECALC\_08 is

regularly updated, as soon as coefficients for the next epoch become available. When

calculating the IGRF field at large distances, there is no need to retain all terms in the

expansion, since the relative contribution from higher-order multipoles rapidly decreases

with altitude. To save calculation, the subroutine IGRF\_GSW\_08 automatically truncates

the summation, so that at any distance the error does not exceed 0.01 nT. For more details

on the main geomagnetic field models, see, e.g., *Langel* [1987] and *Tsyganenko* [1990].

**2.** SUBROUTINE: **IGRF\_GEO\_08**

FUNCTION: Calculates three components of the main (internal) geomagnetic field in

spherical geocentric geographic (GEO) coordinate system.

FORTRAN STATEMENT: CALL IGRF\_GEO\_08 (R, THETA, PHI, BR, BTHETA, BPHI)

INPUT PARAMETERS: R, THETA, PHI - position in spherical geocentric GEO coordinates:

R is the radial distance (in Earth's radii, RE =6371.2 km), THETA and PHI are the

colatitude and longitude (in radians), respectively.

OUTPUT PARAMETERS: BR, BTHETA, BPHI - spherical components of the main geomagnetic

field (in nanotesla; positive BR outward, BTHETA southward, BPHI eastward).

COMMON BLOCKS: /GEOPACK2/.

OTHER SUBROUTINES INVOKED: None.

COMMENTS: In this case the Earth's internal field is calculated in the geographic (geocentric)

coordinate system, rigidly fixed with respect to Earth. In this system, there are no

diurnal/seasonal variations of the internal field, and the position of Sun is irrele-

vant. The only effect to be taken into account here is a slow (secular) variation of

the internal field. As in the case of IGRF\_GSW\_08, this should be done by calling the

subroutine RECALC\_08, but only year and day of the year are important here, while

the universal time of the day and the solar wind velocity do not matter and can be

set arbitrarily.

**3.** SUBROUTINE: **DIP\_08**

FUNCTION: Calculates Cartesian Geocentric Solar-Wind (GSW) components of the Earth's magnetic

field, corresponding to the first (dipolar) term in its spherical harmonic expansion for a

specified epoch.

FORTRAN STATEMENT: CALL DIP\_08 (XGSW,YGSW,ZGSW,BXGSW,BYGSW,BZGSM)

INPUT PARAMETERS: XGSW,YGSW, ZGSW - position in the Cartesian GSW coordinates (in

Earth's radii, RE =6371.2 km).

OUTPUT PARAMETERS: BXGSW, BYGSW, BZGSW - geodipole field components, in nanotesla.

COMMON BLOCKS: /GEOPACK1/, /GEOPACK2/.

OTHER SUBROUTINES INVOKED: None.

COMMENTS: (1) The Earth's dipole is assumed to be centered at the origin.

(2) The geodipole axis is rigidly tied to the rotating Earth, and hence its position with

respect to Sun varies with universal time and day of year. In addition, the solar wind

direction fluctuates around the (aberrated) Sun-Earth line, and both the magnitude and

orientation of the geodipole moment slowly change with time (secular variation). Because

of that, before calculating the dipole field in the GSW system one should first determine the

transformation between the geographic and GSW coordinates and initialize/update the geo-

dipole moment vector by specifying the universal time and date. This should be done before

the first invocation of DIP\_08 (and then each time the time/date/solar wind direction are

changed) by calling the subroutine RECALC\_08, which calculates the current orientation of

the solar wind flow with respect to the geodipole, taking into account the secular variation

of the internal field. See also comments for IGRF\_GSW\_08 and RECALC\_08.

**4.** SUBROUTINE: **SUN\_08**

FUNCTION: This is a subsidiary subroutine, which is usually called from the subroutine

RECALC\_08. It calculates the orientation of the Earth-Sun line in the geocentric

inertial coordinate system (GEI), and the Greenwich mean sidereal time.

FORTRAN STATEMENT:

CALL SUN\_08 (IYEAR,IDAY,IHOUR,MIN,ISEC,GST,SLONG,SRASN,SDEC)

INPUT PARAMETERS: IYEAR,IDAY,IHOUR,MIN,ISEC - year (four digits), day of year, hour,

minute, and second, respectively;

OUTPUT PARAMETERS:

GST - Greenwich mean sidereal time,

SLONG - ecliptic longitude of Sun

SRASN - right ascension of Sun

SDEC - declination of Sun

Note: all the above output parameters are **in radians**.

COMMON BLOCKS: None.

OTHER SUBROUTINES INVOKED: None.

COMMENTS: (1) 1901<IYR<2099

(2) IDAY=1 is January 1

(3) This subroutine, authored by G. D. Mead, was compiled with minor

changes from the paper by *Russell* [1971].

**5.** SUBROUTINE: **SPHCAR\_08**

FUNCTION: Computes components of a position vector in spherical coordinates from its

Cartesian components or vice versa.

FORTRAN STATEMENT: CALL SPHCAR\_08 (R, THETA, PHI, X, Y, Z, J)

INPUT PARAMETERS: (a) J - integer switch parameter

(b) if J>0, then spherical coordinates R,THETA,PHI (colatitude THETA

and longitude PHI are **in radians**)

if J<0, then Cartesian coordinates X,Y,Z

OUTPUT PARAMETERS: if J>0 then Cartesian coordinates X,Y,Z

if J<0 then spherical coordinates R,THETA,PHI.

COMMON BLOCKS: None.

OTHER SUBROUTINES INVOKED: None.

COMMENTS: If X=0 and Y=0, then PHI is set equal to 0 (J<0).

**6.** SUBROUTINE: **BSPCAR\_08**

FUNCTION: Calculates Cartesian components of a field vector from its known local spherical

components (e.g., returned by IGRF\_GEO\_08) and spherical angles THETA

and PHI of the observation point.

FORTRAN STATEMENT: CALL BSPCAR\_08 (THETA,PHI,BR,BTHETA,BPHI,BX,BY,BZ)

INPUT PARAMETERS: THETA, PHI - colatitude and longitude of the observation point (**radians**)

BR, BTHETA, BPHI - spherical components of the field vector in a local

orthogonal coordinate system with its origin at the observation point.

OUTPUT PARAMETERS: BX,BY,BZ - Cartesian components of the vector.

COMMON BLOCKS: None.

OTHER SUBROUTINES INVOKED: None.

**7.** SUBROUTINE: **BCARSP\_08**

FUNCTION: Calculates spherical components of a field vector in a local orthogonal coordinate

system, based on the known position of the observation point and the field vector

components in the corresponding Cartesian coordinate system.

FORTRAN STATEMENT: CALL BCARSP\_08 (X,Y,Z,BX,BY,BZ,BR,BTHETA,BPHI)

INPUT PARAMETERS: X, Y, Z - position of the observation point in the Cartesian coordinate system,

BX, BY, BZ - Cartesian field components at that location

OUTPUT PARAMETERS: BR,BTHETA,BPHI - spherical components of the vector in the **local**

orthogonal coordinate system with its origin at the observation point.

COMMON BLOCKS: None.

OTHER SUBROUTINES INVOKED: None.

**8.** SUBROUTINE: **RECALC\_08**

FUNCTIONS: (1) Calculates the angles defining the geodipole axis orientation for a given year, day of

year, and universal time of day, as well as elements of rotation matrices, needed for

transformations between the following Cartesian geocentric coordinate systems:

geographic geocentric (GEO), geomagnetic (MAG), solar-magnetic (SM), geocentric

solar-wind (GSW), geocentric solar-ecliptic GSE), and geocentric equatorial inertial (GEI).

(2) Initializes or updates the values of the spherical harmonic coefficients for the model

(IGRF/DGRF) main geomagnetic field expansions, and coefficients of the recursion

relations, entering in those expansions.

FORTRAN STATEMENT:

CALL RECALC\_08 (IYEAR,IDAY,IHOUR,MIN,ISEC,VGSEX,VGSEY,VGSEZ)

INPUT PARAMETERS: IYEAR, IDAY, IHOUR, MIN, ISEC, VGSEX, VGSEY, VGSEZ - year

(four digits), day, UT hour, minute, second, and 3 GSE components of the solar wind velocity.

OUTPUT PARAMETERS: None.

OTHER SUBROUTINES INVOKED: SUN\_08.

COMMON BLOCKS: Output parameters are placed into two named common blocks:

/GEOPACK1/ (containing 34 four-byte variables) and

/GEOPACK2/ (containing 198 four-byte variables).

COMMENTS: (1) This subroutine should be called at least once before using the following

subroutines from this package: IGRF\_GEO\_08, IGRF\_GSW\_08, DIP\_08,

GEOMAG\_08, GEOGSW\_08, MAGSM\_08, SMGSW\_08, GSWGSE\_08,

GEIGEO\_08, TRACE\_08.

(2) If only questionable information (or no information at all) is available on the solar

wind flow velocity, or, if the standard GSM and/or SM coordinates are to be used,

then set VGSEX= − 400.0, VGSEY = 0.0, and VGSEZ= 0.0. In this case the Solar-

Wind (GSW) coordinate system becomes identical to the standard GSM.

**9.** SUBROUTINE: **GEOMAG\_08**

FUNCTION: Transformation of components of a vector from the geographic (geocentric)

Cartesian coordinate system (GEO) to the dipolar geomagnetic (MAG) or vice

versa.

FORTRAN STATEMENT: CALL GEOMAG\_08 (XGEO,YGEO,ZGEO,XMAG,YMAG,ZMAG,J)

INPUT PARAMETERS: (a) J - integer switch parameter,

(b) if J>0, then geographic (geocentric) coordinates XGEO, YGEO, ZGEO

if J<0, then geomagnetic coordinates XMAG, YMAG, ZMAG

OUTPUT PARAMETERS: If J>0 then XMAG, YMAG, ZMAG; if J<0 then XGEO, YGEO, ZGEO.

COMMON BLOCKS: /GEOPACK1/

OTHER SUBROUTINES INVOKED: None.

COMMENTS: Subroutine RECALC\_08 must be called before GEOMAG\_08 in two cases:

(a) before the first use, or

(b) if the previously defined values of IYEAR and/or IDAY got changed

No information is required in this case on the solar wind velocity, so one can set

VGSEX= −400.0, VGSEY=0.0, VGSEZ=0.0 in RECALC\_08.

**10.** SUBROUTINE: **GEIGEO\_08**

FUNCTION: Transformation of components of a vector from the Geocentric Equatorial

Inertial (GEI) coordinate system into Geographic geocentric (GEO) or

vice versa.

FORTRAN STATEMENT: CALL GEIGEO\_08 (XGEI,YGEI,ZGEI,XGEO,YGEO,ZGEO,J)

INPUT PARAMETERS: (a) J - integer switch parameter:

(b) if J>0, then GEI coordinates XGEI, YGEI, ZGEI

if J<0, then the Geographic coordinates XGEO, YGEO, ZGEO

OUTPUT PARAMETERS: If J>0 then XGEO, YGEO, ZGEO; if J<0 then XGEI, YGEI, ZGEI.

COMMON BLOCKS: /GEOPACK1/

OTHER SUBROUTINES INVOKED: None.

COMMENTS: Subroutine RECALC\_08 must be called before GEIGEO\_08 in two cases:

(a) before the first use, or

(b) if the current values of IYEAR, IDAY, IHOUR, MIN, ISEC have changed

No information is required here on the solar wind velocity, so one can set in RECALC\_08

VGSEX = −400.0, VGSEY= 0.0, VGSEZ = 0.0.

**11.** SUBROUTINE: **MAGSM\_08**

FUNCTION: Converts components of a vector from the Dipolar Geomagnetic (MAG)

coordinate system into the Solar Magnetic (SM) system or vice versa.

FORTRAN STATEMENT: CALL MAGSM\_08 (XMAG,YMAG,ZMAG,XSM,YSM,ZSM,J)

INPUT PARAMETERS: (a) J - integer switch parameter:

(b) if J>0, then MAG coordinates XMAG, YMAG, ZMAG

if J<0, then SM coordinates XSM, YSM, ZSM

OUTPUT PARAMETERS: If J>0 then XSM, YSM, ZSM; if J<0 then XMAG, YMAG, ZMAG.

COMMON BLOCKS: /GEOPACK1/

OTHER SUBROUTINES INVOKED: None.

COMMENTS: 1. Subroutine RECALC\_08 must be called before MAGSM\_08 in three cases:

(a) before the first use, or

(b) if the current values of IYEAR, IDAY, IHOUR, MIN, ISEC have changed, and/or

(c) if the solar wind velocity components VGSEX, VGSEY, VGSEZ have changed

2. A general implicit assumption here is that the position of the noon meridian plane in the

SM system is defined by the observed direction of the incoming solar wind flow, rather

than by the Earth-Sun line. To convert vectors to/from the standard SM system, set in

RECALC\_08 VGSEX= −400.0, VGSEY= 0.0, and VGSEZ= 0.0.

**12.** SUBROUTINE: **GSWGSE\_08**

FUNCTION: Transformation of components of a vector from the Geocentric Solar-Wind (GSW)

coordinate system into the Geocentric Solar Ecliptic (GSE) system or vice versa.

FORTRAN STATEMENT: CALL GSWGSE\_08 (XGSW,YGSW,ZGSW,XGSE,YGSE,ZGSE,J)

INPUT PARAMETERS: (a) J - integer switch parameter:

(b) if J>0 then GSW coordinates XGSW, YGSW, ZGSW

if J<0 then GSE coordinates XGSE, YGSE, ZGSE

OUTPUT PARAMETERS: If J>0 then XGSE, YGSE, ZGSE; if J<0 then XGSW, YGSW, ZGSW.

COMMON BLOCKS: /GEOPACK1/

OTHER SUBROUTINES INVOKED: None.

COMMENTS: 1. Subroutine RECALC\_08 must be called before GSWGSE\_08 in three cases:

(a) before the first use, or

(b) if the current values of IYEAR, IDAY, IHOUR, MIN, ISEC have changed, and/or

(c) if the solar wind velocity components VGSEX, VGSEY, VGSEZ have changed

2. Setting VGSEX = −400.0, VGSEY = 0.0, and VGSEZ = 0.0 in RECALC\_08 results in

reduction of all GSW vector components to those in the standard GSM; in that case, this

subroutine becomes fully equivalent to GSMGSE from previous releases of this package.

**13.** SUBROUTINE: **SMGSW\_08**

FUNCTION: Transformation of components of a vector from the Solar Magnetic (SM) coordinate

system into the Geocentric Solar-Wind (GSW) system and vice versa.

FORTRAN STATEMENT: CALL SMGSW\_08 (XSM,YSM,ZSM,XGSW,YGSW,ZGSW,J)

INPUT PARAMETERS: (a) J - integer switch parameter:

(b) if J>0 then SM coordinates XSM, YSM, ZSM

if J<0 then GSW coordinates XGSW, YGSW, ZGSW

OUTPUT PARAMETERS: If J>0 then XGSW, YGSW, ZGSW; if J<0 then XSM, YSM, ZSM.

COMMON BLOCKS: /GEOPACK1/

OTHER SUBROUTINES INVOKED: None.

COMMENTS: 1. Subroutine RECALC\_08 must be called before SMGSW\_08 in three cases:

(a) before the first use, or

(b) if the current values of IYEAR, IDAY, IHOUR, MIN, ISEC have changed, and/or

(c) if the solar wind velocity components VGSEX, VGSEY, VGSEZ have changed

2. A general implicit assumption here is that the position of the noon meridian plane in the

SM system (as well as the orientation of X axis in GSW) are defined by the observed

direction of the incoming solar wind flow, rather than by the Earth-Sun line. To convert

vectors between standard SM and GSM systems, set in RECALC\_08: VGSEX = −400.0

(or any other non-zero **negative** value), VGSEY=0.0, and VGSEZ=0.0.

**14.** SUBROUTINE: **GEOGSW\_08**

FUNCTION: Transformation of components of a vector from the Geographic Geocentric (GEO)

coordinates into the Geocentric Solar-Wind (GSW) system and vice versa.

FORTRAN STATEMENT: CALL GEOGSW\_08 (XGEO,YGEO,ZGEO,XGSW,YGSW,ZGSW,J)

INPUT PARAMETERS: (a) J - integer switch parameter:

(b) if J>0 then GEO coordinates XGEO, YGEO, ZGEO

if J<0 then GSW coordinates XGSW, YGSW, ZGSW

OUTPUT PARAMETERS: If J>0 then XGSW, YGSW, ZGSW; if J<0 then XGEO, YGEO, ZGEO.

COMMON BLOCKS: /GEOPACK1/

OTHER SUBROUTINES INVOKED: None.

COMMENTS: 1. Subroutine RECALC\_08 must be called before GEOGSW\_08 in three cases:

(a) before the first use, or

(b) if the current values of IYEAR, IDAY, IHOUR, MIN, ISEC have changed, and/or

(c) if the solar wind velocity components VGSEX, VGSEY, VGSEZ have changed

2. Setting VGSEX = −400.0, VGSEY= 0.0, and VGSEZ = 0.0 in RECALC\_08 makes

XGSW,YGSW,ZGSW identical to the standard XGSM,YGSM,ZGSM.

**15.** SUBROUTINE: **GEODGEO\_08**

FUNCTION: Converts geodetic coordinates {H,****} of a point in space (local vertical height, and geodetic latitude, respectively) to geocentric coordinates {R,} (radial distance and spherical co-latitude, respectively) and vice versa.

FORTRAN STATEMENT: CALL GEODGEO\_08 (H,XMU,R,THETA,J)

INPUT PARAMETERS: (a) J - integer switch parameter:

(b) if J>0 then geodetic coordinates H (km), XMU (radians)

if J<0 then geocentric coordinates R (km), THETA (radians)

OUTPUT PARAMETERS: If J>0 then R (km), THETA (radians); if J<0 then H (km), XMU (radians).

COMMON BLOCKS: None.

OTHER SUBROUTINES INVOKED: None.

**16.** SUBROUTINE: **RHAND\_08**

FUNCTION: Subsidiary subroutine, calculating the right-hand side vector in the field line

equation (that is, components of the unit vector along the local direction of **B**)

FORTRAN STATEMENT:

CALL RHAND\_08 (X,Y,Z,R1,R2,R3,IOPT,PARMOD,EXNAME,INNAME)

INPUT PARAMETERS:

X, Y, Z - GSW (or GSM) coordinates of the current point on a field line;

IOPT - integer index, reserved for specifying a version of the external magnetic field

model. In the case of T87 or T89 model [*Tsyganenko*, 1987; 1989], this parameter can

be used for specifying the range of the Kp-index;

PARMOD - a 10-element array, reserved for other input parameters of the external

field model, e.g., solar wind pressure, interplanetary magnetic field components, Dst-

index, as in the T96 model [*Tsyganenko*, 1995; 1996];

EXNAME - name of an external field model subroutine (see below the description of

TRACE\_08 for more details).

INNAME - name of an internal field model subroutine (see the description of

TRACE\_08 below for more details).

OUTPUT PARAMETERS: R1, R2, R3 – right hand side quantities (components of the unit vector

**B**/B).

COMMON BLOCKS: /GEOPACK1/

OTHER SUBROUTINES INVOKED: EXNAME and INNAME (replaced by actual names of

external and internal model field subroutines).

**17.** SUBROUTINE: **STEP\_08**

FUNCTION: Makes one step along a model magnetic field line. The model field is a sum of

contributions from internal and external sources, provided by the subroutines

IGRF\_GSW\_08 (or DIP\_08) and EXNAME, respectively.

FORTRAN STATEMENT:

CALL STEP\_08 (X, Y, Z, DS, DSMAX, ERRIN, IOPT, PARMOD, EXNAME, INNAME)

INPUT PARAMETERS:

X, Y, Z - GSW (or GSM) position of the initial point on a field line;

DS - tentative step size along the line;

DSMAX – upper limit on the step size

ERRIN - upper limit of the permissible error;

IOPT - integer index, reserved for specifying a version of the external magnetic field

model (in the case of T87 or T89 model this parameter can be used for speci-

fying the range of the Kp-index)

PARMOD - a 10-element array, reserved for other input parameters of the external

field model (e.g., solar wind pressure, interplanetary magnetic field compo-

nents, and Dst, as in the T96 model)

EXNAME - name of an external field model subroutine (see below description of the

subroutine TRACE\_08 for more details)

INNAME - name of an internal field model subroutine (see below description of

TRACE\_08 for more details).

OUTPUT PARAMETERS: X, Y, Z - GSW (or GSM) coordinates of the next point on the field line:

**note that the input values of X,Y,Z are replaced by their output values**,

corresponding to the next point on the line.

COMMON BLOCKS: /GEOPACK1/

OTHER SUBROUTINES INVOKED: RHAND\_08.

COMMENTS: (1) Do not forget to specify the actual names of the external and internal model field

subroutines in the EXTERNAL statement of your own subroutine or main program, from

which STEP\_08 is invoked (see also comments 1-3 in the description of TRACE\_08).

(2) The parameter DS can change its value as a result of having invoked STEP\_08,

because (a) if the actual error estimate exceeds ERRIN, the step is repeated with

a halved value of the stepsize DS, (b) if the actual error is too small (less than

0.04\*ERRIN), the current step is **not** repeated, and the value of DS for the next

step is doubled (but not to exceed DSMAX), in anticipation of a further decrease of the

field line curvature.

**18.** SUBROUTINE: **TRACE\_08**

FUNCTION: Calculates GSW (or GSM) positions of a sequence of points lying on a field line. The

tracing starts at a given initial point and terminates (i) upon crossing inner spherical

boundary of the tracing region (Earth's surface or the ionosphere), (ii) upon exiting from the

modeling region, (iii) if the field line makes more than 2 loops inside the tracing region

around an O-type quasi-neutral line, or (iv) if a prescribed upper limit on the number of field

line points is exceeded.

FORTRAN STATEMENT:

CALL TRACE\_08 (XI,YI,ZI,DIR,DSMAX,ERR,RLIM,R0,IOPT,

\* PARMOD,EXNAME,INNAME,XF,YF,ZF,XX,YY,ZZ,L,LMAX)

INPUT PARAMETERS:

XI, YI, ZI, - GSW (or GSM) position of the initial point (in Earth's radii, RE);

DIR - defines the tracing direction: assign DIR=1.0 if the line should be traced oppositely to

the **B** vector (e.g., from the northern polar ionosphere down the northern tail lobe), or

DIR = −1.0 in the opposite case.

DSMAX – a desired value (in RE) of the upper limit on the step size along the field line.

ERR – permissible error at each step. A reasonable estimate that ensures a sufficient accuracy for

most applications is ERR=0.0001. Smaller/larger values will result in larger/smaller number

of steps (hence, more field line points). Note that using much smaller values of this parameter

(such as 10-10) may not necessarily result in a tangible improvement of the accuracy, unless

the entire source code (including this package) is converted to double precision.

RLIM - geocentric radius of the outer boundary of the tracing region (in RE); tracing is

terminated once R>RLIM;

R0 - radius of the inner boundary of the tracing region (usually R0=1.0, corresponding to

the Earth's surface);

IOPT - an integer index, reserved for specifying a version of the external magnetic field

model (in the case of T87 or T89 model, this parameter can be used for specifying

the range of the Kp-index);

PARMOD - a 10-element array, reserved for other input parameters of the external field

model (e.g., solar wind pressure, interplanetary magnetic field components, and

Dst, as in the T96 model);

EXNAME - name of an external field model subroutine. The corresponding actual argu-

ment should be specified in the EXTERNAL statement of the main module. The

list of formal parameters of the subroutine EXNAME must be as follows:

(IOPT, PARMOD, PS, X, Y, Z, BX, BY, BZ), where IOPT is an integer, PARMOD

is a 10-element array of REAL\*4 type, and the remaining parameters are real

variables, standing for the dipole tilt angle (in radians), GSW position (in Re) and

the external field components.

INNAME - name of a subroutine providing components of the internal magnetic field

(either IGRF\_GSW\_08 or DIP\_08).

LMAX – maximal length of the arrays XX, YY, ZZ in which coordinates of the field line

points are stored. LMAX should be set equal to the actual length of the arrays,

defined in the main program as actual arguments of this subroutine

OUTPUT PARAMETERS:

XX, YY, ZZ – arrays containing GSW/GSM coordinates (in RE) of the field line points;

XF, YF, ZF – coordinates of the field line ending point;

L – the number of calculated field line points.

COMMON BLOCKS: /GEOPACK1/

OTHER SUBROUTINES INVOKED: STEP\_08, RHAND\_08.

COMMENTS:

(1) This subroutine allows two options:

(a) If INNAME=IGRF\_GSW\_08, then the IGRF model will be used for calculating the

contribution from earth's internal sources. In this case, subroutine RECALC\_08 must be

called before using TRACE\_08, with properly specified date, universal time, and solar

wind velocity components, to calculate in advance all quantities needed for the main

field model and for transformations between involved coordinate systems.

(b) If INNAME=DIP\_08, then a pure dipole field will be used instead of the IGRF model.

As in the case (a), the subroutine RECALC\_08 must also be called before TRACE\_08.

Here we can choose either to (i) calculate dipole tilt angle based on date, time, and

solar wind direction, or (ii) explicitly specify that angle, without any reference to

date/time/solar wind. In the last case, the sine (SPS) and cosine (CPS) of the

dipole tilt angle must be specified in advance (**but after** **the invocation of** RECALC\_08)

and forwarded in the common block /GEOPACK1/ (in its 11th and 12th elements,

respectively). In this case the role of the subroutine RECALC\_08 is to only initialize the

components of the Earth's dipole moment.

(2) Any external field model subroutine EXNAME can be used, provided it has the same structure

of the list of formal arguments and its actual name is included in the EXTERNAL statement in the user's

module that invokes TRACE\_08.

(3) If the field line is closed (i.e., returns back to Earth), then the last (L-th) element in the arrays

XX, YY, ZZ (and the triplet XF, YF, ZF) will correspond to the footpoint of the line at R=R0.

(4) If in the process of the tracing the number of field line points exceeds LMAX, computation

is aborted and a warning message displayed.

For more details, see examples of using this subroutine in the end of this file.

**19.** SUBROUTINE: **SHUETAL\_MGNP\_08**

FUNCTION: For a given point of space (either inside or outside of the magnetosphere) finds a point on

the model magnetopause by *Shue et al*. [1998], lying in the plane containing XGSM-axis

and the original point, and nearly closest to that point. The model magnetopause is specified

by setting parameters of the incoming solar wind and Bz component of IMF.

FORTRAN STATEMENT:

CALL SHUETAL\_MGNP (XN\_PD, VEL, BZIMF, XGSM, YGSM, ZGSM,

\*XMGNP, YMGNP, ZMGNP, DIST, ID)

INPUT PARAMETERS: XN\_PD - either the solar wind proton number density in particles per cubic

centimeter (if VEL>0), or the solar wind ram pressure in nanoPascals (if VEL<0)

VEL - either the solar wind speed (km/s) or any negative value, which in

that case indicates that XN\_PD should be interpreted as the solar wind

ram pressure in nPa.

BZIMF - Bz component of the interplanetary magnetic field.

XGSM, YGSM, ZGSM - GSM position of the input observation point (in RE).

OUTPUT PARAMETERS:

XMGNP, YMGNP, ZMGNP - GSM position of the output boundary point

DIST - distance (in RE) between the input point (XGSM, YGSM, ZGSM) and the model

magnetopause

ID - position flag: ID=+1 (-1) means that the input point lies inside (outside) of the model

magnetopause.

COMMON BLOCKS: None.

OTHER SUBROUTINES INVOKED: T96\_MGNP\_08.

COMMENTS: Position vectors (XGSM, YGSM, ZGSM) and (XMGNP,YMGNP,ZMGNP) can be

interpreted as referring to the GSW system (assuming that the magnetopause orients itself

following the direction of the solar wind flow).

**20.** SUBROUTINE: **T96\_MGNP\_08**

FUNCTION: For a given point of space (either inside or outside of the magnetosphere) finds a point on

the model magnetopause used in the T96 model [*Tsyganenko*, 1996], lying on the plane

containing XGSM axis and the original point, and nearly closest to that point. The model

magnetopause is specified by setting parameters of the incoming solar wind.

FORTRAN STATEMENT:

CALL T96\_MGNP\_08 (XN\_PD, VEL, XGSM, YGSM, ZGSM, XMGNP, YMGNP, ZMGNP, DIST, ID)

INPUT PARAMETERS:

XN\_PD - either the solar wind proton number density in particles per cubic cm (if VEL>0),

or the solar wind ram pressure in nPa (if VEL<0).

VEL - either the solar wind speed (km/s) or any negative value, which in this case

indicates that XN\_PD should be interpreted as the solar wind ram pressure.

BZIMF - Bz component of the interplanetary magnetic field.

XGSM, YGSM, ZGSM - GSM position of the input observation point (in Re).

OUTPUT PARAMETERS:

XMGNP, YMGNP, ZMGNP - GSM position of the output point on the boundary.

DIST - distance (in Re) between the observation point (XGSM, YGSM, ZGSM) and the

model magnetopause

ID - position flag: ID=+1 (-1) means that the input point lies inside (outside) of the model

magnetopause.

COMMON BLOCKS: None.

OTHER SUBROUTINES INVOKED: None.

COMMENTS: Position vectors (XGSM, YGSM, ZGSM) and (XMGNP,YMGNP,ZMGNP) can be

interpreted as referring to the GSW system (assuming that the magnetopause orients itself

following the direction of the solar wind flow).

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**All further questions/comments on the GEOPACK-2008 are welcome.**

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C

C ############################################################################

C # THE MAIN PROGRAMS BELOW GIVE TWO EXAMPLES OF TRACING FIELD LINES #

C # USING THE GEOPACK-2008 SOFTWARE (release of Feb 08, 2008) #

C ############################################################################

C

PROGRAM EXAMPLE1

C

C IN THIS EXAMPLE IT IS ASSUMED THAT WE KNOW GEOGRAPHIC COORDINATES OF A FOOTPOINT

C OF A FIELD LINE AT THE EARTH'S SURFACE AND TRACE THAT LINE FOR A SPECIFIED

C MOMENT OF UNIVERSAL TIME, USING A FULL IGRF EXPANSION FOR THE INTERNAL FIELD

C

PARAMETER (LMAX=500)

C

C LMAX IS THE UPPER LIMIT ON THE NUMBER OF FIELD LINE POINTS RETURNED BY THE TRACER.

C IT CAN BE SET ARBITRARILY LARGE, DEPENDING ON THE SPECIFICS OF A PROBLEM UNDER STUDY.

C IN THIS EXAMPLE, LMAX IS TENTATIVELY SET EQUAL TO 500.

C

DIMENSION XX(LMAX),YY(LMAX),ZZ(LMAX), PARMOD(10)

c

c Be sure to include an EXTERNAL statement in your codes, specifying the names

c of external and internal field model subroutines in the package, as shown below.

c In this example, the external and internal field models are T96\_01 and IGRF\_GSW\_08,

c respectively. Any other models can be used, provided they have the same format

c and the same meaning of the input/output parameters.

c

EXTERNAL T96\_01,IGRF\_GSW\_08

C

C DEFINE THE UNIVERSAL TIME AND PREPARE THE COORDINATE TRANSFORMATION PARAMETERS

C BY INVOKING THE SUBROUTINE RECALC\_08: IN THIS PARTICULAR CASE WE TRACE A LINE

C FOR YEAR=1997, IDAY=350, UT HOUR = 21, MIN = SEC = 0

C

IYEAR=1997

IDAY=350

IHOUR=21

MIN=0

ISEC=0

C

C AT THAT TIME, ACCORDING TO THE OMNI DATABASE, THE SOLAR WIND VELOCITY IN GSE HAD THE

C COMPONENTS

C

VGSEX=-304.0

VGSEY= -16.0

VGSEZ= 4.0

C

C NOTE, HOWEVER, THAT THE ABERRATION CORRECTION WAS ALREADY MADE IN THE SOLAR WIND DATA.

C THEREFORE, TO CORRECTLY TRANSFORM THE DATA TO GSM COORDINATE SYSTEM, WE HAVE TO RESTORE C VGSEY TO ITS ORIGINAL OBSERVED VALUE:

C

VGSEY=VGSEY+29.78

C

CALL RECALC\_08 (IYEAR,IDAY,IHOUR,MIN,ISEC,VGSEX,VGSEY,VGSEZ)

C

OPEN(UNIT=1,FILE='LINTEST1.DAT')

C

WRITE (1,100) IYEAR, IDAY, IHOUR, MIN

100 FORMAT (' IYEAR=',I4,' IDAY=',I3,' IHOUR=',I2,' MIN=',I2,/)

C

PARMOD(1)=3.

PARMOD(2)=-20.

PARMOD(3)=3.

PARMOD(4)=-5.

WRITE (1,110) PARMOD(1)

110 FORMAT(' SOLAR WIND RAM PRESSURE (NANOPASCALS):',F6.1,/)

C

WRITE (1,120) PARMOD(2)

120 FORMAT (' DST-INDEX: ',F6.0,/)

C

WRITE (1,130) PARMOD(3),PARMOD(4)

130 FORMAT (' IMF By and Bz: ',2F6.1,/)

C

C THE LINE WILL BE TRACED FROM A GROUND (RE=1.0) FOOTPOINT WITH GEOGRAPHICAL

C LONGITUDE 45 DEGREES AND LATITUDE 75 DEGREES:

C

GEOLAT=75.

GEOLON=45.

RE=1.0

PRINT \*, ' GEOGRAPHIC (GEOCENTRIC) LATITUDE (degs): ',GEOLAT

PRINT \*, ' GEOGRAPHIC (GEOCENTRIC) LONGITUDE (degs): ',GEOLON

COLAT=(90.-GEOLAT)\*.01745329

XLON=GEOLON\*.01745329

C

C CONVERT SPHERICAL COORDS INTO CARTESIAN :

C

CALL SPHCAR\_08 (RE,COLAT,XLON,XGEO,YGEO,ZGEO,1)

C

C TRANSFORM GEOGRAPHICAL GEOCENTRIC COORDS INTO SOLAR WIND MAGNETOSPHERIC ONES:

C

CALL GEOGSW\_08 (XGEO,YGEO,ZGEO,XGSW,YGSW,ZGSW,1)

C

c SPECIFY TRACING PARAMETERS:

C

DIR=1.

C (TRACE THE LINE WITH A FOOTPOINT IN THE NORTHERN HEMISPHERE, THAT IS,

C ANTIPARALLEL TO THE MAGNETIC FIELD)

C

DSMAX=1.0

C (MAXIMAL SPACING BETWEEN THE FIELD LINE POINTS SET EQUAL TO 1 RE)

C

ERR=0.0001

C (PERMISSIBLE STEP ERROR SET AT ERR=0.0001)

RLIM=60.

C (LIMIT THE TRACING REGION WITHIN R=60 Re)

C

R0=1.

C (LANDING POINT WILL BE CALCULATED ON THE SPHERE R=1,

C I.E. ON THE EARTH'S SURFACE)

IOPT=0

C (IN THIS EXAMPLE IOPT IS JUST A DUMMY PARAMETER,

C WHOSE VALUE DOES NOT MATTER)

C

C TRACE THE FIELD LINE:

C

CALL TRACE\_08 (XGSW,YGSW,ZGSW,DIR,DSMAX,ERR,RLIM,R0,IOPT,

\* PARMOD,T96\_01,IGRF\_GSW\_08,XF,YF,ZF,XX,YY,ZZ,M,LMAX)

C

C WRITE THE RESULTS IN THE DATAFILE 'LINTEST1.DAT':

C

WRITE (1,20)

20 FORMAT(' THE LINE IN GSW COORDS:',/)

WRITE (1,21) (XX(L),YY(L),ZZ(L),L=1,M)

21 FORMAT ((2X,3F6.2))

CLOSE(UNIT=1)

END

C\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

C

PROGRAM EXAMPLE2

C

C THIS IS ANOTHER EXAMPLE OF USING THE GEOPACK SUBROUTINE "TRACE\_08". UNLIKE IN

C THE EXAMPLE1, HERE WE ASSUME A PURELY DIPOLAR APPROXIMATION FOR THE EARTH'S

C INTERNAL FIELD.

C IN THIS CASE WE ALSO EXPLICITLY SPECIFY THE TILT ANGLE OF THE GEODIPOLE,

C INSTEAD OF CALCULATING IT FROM THE DATE/TIME.

C

PARAMETER (LMAX=500)

C

C LMAX IS THE UPPER LIMIT ON THE NUMBER OF FIELD LINE POINTS RETURNED BY THE TRACER.

C IT CAN BE SET ARBITRARILY LARGE, DEPENDING ON THE SPECIFICS OF A PROBLEM UNDER STUDY.

C IN THIS EXAMPLE, LMAX IS TENTATIVELY SET EQUAL TO 500.

C

DIMENSION XX(LMAX),YY(LMAX),ZZ(LMAX), PARMOD(10)

c

C Unlike in the EXAMPLE1, here we "manually" specify the tilt angle and its sine/cosine.

c To forward them to the coordinate transformation subroutines, we need to explicitly

c include the common block /GEOPACK1/:

C

COMMON /GEOPACK1/ AA(10),SPS,CPS,BB(3),PSI,CC(18)

C

c be sure to include an EXTERNAL statement with the names of (i) a magnetospheric

c external field model and (ii) Earth's internal field model.

c

EXTERNAL T96\_01, DIP\_08

C

C First, call RECALC\_08, to define the main field coefficients and, hence, the magnetic

C moment of the geodipole for IYEAR=1997 and IDAY=350.

C The universal time and solar wind direction does not matter in this example,

C because here we explicitly specify the tilt angle (hence, the orientation of

C dipole in the GSW coordinates), so we arbitrarily set IHOUR=MIN=ISEC=0 and

C VGSEX=-400.0, VGSEY=VGSEZ=0 (any other values would be equally OK):

C

CALL RECALC\_08 (1997,350,0,0,0,-400.0,0.0,0.0)

c

c Enter input parameters for T96\_01:

c

PRINT \*, ' ENTER SOLAR WIND RAM PRESSURE IN NANOPASCALS'

READ \*, PARMOD(1)

C

PRINT \*, ' ENTER DST '

READ \*, PARMOD(2)

C

PRINT \*, ' ENTER IMF BY AND BZ'

READ \*, PARMOD(3),PARMOD(4)

C

c Define the latitude (XLAT) and longitude (XLON) of the field line footpoint

c in the GSW coordinate system:

c

XLAT=75.

XLON=180.

C

C Specify the dipole tilt angle PS, its sine SPS and cosine CPS, entering

c in the common block /GEOPACK1/:

C

PSI=0.

SPS=SIN(PSI)

CPS=COS(PSI)

c

c Calculate Cartesian coordinates of the starting footpoint:

c

T=(90.-XLAT)\*.01745329

XL=XLON\*.01745329

XGSW=SIN(T)\*COS(XL)

YGSW=SIN(T)\*SIN(XL)

ZGSW=COS(T)

C

c SPECIFY TRACING PARAMETERS:

C

DIR=1.

C (TRACE THE LINE WITH A FOOTPOINT IN THE NORTHERN HEMISPHERE, THAT IS,

C ANTIPARALLEL TO THE MAGNETIC FIELD)

C

DSMAX=1.0

C (SETS THE MAXIMAL SPACING BETWEEN CONSECUTIVE POINTS ON THE LINE)

ERR=0.0001

C (PERMISSIBLE STEP ERROR SET AT ERR=0.0001)

RLIM=60.

C (LIMIT THE TRACING REGION WITHIN R=60 Re)

C

R0=1.

C (LANDING POINT WILL BE CALCULATED ON THE SPHERE R=1,

C I.E. ON THE EARTH'S SURFACE)

c

IOPT=0

C (IN THIS EXAMPLE IOPT IS JUST A DUMMY PARAMETER,

C WHOSE VALUE DOES NOT MATTER)

c

c Trace the field line:

c

CALL TRACE\_08 (XGSW,YGSW,ZGSW,DIR,DSMAX,ERR,RLIM,R0,IOPT,

\* PARMOD,T96\_01,DIP\_08,XF,YF,ZF,XX,YY,ZZ,M,LMAX)

C

C Write the result in the output file 'LINTEST2.DAT':

C

OPEN(UNIT=1, FILE='LINTEST2.DAT')

1 WRITE (1,20) (XX(L),YY(L),ZZ(L),L=1,M)

20 FORMAT((2X,3F6.2))

CLOSE(UNIT=1)

END