



# **MAGLIB**

**REFERENCE MANUAL OF MAGLIB LIBRARY:**

**GEOGRAPHIC, GEOPHYSICS AND GEOMAGNETIC CALCULATION**

**ROUTINES**

**PLASMA-LO-MAGLIB-00067-CN**

**Version 1, Revision 0, 1998/11/23**

**Version 1, Revision 1, 1999/12/21**

**Version 2, Revision 0, 2001/06/18**

**Version 2, Revision 1, 2003/01/18**

**Version 3, Revision 0, 2007/01/01**

**Version 4, Revision 0, 2010/12/09**



**MAGLIB**

Jean-Claude KOSIK

CNES

18, avenue Edouard Belin

31055 Toulouse Cedex, France

## Table of contents

<b>INTRODUCTION.....</b>	<b>8</b>
<b>MAGLIB ORGANIZATION .....</b>	<b>17</b>
<b>MAGLIB ROUTINES .....</b>	<b>18</b>
<b>1. STARTING ROUTINES.....</b>	<b>7</b>
1.1 INIGEO1 .....	8
1.2 INIGEOM .....	11
1.3 INIGEOMV .....	14
1.4 VALFIX .....	17
<b>2. COORDINATE TRANSFORMATIONS.....</b>	<b>19</b>
2.1 DIPGEO .....	21
2.2 GCVGD .....	22
2.3 GDVGC .....	23
2.4 GEODIP .....	24
2.5 GEOGKM .....	25
2.6 GEOGSM .....	26
2.7 GEORRE .....	28
2.8 GEOSE .....	29
2.9 GEOSM .....	31
2.10 GGEOM .....	33
2.11 GSMGEO .....	34
2.12 ROGDIP .....	36
2.13 ROGGSM .....	37
2.14 ROGSE .....	38
2.15 ROGSM .....	39
2.16 ROIG .....	40
2.17 ROIGSM .....	41
2.18 ROISE .....	42
2.19 ROSMGS .....	43
2.20 ROVDH .....	44
2.21 SEGEO .....	45
2.22 SMGEO .....	46
<b>3. BOUNDARIES AND REGIONS .....</b>	<b>47</b>
3.1 ABERRM .....	49
3.2 BWSHFF .....	50
3.3 CAHSL .....	52
3.4 CALDIS .....	53
3.5 CALPHI .....	55
3.6 CALPOL .....	57

3.7	CALTHETA .....	58
3.8	CHAPEL.....	59
3.9	CLUSDIS.....	60
3.10	CUSP.....	62
3.11	DCHAPP .....	63
3.12	DDPARAB.....	64
3.13	GUSSEN .....	65
3.14	MPAUSE.....	66
3.15	MPSIB.....	68
3.16	MSHEATH.....	69
3.17	OLSDON.....	71
3.18	OVAL.....	72
3.19	POSMAG.....	73
3.20	POSNS.....	76
3.21	POSNSH.....	77
3.22	POSPS .....	79
3.23	POSPSH.....	81
3.24	RBELT.....	83
<b>4.</b>	<b>INTERNAL MAGNETIC FIELD MODELS.....</b>	<b>84</b>
4.1	CHP10 .....	86
4.2	CHP05 .....	87
4.3	CHP00.....	88
4.4	CHP95.....	89
4.5	CHP95_10 .....	90
4.6	CHP70_95.....	91
4.7	CHP45_70.....	92
4.8	IGRF10.....	93
4.9	DGRF05 .....	94
4.10	DGRF00 .....	95
4.11	DGRF95 .....	96
4.12	IGRF95_10 .....	97
4.13	DGRF70_95 .....	98
4.14	DGRF45_70 .....	99
4.15	GRAD10.....	100
4.16	GRAD05.....	102
4.17	GRAD00.....	104
4.18	GRAD95.....	106
4.19	DIPOL .....	108
4.20	DIPOLS.....	109
4.21	GSFC65.....	110
4.22	INCLINE .....	111
4.23	VS_CHP .....	112
4.24	VS_IGRF .....	113
<b>5.</b>	<b>EXTERNAL MAGNETIC FIELD MODELS.....</b>	<b>114</b>
5.1	DBTOT .....	115
5.2	EX89AE.....	117
5.3	EX89KP .....	119

5.4	KK97KP .....	121
5.5	MF75 .....	123
5.6	TSYG87 .....	125
<b>6.</b>	<b>MAGNETOSPHERIC PHYSICS CALCULATIONS .....</b>	<b>127</b>
6.1	ANGDIP .....	129
6.2	BGSM .....	130
6.3	CALCDS .....	132
6.4	CALPOS .....	133
6.5	CHAPP2 .....	136
6.6	CONJDIP .....	137
6.7	CORGM .....	139
6.8	DCONJR .....	142
6.9	DLGALP .....	145
6.10	ECONJR .....	147
6.11	FLGALP .....	150
6.12	GEOPHYS .....	152
6.13	INMAG .....	155
6.14	INVAR .....	157
6.15	INVLAT .....	158
6.16	MAGTOT .....	159
6.17	MCILWE .....	161
6.18	OUTMA1 .....	162
6.19	PCONJR .....	164
6.20	TGEOGR .....	167
6.21	TGML .....	170
6.22	TGML2 .....	171
6.23	TLOCAL .....	172
<b>7.</b>	<b>ASTRONOMY AND CELESTIAL MECHANICS .....</b>	<b>173</b>
7.1	ORBIT .....	175
7.2	POSIN .....	178
7.3	PR2000 .....	180
7.4	PVIG .....	181
7.5	SOLTER00 .....	183
7.6	SOLTER05 .....	185
7.7	SOLTER10 .....	187
7.8	SOLTERV .....	189
7.9	SOLTERVO .....	191
7.10	SUN .....	193
7.11	TSIDRG .....	194
<b>8.</b>	<b>MATHEMATICS .....</b>	<b>195</b>
8.1	ANGLEG .....	196
8.2	BESSEL .....	197
8.3	CARSP .....	198
8.4	FACT .....	200
8.5	KARDAN .....	201
8.6	NORMA .....	202

8.7	NURACI .....	203
8.8	PARABN.....	205
8.9	PROMAL.....	206
8.10	PROMAT.....	207
8.11	SPCAR.....	208
8.12	TRADEG.....	210
8.13	TSPCAR.....	211
8.14	VCARVSP.....	212
8.15	VSPVCAR.....	213
<b>9.</b>	<b>DATE CALCULATIONS .....</b>	<b>214</b>
9.1	CALDAJ.....	215
9.2	CALENDG.....	217
9.3	DATJHMS .....	218
9.4	DJGREG.....	219
9.5	JD2000 .....	220
9.6	JULG .....	221
<b>10.</b>	<b>CONTROL ROUTINES .....</b>	<b>222</b>
10.1	CTRLDAT .....	223
10.2	CTRLDIS.....	225
10.3	CTRLIND .....	227
10.4	CTRLPAR.....	229
10.5	CTRLPOS.....	232

# INTRODUCTION

The MAGLIB software results from our thirty-year experience in mission analysis and geophysics software for magnetospheric projects as well as personal research on charged particle motion and quantitative magnetic field modeling. In the early times, (Araks I & II, 1972), the main demand was a correct description of the near Earth magnetic field. We used the external magnetic field model of Roederer and Sauer based on two dipoles to obtain the conjugacy in the northern hemisphere for the rockets launched in the Kerguelen islands. The results were very rough but showed both the diurnal and the seasonal motion of the conjugate points. The same model was used for Geos I. The partial failure of the launch of Geos I by a Mc Donnell Douglas Thor Delta rocket led W.P. Olson of the same Company to offer us an advanced model as a compensation in 1974. This model was used for mission analysis and projects like Geos II, Sambo, Arcade3 and Viking (French experiments). The version in our hands was limited to distances less than 15 Re in the night side but gave reasonable excursions of the conjugate points for asynchronous spacecraft. All these low-altitude spacecraft (we consider the synchronous altitude as near-Earth compared to the size of the Magnetosphere) were not very demanding in terms of software: calculation of the geomagnetic local time, calculation of the Mc Ilwain L, etc. With Interball and its auroral and eccentric probes, a great step was accomplished. It was necessary to use more accurate external magnetic field models with a realistic topology of the field lines in the tail region. This was achieved with the Tsyganenko models (1982, 1987 and 1989). These models were incorporated in the software. It was also necessary to take into account the crossing of the Magnetopause and to avoid any calculation involving the magnetic field outside the Magnetosphere. The eccentric Interball spacecraft with a 200000 km apogee crossed different magnetospheric regions, radiation belts, aurora oval, polar cap, Magnetosheath, Neutral Sheet: adequate routines were developed to define the boundaries of these regions. This software paved the way to the development of an interactive calculation and visualization tool, the OCGM, which also incorporated sophisticated orbit extrapolation. A further step was accomplished for the Cluster project with the calculation of the distances to the different boundaries, spacecraft speed in various coordinate systems and a variable Solar Wind velocity inducing a variable subsolar distance. In between we finally clarified the mysterious corrected geomagnetic coordinates (mysterious only for the low latitude Space physicist!) and added the calculation of the eccentric-tilted dipole. Unfortunately all the mysteries have not been solved. Among these, the absence of a renewed B, L coordinates system, the present one being defined for an internal geomagnetic field of the early sixties. Also the comparison of observations labeled in geophysical coordinates of same L and MLT separated by a fifteen-year interval. For Geos I we were very active finding some reasonable magnetospheric model. Later studies (Kosik, 1983) showed that during quiet times a tilted dipole proved sufficient, the ring current giving axisymmetric results for the synchronous altitude. The continuous advance in the knowledge of the Magnetosphere as well as the improvement of the models will lead to further modifications of this library, not to mention future interplanetary missions to Jupiter or Io. For the immediate needs the library contains about 160 routines. The routines have been divided into 9 sections. The first section contains the initialization routines to be called before any geophysical calculation or after a time update. The coordinate transformations form the second chapter. The regions and boundaries are described in the third chapter. The section on models

comprises internal and external magnetic field models. In this section all the DGRF internal field models since 1945 have been included.

To avoid errors the internal magnetic field is calculated with two types of routines where the coefficients are stored differently. The comparison of the results thus guarantees the correct use of the coefficients. For the external models, model Kosik 99 has been added, its field line topology being a good compromise between the fast Tsyganenko 87, 89 models and the more precise but time consuming Tsyganenko 96. The calculation of the geomagnetic local time and of the Mc Ilwain L parameter are in the geophysics calculations chapter. The calculations of the geomagnetic local time or the tilt angle require the knowledge of the Sun position and of the Greenwich Meridian with respect to an inertial coordinate system. These calculations and related subjects form the core of the astronomical and celestial mechanics chapter. Basic mathematical routines such as matrix multiplication or determination of roots are in the mathematics chapter. Time and date calculations, transformations between julian and gregorian dates are collected in one chapter, the date calculations. Finally to avoid unnecessary headaches caused by stupid results whose origin lie in a wrong choice of parameters a series of control routines have been developed and form the control routines chapter. The whole set of routines represents 24000 lines of documented fortran77. The software was carefully tested and set to quality standards by Michel Lagreca and Suzanne Le Guillou from CS-SI. In a separate volume a series of user routines give practical examples of calculations by combining the elementary bricks of the library. Finally a third volume will contain the physics and the corresponding mathematical equations. In 2000 an HTML version should be available offering a hypertext search of the type of calculation in its three aspects: the physics and the mathematics, the basic routine and the example. This work has benefited from the interaction with numerous Space physicists involved both in the projects and fundamental research. We particularly acknowledge Roger Gendrin for his encouragement and support during two decades.

In this chapter we review the different coordinate systems in use in magnetospheric physics: geocentric inertial, geocentric, solar ecliptic, geomagnetic or dipolar, solar magnetic, solar magnetospheric and the aberrated or Solar Wind coordinate system.



## MAGLIB revision 4.0

Since the first edition of the MAGLIB twenty years have elapsed. In this time interval the coefficients of the internal magnetic field have changed. To take into account these changes new models of the internal magnetic field have been introduced and coefficients of the old models have been updated.

### Internal magnetic fields:

IGRF 2010 is now available. As a consequence, DGRF 2000 and DGRF 2005 have now definitive coefficients and are called in the international standard DGRF 2000 and DGRF 2005. The spherical harmonics expansion has been extended to the 13<sup>th</sup> order since the DGRF 2000.

As the secular variations are only available for the last updated model, i.e., IGRF 2010, calculated secular variations have been introduced for the previous models DGRF 2000 and DGRF 2005. These were calculated using a linear interpolation.

A new interim geomagnetic field model has been introduced, the IGRF 2010. A new interpolation model for the time period between 1995 and 2010 has been introduced. The internal magnetic field is calculated using two different methods which allow a cross checking of the coefficients.

The routine DIPOLE calculates the magnetic field of the dipole and the first harmonics using IGRF 2010 coefficients.

For sake of simplicity some routines have been renamed:

Old name	New name
dgchnew	chp70_95
dgrfnew	dgrf70_95
dgchold	chp45_70
dgrfold	dgrf45_70

### Orientation of the dipole:

The introduction of the new magnetic field models has immediate consequences on the calculation of the dipole parameters  $\theta_{\text{dip}}$  and  $\phi_{\text{dip}}$  respectively the geographic colatitude and longitude of the dip – pole. The routine SOLTERV calculates these elements for the interval 1970 – 2000, SOLTER00 calculates these elements in the interval 2000-2005, SOLTER05 in the interval 2005-2010, and SOLTER10 in the interval 2010-2015.

### Calculation of the rotation matrices:

The calculations of the rotation matrices which involve the dipole orientation are performed in two routines INIGEOMV for the interval 1945 – 2000, and INIGEOM for the INTERVAL 2000 – 2015.

The INIGEO1 routine used for the CLUSTER Project calculates all the rotation matrices for the interval 2000 – 2015. INIGEO1 is simply an extension of INIGEOM as it calculates three additional rotation matrices.

### Upper level routines:

These routines calculate the total magnetic field as a combination of internal and external magnetic fields.

DCONJR, PCONJR and ECONJR calculate the field lines and the conjugate points. The routines DLGALP and FLGALP calculate the Galperin L parameter.

CORGM calculates the corrected geomagnetic coordinates. No major extension has been added to the external magnetic field models.

### External magnetic field models:

Tsyganenko models 1987 and 1989 are still available as well as the Kosik 97 model.

The Tsyganenko 1987 and Kosik 1997 models use only the Kp magnetic activity index.

The Tsyganenko 1989 uses the Kp or the Ae magnetic activity index.

The table below describes the relationships between the external magnetic field models and the geomagnetic activity indices.

External magnetic field	Magout	Geomagnetic index	Geomagnetic activity index, indval
tsyg87	1	none	1 to 6
ex89kp	2	Kp	1 to 6
ex89ae	2	Ae	1 to 6
kk97kp	3	Kp	1 to 5

Finally, the whole documentation has been updated according to the corrections described above.

**Table of the changes in the internal magnetic field routines and the related routines.**

Type of calculation	MAGLIB routines		Revision 4.0
Magnetic field: $1945 \leq T < 1970$	<b>chp45_70</b> <b>dgrf45_70</b>		Unchanged.
Magnetic field: $1970 \leq T < 1995$	<b>chp70_95</b> <b>dgrf70_95</b>		Unchanged.
Magnetic field: $1995 \leq T < 2010$	<b>chp95_10</b> <b>igrf95_10</b>		New set of coefficients for year 2010.
Magnetic field: $1995 \leq T < 2000$	<b>chp95</b> <b>dgrf95</b>		Unchanged
Magnetic field: $2000 \leq T < 2005$	<b>chp00</b> <b>dgrf00</b>		Definitive set of coefficients unchanged, definitive calculated secular variations.
Magnetic field: $2005 \leq T < 2010$	<b>chp05</b> <b>dgrf05</b>		Definitive set of coefficients, interim calculated secular variation.
Magnetic field: $2010 \leq T < 2015$	<b>chp10</b> <b>igrf10</b>	New New	New CHP model, New IGRF model.
Magnetic field gradients: $1995 \leq T < 2000$	<b>grad95</b>		Unchanged.
Magnetic field gradients: $2000 \leq T < 2005$	<b>grad00</b>		Definitive coefficients unchanged, definitive calculated secular variations.
Magnetic field gradients: $2005 \leq T < 2010$	<b>grad05</b>		Definitive coefficients, interim calculated secular variations.
Magnetic field gradients: $2010 \leq T < 2015$	<b>grad10</b>	New	Interim coefficients, interim secular variations.
Orientation of the dipole: $1945 \leq T < 1970$	<b>soltervo</b>		Unchanged
Orientation of the dipole: $1970 \leq T < 2000$	<b>solterv</b>		Unchanged
Orientation of the dipole: $2000 \leq T < 2005$	<b>solter00</b>		Unchanged, previous "solter" is now renamed to "solter00".
Orientation of the dipole: $2005 \leq T < 2010$	<b>solter05</b>		Updated coefficients, previous "soltern" is now renamed to "solter05".
Orientation of the dipole: $2010 \leq T < 2015$	<b>solter10</b>	New	New coefficients.
Rotation matrices: $1945 \leq T < 2000$	<b>inigeomv</b>		Unchanged.
Rotation matrices: $2000 \leq T < 2015$	<b>inigeom</b>		New solter10 involved.
Rotation matrices: $2000 \leq T < 2015$	<b>inigeo1</b>		Updated internal field models dedicated to Cluster.
Transformation matrix from the geocentric coordinate system into the field coordinate system	<b>rovdh</b>		Updated coefficients.
Conjugate points: $2000 \leq T < 2015$	<b>dconjr</b> <b>pconjr</b>		Updated internal field models.
Equatorial conjugate: $2000 \leq T < 2015$	<b>econjr</b>		Updated internal field models.
Galperin L parameter: $2000 \leq T < 2015$	<b>dlgalp</b> <b>flgalp</b>		Updated internal field models.

# MAGLIB ORGANIZATION

Maglib library contains 140 accessible fortran routines organized by theme.

Maglib is divided in 9 chapters:

- starting routines,
- coordinate transformations,
- boundaries and regions,
- magnetic field models,
- magnetospheric physics calculations,
- astronomy and celestial mechanics,
- mathematics,
- date calculations,
- control routines.

Chapters 1 to 4 refer to magnetospheric physics. Chapter 5 provides orbital mechanics tools for mission analysis. Chapter 6 collects all the mathematical routines used throughout the package that can also be used for more general purposes. Chapter 8 provides date calculations routines and Chapter 9 provides parameter control routines.

All the routines are independent of each other, but before starting any calculation, the constants must be determined and the matrix transformations must be updated (Starting Routines).

The routines VALFIX and INIGEOM or INIGEO1 or INIGEOMV (whatever needed) are mandatory.

Subroutine VALFIX provides necessary constants in the common /UTIL/: pi, dpi, rad, deg, pid, xmu, rayt.

Subroutines INIGEOM and INIGEOMV calculate the necessary transformations for each time.

Subroutine INIGEO1 calculates the necessary transformations for CLUSTER specific routines.

In all the routines angles are given in **radians** for input or output. In the magnetospheric physics we use now the **earth radius** as a standard unit of distance (1 earth radius = 6378,16 km).

# MAGLIB ROUTINES

## 1. STARTING ROUTINES

The "inigeo..." routines calculate all the useful rotation matrices and the different angles.

- inigeo1:** for CLUSTER spacecraft.  
These calculations are done for all epochs from January 2000 the 1<sup>st</sup> to December 2014 the 31<sup>st</sup>.
- inigeom:** Calculations are done for all epochs from January 2000 the 1<sup>st</sup> to December 2014 the 31<sup>st</sup>.
- inigeomv:** These calculations are done for all epochs from January 1945 the 1<sup>st</sup> to December 1999 the 31<sup>st</sup>.
- valfix:** initialize the different constants.

**When creating a program with MAGLIB, only one call to VALFIX routine is necessary, but each time update requires a call to INIGEO1, INIGEOM or INIGEOMV routine.**

## 1.1 INIGEO1

**Author:** CNES - JC KOSIK – December 2010

### **Purpose:**

This routine calculates all the rotation matrices and the different angles used in all calculation routines specific to CLUSTER spacecraft: tilt angle, orientation of the dipole axis, right ascension and declination of the Sun.

These calculations are done for all epochs from January 2000 the 1<sup>st</sup> to December 2014 the 31<sup>st</sup>.

### **Specifications:**

integer iyear, imonth, iday, ihour, imin, isec  
double precision djulc, year, alfag, tetdip, phidip, alfas, deltas, obliq  
double precision rig(3,3), rgi(3,3), rgdip(3,3), rdipg(3,3)  
double precision rgsm(3,3), rsmg(3,3)  
double precision tilt  
double precision rggsm(3,3), rgsmg(3,3), rmgsm(3,3), rgsmsm(3,3)  
double precision rise(3,3), rsei(3,3)  
integer ifail

**call inigeo1 (iyear, imonth, iday, ihour, imin, isec, year, djulc,**  
> **alfag, tetdip, phidip, alfas, deltas, obliq, rig, rgi, rgdip, rdipg,**  
> **rgsm, rsmg, tilt, rggsm, rgsmg, rmgsm, rgsmsm, rgse, rseg, rise, rsei,**  
> **rgsmi, ifail)**

### **Input parameters:**

iyear	year	(≥ 2000)
imonth	month	(1 to 12)
iday	day	(1 to 31)
ihour	hours	(0 to 23)
imin	minutes	(0 to 23)
isec	seconds	(0 to 59)

## Output parameters:

year	real epoch	(years and fractions)
djulg	julian CNES date	
alfag	right ascension of Greenwich	(radians)
tetdip	geocentric colatitude of the point where the dipole cuts the northern hemisphere	(radians)
phidip	geocentric longitude of the point where the dipole cuts the northern hemisphere	(radians)
alfas	right ascension of the Sun	(radians)
deltas	declination of the Sun	(radians)
obliq	ecliptic obliquity	(radians)
rig	transformation matrix (3,3) from the inertial coordinate system into the geocentric coordinate system	
rgi	transformation matrix (3,3) from the geocentric coordinate system into the inertial coordinate system	
rgdip	transformation matrix (3,3) from the geocentric coordinate system into the dipolar coordinate system	
rdipg	transformation matrix (3,3) from the dipolar coordinate system into the geocentric coordinate system	
rgsm	transformation matrix (3,3) from the geocentric coordinate system into the solar magnetic coordinate system	
rsmg	transformation matrix (3,3) from the solar magnetic coordinate system into the geocentric coordinate system	
tilt	tilt angle or geocentric latitude of the Sun	(radians)
rggsm	transformation matrix (3,3) from the geocentric coordinate system into the solar magnetospheric coordinate system	
rgsmg	transformation matrix (3,3) from the solar magnetospheric coordinate system into the geocentric coordinate system	
rsmgsm	transformation matrix (3,3) from the solar magnetic coordinate system into the solar magnetospheric coordinate system	
rgsmgm	transformation matrix (3,3) from the solar magnetospheric coordinate system into the solar magnetic coordinate system	
rgse	transformation matrix (3,3) from the geocentric coordinate system into the solar ecliptic coordinate system	
rseg	transformation matrix (3,3) from the solar ecliptic coordinate system into the geocentric coordinate system	
rise	transformation matrix (3,3) from the inertial coordinate system into the solar ecliptic coordinate system	
rsei	transformation matrix (3,3) from the solar ecliptic coordinate system into the inertial coordinate system	
ifail	return code	

**Remarks:**

ifail: 0 = no problem  
ifail: 1 = if year < 2000

**Called routines:**

julg	rogdip	roggsm	rogse	rogsm	roig	roise
rosmsg	solter10	solter05	solter00			

**Used by:**

users programs:

testdist2 testinige1



## 1.2 INIGEOM

**Author:** CNES - JC KOSIK – December 2010

### **Purpose:**

This routine calculates all the rotation matrices and the different angles used in all the calculation routines: tilt angle, orientation of the dipole axis, right ascension and declination of the Sun.

These calculations are done for all epochs from January 2000 the 1<sup>st</sup> to December 2014 the 31<sup>st</sup>.

### **Specifications:**

integer iyear, imonth, iday, ihour, imin, isec  
double precision year, alfag, tetdip, phidip, alfas, deltas  
double precision rig(3,3), rgi(3,3), rgdip(3,3), rdipg(3,3)  
double precision rgsm(3,3), rsmg(3,3)  
double precision tilt  
double precision rggsm(3,3), rgsmg(3,3), rgse(3,3), rseg(3,3)  
double precision rigsm(3,3), rgsmi(3,3)  
integer ifail

**call inigeom (iyear, imonth, iday, ihour, imin, isec, year,**  
> **alfag, tetdip, phidip, alfas, deltas, rig, rgi, rgdip, rdipg,**  
> **rgsm, rsmg, tilt, rggsm, rgsmg, rgse, rseg, rigsm, rgsmi, ifail)**

### **Input parameters:**

iyear	year	(≥ 2000)
imonth	month	(1 to 12)
iday	day	(1 to 31)
ihour	hours	(0 to 23)
imin	minutes	(0 to 23)
isec	seconds	(0 to 59)

## Output parameters:

year	real epoch	(years and fractions)
alfag	right ascension of Greenwich	(radians)
tetdip	geocentric colatitude of the point where the dipole cuts the northern hemisphere	(radians)
phidip	geocentric longitude of the point where the dipole cuts the northern hemisphere	(radians)
alfas	right ascension of the Sun	(radians)
deltas	declination of the Sun	(radians)
rig	transformation matrix (3,3) from the inertial coordinate system into the geocentric coordinate system	
rgi	transformation matrix (3,3) from the geocentric coordinate system into the inertial coordinate system	
rgdip	transformation matrix (3,3) from the geocentric coordinate system into the dipolar coordinate system	
rdipg	transformation matrix (3,3) from the dipolar coordinate system into the geocentric coordinate system	
rgsm	transformation matrix (3,3) from the geocentric coordinate system into the solar magnetic coordinate system	
rsmg	transformation matrix (3,3) from the solar magnetic coordinate system into the geocentric coordinate system	
tilt	tilt angle or geocentric latitude of the Sun	(radians)
rggsm	transformation matrix (3,3) from the geocentric coordinate system into the solar magnetospheric coordinate system	
rgsmg	transformation matrix (3,3) from the solar magnetospheric coordinate system to the geocentric coordinate system	
rgse	transformation matrix (3,3) from the geocentric coordinate system into the solar ecliptic coordinate system	
rseg	transformation matrix (3,3) from the solar ecliptic coordinate system into the geocentric coordinate system	
rigsm	transformation matrix (3,3) from the inertial coordinate system into the solar magnetospheric coordinate system	
rgsmi	transformation matrix (3,3) from the solar magnetospheric coordinate system into the inertial coordinate system	
ifail	return code	

## Remarks:

ifail: 0 = no problem  
ifail: 1 = if year < 2000

## Called routines:

rogdip roggsm rogse rogsm roig roigsm solter10  
solter05 solter00

**Used by:**

routines:

ctrlpos

users programs:

testbgsm testcoord testcorgm testdconj testdlgalp testeconj

testflgalp testgeog testinige testpconj testrad testsph

### 1.3 INIGEOMV

**Author:** CNES - JC KOSIK - January 1998

#### **Purpose:**

This routine calculates all the rotation matrices and the different angles used in all the calculation routines: tilt angle, orientation of the dipole axis, right ascension and declination of the Sun.

These calculations are done for all epochs from January 1945 the 1<sup>st</sup> to December 1999 the 31<sup>st</sup>.

#### **Specifications:**

integer iyear, imonth, iday, ihour, imin, isec  
double precision year, alfag, tetdip, phidip, alfas, deltas  
double precision rig(3,3), rgi(3,3), rgdip(3,3), rdipg(3,3)  
double precision rgsm(3,3), rsmg(3,3)  
double precision tilt  
double precision rggsm(3,3), rgsmg(3,3), rgse(3,3), rseg(3,3)  
double precision rigsm(3,3), rgsmi(3,3)  
integer ifail

**call inigeomv (iyear, imonth, iday, ihour, imin, isec, year,**  
> **alfag, tetdip, phidip, alfas, deltas, rig, rgi, rgdip, rdipg,**  
> **rgsm, rsmg, tilt, rggsm, rgsmg, rgse, rseg, rigsm, rgsmi, ifail)**

#### **Input parameters:**

iyear	year	(1945 ≤ iyear < 2000)
imonth	month	(1 to 12)
iday	day	(1 to 31)
ihour	hours	(0 to 23)
imin	minutes	(0 to 23)
isec	seconds	(0 to 59)

## Output parameters:

year	real epoch	(years and fractions)
alfag	right ascension of Greenwich	(radians)
tetdip	geocentric colatitude of the point where the dipole cuts the northern hemisphere	(radians)
phidip	geocentric longitude of the point where the dipole cuts the northern hemisphere	(radians)
alfas	right ascension of the Sun	(radians)
deltas	declination of the Sun	(radians)
rig	transformation matrix (3,3) from the inertial coordinate system into the geocentric coordinate system	
rgi	transformation matrix (3,3) from the geocentric coordinate system into the inertial coordinate system	
rgdip	transformation matrix (3,3) from the geocentric coordinate system into the dipolar coordinate system	
rdipg	transformation matrix (3,3) from the dipolar coordinate system into the geocentric coordinate system	
rgsm	transformation matrix (3,3) from the geocentric coordinate system into the solar magnetic coordinate system	
rsmg	transformation matrix (3,3) from the solar magnetic coordinate system into the geocentric coordinate system	
tilt	tilt angle or geocentric latitude of the Sun	
rggsm	transformation matrix (3,3) from the geocentric coordinate system into the solar magnetospheric coordinate system	
rgsmg	transformation matrix (3,3) from the solar magnetospheric coordinate system into the geocentric coordinate system	
rgse	transformation matrix (3,3) from the geocentric coordinate system into the solar ecliptic coordinate system	
rseg	transformation matrix (3,3) from the solar ecliptic coordinate system into the geocentric coordinate system	
rigsm	transformation matrix (3,3) from the inertial coordinate system into the solar magnetospheric coordinate system	
rgsmi	transformation matrix (3,3) from the solar magnetospheric coordinate system to the inertial coordinate system	
ifail	return code	

## Remarks:

ifail: 0 = no problem

ifail: 1 = if  $iyear < 1945$  or  $iyear \geq 2000$

## Called routines:

rogdip roggsm rogse rogsm roig roigsm solterv  
soltervo

**Used by:**

users programs:

testiniv testvdh

## 1.4 VALFIX

**Author:** CNES - JC KOSIK – December 2010

**Purpose:**

This routine initializes the different constants used by calculations.  
These numerical constants belong to the fortran "commons" named "util" and "util2".

**Specifications:**

integer ifail

**call valfix (ifail)**

**Input parameters:** none

**Output parameters:**

ifail          return code

**Remarks:**

ifail: useless

Common "util" is declared as follows:

double precision pi, dpi, rad, deg, pid, xmu, rayt

$$pi = \pi = \cos^{-1}(-1.d0)$$

$$dpi = 2\pi$$

$$deg = 180.d0 / \pi$$

$$rad = \pi / 180.d0$$

$$pid = \pi / 2.d0$$

$$xmu = 398600.5km^3 / s^2$$

$$rayt = 6378.137km$$

Common "util2" is declared as follows:

double precision rgmt

$$rgmt = 6371.2km$$

**Called routines:** none

**Used by:**

users programs: all users programs



## 2. COORDINATE TRANSFORMATIONS

This chapter contains 22 coordinate transformation routines in use in magnetospheric physics:

- dipgeo:** transforms the dipolar components of a vector into geocentric components.
- gcvgd:** transforms the geocentric coordinates of a point into geodetic coordinates.
- gdvgc:** transforms the geodetic coordinates of a point into geocentric coordinates.
- geodip:** transforms the geocentric components of a vector into dipolar components
- geogkm:** transforms the cartesian components of a vector into spherical components.
- geogsm:** transforms the geocentric components of a vector into solar magnetospheric components.
- georre:** transforms the geocentric cartesian components of a vector in kilometers into geocentric cartesian components in Earth units and into Earth spherical components.
- geose:** transforms the geocentric components of a vector into solar ecliptic components.
- geosm:** transforms the geocentric components of a vector into solar magnetic components.
- ggeom:** transforms the geocentric spherical coordinates of a point into geomagnetic coordinates.
- gsmgeo:** transforms the solar magnetospheric components of a vector into geocentric components.
- rogdip:** calculates the transformation matrix from the geocentric coordinate system to the dipolar coordinate system and the inverse matrix.
- roggsm:** calculates the transformation matrix from the geocentric coordinate system to the solar magnetospheric coordinate system and the inverse matrix.
- rogse:** calculates the transformation matrix from the geocentric coordinate system to the solar ecliptic coordinate system and the inverse matrix.
- rogsm:** calculates the transformation matrix from the geocentric coordinate system to the solar magnetic coordinate system and the inverse matrix.
- roig:** calculates the transformation matrix from the inertial coordinate system to the geocentric coordinate system and the inverse matrix.
- roigsm:** calculates the transformation matrix from the inertial coordinate system to the solar magnetospheric coordinate system and the inverse matrix.

- roise:** calculates the transformation matrix from the inertial coordinate system to the solar ecliptic coordinate system and the inverse matrix.
- rosmps:** calculates the transformation matrix from the solar magnetic coordinate system to the solar magnetospheric coordinate system and the inverse matrix.
- rovdh:** calculates the transformation matrix from the geocentric coordinate system into the field coordinate system and the inverse matrix.
- segeo:** transforms the solar ecliptic components of a vector into geocentric components.
- smgeo:** transforms the solar magnetic components of a vector into geocentric components.

Most of the transformations are time dependent as the orientation of the dipole with respect to the solar wind changes with the hours in the day and the day in the year. The time dependent transformation involves transformation matrices which are derived by calling INIGEOM, INIGEOMV or INIGEO1 routine.

## 2.1 DIPGEO

**Author:** CNES - JC KOSIK - January 1991

### **Purpose:**

This routine transforms the dipolar components of a vector into geocentric components.

### **Specifications:**

double precision rdipg(3,3)  
double precision xdip, ydip, zdip  
double precision xg, yg, zg  
integer ifail

**call dipgeo (rdipg, xdip, ydip, zdip, xg, yg, zg, ifail)**

### **Input parameters:**

rdipg	transformation matrix (3,3) from the dipolar coordinate system to the geocentric coordinate system	
xdip	x component in the dipolar coordinate system	(any unit)
ydip	y component in the dipolar coordinate system	(any unit)
zdip	z component in the dipolar coordinate system	(any unit)

### **Output parameters:**

xg	x component in the geocentric coordinate system	(same unit as input)
yg	y component in the geocentric coordinate system	(same unit as input)
zg	z component in the geocentric coordinate system	(same unit as input)
ifail	return code	

### **Remarks:**

ifail: useless

### **Called routines:**

promal

### **Used by:**

routines:  
conjdip

## 2.2 GCVGD

**Author:** CNES - JC KOSIK - January 1991

### **Purpose:**

This routine transforms the geocentric coordinates of a point into geodetic coordinates.

### **Specifications:**

double precision rr, dlatr  
double precision alt, dlatgr  
integer ifail

**call gcvgd (rr, dlatr, alt, dlatgr, ifail)**

### **Input parameters:**

rr	geocentric distance	(kilometers)
dlatr	geocentric latitude	(radians)

### **Output parameters:**

alt	altitude above geoid	(kilometers)
dlatgr	geodetic (geographic) latitude	(radians)
ifail	return code	

### **Remarks:**

ifail: useless

**Called routines:** none

### **Used by:**

routines:  
tgeogr

## 2.3 GDVGC

**Author:** CNES - JC KOSIK - January 1991

**Purpose:**

This routine transforms the geodetic coordinates of a point into geocentric coordinates.

**Specifications:**

double precision alt, dlatgr  
double precision rr, dlatr  
integer ifail

**call gdvgc (alt, dlatgr, rr, dlatr, ifail)**

**Input parameters:**

alt	altitude above geoid	(kilometers)
dlatgr	geodetic (geographic) latitude	(radians)

**Output parameters:**

rr	geocentric distance	(kilometers)
dlatr	geocentric latitude	(radians)
ifail	return code	

**Remarks:**

ifail: useless

**Called routines:** none

**Used by:** none

## 2.4 GEODIP

**Author:** CNES - JC KOSIK - January 1991

### **Purpose:**

This routine transforms the geocentric components of a vector into dipolar components.

### **Specifications:**

double precision rgdip(3,3)  
double precision xg, yg, zg  
double precision xdip, ydip, zdip  
integer ifail

**call geodip (rgdip, xg, yg, zg, xdip, ydip, zdip, ifail)**

### **Input parameters:**

rgdip	transformation matrix (3,3) from the geocentric coordinate system to the dipolar coordinate system	
xg	x component in the geocentric coordinate system	(any unit)
yg	y component in the geocentric coordinate system	(any unit)
zg	z component in the geocentric coordinate system	(any unit)

### **Output parameters:**

xdip	x component in the dipolar coordinate system	(same unit as input)
ydip	y component in the dipolar coordinate system	(same unit as input)
zdip	z component in the dipolar coordinate system	(same unit as input)
ifail	return code	

### **Remarks:**

ifail: useless

### **Called routines:**

promal

### **Used by:**

routines:  
    angdip    conj dip    ggeom    rogsm

## 2.5 GEOGKM

**Author:** CNES - JC KOSIK - January 1991

### **Purpose:**

This routine transforms the cartesian components of a vector into spherical components.

### **Specifications:**

double precision *xg*, *yg*, *zg*  
double precision *rr*, *dlatr*, *dlonr*  
integer *ifail*

**call geogkm (*xg*, *yg*, *zg*, *rr*, *dlatr*, *dlonr*, *ifail*)**

### **Input parameters:**

<i>xg</i>	x component in the geocentric coordinate system	(earth radii or kilometers)
<i>yg</i>	y component in the geocentric coordinate system	(earth radii or kilometers)
<i>zg</i>	z component in the geocentric coordinate system	(earth radii or kilometers)

### **Output parameters:**

<i>rr</i>	geocentric distance	(same unit as input)
<i>dlatr</i>	geocentric latitude	(radians)
<i>dlonr</i>	geocentric longitude	(radians)
<i>ifail</i>	return code	

### **Remarks:**

*ifail*: useless

### **Called routines:**

angleg

### **Used by:**

routines:  
tgeogr

## 2.6 GEOGSM

**Author:** CNES - JC KOSIK - June 1995

### **Purpose:**

This routine transforms the geocentric components of a vector into solar magnetospheric components.

### **Specifications:**

double precision rggsm(3,3)  
double precision xg, yg, zg  
double precision xgsm, ygsm, zgsm  
integer ifail

**call geogsm (rggsm, xg, yg, zg, xgsm, ygsm, zgsm, ifail)**

### **Input parameters:**

rggsm	transformation matrix (3,3) from the geocentric coordinate system to the solar magnetospheric coordinate system	
xg	x component in the geocentric coordinate system	(any unit)
yg	y component in the geocentric coordinate system	(any unit)
zg	z component in the geocentric coordinate system	(any unit)

### **Output parameters:**

xgsm	x component in the solar magnetospheric coordinate system	(same unit as input)
ygsm	y component in the solar magnetospheric coordinate system	(same unit as input)
zgsm	z component in the solar magnetospheric coordinate system	(same unit as input)
ifail	return code	

### **Remarks:**

ifail: useless

### **Called routines:**

promal



**Used by:**

routines:

bgsm geophys mpause outmal posmag tgeogr

users programs:

testcoord testinige testinige1 testmodel

## 2.7 GEORRE

**Author:** CNES - JC KOSIK - January 1991

### **Purpose:**

This routine transforms the geocentric cartesian components of a vector in kilometers into geocentric cartesian components in Earth units and into Earth spherical components. In both coordinates systems the distances are given in earth radii. (1 earth radius = 6378.16 kilometers).

### **Specifications:**

double precision xg, yg, zg  
double precision xre, yre, zre  
double precision rre, thetr, phir  
integer ifail

**call georre (xg, yg, zg, xre, yre, zre, rre, thetr, phir, ifail)**

### **Input parameters:**

xg	x component in the geocentric coordinate system	(kilometers)
yg	y component in the geocentric coordinate system	(kilometers)
zg	z component in the geocentric coordinate system	(kilometers)

### **Output parameters:**

xre	x component in the geocentric coordinate system	(earth radii)
yre	y component in the geocentric coordinate system	(earth radii)
zre	z component in the geocentric coordinate system	(earth radii)
rre	geocentric radial distance	(earth radii)
thetr	geocentric colatitude	(radians)
phir	geocentric longitude	(radians)
ifail	return code	

### **Remarks:**

ifail: useless

### **Called routines:**

carsp

### **Used by:**

routines:  
tgeogr

## 2.8 GEOSE

**Author:** CNES - JC KOSIK - January 1991

### **Purpose:**

This routine transforms the geocentric components of a vector into solar ecliptic components.

### **Specifications:**

double precision rgse(3,3)  
double precision xg, yg, zg  
double precision xgse, ygse, zgse  
integer ifail

**call geose (rgse, xg, yg, zg, xgse, ygse, zgse, ifail)**

### **Input parameters:**

rgse	transformation matrix (3,3) from the geocentric coordinate system to the solar ecliptic coordinate system	
xg	x component in the geocentric coordinate system	(any unit)
yg	y component in the geocentric coordinate system	(any unit)
zg	z component in the geocentric coordinate system	(any unit)

### **Output parameters:**

xgse	x component in the solar ecliptic coordinate system	(same unit as input)
ygse	y component in the solar ecliptic coordinate system	(same unit as input)
zgse	z component in the solar ecliptic coordinate system	(same unit as input)
ifail	return code	

### **Remarks:**

ifail: useless

### **Called routines:**

promal

**Used by:**

routines:

bgsm geophys posmag tgeogr

users programs:

testcoord testdist2 testinige testtinige1

## 2.9 GEOSM

**Author:** CNES - JC KOSIK - January 1991

### **Purpose:**

This routine transforms the geocentric components of a vector into solar magnetic components.

### **Specifications:**

double precision rgsm(3,3)  
double precision xg, yg, zg  
double precision xsm, ysm, zsm  
integer ifail

**call geosm (rgsm, xg, yg, zg, xsm, ysm, zsm, ifail)**

### **Input parameters:**

rgsm	transformation matrix (3,3) from the geocentric coordinate system to the solar magnetic coordinate system	
xg	x component in the geocentric coordinate system	(any unit)
yg	y component in the geocentric coordinate system	(any unit)
zg	z component in the geocentric coordinate system	(any unit)

### **Output parameters:**

xsm	x component in the solar magnetic coordinate system	(same unit as input)
ysm	y component in the solar magnetic coordinate system	(same unit as input)
zsm	z component in the solar magnetic coordinate system	(same unit as input)
ifail	return code	

### **Remarks:**

ifail: useless

### **Called routines:**

promal

**Used by:**

routines:

geophys tgml

users programs:

testdist2 testinige testinige1

## 2.10 GGEOM

**Author:** CNES - JC KOSIK - January 1991

### **Purpose:**

This routine transforms the geocentric spherical coordinates of a point into geomagnetic coordinates.

### **Specifications:**

double precision rgdip(3,3)  
double precision thetr, phir  
double precision xlatgm, xlongm  
integer ifail

**call ggeom (rgdip, thetr, phir, xlatgm, xlongm, ifail)**

### **Input parameters:**

rgdip	transformation matrix (3,3) from the geocentric coordinate system to the dipolar coordinate system	
thetr	geocentric colatitude	(radians)
phir	geocentric longitude	(radians)

### **Output parameters:**

xlatgm	geomagnetic latitude	(radians)
xlongm	geomagnetic longitude	(radians)
ifail	return code	

### **Remarks:**

ifail: useless

### **Called routines:**

carsp    geodip    spcar

### **Used by:**

routines:  
    calpos    posmag    tgeogr

## 2.11 GSMGEO

**Author:** CNES - JC KOSIK - January 1991

### **Purpose:**

This routine transforms the solar magnetospheric components of a vector into geocentric components.

### **Specifications:**

double precision rgsmg(3,3)  
double precision xgsm, ygsm, zgsm  
double precision xg, yg, zg  
integer ifail

**call gsmgeo (rgsmg, xgsm, ygsm, zgsm, xg, yg, zg, ifail)**

### **Input parameters:**

rgsmg	transformation matrix (3,3) from the solar magnetospheric coordinate system to the geocentric coordinate system	
xgsm	x component in the solar magnetospheric coordinate system	(any unit)
ygsm	y component in the solar magnetospheric coordinate system	(any unit)
zgsm	z component in the solar magnetospheric coordinate system	(any unit)

### **Output parameters:**

xg	x component in the geocentric coordinate system	(same unit as input)
yg	y component in the geocentric coordinate system	(same unit as input)
zg	z component in the geocentric coordinate system	(same unit as input)
ifail	return code	

### **Remarks:**

ifail: useless

### **Called routines:**

promal



**Used by:**

routines:

outma1

users programs:

testdist2

## 2.12 *ROGDIP*

**Author:** CNES - JC KOSIK - January 1991

### **Purpose:**

This routine calculates the transformation matrix from the geocentric coordinate system into the dipolar coordinate system and the inverse matrix.

### **Specifications:**

double precision tetdip, phidip  
double precision rgdip(3,3), rdipg(3,3)  
integer ifail

**call rogdip (tetdip, phidip, rgdip, rdipg, ifail)**

### **Input parameters:**

tetdip	geocentric colatitude of the point where the dipole cuts the northern hemisphere	(radians)
phidip	geocentric longitude of the point where the dipole cuts the northern hemisphere	(radians)

### **Output parameters:**

rgdip	transformation matrix (3,3) from the geocentric coordinate system into the dipolar coordinate system
rdipg	transformation matrix (3,3) from the dipolar coordinate system into the geocentric coordinate system
ifail	return code

### **Remarks:**

ifail: useless

**Called routines:** none

### **Used by:**

routines:  
inigeo1 inigeom inigeomv

## 2.13 ROGGSM

**Author:** CNES - JC KOSIK - January 1991

### **Purpose:**

This routine calculates the transformation matrix from the geocentric coordinate system into the solar magnetospheric coordinate system and the inverse matrix.

### **Specifications:**

double precision tilt, rgs<sub>m</sub>(3,3)  
double precision rgg<sub>m</sub>(3,3), rgs<sub>m</sub><sub>g</sub>(3,3)  
integer ifail

**call roggsm (tilt, rgs<sub>m</sub>, rgg<sub>m</sub>, rgs<sub>m</sub><sub>g</sub>, ifail)**

### **Input parameters:**

tilt	tilt angle or geomagnetic latitude of the Sun	(radians)
rgs <sub>m</sub>	transformation matrix (3,3) from the geocentric coordinate system into the solar magnetic coordinate system	

### **Output parameters:**

rgg <sub>m</sub>	transformation matrix (3,3) from the geocentric coordinate system into the solar magnetospheric coordinate system
rgs <sub>m</sub> <sub>g</sub>	transformation matrix (3,3) from the solar magnetospheric coordinate system into the geocentric coordinate system
ifail	return code

### **Remarks:**

ifail: useless

### **Called routines:**

promat

### **Used by:**

routines:  
inigeo1 inigeom inigeomv

## 2.14 ROGSE

**Author:** CNES - JC KOSIK - January 1991

### **Purpose:**

This routine calculates the transformation matrix from the geocentric coordinate system into the solar ecliptic coordinate system and the inverse matrix.

### **Specifications:**

double precision alfag, alfas, deltas, obliq  
double precision rgse(3,3), rseg(3,3)  
integer ifail

**call rogse (alfag, alfas, deltas, obliq, rgse, rseg, ifail)**

### **Input parameters:**

alfag	right ascension of Greenwich	(radians)
alfas	right ascension of the Sun	(radians)
deltas	declination of the Sun	(radians)
obliq	ecliptic obliquity	(radians)

### **Output parameters:**

rgse	transformation matrix (3,3) from the geocentric coordinate system into the solar ecliptic coordinate system
rseg	transformation matrix (3,3) from the solar ecliptic coordinate system into the geocentric coordinate system
ifail	return code

### **Remarks:**

ifail: useless

**Called routines:** none

### **Used by:**

routines:  
inigeo1 inigeom inigeomv

## 2.15 ROGSM

**Author:** CNES - JC KOSIK - January 1991

### **Purpose:**

This routine calculates the transformation matrix from the geocentric coordinate system into the solar magnetic coordinate system and the inverse matrix.

### **Specifications:**

double precision rgdip(3,3), alfag, alfas, deltas  
double precision rgsm(3,3), rsmg(3,3), tilt  
integer ifail

**call rogsm (rgdip, alfag, alfas, deltas, rgsm, rsmg, tilt, ifail)**

### **Input parameters:**

rgdip	transformation matrix (3,3) from the geocentric coordinate system into the dipolar coordinate system	
alfag	right ascension of Greenwich	(radians)
alfas	right ascension of the Sun	(radians)
deltas	declination of the Sun	(radians)

### **Output parameters:**

rgsm	transformation matrix (3,3) from the geocentric coordinate system into the solar magnetic coordinate system	
rsmg	transformation matrix (3,3) from the solar magnetic coordinate system into the geocentric coordinate system	
tilt	tilt angle or geomagnetic latitude of the Sun	(radians)
ifail	return code	

### **Remarks:**

ifail: useless

### **Called routines:**

geodip    promat

### **Used by:**

routines:  
inigeo1    inigeom    inigeomv

## 2.16 ROIG

**Author:** CNES - JC KOSIK - January 1991

### **Purpose:**

This routine calculates the transformation matrix from the inertial coordinate system into the geocentric coordinate system and the inverse matrix.

### **Specifications:**

double precision alfag  
double precision rig(3,3), rgi(3,3)  
integer ifail

**call roig (alfag, rig, rgi, ifail)**

### **Input parameters:**

alfag      right ascension of Greenwich      (radians)

### **Output parameters:**

rig      transformation matrix (3,3) from the inertial coordinate system  
         into the geocentric coordinate system  
rgi      transformation matrix (3,3) from the geocentric coordinate  
         system into the inertial coordinate system  
ifail     return code

### **Remarks:**

ifail: useless

**Called routines:** none

### **Used by:**

routines:  
    inigeo1    inigeom    inigeomv

## 2.17 ROIGSM

**Author:** CNES - JC KOSIK - January 1991

### **Purpose:**

This routine calculates the transformation matrix from the inertial coordinate system into the solar magnetospheric coordinate system and the inverse matrix.

### **Specifications:**

double precision rig(3,3), rggsm(3,3)  
double precision rigsm(3,3), rgsmi(3,3)  
integer ifail

**call roigsm (rig, rggsm, rigsm, rgsmi, ifail)**

### **Input parameters:**

rig            transformation matrix (3,3) from the inertial coordinate system  
                 into the geocentric coordinate system  
rggsm        transformation matrix (3,3) from the geocentric coordinate  
                 system into the solar magnetospheric coordinate system

### **Output parameters:**

rigsm        transformation matrix (3,3) from the inertial coordinate system  
                 into the solar magnetospheric coordinate system  
rgsmi        transformation matrix (3,3) from the solar magnetic coordinate  
                 system into the inertial coordinate system  
ifail        return code

### **Remarks:**

ifail: useless

### **Called routines:**

promat

### **Used by:**

routines:  
    inigeom    inigeomv

## 2.18 ROISE

**Author:** CNES - JC KOSIK - June 1995

### **Purpose:**

This routine calculates the transformation matrix from the inertial coordinate system into the solar ecliptic coordinate system and the inverse matrix.

### **Specifications:**

double precision alfas, deltas, obliq  
double precision rise(3,3), rsei(3,3)  
integer ifail

**call roise (alfas, deltas, obliq, rise, rsei, ifail)**

### **Input parameters:**

alfas	right ascension of the Sun	(radians)
deltas	declination of the Sun	(radians)
obliq	ecliptic obliquity	(radians)

### **Output parameters:**

rise	transformation matrix (3,3) from the inertial coordinate system into the solar ecliptic coordinate system
rsei	transformation matrix (3,3) from the solar ecliptic coordinate system into the inertial coordinate system
ifail	return code

### **Remarks:**

ifail: useless

**Called routines:** none

### **Used by:**

routines:  
inigeo1



## 2.19 ROSMGS

**Author:** CNES - JC KOSIK - June 1995

### **Purpose:**

This routine calculates the transformation matrix from the solar magnetic coordinate system into the solar magnetospheric coordinate system and the inverse matrix.

### **Specifications:**

double precision tilt  
double precision rsmgsm(3,3), rgsmsm(3,3)  
integer ifail

**call rosmgs (tilt, rsmgsm, rgsmsm, ifail)**

### **Input parameters:**

tilt            tilt angle or geomagnetic latitude of the Sun            (radians)

### **Output parameters:**

rsmgsm        transformation matrix (3,3) from the solar magnetic coordinate  
                 system into the solar magnetospheric coordinate system  
rgsmsm        transformation matrix (3,3) from the solar magnetospheric  
                 coordinate system into the solar magnetic coordinate system  
ifail           return code

### **Remarks:**

ifail: useless

**Called routines:** none

### **Used by:**

routines:  
    inigeo1

## 2.20 ROVDH

**Author:** CNES - JC KOSIK – December 2010

### **Purpose:**

This routine calculates the transformation matrix from the geocentric coordinate system into the field coordinate system and the inverse matrix..

### **Specifications:**

double precision year,rre,thetr,phir  
double precision rgvd(3,3), rvdhg(3,3)  
integer ifail

**call rovdh (year, rre, thetr, phir, rgvdh, rvdhg, ifail)**

### **Input parameters:**

year	real epoch	(years and fractions)
rre	geocentric radial distance	(earth radii)
thetr	geocentric colatitude	(radians)
phir	geocentric longitude	(radians)

### **Output parameters:**

rgvdh	transformation matrix (3,3) from the geocentric coordinate system into the field coordinate system
rvdhg	transformation matrix (3,3) from the field coordinate system into the geocentric coordinate system
ifail	return code

### **Remarks:**

ifail: useless

### **Called routines:**

angleg, igrf10, promat

### **Used by:**

users programs:  
testvdh

## 2.21 SEGEO

**Author:** CNES - JC KOSIK - January 1991

**Purpose:**

This routine transforms the solar ecliptic components of a vector into geocentric components.

**Specifications:**

double precision rseg(3,3)  
double precision xgse, ygse, zgse  
double precision xg, yg, zg  
integer ifail

**call segeo (rseg, xgse, ygse, zgse, xg, yg, zg, ifail)**

**Input parameters:**

rseg	transformation matrix (3,3) from the solar ecliptic coordinate system into the geocentric coordinate system	
xgse	x component in the solar ecliptic coordinate system	(any unit)
ygse	y component in the solar ecliptic coordinate system	(any unit)
zgse	z component in the solar ecliptic coordinate system	(any unit)

**Output parameters:**

xg	x component in the geocentric coordinate system	(same unit as input)
yg	y component in the geocentric coordinate system	(same unit as input)
zg	z component in the geocentric coordinate system	(same unit as input)
ifail	return code	

**Remarks:**

ifail: useless

**Called routines:**

promal

**Used by:** none

## 2.22 SMGEO

**Author:** CNES - JC KOSIK - January 1991

### **Purpose:**

This routine transforms the solar magnetic components of a vector into geocentric components.

### **Specifications:**

double precision rsmg(3,3)  
double precision xsm, ysm, zsm  
double precision xg, yg, zg  
integer ifail

**call smgeo (rsmg, xsm, ysm, zsm, xg, yg, zg, ifail)**

### **Input parameters:**

rsmg	transformation matrix (3,3) from the solar magnetic coordinate system into the geocentric coordinate system	
xsm	x component in the solar magnetic coordinate system	(any unit)
ysm	y component in the solar magnetic coordinate system	(any unit)
zsm	z component in the solar magnetic coordinate system	(any unit)

### **Output parameters:**

xg	x component in the geocentric coordinate system	(same unit as input)
yg	y component in the geocentric coordinate system	(same unit as input)
zg	z component in the geocentric coordinate system	(same unit as input)
ifail	return code	

### **Remarks:**

ifail: useless

### **Called routines:**

promal

**Used by:** none

### 3. BOUNDARIES AND REGIONS

This chapter describes 24 routines:

- aberrm:** corrects the aberration due to Earth motion. Aberration angle is set to 4.0 degrees.
- bwshff:** calculates if the spacecraft is inside the bow shock region (Fairfield model).
- cahsl:** calculates if the spacecraft is inside the shade of the Earth and in this case what is the distance between the spacecraft and the shade cylinder in kilometers.
- caldis:** calculates the distance of the spacecraft to the magnetopause or the bow shock boundary (CLUSTER) and takes into account the change in the solar wind pressure.
- calphi:** calculates the timezone that includes a given point. The two meridians are given by there longitude.
- calpol:** calculates if the spacecraft is inside the polar cap region.
- caltheta:** calculates the distances to the magnetosphere axis and the x solar ecliptic coordinates of a given time zone.
- chapel:** calculates if the spacecraft is inside the Chappell plasmasphere region.
- clusdis:** calculates the distances of the spacecraft to several boundaries.
- cusp:** calculates if the spacecraft is inside the cusp region.
- dchapp:** calculates the distance of the spacecraft to the plasmaspause.
- ddparab:** calculates the distance of the spacecraft to the magnetopause region as defined by the Shabansky type parabola.
- gussen:** tests if the spacecraft is inside the diffuse aurora region defined by Gussenhoven. It calculates the south boundary of the diffuse aurora region according to the Gussenhoven model for the magnetospheric activity:  $K_p = 3$ .
- mpause:** calculates if the spacecraft is inside the magnetosphere. The magnetopause boundary is defined by the Shabansky type parabola.
- mpsib:** calculates if the spacecraft is inside the Sibeck magnetopause region. Two medium values of the solar wind activity are used to calculate the internal and external boundaries.
- msheath:** calculates directly if the spacecraft is inside the magnetosheath region.
- olsdon:** returns the Olson's data corresponding to a given tilt angle.

- oval:** calculates if the spacecraft is inside the Feldstein aurora oval region.
- posmag:** calculates in which region of the magnetosphere is located the spacecraft. The near Earth region is divided in 15 regions, including the solar wind. The spacecraft geomagnetic local time, the Mac Ilwain L parameter and the geomagnetic parameters are calculated. The coordinates in several systems are also calculated.
- posns:** calculates the distance of the spacecraft to the neutral sheet along the Z solar magnetospheric direction (CLUSTER).
- posnsh:** calculates if the spacecraft is inside the neutral sheet and calculates the distance of the spacecraft to the neutral sheet along the Z solar magnetospheric direction (INTERBALL).
- posps:** calculates the position of the spacecraft with respect to the plasma sheet region (CLUSTER).
- pospsh:** calculates if the spacecraft is inside the plasma sheet region (INTERBALL).
- rbelt:** calculates if the spacecraft is inside the Van Allen radiation belt region.

### 3.1 ABERRM

**Author:** CNES - JC KOSIK - January 1991

**Purpose:**

Transforms a vector in the solar magnetospheric or ecliptic system into the aberrated solar magnetospheric or ecliptic system.

In the aberrated solar system, the x axis is rotated in the direction of the aberrated Sun. The aberration angle is 4 degrees.

**Specifications:**

double precision xgse, ygse, zgse  
double precision xgsa, ygsa, zgsa  
integer ifail

**call aberrm (xgse, ygse, zgse, xgsa, ygsa, zgsa, ifail)**

**Input parameters:**

xgse	x component in the solar magnetospheric or ecliptic coordinate system	(earth radii)
ygse	y component in the solar magnetospheric or ecliptic coordinate system	(earth radii)
zgse	z component in the solar magnetospheric or ecliptic coordinate system	(earth radii)

**Output parameters:**

xgsa	corrected x component in the aberrated solar magnetospheric or ecliptic coordinate system	(earth radii)
ygsa	corrected y component in the aberrated solar magnetospheric or ecliptic coordinate system	(earth radii)
zgsa	corrected z component in the aberrated solar magnetospheric or ecliptic coordinate system	(earth radii)
ifail	return code	

**Remarks:**

ifail: useless

**Called routines:** none

**Used by:**

routines:  
    bwshff    caldis    calphi    mpsib

## 3.2 BWSHFF

**Author:** CNES - JC KOSIK - January 1991

### **Purpose:**

This routine calculates if the spacecraft is inside the bow shock region according to Fairfield model (INTERBALL).

### **Specifications:**

double precision xgsm, ygsm, zgsm  
integer ibwsh  
integer ifail

**call bwshff (xgsm, ygsm, zgsm, ibwsh, ifail)**

### **Input parameters:**

xgsm	x coordinate in the solar magnetospheric system	(earth radii)
ygsm	y coordinate in the solar magnetospheric system	(earth radii)
zgsm	z coordinate in the solar magnetospheric system	(earth radii)

### **Output parameters:**

ibwsh	index indicating if the spacecraft is inside the bow shock region	(Fairfield model)
ifail	return code	

### **Remarks:**

ibwsh: 0 = the spacecraft is in the magnetosheath or in the magnetosphere  
ibwsh: 1 = the spacecraft is inside the bow shock region  
ibwsh: 2 = the spacecraft is outside the bow shock region, in the solar wind

ifail: useless

The spacecraft is considered as inside a box of finite size *delta*. When the bow shock crosses the square box, the spacecraft is considered in the bow shock region. When the square box is outside, the spacecraft is in the solar wind.

If the square box is under the bow shock, the spacecraft is in the magnetosheath or in the magnetosphere.

### **Called routines:**

aberrm



**Used by:**

routines:

msheath posmag

### 3.3 CAHSL

**Author:** CNES - JC KOSIK - January 1991

**Purpose:**

This routine calculates if the spacecraft is inside the shade of the Earth and in this case what is the distance between the spacecraft and the shade cylinder in kilometers.  
The spacecraft position is given in geocentric coordinates.

**Specifications:**

double precision alfag, alfas, deltas  
double precision rrs, thets, phis, hsl  
integer ihsl  
integer ifail

**call cahsl (alfag, alfas, deltas, rrs, thets, phis, hsl, ihsl, ifail)**

**Input parameters:**

alfag	right ascension of Greenwich	(radians)
alfas	right ascension of the Sun	(radians)
deltas	declination of the Sun	(radians)
rrs	geocentric radial distance	(earth radii)
thets	geocentric colatitude	(radians)
phis	geocentric longitude	(radians)

**Output parameters:**

hsl	height of the shade above the spacecraft when the spacecraft is in the shade	(kilometers)
ihsl	index indicating if the spacecraft is in the shade of the Earth	
ifail	return code	

**Remarks:**

ihsl: 1 = the spacecraft is inside the shade of the Earth  
ihsl: 0 = the spacecraft is outside the shade of the Earth (hsl is set to 999.)

ifail: useless.

**Called routines:** none

**Used by:**

routines:  
posmag

### 3.4 CALDIS

**Author:** CNES - JC KOSIK - June 1995

**Purpose:**

This routine calculates the distance of the spacecraft to the magnetopause or the bow shock boundary and takes into account the change in the solar wind pressure (CLUSTER).

**Specifications:**

integer ityp, isw  
double precision xgse, ygse, zgse  
double precision distby  
integer ifail

**call caldis (ityp, isw, xgse, ygse, zgse, distby, ifail)**

**Input parameters:**

ityp	boundary type	(1 or 2)
isw	solar wind variability	( $1 \leq isw \leq 5$ )
xgse	x coordinate in the solar ecliptic system	(earth radii)
ygse	y coordinate in the solar ecliptic system	(earth radii)
zgse	z coordinate in the solar ecliptic system	(earth radii)

**Output parameters:**

distby	distance to the magnetopause or the bow shock, negative under, positive above	(earth radii)
ifail	return code	

**Remarks:**

ityp: 1 = magnetopause (Sibeck model)  
ityp: 2 = bow shock (Fairfield model)

isw: defines the subsolar distance rb  
isw: 1: rb = 12.6 earth radii  
isw: 2: rb = 11.7 earth radii  
isw: 3: rb = 11. earth radii  
isw: 4: rb = 10. earth radii  
isw: 5: rb = 8.8 earth radii

ifail: useless

**Called routines:**

aberm

**Used by:**

routines:

clusdis

### 3.5 CALPHI

**Author:** CNES - JC KOSIK - October 2001

**Purpose:**

This routine calculates the time zone that includes a given point.  
The two meridians are given by there longitude.

**Specifications:**

double precision xgse, ygse, zgse  
double precision rgsa  
double precision thetd, phid  
integer ival  
double precision phi1, phi2  
integer ifail

**call calphi (xgse, ygse, zgse, rgsa, thetd, phid,  
> ival, phi1, phi2, ifail)**

**Input parameters:**

xgse	x coordinate in the solar ecliptic system	(earth radii)
ygse	y coordinate in the solar ecliptic system	(earth radii)
zgse	z coordinate in the solar ecliptic system	(earth radii)
rgsa	corrected solar component	
thetd	geocentric colatitude of the dipole	(degrees)
phid	geocentric longitude of the dipole	(degrees)

**Output parameters:**

ival	zone time number	
phi1	longitude of the first meridian	(degrees)
phi2	longitude of the second meridian	(degrees)
ifail	return code	

**Remarks:**

ifail: 0 = no problem  
ifail: 1 = thetd > 165. degrees

**Called routines:**

aberrm

**Used by:**

users programs:  
testolsdon

### 3.6 CALPOL

**Author:** CNES - JC KOSIK - January 1991

**Purpose:**

This routine calculates if the spacecraft is inside the polar cap region.  
The southern boundary of the polar cap is the northern boundary of the aurora oval.

**Specifications:**

double precision tgml, xlatgm  
integer ipol  
integer ifail

**call calpol (tgml, xlatgm, ipol, ifail)**

**Input parameters:**

tgml	geomagnetic local time of the conjugate point	(hours and fractions)
xlatgm	geomagnetic latitude of the conjugate point	(radians)

**Output parameters:**

ipol	index indicating if the spacecraft is inside the polar cap
ifail	return code

**Remarks:**

ipol: 1 = the spacecraft is inside the polar cap  
ipol: 0 = the spacecraft is outside the polar cap

ifail: useless

**Called routines:** none

**Used by:**

routines:  
posmag

### 3.7 CALTHETA

**Author:** CNES - JC KOSIK - October 2001

**Purpose:**

This routine calculates the distances to the magnetosphere axis and the x solar ecliptic coordinates of a given time zone.

**Specifications:**

integer ival  
double precision trc(13,12)  
double precision tro1(12), tro2(12)  
double precision txs1(12), txs2(12)  
integer ifail

**call caltheta (ival, trc, tro1, tro2, txs1, txs2, ifail)**

**Input parameters:**

ival	zone time number	
trc	Olson's data for the given point	(tens of earth radii)

**Output parameters:**

tro1	distances to the axis of the magnetosphere of the first meridian	(earth radii)
tro2	distances to the axis of the magnetosphere of the second meridian	(earth radii)
txs1	x coordinates of the first meridian in the solar ecliptic coordinate system	(earth radii)
txs2	x coordinates of the second meridian in the solar ecliptic coordinate system	(earth radii)
ifail	return code	

**Remarks:**

ifail: useless

**Called routines:** none

**Used by:**

users programs:  
testolsdon



### 3.8 CHAPEL

**Author:** CNES - JC KOSIK - January 1991

**Purpose:**

This routine calculates if the spacecraft is inside the Chappell plasmasphere region.

**Specifications:**

double precision tgl, xls  
integer ichapp  
integer ifail

**call chapel (tgl, xls, ichapp, ifail)**

**Input parameters:**

tgl	geomagnetic local time of the conjugate point	(hours and fractions)
xls	Mac Ilwain parameter L value	

**Output parameters:**

ichapp	index indicating if the spacecraft is inside the plasmasphere
ifail	return code

**Remarks:**

ichapp: 1 = the spacecraft is inside the plasmasphere  
ichapp: 0 = the spacecraft is outside the plasmasphere

ifail: useless

**Called routines:** none

**Used by:**

routines:  
posmag

### 3.9 CLUSDIS

**Author:** CNES - JC KOSIK - June 1995

**Purpose:**

This routine calculates the distances of the spacecraft to several boundaries.

**Specifications:**

integer isw  
double precision tilt  
double precision xsm, ysm, zsm, xgsm, ygsm, zgsm, xgse, ygse, zgse  
double precision dischap, dismp, disbwsh, dznsh, dzpshn, dzpshs  
integer ifail

**call clusdis (isw, tilt, xsm, ysm, zsm, xgsm, ygsm, zgsm, xgse,**  
> **ygse, zgse, dischap, dismp, disbwsh, dznsh,**  
> **dzpshn, dzpshs, ifail)**

**Input parameters:**

isw	solar wind variability	(1 ≤ isw ≤ 5)
tilt	tilt angle or geomagnetic latitude of the Sun	(radians)
xsm	x coordinate in the solar magnetic system	(earth radii)
ysm	y coordinate in the solar magnetic system	(earth radii)
zsm	z coordinate in the solar magnetic system	(earth radii)
xgsm	x coordinate in the solar magnetospheric system	(earth radii)
ygsm	y coordinate in the solar magnetospheric system	(earth radii)
zgsm	z coordinate in the solar magnetospheric system	(earth radii)
xgse	x coordinate in the solar ecliptic system	(earth radii)
ygse	y coordinate in the solar ecliptic system	(earth radii)
zgse	z coordinate in the solar ecliptic system	(earth radii)

**Output parameters:**

dischap	distance to the plasmasphere	(earth radii)
dismp	distance to the magnetopause, negative inside, positive outside	(earth radii)
disbwsh	distance to the bow shock, negative inside, positive outside	(earth radii)
dznsh	distance to the neutral sheet, negative under neutral sheet, positive above	(earth radii)
dzpshn	distance to the northern plasma sheet	(earth radii)
dzpshs	distance to the southern plasma sheet	(earth radii)
ifail	return code	

**Remarks:**

isw: defines the subsolar distance  $r_b$

isw: 1:  $r_b = 12.6$  earth radii

isw: 2:  $r_b = 11.7$  earth radii

isw: 3:  $r_b = 11.$  earth radii

isw: 4:  $r_b = 10.$  earth radii

isw: 5:  $r_b = 8.8$  earth radii

ifail: useless

**Called routines:**

caldis    dchapp    posns    posps

**Used by:**

users programs:

testdist2

### 3.10 CUSP

**Author:** CNES - JC KOSIK - January 1991

**Purpose:**

This routine calculates if the spacecraft is inside the cusp region.

**Specifications:**

double precision xlatgm, tgml  
integer icusp  
integer ifail

**call cusp (xlatgm, tgml, icusp, ifail)**

**Input parameters:**

xlatgm	geomagnetic latitude of the conjugate point	(radians)
tgml	geomagnetic local time of the conjugate point	(hours and fractions)

**Output parameters:**

icusp	index indicating if the spacecraft is inside the cusp region
ifail	return code

**Remarks:**

icusp: 1 = the spacecraft is inside the cusp region  
icusp: 0 = the spacecraft is outside the cusp region

ifail: useless

**Called routines:** none

**Used by:**

routines:  
posmag

### 3.11 DCHAPP

**Author:** CNES - JC KOSIK - June 1995

**Purpose:**

This routine calculates the distance of the spacecraft to the plasmopause.

**Specifications:**

double precision xsm, ysm, zsm  
double precision discha  
integer ifail

**call dchapp (xsm, ysm, zsm, discha, ifail)**

**Input parameters:**

xsm	x coordinate in the solar magnetic system	(earth radii)
ysm	y coordinate in the solar magnetic system	(earth radii)
zsm	z coordinate in the solar magnetic system	(earth radii)

**Output parameters:**

discha	distance to the plasmasphere	(earth radii)
ifail	return code	

**Remarks:**

ifail: useless

**Called routines:**

carsp    chapp2    tgml2

**Used by:**

routines:  
clusdis

### 3.12 DDPARAB

**Author:** CNES - JC KOSIK - January 1991

**Purpose:**

This routine calculates the distance of the spacecraft to the magnetopause region as defined by the Shabansky parabola.

**Specifications:**

double precision rb, x1, y1, z1  
double precision dd  
integer ifail

**call ddparab (rb, x1, y1, z1, dd, ifail)**

**Input parameters:**

rb	subsolar distance of the magnetopause	(earth radii)
x1	x coordinate in the solar ecliptic system	(earth radii)
y1	y coordinate in the solar ecliptic system	(earth radii)
z1	z coordinate in the solar ecliptic system	(earth radii)

**Output parameters:**

dd	shorter distance to the Shabansky type parabola magnetopause, negative inside, positive outside	(earth radii)
ifail	return code	

**Remarks:**

rb: subsolar distance of the magnetopause = 11. earth radii

ifail: useless

**Called routines:**

kardan

**Used by:**

users programs:  
testdist

### 3.13 GUSSEN

**Author:** CNES - JC KOSIK - January 1991

**Purpose:**

This routine calculates if the spacecraft is inside the diffuse aurora region defined by Gussenhoven.

The southern boundary of the diffuse aurora region is defined using the Gurrenhoven model for the magnetic activity  $K_p = 3$ .

**Specifications:**

double precision tgls, xinvla  
integer iguss  
integer ifail

**call gussen (tgls, xinvla, iguss, ifail)**

**Input parameters:**

tgls	geomagnetic local time of the conjugate point	(hours and fractions)
xinvla	invariant latitude	(radians)

**Output parameters:**

iguss	index indicating if the spacecraft is inside the diffuse aurora region
ifail	return code

**Remarks:**

iguss: 1 = the spacecraft is inside the diffuse aurora region  
iguss: 0 = the spacecraft is outside the diffuse aurora region

ifail: useless

**Called routines:** none

**Used by:**

routines:  
posmag

### 3.14 MPAUSE

**Author:** CNES - JC KOSIK - January 1991

**Purpose:**

This routine calculates if the spacecraft is inside the magnetosphere region (magnetopause boundary) as defined by the Shabansky type parabola.

**Specifications:**

double precision rb, rggsm(3,3), rre, thet, phi  
integer ipop  
integer ifail

**call mpause (rb, rggsm, rre, thet, phi, ipop, ifail)**

**Input parameters:**

rb	subsolar distance of the magnetopause	(earth radii)
rggsm	transformation matrix (3,3) from the geocentric coordinate system into the solar magnetospheric coordinate system	
rre	geocentric radial distance	(earth radii)
thet	geocentric colatitude	(radians)
phi	geocentric longitude	(radians)

**Output parameters:**

ipop	index indicating if the spacecraft is inside the magnetosphere (magnetopause boundary)
ifail	return code

**Remarks:**

rb: subsolar distance to the magnetopause = 11. earth radii

ipop: 0 = the spacecraft is inside the magnetosphere  
ipop: 2 = the spacecraft is outside the magnetosphere

ifail: useless

**Called routines:**

geogsm spcar



**Used by:**

routines:

corgm

ctrlpos

dconjr

econjr

pconjr

### 3.15 MPSIB

**Author:** CNES - JC KOSIK - January 1991

#### **Purpose:**

This routine calculates if the spacecraft is inside the Sibeck magnetopause region. Two mean values of the solar wind activity are used to calculate the internal and external boundaries (INTERBALL).

#### **Specifications:**

double precision xgsm, ygsm, zgsm  
integer imp  
integer ifail

**call mpsib (xgsm, ygsm, zgsm, imp, ifail)**

#### **Input parameters:**

xgsm	x coordinate in the solar magnetospheric system	(earth radii)
ygsm	y coordinate in the solar magnetospheric system	(earth radii)
zgsm	z coordinate in the solar magnetospheric system	(earth radii)

#### **Output parameters:**

imp	index indicating if the spacecraft is inside Sibeck magnetopause
ifail	return code

#### **Remarks:**

imp: 0 = the spacecraft is under the magnetopause, in the magnetosphere  
imp: 1 = the spacecraft is inside the magnetopause  
imp: 2 = the spacecraft is outside the magnetopause

ifail: useless

#### **Called routines:**

aberrm

#### **Used by:**

routines:  
msheath posmag

### 3.16 MSHEATH

**Author:** CNES - JC KOSIK - January 1991

**Purpose:**

This routine calculates directly if the spacecraft is inside the magnetosheath region.

**Specifications:**

double precision xgsm, ygsm, zgsm  
integer imagn, isheath, isolw  
integer ifail

**call msheath (xgsm, ygsm, zgsm, imagn, isheath, isolw, ifail)**

**Input parameters:**

xgsm	x coordinate in the solar magnetospheric system	(earth radii)
ygsm	y coordinate in the solar magnetospheric system	(earth radii)
zgsm	z coordinate in the solar magnetospheric system	(earth radii)

**Output parameters:**

imagn	index indicating if the spacecraft is inside the magnetosphere
isheath	index indicating if the spacecraft is inside the magnetosheath
isolw	index indicating if the spacecraft is inside the solar wind
ifail	return code

**Remarks:**

isheath: 1 = the spacecraft is inside the magnetosheath  
isheath: 0 = the spacecraft is outside the magnetosheath

isolw: 1 = the spacecraft is inside the solar wind  
isolw: 0 = the spacecraft is outside the solar wind

imagn: 1 = the spacecraft is inside the magnetosphere  
imagn: 0 = the spacecraft is outside the magnetosphere

ifail: useless

**Called routines:**

bwshff    mpsib

**Used by:**

routines:

posmag



### 3.18 OVAL

**Author:** CNES - JC KOSIK - January 1991

**Purpose:**

This routine calculates if the spacecraft is inside the Feldstein aurora oval region.

**Specifications:**

double precision tgml, xlatgm  
integer ioval  
integer ifail

**call oval (tgml, xlatgm, ioval, ifail)**

**Input parameters:**

tgml	geomagnetic local time of the conjugate point in the northern hemisphere	(hours and fractions)
xlatgm	geomagnetic latitude of the conjugate point in the northern hemisphere	(radians)

**Output parameters:**

ioval	index indicating if the spacecraft is inside the aurora oval region
ifail	return code

**Remarks:**

ioval: 1 = the spacecraft is inside the aurora oval region  
ioval: 0 = the spacecraft is outside the aurora oval region

ifail: useless

**Called routines:** none

**Used by:**

routines:  
posmag

### 3.19 POSMAG

**Author:** CNES - JC KOSIK - January 1991

**Purpose:**

This routine calculates in which region of the magnetosphere is located the spacecraft. The near Earth region is divided in 15 regions, including the solar wind. The spacecraft geomagnetic local time, the Mac Ilwain L parameter and the geomagnetic parameters are calculated. The coordinates in several systems are also calculated.

**Specifications:**

integer magout, isatex  
double precision year, rre, thetr, phir  
double precision alfag, alfas, deltas, tilt  
double precision rgsm(3,3), rggsm(3,3), rgsmg(3,3)  
double precision rgdip(3,3), rgse(3,3)  
double precision tetdip, phidip  
double precision xgsm, ygsm, zgsm, xgse, ygse, zgse  
double precision tgl, flg, tglc, hsl, xlamb  
double precision clatgm, clongm  
integer iposmg(15)  
double precision dist1, dist2, dznsh  
integer ifail

**call posmag (magout, isatex, year, rre, thetr, phir, alfag, alfas,  
> deltas, tilt, rgsm, rggsm, rgsmg, rgdip, rgse, tetdip,  
> phidip, xgsm, ygsm, zgsm, xgse, ygse, zgse, tgl, flg,  
> xlamb, tglc, hsl, clatgm, clongm, iposmg, ifail)**

### Input parameters:

magout	external magnetic field type	(from 0 to 2)
isatex	orbit type of the spacecraft	(1 or 2)
year	real epoch	(years and fractions)
rre	geocentric radial distance	(earth radii)
thetr	geocentric colatitude	(radians)
phir	geocentric longitude	(radians)
alfag	right ascension of Greenwich	(radians)
alfas	right ascension of the Sun	(radians)
deltas	declination of the Sun	(radians)
tilt	tilt angle or geomagnetic latitude of the Sun	(radians)
rgsm	transformation matrix (3,3) from the geocentric coordinate system into the solar magnetic coordinate system	
rggsm	transformation matrix (3,3) from the geocentric coordinate system into the solar magnetospheric coordinate system	
rgsmg	transformation matrix (3,3) from the solar magnetospheric coordinate system to the geocentric coordinate system	
rgdip	transformation matrix (3,3) from the geocentric coordinate system into the dipolar coordinate system	
rgse	transformation matrix (3,3) from the geocentric coordinate system into the solar ecliptic coordinate system	
tetdip	geocentric colatitude of the point where the dipole cuts the northern hemisphere	(radians)
phidip	geocentric longitude of the point where the dipole cuts the northern hemisphere	(radians)

### Output parameters:

xgsm	x coordinate in the solar magnetospheric system	(earth radii)
ygsm	y coordinate in the solar magnetospheric system	(earth radii)
zgsm	z coordinate in the solar magnetospheric system	(earth radii)
xgse	x coordinate in the solar ecliptic system	(earth radii)
ygse	y coordinate in the solar ecliptic system	(earth radii)
zgse	z coordinate in the solar ecliptic system	(earth radii)
tgl	geomagnetic local time	(hours and fractions)
flg	Mac Ilwain L parameter	(Galperin's method)
xlamb	invariant latitude	(radians)
tglc	geomagnetic local time of the conjugate point in the same hemisphere	(hours and fractions)
hsl	height of the shade above the spacecraft	(kilometers)
clatgm	geomagnetic latitude of conjugate point on Earth	(radians)
clongm	geomagnetic longitude of conjugate point on Earth	(radians)
iposmg	array of 15 indexes indicating the location of the spacecraft in each region	
ifail	return code	



## Remarks:

magin: 3 = IGRF 2005

magout: 0 = no external field

magout: 1 = Tsyganenko 87 field

magout: 2 = Tsyganenko 89 field, indgm = 1, (Kpindex), indval = 3 (mean geomagnetic activity)

isatex: 0 = apogee < 8. earth radii

isatex: 1 = apogee > 8. earth radii

iposmg: 1 = spacecraft belongs to region

iposmg: 0 = spacecraft doesn't belong to region

iposmg(1): polar cap region

iposmg(2): aurora oval region

iposmg(3): cusp region

iposmg(4): diffuse aurora region

iposmg(5): Van Allen belt region for xbelt = 6. earth radii

iposmg(6): plasmasphere region

iposmg(7): neutral sheet region

iposmg(8): plasma sheet region

iposmg(9): magnetosphere region

iposmg(10): magnetopause region

iposmg(11): magnetosheath region

iposmg(12): bow shock region

iposmg(13): solar wind region

iposmg(14): shade of Earth region

iposmg(15): Van Allen belt region for xbelt = 3.5 earth radii

ifail: useless

This routine was used for INTERBALL. The bow shock and the magnetopause regions have probabilistic revue: when iposmg = 1, the probability to encounter the bow shock or the magnetopause is great.

## Called routines:

bwshff	cahsl	calpol	chapel	cusp	dconjr	geogsm
geose	ggeom	gussen	invar	invlat	mpsib	msh Heath
oval	posnsh	pospsh	rbelt	spcar	tgml	

## Used by:

users programs:

testrad test sph

### 3.20 POSNS

**Author:** CNES - JC KOSIK - June 1995

**Purpose:**

This routine calculates the distance of the spacecraft to the neutral sheet along the Z solar magnetospheric direction (CLUSTER).

**Specifications:**

double precision tilt  
double precision xgsm, ygsm, zgsm  
double precision dznsh  
integer ifail

**call posns (tilt, xgsm, ygsm, zgsm, dznsh, ifail)**

**Input parameters:**

tilt	tilt angle or geomagnetic latitude of the Sun	(radians)
xgsm	x coordinate in the solar magnetospheric system	(earth radii)
ygsm	y coordinate in the solar magnetospheric system	(earth radii)
zgsm	z coordinate in the solar magnetospheric system	(earth radii)

**Output parameters:**

dznsh	distance to the neutral sheet along the Z solar magnetospheric direction, negative under neutral sheet, positive above	(earth radii)
ifail	return code	

**Remarks:**

ifail: useless

The Fairfield neutral sheet model is used.

The width of the neutral sheet is one geocentric earth radius.

**Called routines:** none

**Used by:**

routines:  
clusdis

### 3.21 POSNSH

**Author:** CNES - JC KOSIK - January 1991

**Purpose:**

This routine calculates if the spacecraft is inside the neutral sheet and calculates the distance of the spacecraft to the neutral sheet along the Z solar magnetospheric direction.

**Specifications:**

double precision tilt  
double precision xgsm, ygsm, zgsm  
integer insh  
double precision dznsh  
integer ifail

**call posnsh (tilt, xgsm, ygsm, zgsm, insh, dznsh, ifail)**

**Input parameters:**

tilt	tilt angle or geomagnetic latitude of the Sun	(radians)
xgsm	x coordinate in the solar magnetospheric system	(earth radii)
ygsm	y coordinate in the solar magnetospheric system	(earth radii)
zgsm	z coordinate in the solar magnetospheric system	(earth radii)

**Output parameters:**

insh	index indicating if the spacecraft is inside or above the neutral sheet	
dznsh	distance to the neutral sheet along the Z solar magnetospheric direction, negative under the neutral sheet, positive above	(earth radii)
ifail	return code	

**Remarks:**

insh: 1 = if  $y \geq y_0$ ,  $y_0 = 15$  earth radii  
insh: 0 = in other cases

ifail: useless

The Fairfield neutral sheet model is used.

The width of the neutral sheet is one geocentric earth radius.

**Called routines:** none

**Used by:**

routines:

posmag

## 3.22 POSPS

**Author:** CNES - JC KOSIK - June 1995

### **Purpose:**

This routine calculates the position of the spacecraft with respect to the plasma sheet region along the Z solar magnetospheric direction.

### **Specifications:**

double precision tilt  
double precision xgsm, ygsm, zgsm  
double precision dzpshn, dzpshs  
integer ifail

**call posps (tilt, xgsm, ygsm, zgsm, dzpshn, dzpshs, ifail)**

### **Input parameters:**

tilt	tilt angle or geomagnetic latitude of the Sun	(radians)
xgsm	x coordinate in the solar magnetospheric system	(earth radii)
ygsm	y coordinate in the solar magnetospheric system	(earth radii)
zgsm	z coordinate in the solar magnetospheric system	(earth radii)

### **Output parameters:**

dzpshn	distance with respect to the northern plasma sheet	(earth radii)
dzpshs	distance with respect to the southern plasma sheet	(earth radii)
ifail	return code	

### **Remarks:**

ifail: useless

The Dandouras neutral sheet model is used.

The spacecraft shall be in the neutral sheet.

The northern and southern boundaries of the plasma sheet are defined with respect to the neutral sheet and the distance is calculated along the Z solar magnetospheric direction.

**Called routines:** none

**Used by:**

  routines:

    clusdis

### 3.23 POSPSH

**Author:** CNES - JC KOSIK - January 1991

**Purpose:**

This routine calculates if the spacecraft is inside the plasma sheet region.

**Specifications:**

double precision tilt  
double precision xgsm, ygsm, zgsm  
integer ipsh  
integer ifail

**call pospsh (tilt, xgsm, ygsm, zgsm, ipsh, ifail)**

**Input parameters:**

tilt	tilt angle or geomagnetic latitude of the Sun	(radians)
xgsm	x coordinate in the solar magnetospheric system	(earth radii)
ygsm	y coordinate in the solar magnetospheric system	(earth radii)
zgsm	z coordinate in the solar magnetospheric system	(earth radii)

**Output parameters:**

ipsh	index indicating if the spacecraft is inside the plasma sheet
ifail	return code

**Remarks:**

ipsh: 1 = the spacecraft is inside the plasma sheet  
ipsh: 0 = the spacecraft is outside the plasma sheet

ifail: useless

The Dandouras neutral sheet model is used.

The spacecraft shall be in the neutral sheet.

The northern and southern boundaries of the plasma sheet are defined with respect to the neutral sheet and the Z solar magnetospheric direction is tested.

**Called routines:** none

**Used by:**

routines:

posmag



### 3.24 RBELT

**Author:** CNES - JC KOSIK - January 1991

**Purpose:**

This routine calculates if the spacecraft is inside the Van Allen radiation belt region.

**Specifications:**

double precision xbelt, tetdip, phidip, rmag, thetr, phir  
integer iallen  
integer ifail

**call rbelt (xbelt, tetdip, phidip, rmag, thetr, phir, iallen, ifail)**

**Input parameters:**

xbelt	L outer belt boundary limit: $xbelt = +3.5$ or $xbelt = +6$	(earth radii)
tetdip	geocentric colatitude of the point where the dipole cuts the northern hemisphere	(radians)
phidip	geocentric longitude of the point where the dipole cuts the northern hemisphere	(radians)
rmag	geocentric radial distance	(earth radii)
thetr	geocentric colatitude	(radians)
phir	geocentric longitude	(radians)

**Output parameters:**

iallen	index indicating if the spacecraft is inside the Van Allen radiation belt region
ifail	return code

**Remarks:**

The shape of the outer boundary is assumed dipolar and defined by its L parameter.

iallen: 1 = the spacecraft is inside the Van Allen radiation belt  
iallen: 0 = the spacecraft is outside the Van Allen radiation belt

ifail: useless

**Called routines:** none

**Used by:**

routines:  
posmag

## 4. INTERNAL MAGNETIC FIELD MODELS

In this part have been collected various models of the internal magnetic field of the Earth. The tilted dipole model is based on the first three harmonics of the IGRF10 model which contains coefficients defined for epoch 2010. The GSFC65 model contains the coefficients which were used by Mc Ilwain to calculate the B-L coordinate system.

This chapter describes 24 routines:

- chp10:** calculates the magnetic field components for epochs  $\geq 2010$ .
- chp05:** calculates the magnetic field components for epochs  $\geq 2005$ .
- chp00:** calculates the magnetic field components for epochs  $\geq 2000$ .
- chp95:** calculates the magnetic field components for epochs  $\geq 1995$ .
- chp95\_10:** calculates the magnetic field for all epochs between 1995 and 2010.
- chp70\_95:** calculates the magnetic field for all epochs between 1970 and 1995.
- chp45\_70:** calculates the magnetic field for all epochs between 1945 and 1970.
  
- igrf10:** calculates the internal magnetic field components of the IGRF10 model.
- dgrf05:** calculates the internal magnetic field components of the DGRF05 model.
- dgrf00:** calculates the internal magnetic field components of the DGRF00 model.
- dgrf95:** calculates the internal magnetic field components of the DGRF95 model.
- igrf95\_10:** calculates the internal magnetic field components between 1995 and 2010.
- dgrf70\_95:** calculates the internal magnetic field components between 1970 and 1995.
- dgrf45\_70:** calculates the internal magnetic field components between 1945 and 1970.
  
- grad10:** calculates the internal magnetic field components of the IGRF 10 model and the nine associated gradients.
- grad05:** calculates the internal magnetic field components of the DGRF 05 model and the nine associated gradients.
- grad00:** calculates the internal magnetic field components of the DGRF00 model and the nine associated gradients.
- grad95:** calculates the internal magnetic field components of the DGRF95 model and the nine associated gradients.

- dipol:** calculates the magnetic field of a tilted dipole. The dipole orientation is given by g11 and h11 coefficients of the IGRF10 magnetic field.
- dipols:** calculates the dipolar field and its components in a cartesian coordinate system.
- gsfc65:** calculates the Earth magnetic field components of the Hendricks and Cain 1965 model.
- incline:** updates the components and calculates the ginc10 module of the tilted dipole and the tilted dipole orientation.
- vs\_chp:** calculates the secular variations of the CHP05 or CHP10 coefficients
- vs\_igrf:** calculates the secular variations of the DGRF05 or IGRF10 coefficients

## 4.1 CHP10

**Author:** updated from CNES - JC KOSIK – December 2010

### **Purpose:**

This routine calculates the magnetic field components from 2010 to 2015.

### **Specifications:**

double precision year, rre, thetr, phir  
double precision br, bt, bp, bb  
integer ifail

**call chp10 (year, rre, thetr, phir, br, bt, bp, bb, ifail)**

### **Input parameters:**

year	real epoch ( $\geq 2010$ .)	(years and fractions)
rre	geocentric radial distance	(earth radii)
thetr	geocentric colatitude	(radians)
phir	geocentric longitude	(radians)

### **Output parameters:**

br	magnetic field radial component along the meridian, positive outwards	(gauss)
bt	magnetic field tangential component along the meridian, positive southwards	(gauss)
bp	magnetic field eastward component, positive eastwards	(gauss)
bb	magnetic field modulus	(gauss)
ifail	return code	

### **Remarks:**

ifail: useless

**Called routines:** none

### **Used by:**

users programs:  
testchp10

## 4.2 CHP05

**Author:** updated from CNES - JC KOSIK – December 2010

### **Purpose:**

This routine calculates the magnetic field components from 2005 to 2010.

### **Specifications:**

double precision year, rre, thetr, phir  
double precision br, bt, bp, bb  
integer ifail

**call chp05 (year, rre, thetr, phir, br, bt, bp, bb, ifail)**

### **Input parameters:**

year	real epoch ( $\geq 2005$ .)	(years and fractions)
rre	geocentric radial distance	(earth radii)
thetr	geocentric colatitude	(radians)
phir	geocentric longitude	(radians)

### **Output parameters:**

br	magnetic field radial component along the meridian, positive outwards	(gauss)
bt	magnetic field tangential component along the meridian, positive southwards	(gauss)
bp	magnetic field eastward component, positive eastwards	(gauss)
bb	magnetic field modulus	(gauss)
ifail	return code	

### **Remarks:**

ifail: useless

**Called routines:** none

### **Used by:**

users programs:  
testchp05

### 4.3 CHP00

**Author:** updated from CNES - JC KOSIK – December 2010

**Purpose:**

This routine calculates the magnetic field components after 2000.

**Specifications:**

double precision year, rre, thetr, phir  
double precision br, bt, bp, bb  
integer ifail

**call chp00 (year, rre, thetr, phir, br, bt, bp, bb, ifail)**

**Input parameters:**

year	real epoch ( $\geq 2000.$ )	(years and fractions)
rre	geocentric radial distance	(earth radii)
thetr	geocentric colatitude	(radians)
phir	geocentric longitude	(radians)

**Output parameters:**

br	magnetic field radial component along the meridian, positive outwards	(gauss)
bt	magnetic field tangential component along the meridian, positive southwards	(gauss)
bp	magnetic field eastward component, positive eastwards	(gauss)
bb	magnetic field modulus	(gauss)
ifail	return code	

**Remarks:**

ifail: useless

**Called routines:** none

**Used by:**

users programs:  
testchp00

## 4.4 CHP95

**Author:** CNES - JC KOSIK - January 1991

### **Purpose:**

This routine calculates the magnetic field components after 1995.

### **Specifications:**

double precision year, rre, thetr, phir  
double precision br, bt, bp, bb  
integer ifail

**call chp95 (year, rre, thetr, phir, br, bt, bp, bb, ifail)**

### **Input parameters:**

year	real epoch ( $\geq 1995.$ )	(years and fractions)
rre	geocentric radial distance	(earth radii)
thetr	geocentric colatitude	(radians)
phir	geocentric longitude	(radians)

### **Output parameters:**

br	magnetic field radial component along the meridian, positive outwards	(gauss)
bt	magnetic field tangential component along the meridian, positive southwards	(gauss)
bp	magnetic field eastward component, positive eastwards	(gauss)
bb	magnetic field modulus	(gauss)
ifail	return code	

### **Remarks:**

ifail: useless

**Called routines:** none

### **Used by:**

users programs:  
testchp95

## 4.5 CHP95\_10

**Author:** updated from CNES - JC KOSIK – December 2010

### **Purpose:**

This routine calculates the magnetic field for all epochs between 1995 and 2010.

### **Specifications:**

double precision year, rre, thetr, phir  
double precision br, bt, bp, bb  
integer ifail

**call chp95\_10 (year, rre, thetr, phir, br, bt, bp, bb, ifail)**

### **Input parameters:**

year	epoch ( $1995 \leq \text{year} < 2010$ )	(years and fractions)
rre	geocentric radial distance	(earth radii)
thetr	geocentric colatitude	(radians)
phir	geocentric longitude	(radians)

### **Output parameters:**

br	magnetic field radial component along the meridian, positive outwards	(gauss)
bt	magnetic field tangential component along the meridian, positive southwards	(gauss)
bp	magnetic field eastward component, positive eastwards	(gauss)
bb	magnetic field modulus	(gauss)
ifail	return code	

### **Remarks:**

ifail: useless

**Called routines:** none

### **Used by:**

users programs:  
testdgn95\_10



## 4.6 CHP70\_95

**Author:** CNES - JC KOSIK - January 1991

### **Purpose:**

This routine calculates the magnetic field for all epochs between 1970 and 1995.

### **Specifications:**

double precision year, rre, thetr, phir  
double precision br, bt, bp, bb  
integer ifail

**call chp70\_95 (year, rre, thetr, phir, br, bt, bp, bb, ifail)**

### **Input parameters:**

year	epoch ( $1970 \leq \text{year} < 1995$ )	(years and fractions)
rre	geocentric radial distance	(earth radii)
thetr	geocentric colatitude	(radians)
phir	geocentric longitude	(radians)

### **Output parameters:**

br	magnetic field radial component along the meridian, positive outwards	(gauss)
bt	magnetic field tangential component along the meridian, positive southwards	(gauss)
bp	magnetic field eastward component, positive eastwards	(gauss)
bb	magnetic field modulus	(gauss)
ifail	return code	

### **Remarks:**

ifail: useless

**Called routines:** none

### **Used by:**

users programs:  
testdgn

## 4.7 CHP45\_70

**Author:** CNES - JC KOSIK - January 1991

### **Purpose:**

This routine calculates the magnetic field for all epochs between 1945 and 1970.

### **Specifications:**

double precision year, rre, thetr, phir  
double precision br, bt, bp, bb  
integer ifail

**call chp45\_70 (year, rre, thetr, phir, br, bt, bp, bb, ifail)**

### **Input parameters:**

year	real epoch ( $1945 < \text{year} \leq 1970$ )	(years and fractions)
rre	geocentric radial distance	(earth radii)
thetr	geocentric colatitude	(radians)
phir	geocentric longitude	(radians)

### **Output parameters:**

br	magnetic field radial component along the meridian, positive outwards	(gauss)
bt	magnetic field tangential component along the meridian, positive southwards	(gauss)
bp	magnetic field eastward component, positive eastwards	(gauss)
bb	magnetic field modulus	(gauss)
ifail	return code	

### **Remarks:**

ifail: useless

**Called routines:** none

### **Used by:**

users programs:  
testdgn2

## 4.8 IGRF10

**Author:** updated from CNES - JC KOSIK – December 2010

### **Purpose:**

This routine calculates the magnetic field components for epochs between 2010 to 2015.

### **Specifications:**

double precision year, rre, thet, phi  
double precision br, bt, bp, bb  
integer ifail

**call igrf10 (year, rre, thet, phi, br, bt, bp, bb, ifail)**

### **Input parameters:**

year	real epoch ( $\geq 2010.$ )	(years and fractions)
rre	geocentric radial distance	(earth radii)
thet	geocentric colatitude	(radians)
phi	geocentric longitude	(radians)

### **Output parameters:**

br	magnetic field radial component along the meridian, positive outwards	(gauss)
bt	magnetic field tangential component along the meridian, positive southwards	(gauss)
bp	magnetic field eastward component positive eastwards	(gauss)
bb	magnetic field modulus	(gauss)
ifail	return code	

### **Remarks:**

ifail: useless

**Called routines:** none

### **Used by:**

users programs:  
testchp10 testgrad10

## 4.9 DGRF05

**Author:** updated from CNES - JC KOSIK – December 2010

### **Purpose:**

This routine calculates the magnetic field components for epochs between 2005 to 2010.

### **Specifications:**

double precision year, rre, thet, phi  
double precision br, bt, bp, bb  
integer ifail

**call dgrf05 (year, rre, thet, phi, br, bt, bp, bb, ifail)**

### **Input parameters:**

year	real epoch ( $\geq 2005$ .)	(years and fractions)
rre	geocentric radial distance	(earth radii)
thet	geocentric colatitude	(radians)
phi	geocentric longitude	(radians)

### **Output parameters:**

br	magnetic field radial component along the meridian, positive outwards	(gauss)
bt	magnetic field tangential component along the meridian, positive southwards	(gauss)
bp	magnetic field eastward component positive eastwards	(gauss)
bb	magnetic field modulus	(gauss)
ifail	return code	

### **Remarks:**

ifail: useless

**Called routines:** none

### **Used by:**

users programs:  
testchp05 testgrad05

## 4.10 DGRF00

**Author:** updated from CNES - JC KOSIK – December 2010

### **Purpose:**

This routine calculates the magnetic field components for epochs between 2000 to 2005.

### **Specifications:**

double precision year, rre, thet, phi  
double precision br, bt, bp, bb  
integer ifail

**call dgrf00 (year, rre, thet, phi, br, bt, bp, bb, ifail)**

### **Input parameters:**

year	real epoch ( $\geq 2000.$ )	(years and fractions)
rre	geocentric radial distance	(earth radii)
thet	geocentric colatitude	(radians)
phi	geocentric longitude	(radians)

### **Output parameters:**

br	magnetic field radial component along the meridian, positive outwards	(gauss)
bt	magnetic field tangential component along the meridian, positive southwards	(gauss)
bp	magnetic field eastward component positive eastwards	(gauss)
bb	magnetic field modulus	(gauss)
ifail	return code	

### **Remarks:**

ifail: useless

**Called routines:** none

### **Used by:**

users programs:  
testchp00 testgrad00

## 4.11 DGRF95

**Author:** CNES - JC KOSIK - July 1995

### **Purpose:**

This routine calculates the magnetic field components for epochs between 1995 to 2000.

### **Specifications:**

double precision year, rre, thet, phi  
double precision br, bt, bp, bb  
integer ifail

**call dgrf95 (year, rre, thet, phi, br, bt, bp, bb, ifail)**

### **Input parameters:**

year	real epoch ( $\geq 1995$ .)	(years and fractions)
rre	geocentric radial distance	(earth radii)
thet	geocentric colatitude	(radians)
phi	geocentric longitude	(radians)

### **Output parameters:**

br	magnetic field radial component along the meridian, positive outwards	(gauss)
bt	magnetic field tangential component along the meridian, positive southwards	(gauss)
bp	magnetic field eastward component positive eastwards	(gauss)
bb	magnetic field modulus	(gauss)
ifail	return code	

### **Remarks:**

ifail: useless

**Called routines:** none

### **Used by:**

routines:  
    inmag  
users programs:  
    testchp95 testgrad95

## 4.12 IGRF95\_10

**Author:** from CNES - JC KOSIK – December 2010

### **Purpose:**

This routine calculates the magnetic field for all epochs between 1995 and 2010.

### **Specifications:**

double precision year, rre, thet, phi  
double precision br, bt, bp, bb  
integer ifail

**call igrf95\_10 (year, rre, thet, phi, br, bt, bp, bb, ifail)**

### **Input parameters:**

year	real epoch ( $1995 \leq \text{year} < 2010$ )	(years and fractions)
rre	geocentric radial distance	(earth radii)
thet	geocentric colatitude counted from the north pole	(radians)
phi	geocentric longitude positive eastwards from 0 to $2\pi$	(radians)

### **Output parameters:**

br	magnetic field radial component along the meridian, positive outwards	(gauss)
bt	magnetic field tangential component along the meridian, positive southwards	(gauss)
bp	magnetic field eastward component, positive eastwards	(gauss)
bb	magnetic field modulus	(gauss)
ifail	return code	

### **Remarks:**

ifail: useless

**Called routines:** none

### **Used by:**

users programs:  
testdgn95\_10

### 4.13 DGRF70\_95

**Author:** CNES - JC KOSIK - January 1996

**Purpose:**

This routine calculates the magnetic field for all epochs between 1970 and 1995.

**Specifications:**

double precision year, rre, thet, phi  
double precision br, bt, bp, bb  
integer ifail

**call dgrf70\_95 (year, rre, thet, phi, br, bt, bp, bb, ifail)**

**Input parameters:**

year	real epoch ( $1970 < \text{year} \leq 1995$ )	(years and fractions)
rre	geocentric radial distance	(earth radii)
thet	geocentric colatitude counted from the north pole	(radians)
phi	geocentric longitude positive eastwards from 0 to $2\pi$	(radians)

**Output parameters:**

br	magnetic field radial component along the meridian, positive outwards	(gauss)
bt	magnetic field tangential component along the meridian, positive southwards	(gauss)
bp	magnetic field eastward component, positive eastwards	(gauss)
bb	magnetic field modulus	(gauss)
ifail	return code	

**Remarks:**

ifail: useless

**Called routines:** none

**Used by:**

users programs:  
testdgn



## 4.14 DGRF45\_70

**Author:** CNES - JC KOSIK - January 1996

### **Purpose:**

This routine calculates the magnetic field for all epochs between 1945 and 1970.

### **Specifications:**

double precision year, rre, thet, phi  
double precision br, bt, bp, bb  
integer ifail

**call dgrf45\_70 (year, rre, thet, phi, br, bt, bp, bb, ifail)**

### **Input parameters:**

year	real epoch ( $1945 < \text{year} \leq 1970$ )	(years and fractions)
rre	geocentric radial distance	(earth radii)
thet	geocentric colatitude calculated from north to south pole	(radians)
phi	geocentric longitude positive eastwards, from 0 to $2\pi$	(radians)

### **Output parameters:**

br	magnetic field radial component along the meridian, positive outwards	(gauss)
bt	magnetic field tangential component along the meridian, positive southwards	(gauss)
bp	magnetic field eastward component, positive eastwards	(gauss)
bb	magnetic field modulus	(gauss)
ifail	return code	

### **Remarks:**

ifail: useless

**Called routines:** none

### **Used by:**

users programs:  
testdgn2

## 4.15 GRAD10

**Author:** updated from CNES - JC KOSIK – December 2010

### **Purpose:**

This routine calculates the internal magnetic field components of the IGRF 10 model and the nine associated gradients.

### **Specifications:**

double precision year, rre, thet, phi  
double precision br, bt, bp, bb  
double precision gradb(3,3)  
integer ifail

**call grad10 (year, rre, thet, phi, br, bt, bp, bb, gradb,ifail)**

### **Input parameters:**

year	real epoch ( $\geq 2010$ .)	(years and fractions)
rre	geocentric radial distance	(earth radii)
thet	geocentric colatitude	(radians)
phi	geocentric longitude	(radians)

### **Output parameters:**

br	magnetic field radial component along the meridian, positive outwards	(gauss)
bt	magnetic field tangential component along the meridian positive southwards	(gauss)
bp	magnetic field eastward component positive eastwards	(gauss)
bb	magnetic field modulus	(gauss)
gradb	magnetic field gradients	(gauss)
ifail	return code	

### **Remarks:**

ifail: useless

In case thet angle is equal to  $\pi$ , it's sinus is set to  $1.d^{-15}$  and it's cosinus is set to  $-1.d0$  to avoid mathematical failure.

**Called routines:** none

**Used by:**

users programs:  
testgrad10

## 4.16 GRAD05

**Author:** updated from CNES - JC KOSIK – December 2010

### **Purpose:**

This routine calculates the internal magnetic field components of the DGRF05 model and the nine associated gradients.

### **Specifications:**

double precision year, rre, thet, phi  
double precision br, bt, bp, bb  
double precision gradb(3,3)  
integer ifail

**call grad05 (year, rre, thet, phi, br, bt, bp, bb, gradb,ifail)**

### **Input parameters:**

year	real epoch ( $\geq 2005$ .)	(years and fractions)
rre	geocentric radial distance	(earth radii)
thet	geocentric colatitude	(radians)
phi	geocentric longitude	(radians)

### **Output parameters:**

br	magnetic field radial component along the meridian, positive outwards	(gauss)
bt	magnetic field tangential component along the meridian positive southwards	(gauss)
bp	magnetic field eastward component positive eastwards	(gauss)
bb	magnetic field modulus	(gauss)
gradb	magnetic field gradients	(gauss)
ifail	return code	

### **Remarks:**

ifail: useless

In case thet angle is equal to  $\pi$ , it's sinus is set to  $1.d^{-15}$  and it's cosinus is set to  $-1.d0$  to avoid mathematical failure.

**Called routines:** none

**Used by:**

users programs:  
testgrad05

## 4.17 GRAD00

**Author:** updated from CNES - JC KOSIK – December 2010

### **Purpose:**

This routine calculates the internal magnetic field components of the DGRF00 model and the nine associated gradients.

### **Specifications:**

double precision year, rre, thet, phi  
double precision br, bt, bp, bb  
double precision gradb(3,3)  
integer ifail

**call grad00 (year, rre, thet, phi, br, bt, bp, bb, gradb,ifail)**

### **Input parameters:**

year	real epoch ( $\geq 2000.$ )	(years and fractions)
rre	geocentric radial distance	(earth radii)
thet	geocentric colatitude	(radians)
phi	geocentric longitude	(radians)

### **Output parameters:**

br	magnetic field radial component along the meridian, positive outwards	(gauss)
bt	magnetic field tangential component along the meridian positive southwards	(gauss)
bp	magnetic field eastward component positive eastwards	(gauss)
bb	magnetic field modulus	(gauss)
gradb	magnetic field gradients	(gauss)
ifail	return code	

### **Remarks:**

ifail: useless

In case thet angle is equal to  $\pi$ , it's sinus is set to  $1.d^{-15}$  and it's cosinus is set to  $-1.d0$  to avoid mathematical failure.

**Called routines:** none

**Used by:**

users programs:  
testgrad00

## 4.18 GRAD95

**Author:** CNES - JC KOSIK - Mars 2001

### **Purpose:**

This routine calculates the internal magnetic field components of the DGRF95 model and the nine associated gradients.

### **Specifications:**

double precision year, rre, thet, phi  
double precision br, bt, bp, bb  
double precision gradb(3,3)  
integer ifail

**call grad95 (year, rre, thet, phi, br, bt, bp, bb, gradb,ifail)**

### **Input parameters:**

year	real epoch ( $\geq 1995.$ )	(years and fractions)
rre	geocentric radial distance	(earth radii)
thet	geocentric colatitude	(radians)
phi	geocentric longitude	(radians)

### **Output parameters:**

br	magnetic field radial component along the meridian, positive outwards	(gauss)
bt	magnetic field tangential component along the meridian positive southwards	(gauss)
bp	magnetic field eastward component positive eastwards	(gauss)
bb	magnetic field modulus	(gauss)
gradb	magnetic field gradients	(gauss)
ifail	return code	

### **Remarks:**

ifail: useless

In case thet angle is equal to  $\pi$ , it's sinus is set to  $1.d^{-15}$  and it's cosinus is set to  $-1.d0$  to avoid mathematical failure.

**Called routines:** none



**Used by:**

users programs:  
testgrad95

## 4.19 DIPOL

**Author:** updated from CNES - JC KOSIK – December 2010

### **Purpose:**

This routine calculates the dipolar field of a tilted dipole. The dipole orientation is given by g11 and h11 terms from development of the IGRF10 field in spherical harmonics according to the secular change.

### **Specifications:**

double precision year, rr, thet, phi  
double precision brd, btd, bpd, bd  
integer ifail

**call dipol (year, rr, thet, phi, brd, btd, bpd, bd, ifail)**

### **Input parameters:**

year	real epoch (year $\geq$ 2010)	(years and fractions)
rr	geocentric distance	(earth radii)
thet	geocentric colatitude	(radians)
phi	geocentric longitude	(radians)

### **Output parameters:**

brd	dipolar field radial component along the meridian, positive outwards	(gauss)
btd	dipolar field tangential component along the meridian, positive southwards	(gauss)
bpd	dipolar field eastward component positive eastwards	(gauss)
bd	dipolar field modulus	(gauss)
ifail	return code	

### **Remarks:**

ifail: useless

**Called routines:** none

### **Used by:**

routines:  
inmag

## 4.20 DIPOLS

**Author:** CNES - JC KOSIK - July 1998

**Purpose:**

This routine calculates the dipolar field and its components in a cartesian coordinate system.

**Specifications:**

double precision xg, yg, zg  
double precision bxd, byd, bzd, bd  
integer ifail

**call dipols (xg, yg, zg, bxd, byd, bzd, bd, ifail)**

**Input parameters:**

xg	x coordinate in the geocentric system	(earth radii)
yg	y coordinate in the geocentric system	(earth radii)
zg	z coordinate in the geocentric system	(earth radii)

**Output parameters:**

bxd	x component of the dipolar field	(nanoteslas)
byd	y component of the dipolar field	(nanoteslas)
bzd	z component of the dipolar field	(nanoteslas)
bd	dipolar field modulus	
ifail	return code	

**Remarks:**

ifail: useless

**Called routines:** none

**Used by:** none

## 4.21 GSFC65

**Author:** adapt. CNES - JC KOSIK - January 1991

### **Purpose:**

This routine calculates the Earth magnetic field components of the Hendricks and Cain 1965 model.

### **Specifications:**

double precision year, rre, thet, phi  
double precision br, bt, bp, bb  
integer ifail

**call gsfc65 (year, rre, thet, phi, br, bt, bp, bb, ifail)**

### **Input parameters:**

year	real epoch ( $\geq 1965$ .)	(years and fractions)
rre	geocentric radial distance	(earth radii)
thet	geocentric colatitude	(radians)
phi	geocentric longitude	(radians)

### **Output parameters:**

br	magnetic field radial component along the meridian, positive outwards	(gauss)
bt	magnetic field tangential component along the meridian positive southwards	(gauss)
bp	magnetic field eastward component, positive eastwards	(gauss)
bb	magnetic field modulus	(gauss)
ifail	return code	

### **Remarks:**

ifail: useless

The magnetic field model is Hendricks and Cain 1965 which corresponds exactly to the definition and the calculations of the B, L coordinate system of Mac Ilwain.

**Called routines:** none

### **Used by:**

routines:  
inmag

## 4.22 INCLINE

**Author:** CNES - JC KOSIK - January 1998

### **Purpose:**

This routine updates the coefficients and calculates the coefficient `ginc10` of the tilted dipole and the tilted dipole orientation.

### **Specifications:**

double precision `g10`, `g11`, `h11`  
double precision `ginc10`, `tetdip`, `phidip`  
integer `ifail`

**call `incline (g10, g11, h11, ginc10, tetdip, phidip, ifail)`**

### **Input parameters:**

<code>g10</code>	spherical harmonic, dipole term
<code>g11</code>	spherical harmonic, <code>g11</code> coefficient
<code>h11</code>	spherical harmonic, <code>h11</code> coefficient

### **Output parameters:**

<code>ginc10</code>	tilted dipole component	
<code>tetdip</code>	geocentric colatitude of the point where the dipole cuts the northern hemisphere	(radians)
<code>phidip</code>	geocentric longitude of the point where the dipole cuts the northern hemisphere	(radians)
<code>ifail</code>	return code	

### **Remarks:**

`ifail`: useless

**Called routines:** none

### **Used by:**

users programs:  
`testdipex2`

## **4.23 VS\_CHP**

**Author:** from CNES - JC KOSIK – December 2010

**Purpose:**

This routine calculates the secular variations of the CHP05 or CHP10 coefficients.

**Specifications:**

none

**call vs\_chp**

**Input parameters:** none

**Output parameters:** none

**Remarks:**

The secular variations are calculated using consecutive geomagnetic coefficients. In this case, the secular variations for CHP05 are definitive (CHP05 and CHP00 have definitive coefficients). The secular variations for CHP10 are interim variations (CHP05 have definitive coefficients but CHP10 have interim coefficients).

ifail: useless

**Called routines:** none

**Used by:**

users programs:  
testvs

## **4.24 VS\_IGRF**

**Author:** from CNES - JC KOSIK – December 2010

**Purpose:**

This routine calculates the secular variations of the DGRF05 or DGRF10 coefficients.

**Specifications:**

none

**call vs\_igrf**

**Input parameters:** none

**Output parameters:** none

**Remarks:**

The secular variations are calculated using consecutive geomagnetic coefficients. In this case, the secular variations for DGRF05 are definitive (DGRF05 and DGRF00 have definitive coefficients). The secular variations for DGRF10 are interim variations (DGRF05 have definitive coefficients but IGRF10 have interim coefficients).

ifail: useless

**Called routines:**none

**Used by:**

users programs:  
testvs

## 5. EXTERNAL MAGNETIC FIELD MODELS

In this part have been collected various models of the external magnetic field models.

We have not collected all the external magnetic field models, but only the mostly used today: Tsyganenko 1987 and Tsyganenko 1989. Tsyganenko 1987 was reintroduced this model being in better agreement with optical data.

This chapter describes 6 routines:

- dbtot:** calculates a  $\Delta B$  in the midday-midnight plane.  $\Delta B$  contour is the difference between the total magnetic field and the dipolar magnetic field.
- ex89ae:** calculates the external magnetic field of the Tsyganenko 89 Ae model. The magnetic field changes with the tilt angle and the geomagnetic index value Ae.
- ex89kp:** calculates the external magnetic field of the Tsyganenko 89 Kp model. The magnetic field changes with the tilt angle and the geomagnetic index value Kp.
- kk97kp:** calculates the magnetic field of the Kosik 99 model for all tilt angles and various Kp indexes (1 to 5).
- mf75:** calculates the Mead-Fairfiel magnetic field components.
- tsyg87:** calculates the magnetospheric external field components depending on the tilt angle and the geomagnetic index value according to the Tsyganenko model.



## 5.1 DBTOT

**Author:** CNES - JC KOSIK – July 1998

### **Purpose:**

This routine calculates a level curve  $\Delta B$  in the noon-midnight plane. The  $\Delta B$  contour gives the gap between the total magnetic field and the dipolar magnetic field.

### **Specifications:**

integer indval  
double precision tilt, rggsm(3,3), rgsmg(3,3)  
double precision xgsm, ygsm, zgsm, db  
integer ifail

**call dbtot (indval, tilt, rggsm, rgsmg, xgsm, ygsm, zgsm, db, ifail)**

### **Input parameters:**

indval	Kp geomagnetic index value	
tilt	tilt angle or geomagnetic latitude of the Sun	(radians)
rggsm	transformation matrix (3,3) from the geocentric coordinates system into the solar magnetospheric coordinate system	
rgsmg	transformation matrix (3,3) from the solar magnetospheric coordinate system into the geocentric coordinate system	
xgsm	x coordinate in the solar magnetospheric system	(earth radii)
ygsm	y coordinate in the solar magnetospheric system	(earth radii)
zgsm	z coordinate in the solar magnetospheric system	(earth radii)

### **Output parameters:**

db	level curve of the magnetic field	(nanoteslas)
ifail	return code	

### **Remarks:**

indval: amplitude level of the field  
indval: 1: Kp = 0, 0+  
indval: 1: Kp = 1-, 1, 1+  
indval: 1: Kp = 2-, 2, 2+  
indval: 1: Kp = 3-, 3, 3+  
indval: 1: Kp = 4-, 4, 4+  
indval: 1: Kp > 5

ifail: useless

**Called routines:** none

**Used by:**

users programs:  
testmodel

## 5.2 EX89AE

**Author:** Nikolai A. Tsyganenko  
Institute of Physics, Leningrad University  
Stary Petergof 198904 Leningrad USSR

### Purpose:

This routine calculates the magnetospheric external field components. The model is a function of the tilt angle and the geomagnetic index value  $A_e$ .

### Specifications:

integer indval  
double precision tilt, xgsm, ygsm, zgsm  
double precision bx, by, bz  
integer ifail

call ex89ae (indval ,tilt, xgsm, ygsm, zgsm, bx, by, bz, ifail)

### Input parameters:

indval	geomagnetic index value $A_e$	(from 1 to 6)
tilt	tilt angle or geomagnetic latitude of the Sun	(radians)
xgsm	x coordinate in the solar magnetospheric system	(earth radii)
ygsm	y coordinate in the solar magnetospheric system	(earth radii)
zgsm	z coordinate in the solar magnetospheric system	(earth radii)

### Output parameters:

bx	x component in the solar magnetospheric coordinate system	(gauss)
by	y component in the solar magnetospheric coordinate system	(gauss)
bz	z component in the solar magnetospheric coordinate system	(gauss)
ifail	return code	

### Remarks:

indval: amplitude level of the field  
indval: 1:  $A_e = 0 - 50$   
indval: 2:  $A_e = 50 - 100$   
indval: 3:  $A_e = 100 - 150$   
indval: 4:  $A_e = 150 - 250$   
indval: 5:  $A_e = 250 - 400$   
indval: 6:  $A_e \geq 400$

ifail: useless

This routine calculates the magnetic field components of the external magnetic field model 89 Ae.

This model is valid up to geocentric distances of 70 earth radii and is based on the Imp-a, c, d, e, f, g, h, i, j (1966-1974) and Heos-1,-2 (1969-1974) merged spacecraft data set.

Reference: N.A. Tsyganenko, A magnetospheric magnetic field model with a warped tail current sheet: planet. space. SCI., v.37, pp.5-20, 1989.

**Called routines:** none

**Used by:**

routines:

    outma1

users programs:

    testtsy

### 5.3 EX89KP

**Author:** Nikolai A. Tsyganenko  
Institute of Physics, Leningrad University  
Stary Petergof 1989 04 Leningrad USSR

#### Purpose:

This routine calculates the magnetospheric external field components. The model is a function of the tilt angle and the geomagnetic index value  $K_p$ .

#### Specifications:

integer indval  
double precision tilt, xgsm, ygsm, zgsm  
double precision bx, by, bz  
integer ifail

call ex89kp (indval, tilt, xgsm, ygsm, zgsm, bx, by, bz, ifail)

#### Input parameters:

indval	geomagnetic index value $K_p$	(from 1 to 6)
tilt	tilt angle or geomagnetic latitude of the Sun	(radians)
xgsm	x coordinate in the solar magnetospheric system	(earth radii)
ygsm	y coordinate in the solar magnetospheric system	(earth radii)
zgsm	z coordinate in the solar magnetospheric system	(earth radii)

#### Output parameters:

bx	x component in the solar magnetospheric coordinate system	(gauss)
by	y component in the solar magnetospheric coordinate system	(gauss)
bz	z component in the solar magnetospheric coordinate system	(gauss)
ifail	return code	

#### Remarks:

indval: amplitude level of the field  
indval: 1:  $K_p = 0, 0+$   
indval: 2:  $K_p = 1-, 1, 1+$   
indval: 3:  $K_p = 2-, 2, 2+$   
indval: 4:  $K_p = 3-, 3, 3+$   
indval: 5:  $K_p = 4-, 4, 4+$   
indval: 6:  $K_p > 5$

ifail: useless

This routine calculates the magnetic field components of the external magnetic field model 89 Kp.

This model is valid up to geocentric distances of 70 earth radii and is based on union of the Imp-a, c, d, e, f, g, h, i, j (1966-1974) and Heos-1,-2 (1969-1974) merged spacecraft data set.

Reference: N.A. Tsyganenko, A magnetospheric magnetic field model with a warped tail current sheet: planet. space. SCI., v.37, pp.5-20, 1989.

**Called routines:** none

**Used by:**

routines:

outmal

users programs:

testtsy

## 5.4 KK97KP

**Author:** CNES - JC KOSIK - January 1998

### **Purpose:**

This routine calculates the external magnetic field with the Kosik 97 model for all tilt angles and Kp indexes (1 to 5).

### **Specifications:**

double precision tilt, xgsm, ygsm, zgsm  
double precision bxt, byt, bzt, bt  
integer indval  
integer ifail

call kk97kp (indval, tilt, xgsm, ygsm, zgsm,  
> bxt, byt, bzt, bt, ifail)

### **Input parameters:**

indval	geomagnetic index value Kp	(from 1 to 5)
tilt	tilt angle or geomagnetic latitude of the Sun	(radians)
xgsm	x coordinate in the solar magnetospheric system	(earth radii)
ygsm	y coordinate in the solar magnetospheric system	(earth radii)
zgsm	z coordinate in the solar magnetospheric system	(earth radii)

### **Output parameters:**

bxt	magnetic field x component in the solar magnetospheric external coordinate system	(nanoteslas)
byt	magnetic field y component in the solar magnetospheric external coordinate system	(nanoteslas)
bzt	magnetic field z component in the solar magnetospheric external coordinate system	(nanoteslas)
bt	complete field	(nanoteslas)
ifail	return code	

### **Remarks:**

indval: amplitude level of the field  
indval: 1: Kp = 1-, 1+  
indval: 2: Kp = 2, 2+  
indval: 3 Kp = 3-, 3, 3+  
indval: 4: Kp = 4-, 4, 4+  
indval: 5: Kp = 5, 5+

ifail: useless

**Called routines:**

carsp      vspvcar

**Used by:**

users programs:  
testkk97



## 5.5 MF75

**Author:** CNES - JC KOSIK - February 2001

### **Purpose:**

This routine calculates the Mead-Fairfiel magnetic field components.

### **Specifications:**

integer indval  
double precision tilt, xsm, ysm, zsm  
double precision bxsm, bysm, bzsm, bsm  
integer ifail

**call mf75 (indval, tilt, xsm, ysm, zsm, bxsm, bysm, bzsm, bsm, ifail)**

### **Input parameters:**

indval	geomagnetic index value Kp	(from 1 to 5)
tilt	tilt angle or geomagnetic latitude of the Sun	(radians)
xsm	x coordinate in the solar magnetic system	(earth radii)
ysm	y coordinate in the solar magnetic system	(earth radii)
zsm	z coordinate in the solar magnetic system	(earth radii)

### **Output parameters:**

bxsm	x solar magnetic component of the total magnetic field	(earth radii)
bysm	y solar magnetic component of the total magnetic field	(earth radii)
bzsm	z solar magnetic component of the total magnetic field	(earth radii)
bsm	total magnetic field modulus	(gauss)
ifail	return code	

### **Remarks:**

indval: amplitude level of the field  
indval: 1: Kp = 1-, 1+  
indval: 2: Kp = 2 , 2+  
indval: 3 Kp = 3-, 3 , 3+  
indval: 4: Kp = 4-, 4 , 4+  
indval: 5: Kp = 5 , 5+

ifail: useless

**Called routines:** none

**Used by:**

users programs:  
testmf75

## 5.6 TSYG87

**Author:** Nikolai A. TSYGANENKO  
Institute of Physics, Leningrad University  
Stary Petergof 1989 04 Leningrad USSR

### Purpose:

This routine calculates the external magnetic field with the Tsyganenko 87 model.

### Specifications:

integer indval  
double precision tilt, xgsm, ygsm, zgsm  
double precision bxt, byt, bzt  
integer ifail

**call tsyg87 (indval, tilt, xgsm, ygsm, zgsm, bxt, byt, bzt, ifail)**

### Input parameters:

indval	geomagnetic index value Kp	(from 1 to 6)
tilt	tilt angle or geomagnetic latitude of the Sun	(radians)
xgsm	x coordinate in the solar magnetospheric system	(earth radii)
ygsm	y coordinate in the solar magnetospheric system	(earth radii)
zgsm	z coordinate in the solar magnetospheric system	(earth radii)

### Output parameters:

bxt	magnetic field x component in the solar magnetospheric coordinate system	(nanoteslas)
byt	magnetic field y component in the solar magnetospheric coordinate system	(nanoteslas)
bzt	magnetic field z component in the solar magnetospheric coordinate system	(nanoteslas)
ifail	return code	

### Remarks:

indval: amplitude level of the field  
indval: 1: Kp = 0, 0+  
indval: 2: Kp = 1- , 1 , 1+  
indval: 3: Kp = 2- , 2 , 2+  
indval: 4: Kp = 3- , 3 , 3+  
indval: 5: Kp = 4- , 4 , 4+  
indval: 6: Kp > 5

ifail: useless

**Called routines:** none

**Used by:**

routines:

outma1

## 6. MAGNETOSPHERIC PHYSICS CALCULATIONS

In this chapter we have collected routines constantly used in mission analysis or in data treatment: calculation of the geomagnetic local time MLT, calculations of invariant latitude  $\Lambda_0$ , calculation of magnetic field (any combination). It is also possible to trace field lines for any type of magnetic field to calculate conjugate points with a tilted dipole field and thus check numerical calculations. Two more specialized routines are introduced, one calculates the electric field potential according the Mc Ilwain model, the other one is a method of labeling field lines using Galperin's method.

This chapter describes 23 routines:

- angdip:** calculates the colatitude and longitude in a dipole coordinate system.
- bgsbm:** calculates the total magnetic field as sum of the internal magnetic field (Dipole, DGRF00 or DGRF05 or IGRF10) and the external Tsyganenko field (no magnetic field, Tsyganenko 1987, or Tsyganenko 1989, or Kosik 97).
- calcds:** calculates the length of a field line.
- calpos:** calculates the spacecraft coordinates in the inertial system, the geographic system, the solar ecliptic system, the solar magnetic system, the solar magnetospheric system, the latitudes and longitudes, the geomagnetic local time and the local time. These calculations are done from the calculation epoch and the inertial coordinates of the spacecraft.
- chapp2:** calculates the field line apex in the equatorial plan as defined by Chapell.
- conjndip:** calculates the northern and southern conjugate points of a given point in the tilted dipole magnetic field.
- corgm:** calculates the corrected geomagnetic coordinates, the latitude and the longitude, taking in account the internal magnetic field (DGRF00 type) and the external Tsyganenko field (Tsyganenko 1987 or Tsyganenko 1989).
- dconjr:** calculates the conjugated point of a given point taking in account a combination of the internal and the external fields.
- dlgalp:** calculates the Mac Ilwain L parameter according to the Y. Galperin's method. The field line going through the spacecraft is traced down to the point of northern hemisphere with the complete field. Then, L is calculated with the internal field only and the Mac Ilwain associated programs. The invariant latitude is also calculated.

- econjr:** calculates the equatorial conjugate point of a given point taking in account a combination of the internal and the external fields.
- flgalp:** calculates the Mac Ilwain L parameter according to the Y. Galperin's method. the field line going through the spacecraft is traced down to the point of the northern hemisphere with the complete field. Then, L is calculated with the internal field only and the Mac Ilwain associated programs. The invariant latitude is also calculated.
- geophys:** calculates the geophysical quantities and the non local geophysical parameters: magnetic field components spacecraft coordinates, Mac Ilwain parameter, invariant latitude, geographic position, geomagnetic local time of the conjugate point.
- inmag:** calculates the three components of the internal geomagnetic field (dipole, DGRF00 or DGRF05 or IGRF10 magnetic field).
- invar:** calculates the Mac Ilwain L parameter value.
- invlatt:** calculates the absolute value of the invariant latitude knowing its Mac Ilwain L parameter.
- magtot:** calculates the complete magnetic field at a point. This field is the possible combination of a dipolar or an IGRF field with an external field - in this case Tsyganenko.
- mcilwe:** calculates the field electric potential as a function of the equatorial radius and the local time.
- outma1:** calculates the three components of the external magnetic field for any of the external models: Tsyganenko 1987 long version, Tsyganenko 1989 Kp version, Tsyganenko 1989 Ae version.
- pconjr:** calculates the conjugate point of a spacecraft taking in account a combination of internal and external fields and the different values of the geomagnetic indexes if any.
- tgeogr:** calculates the geographic quantities and all the magnetospheric local parameters (except magnetic values) for a given set of orbital elements and a given date.
- tgml:** calculates the geomagnetic local time of the spacecraft in hours and fraction of hours using the spherical geocentric coordinates.
- tgml2:** calculates the geomagnetic local time of the spacecraft in hours and fractions of hours using the solar magnetic coordinates.
- tlocal:** calculates the local time in hours and fractions of hours.

## 6.1 *ANGDIP*

**Author:** CNES - JC KOSIK - January 1991

### **Purpose:**

This routine calculates the colatitude and longitude in a dipole coordinate system.

### **Specifications:**

double precision rgdip(3,3)  
double precision thetr, phir, rr  
double precision thetdp, phidp, rdp  
integer ifail

**call angdip (rgdip, rr, thetr, phir, rdp, thetdp, phidp, ifail)**

### **Input parameters:**

rgdip	transformation matrix (3,3) from the geocentric coordinate system into the dipolar coordinate system	
rr	geocentric distance	(earth radii)
thetr	geocentric colatitude	(radians)
phir	geocentric longitude	(radians)

### **Output parameters:**

rdp	dipolar distance	(earth radii)
thetdp	dipolar colatitude	(radians)
phidp	dipolar longitude	(radians)
ifail	return code	

### **Remarks:**

ifail: useless

### **Called routines:**

carsp    geodip    spcar

### **Used by:**

routines:  
corgm

## 6.2 BGSM

**Author:** CNES - JC KOSIK – January 1991

### **Purpose:**

This routine calculates the total magnetic field as sum of the internal magnetic field (dipole or DGRF00 or DGRF05 or IGRF10) and the external Tsyganenko field (Tsyganenko 1987 or Tsyganenko 1989).

The magnetic field components are calculated in the solar magnetospheric and the solar ecliptic coordinate systems.

### **Specifications:**

integer magin, magout, indgm, indval  
double precision year, tilt  
double precision rggsm(3,3), rgsmg(3,3), rgse(3,3)  
double precision rr, thet, phi, bb  
double precision bxgsm, bygsm, bzgsm  
double precision bxse, byse, bzse  
integer ifail

**call bgsm (magin, magout, indgm, indval, year, tilt, rggsm, rgsmg,  
> rgse, rr, thet, phi, bb, bxgsm, bygsm, bzgsm, bxse, byse, bzse, ifail)**

### **Input parameters:**

magin	internal magnetic field type	(from 1 to 4)
magout	external magnetic field type	(from 0 to 3)
indgm	geomagnetic index type	(1 or 2)
indval	geomagnetic index value for Kp or Ae	(from 1 to 6)
year	epoch (> 2000 if magin = 2) epoch (> 2005 if magin = 3) epoch (> 2010 if magin = 1 or 4)	(years and fractions)
tilt	tilt angle or geomagnetic latitude of the Sun	(radians)
rggsm	transformation matrix (3,3) from the geocentric coordinate system into the solar magnetospheric coordinate system	
rgsmg	transformation matrix (3,3) from the solar magnetospheric coordinate system into the geocentric coordinate system	
rgse	transformation matrix (3,3) from the geocentric coordinate system to the solar ecliptic coordinate system	
rr	geocentric distance	(earth radii)
thet	geocentric colatitude	(radians)
phi	geocentric longitude	(radians)



### Output parameters:

bb	magnetic field amplitude	(gauss)
bxgsm	x solar magnetospheric component of the total magnetic field	(gauss)
bygsm	y solar magnetospheric component of the total magnetic field	(gauss)
bzgsm	z solar magnetospheric component of the total magnetic field	(gauss)
bxse	x solar ecliptic component of the total magnetic field	(gauss)
byse	y solar ecliptic component of the total magnetic field	(gauss)
bzse	z solar ecliptic component of the total magnetic field	(gauss)
ifail	return code	

### Remarks:

magin: 1 = dipole + g11 + h11  
magin: 2 = DGRF00 field  
magin: 3 = DGRF05 field  
magin: 4 = IGRF10 field

magout: 0 = no external field  
magout: 1 = Tsyganenko 87 field  
magout: 2 = Tsyganenko 89 field  
magout: 3 = Kosik 97 field

indgm: geomagnetic index: 1 = Kp, 2 = Ae

indval: geomagnetic index value for Kp or Ae  
indval = 1: Kp = 0, 0+                      Ae = 0 - 50  
indval = 2: Kp = 1- , 1 , 1+                Ae = 50 - 100  
indval = 3: Kp = 2- , 2 , 2+                Ae = 100 - 150  
indval = 4: Kp = 3- , 3 , 3+                Ae = 150 - 250  
indval = 5: Kp = 4- , 4 , 4+                Ae = 250 - 400  
indval = 6: Kp > 5                          Ae ≥ 400

for Kosik 97  $1 \leq \text{indval} \leq 5$  and  $1 \leq Kp \leq 5$

ifail: useless

### Called routines:

geogsm    geose    magtot    vspvcar

### Used by:

users programs:  
testbgsm

## 6.3 CALCDS

**Author:** CNES - JC KOSIK - January 1991

**Purpose:**

This routine calculates the length of a field line.

**Specifications:**

integer np  
double precision tr(500), tthet(500)  
double precision tphi(500)  
double precision flength  
integer ifail

**call calcds (np, tr, tthet, tphi, flength, ifail)**

**Input parameters:**

np	number of calculated points	
tr	array of the geocentric distances of the field line points	(earth radii)
tthet	array of the colatitudes of the calculated points of the field line	(radians)
tphi	array of the longitudes of the calculated points of the field line	(radians)

**Output parameters:**

flength	length of the field line
ifail	return code

**Remarks:**

ifail: useless

**Called routines:** none

**Used by:** none

## 6.4 CALPOS

**Author:** CNES - JC KOSIK - June 1995

### **Purpose:**

This routine calculates the spacecraft coordinates in the inertial system, the geographic system, the solar ecliptic system, the solar magnetic system, the solar magnetospheric system, the geocentric and geomagnetic latitude and longitude, the geomagnetic local time and the local time. The results are obtained for an inertial position of the spacecraft, the rotation matrices being already calculated for a given epoch.

### **Specifications:**

integer ihour, imin, isec  
double precision xikm, yikm, zikm  
double precision rig(3,3), rgdip(3,3)  
double precision rgsm(3,3), rggsm(3,3), rgse(3,3)  
double precision xi, yi, zi  
double precision xg, yg, zg  
double precision rre, thetr, phir  
double precision xlatgm, xlongm  
double precision xse, yse, zse  
double precision xsm, ysm, zsm  
double precision xgsm, ygsm, zgsm  
double precision tgl, tlat  
double precision xlatse, xlonse  
double precision tlose  
integer ifail

**call calpos (ihour, imin, isec, xikm, yikm, zikm, rig, rgdip,**  
> **rgsm, rggsm, rgse, xi, yi, zi, xg, yg, zg, rre, thetr, phir, xlatgm, xlongm,**  
> **xse, yse, zse, xsm, ysm, zsm, xgsm, ygsm, zgsm, tgl, tlat,**  
> **xlatse, xlonse, tlose, ifail)**

### Input parameters:

ihour	hours	(0 to 23)
imin	minutes	(0 to 23)
isec	seconds	(0 to 59)
xikm	x coordinate in the inertial system	(kilometers)
yikm	y coordinate in the inertial system	(kilometers)
zikm	z coordinate in the inertial system	(kilometers)
rig	transformation matrix (3,3) from the inertial coordinate system to the geocentric coordinate system	
rgdip	transformation matrix (3,3) from the geocentric coordinate system into the dipolar coordinate system	
rgsm	transformation matrix (3,3) from the geocentric coordinate system into the solar magnetic coordinate system	
rggsm	transformation matrix (3,3) from the geocentric coordinate system into the solar magnetospheric coordinate system	
rgse	transformation matrix (3,3) from the geocentric coordinate system into the solar ecliptic coordinate system	

## Output parameters:

xi	x coordinate in the inertial system	(earth radii)
yi	y coordinate in the inertial system	(earth radii)
zi	z coordinate in the inertial system	(earth radii)
xg	x coordinate in the geocentric system	(earth radii)
yg	y coordinate in the geocentric system	(earth radii)
zg	z coordinate in the geocentric system	(earth radii)
rre	geocentric radial distance	(earth radii)
thetr	geocentric colatitude	(radians)
phir	geocentric longitude	(radians)
xlatgm	geomagnetic latitude	(radians)
xlongm	geomagnetic longitude	(radians)
xse	x coordinate in the solar ecliptic system	(earth radii)
yse	y coordinate in the solar ecliptic system	(earth radii)
zse	z coordinate in the solar ecliptic system	(earth radii)
xsm	x coordinate in the solar magnetic system	(earth radii)
ysm	y coordinate in the solar magnetic system	(earth radii)
zsm	z coordinate in the solar magnetic system	(earth radii)
xgsm	x coordinate in the solar magnetospheric system	(earth radii)
ygsm	y coordinate in the solar magnetospheric system	(earth radii)
zgsm	z coordinate in the solar magnetospheric system	(earth radii)
tgl	geomagnetic local time	(hours and fractions)
tlsat	local time	(hours and fractions)
xlatse	latitude in the solar ecliptic system	(radians)
xlonse	longitude in the solar ecliptic system	(radians)
tlose	local time in the solar ecliptic system	(hours and fractions)
ifail	return code	

## Remarks:

ifail: useless

## Called routines:

angleg    carsp    ggeom    promal    tgml    tlocal

## Used by:

users programs:  
testclu

## 6.5 CHAPP2

**Author:** CNES - JC KOSIK - June 1995

### **Purpose:**

This routine calculates the dipoles field line for a given local time. The dipole field line defines the local boundary of the plasmasphere for the Chappell model.

### **Specifications:**

double precision tgl  
double precision xlchap  
integer ifail

**call chapp2 (tgl, xlchap ,ifail)**

### **Input parameters:**

tgl	geomagnetic local time	(hours and fractions)
-----	------------------------	-----------------------

### **Output parameters:**

xlchap	field line apex in the equatorial plan
ifail	return code

### **Remarks:**

ifail: useless

**Called routines:** none

### **Used by:**

routines:  
dchapp

## 6.6 CONJDIP

**Author:** CNES - JC KOSIK - January 1991

### **Purpose:**

This routine calculates the northern and southern conjugated points of a given point in the tilted dipole magnetic field.

### **Specifications:**

double precision rgdip(3,3), rdipg(3,3)  
double precision rr, thet, phi  
double precision thetn, phin, thets, phis  
integer ifail

**call conjdip (rgdip, rdipg, rr, thet, phi, thetn, phin, thets, phis, ifail)**

### **Input parameters:**

rgdip	transformation matrix (3,3) from the geocentric coordinate system into the dipolar coordinate system	
rdipg	transformation matrix (3,3) from the dipolar coordinate system into the geocentric coordinate system	
rr	geocentric distance	(earth radii)
thet	geocentric colatitude	(radians)
phi	geocentric longitude	(radians)

### **Output parameters:**

thetn	geocentric colatitude of the northern conjugate point	(radians)
phin	geocentric longitude of the northern conjugate point	(radians)
thets	geocentric colatitude of the southern conjugate point	(radians)
phis	geocentric longitude of the southern conjugate point	(radians)
ifail	return code	

### **Remarks:**

ifail: useless

### **Called routines:**

carsp    dipgeo    geodip    spcar

**Used by:**

users programs:  
testdconj testpconj



## 6.7 CORGM

**Author:** CNES - JC KOSIK - January 1991

### **Purpose:**

This routine calculates the corrected geomagnetic coordinates, the latitude and the longitude, taking in account the internal magnetic field (Dipole, DGRF00 or DRGF05 or IGRF10 type) and the external Tsyganenko field (Tsyganenko 1987, Tsyganenko 1989, or Kosik 1997).

### **Specifications:**

integer magin  
double precision year  
integer magout, indgm, indval  
double precision tilt, rb  
double precision rggsm(3,3), rgsmg(3,3), rgdip(3,3)  
double precision tetdip, phidip  
double precision rre, theto, phio, rmax, alt  
integer np  
double precision tr(500), tthet(500), tphi(500)  
double precision tdr(500), tdtet(500), tdphi(500)  
integer ieq  
double precision dreq  
double precision dteteq, dphieq, corthet, corlat, corlon  
integer ifail

**call corgm (magin, year, magout, indgm, indval, tilt, rb, rggsm,  
> rgsmg, rgdip, tetdip, phidip, rre, theto, phio, rmax,  
> np, tr, tthet, tphi, tdr, tdtet, tdphi, ieq, dreq, dteteq,  
> dphieq, corthet, corlat, corlon, ifail)**

### Input parameters:

magin	internal magnetic field type	(from 1 to 4)
year	real epoch ( $\geq 2000.$ )	(years and fractions)
magout	external magnetic field type	(0, 1, 2 or 3)
indgm	geomagnetic index type	(1 or 2)
indval	geomagnetic index value for Kp or Ae	(from 1 to 6)
tilt	tilt angle or geomagnetic latitude of the Sun	(radians)
rb	subsolar distance of the magnetopause	(earth radii)
rggsm	transformation matrix (3,3) from the geocentric coordinate system into the solar magnetospheric coordinate system	
rgsmg	transformation matrix (3,3) from the solar magnetospheric coordinate system into the geocentric coordinate system	
rgdip	transformation matrix (3,3) from the geocentric coordinate system to the dipolar coordinate system	
tetdip	geocentric colatitude of the point where the dipole cuts the northern hemisphere	(radians)
phidip	geocentric longitude of the point where the dipole cuts the northern hemisphere	(radians)
rre	geocentric distance	(earth radii)
theto	geocentric colatitude	(radians)
phio	geocentric longitude	(radians)
rmax	maximum geocentric distance	(earth radii)

### Output parameters:

np	number of calculated points	
tr	array of the geocentric distances of the field line points	(earth radii)
tthet	array of the colatitudes of the calculated points of the field line	(radians)
tphi	array of the longitudes of the calculated points of the field line	(radians)
tdr	array of the dipolar distances	(earth radii)
tdtet	array of the dipolar colatitudes	(radians)
tdphi	array of the dipolar longitudes	(radians)
ieq	indicator of equator crossing	
dreq	geocentric radial distance of the equatorial point of the field line	(earth radii)
dteteq	geocentric colatitude of the equatorial point of the field line	(radians)
dphieq	geocentric longitude of the equatorial point of the field line	(radians)
corthet	corrected geomagnetic colatitude	(radians)
corlat	corrected geomagnetic latitude	(radians)
corlon	corrected longitude geomagnetic	(radians)
ifail	return code	

**Remarks:**

magin: 1 = Dipole + g11 + h11  
magin: 2 = DGRF 2000 field  
magin: 3 = DGRF 2005 field  
magin: 4 = IGRF 2010 field

magout: 0 = no external field  
magout: 1 = Tsyganenko 87 field  
magout: 2 = Tsyganenko 89 field  
magout: 3 = Kosik 1997

indgm: geomagnetic index: 1 = Kp, 2 = Ae

indval: geomagnetic index value for Kp or Ae

indval = 1: Kp = 0, 0+	Ae = 0 - 50
indval = 2: Kp = 1-, 1, 1+	Ae = 50 - 100
indval = 3: Kp = 2-, 2, 2+	Ae = 100 - 150
indval = 4: Kp = 3-, 3, 3+	Ae = 150 - 250
indval = 5: Kp = 4-, 4, 4+	Ae = 250 - 400
indval = 6: Kp > 5	Ae ≥ 400

for Kosik 97  $1 \leq \text{indval} \leq 5$  and  $1 \leq Kp \leq 5$

dir: +1 = field line tracing goes towards the highest altitudes (from the surface towards the opposite hemisphere)

dir: -1 = field line tracing goes towards the lower altitudes (towards the surface of the same hemisphere)

rmax: maximum radial distance in case of an open field line

ieq: 1 = crossing the equator

ieq: 0 = not crossing the equator

ifail: 0 = no problem

ifail: 1 = field line does not cross the equatorial plan

**Called routines:**

angdip    magtot    mpause

**Used by:**

users programs:

testcorgm

## 6.8 DCONJR

**Author:** CNES - JC KOSIK - June 1995

### **Purpose:**

This routine calculates the conjugate point of a given point taking in account a combination of the internal and the external fields.

This calculation is precise but runs slowly.

### **Specifications:**

integer magin  
double precision year  
integer magout, indgm, indval  
double precision tilt, rb  
double precision rggsm(3,3), rgsmg(3,3)  
double precision dir  
double precision rre, theto, phio, rfin, rmax  
integer np  
double precision tr(500), tthet(500), tphi(500)  
integer ifail

**call dconjr (magin, year, magout, indgm, indval, tilt, rb, rggsm,  
> rgsmg, dir, rre, theto, phio, rfin, rmax, np, tr, tthet,  
> tphi, ifail)**

### **Input parameters:**

magin	internal magnetic field type	(from 1 to 4)
year	epoch ( $\geq 2000$ if magin = 2) epoch ( $\geq 2005$ if magin = 3) epoch ( $\geq 2010$ if magin = 1 or 4)	(years and fractions)
magout	external magnetic field type	(from 0 to 3)
indgm	geomagnetic index type	(1 or 2)
indval	geomagnetic index value for Kp or Ae	(from 1 to 6)
tilt	tilt angle or geomagnetic latitude of the Sun	(radians)
rb	subsolar distance of magnetopause	(earth radii)
rggsm	transformation matrix (3,3) from the geocentric coordinate system into the solar magnetospheric coordinate system	
rgsmg	transformation matrix (3,3) from the solar magnetospheric coordinate system into the geocentric coordinate system	
dir	field lines direction	
rre	geocentric distance	(earth radii)
theto	geocentric colatitude	(radians)
phio	geocentric longitude	(radians)
rfin	geocentric distance where the field line tracing is stopped	(earth radii)
rmax	maximum geocentric distance for the field line tracing	(earth radii)

## Output parameters:

np	number of calculated points	
tr	array of the geocentric distances of the field line points	(earth radii)
tthet	array of the colatitudes of the calculated points of the field line	(radians)
tphi	array of the longitudes of the calculated points of the field line	(radians)
ifail	return code	

## Remarks:

magin: 1 = dipole  
magin: 2 = DGRF00 field  
magin: 3 = DGRF05 field  
magin: 4 = IGRF10 field

magout: 0 = no external field  
magout: 1 = Tsyganenko 87 field  
magout: 2 = Tsyganenko 89 field  
magout: 3 = Kosik 97 field

indgm: geomagnetic index: 1 = Kp, 2 = Ae

indval: geomagnetic index value for Kp or Ae  
indval = 1: Kp = 0, 0+                      Ae = 0 - 50  
indval = 2: Kp = 1-, 1, 1+                Ae = 50 - 100  
indval = 3: Kp = 2-, 2, 2+                Ae = 100 - 150  
indval = 4: Kp = 3-, 3, 3+                Ae = 150 - 250  
indval = 5: Kp = 4-, 4, 4+                Ae = 250 - 400  
indval = 6: Kp > 5                        Ae ≥ 400

for Kosik 97  $1 \leq \text{indval} \leq 5$  and  $1 \leq Kp \leq 5$

dir: +1 = field line tracing towards the highest altitudes (from the surface towards the opposite hemisphere)

dir: -1 = field line tracing towards the lower altitudes (towards the surface of the same hemisphere)

rfin: 1 = corresponds to the final point on the Earth

ifail: 1 =  $L > 500$  or  $rre > rmax$  or  $(rre - 1) \leq 0.01$   
ifail: 2 = getting out of the magnetopause

## Called routines:

carsp    magtot    mpause    spcar

**Used by:**

routines:

    dlgal    posmag

users programs:

    testdconj

## 6.9 DLGALP

**Author:** CNES - JC KOSIK - June 1995

### **Purpose:**

This routine calculates the Mac Ilwain L parameter according to the Y. Galperin's method. The field line tracing from the spacecraft to the northern hemisphere uses the complete field (internal + external). Then, L is calculated with the internal field only and the Mac Ilwain associated programs. The invariant latitude is also calculated.

This calculation is precise but runs slowly.

### **Specifications:**

integer magin, magout  
double precision year, tilt  
double precision rggsm(3,3), rgsmg(3,3)  
double precision rre, theto, phio  
double precision flg, xlamb  
double precision rmagc, thetc, phic  
integer ifail

**call dlgalp (magin, magout, year, tilt, rggsm, rgsmg, rre, theto,  
> phio, flg, xlamb, rmagc, thetc, phic, ifail)**

### **Input parameters:**

magin	internal magnetic field type	(from 1 to 4)
magout	external magnetic field type	(from 1 to 3)
year	epoch ( $\geq 2000$ if magin = 2) epoch ( $\geq 2005$ if magin = 3) epoch ( $\geq 2010$ if magin = 1 or 4)	(years and fractions)
tilt	tilt angle or geomagnetic latitude of the Sun	(radians)
rggsm	transformation matrix (3,3) from the geocentric coordinate system into the solar magnetospheric coordinate system	
rgsmg	transformation matrix (3,3) from the solar magnetospheric coordinate system into the geocentric coordinate system	
rre	geocentric radial distance	(earth radii)
theto	geocentric colatitude	(radians)
phio	geocentric longitude	(radians)

### Output parameters:

flg	Mac Ilwain L parameter	(Galperin's method)
xlamb	invariant latitude	(radians)
rmagc	geocentric radial distance of the conjugate point	(earth radii)
thetc	geocentric colatitude of the conjugate point	(radians)
phic	geocentric longitude of the conjugate point	(radians)
ifail	return code	

### Remarks:

magin: 1 = Dipole + g11 + h11

magin: 2 = DGRF 2000

magin: 3 = DGRF 2005

magin: 4 = IGRF 2010

magout: 1 = Tsyganenko 87 field

magout: 2 = Tsyganenko 89 field

magout: 3 = Kosik 1997

xlamb: if colatitude  $> \pi/2.$ , xlamb is set negative

ifail: 0 = no problem

ifail: 1 = the conjugated point calculation failed

ifail: 2 = L value is zero and xlamb is not calculated

### Called routines:

dconjr    invar    invlat

### Used by:

routines:

    geophys

users programs:

    testdlgalp



## 6.10 *ECONJR*

**Author:** CNES - JC KOSIK - June 1995

### **Purpose:**

This routine calculates the equatorial conjugate point of a given point taking in account a combination of the internal and the external fields.

### **Specifications:**

integer magin  
double precision year  
integer magout, indgm, indval  
double precision tilt, rb  
double precision rggsm(3,3), rgsmg(3,3)  
double precision tetdip, phidip, dir, rre, theto, phio, rmax  
integer np  
double precision tr(500), tthet(500), tphi(500)  
double precision req, theteq, phieq  
integer ieq  
integer ifail

**call econjr (magin, year, magout, indgm, indval, tilt, rb, rggsm,  
> rgsmg, tetdip, phidip, dir, rre, theto, phio,  
> rmax, np, tr, tthet, tphi, req, theteq, phieq, ieq, ifail)**

### Input parameters:

magin	internal magnetic field type	(from 1 to 4)
year	epoch ( $\geq 2000$ if magin = 2) epoch ( $\geq 2005$ if magin = 3) epoch ( $\geq 2010$ if magin = 1 or 4)	(years and fractions)
magout	external magnetic field type	(from 0 to 3)
indgm	geomagnetic index type	(1 or 2)
indval	geomagnetic index value for Kp or Ae	(from 1 to 6)
tilt	tilt angle or geomagnetic latitude of the Sun	(radians)
rb	subsolar distance of magnetopause	(earth radii)
rggsm	transformation matrix (3,3) from the geocentric coordinate system into the solar magnetospheric coordinate system	
rgsmg	transformation matrix (3,3) from the solar magnetospheric coordinate system into the geocentric coordinate system	
tetdip	geocentric colatitude of the point where the dipole cuts the northern hemisphere	(radians)
phidip	geocentric longitude of the point where the dipole cuts the northern hemisphere	(radians)
dir	field lines direction	
rre	geocentric distance	(earth radii)
theto	geocentric colatitude	(radians)
phio	geocentric longitude	(radians)
rmax	maximum geocentric distance for the field line tracing	(earth radii)

### Output parameters:

np	number of calculated points	
tr	array of the geocentric distances of the field line points	(earth radii)
tthet	array of the colatitudes of the calculated points of the field line	(radians)
tphi	array of the longitudes of the calculated points of the field line	(radians)
req	geocentric radial distance to the point of minimum field	(earth radii)
theteq	geocentric colatitude to the point of minimum field	(radians)
phieq	geocentric longitude to the point of minimum field	(radians)
ieq	indicator for equatorial crossing	
ifail	return code	

## Remarks:

magin: 1 = dipole + g11 + h11  
magin: 2 = DGRF 2000 field  
magin: 3 = DGRF 2005 field  
magin: 4 = IGRF 2010 field

magout: 0 = no external field  
magout: 1 = Tsyganenko 87 field  
magout: 2 = Tsyganenko 89 field  
magout: 3 = Kosik 97

indgm: geomagnetic index: 1 = Kp, 2 = Ae

indval: geomagnetic index value for Kp or Ae

indval = 1: Kp = 0, 0+	Ae = 0 - 50
indval = 2: Kp = 1-, 1, 1+	Ae = 50 - 100
indval = 3: Kp = 2-, 2, 2+	Ae = 100 - 150
indval = 4: Kp = 3-, 3, 3+	Ae = 150 - 250
indval = 5: Kp = 4-, 4, 4+	Ae = 250 - 400
indval = 6: Kp > 5	Ae ≥ 400

for Kosik 97  $1 \leq \text{indval} \leq 5$  and  $1 \leq Kp \leq 5$

dir: +1 = field line tracing towards the highest altitudes (from the surface towards the opposite hemisphere)  
dir: -1 = field line tracing towards the lower altitudes (towards the surface of the same hemisphere)

rmax: maximum distance for the field line tracing

ieq: 1 = crossing the equator  
ieq: 0 = not crossing the equator

ifail: 0 = no problem  
ifail: 1 =  $L > 500$  or  $r_{re} > r_{max}$  or  $(r_{re} - 1) \leq 0.01$   
ifail: 2 = getting out of the magnetopause

## Called routines:

carsp    magtot    mpause    spcar

## Used by:

users programs:  
  testeconj

## 6.11 FLGALP

**Author:** CNES - JC KOSIK - January 1991

### **Purpose:**

This routine calculates the Mac Ilwain L parameter according to the Y. Galperin's method. the field line going through the spacecraft is calculated to the point of the Northern hemisphere with the complete field. Then, L is calculated with the internal field only and the Mac Ilwain associated programs. The invariant latitude is also calculated.

This calculation is fast with an average precision.

### **Specifications:**

integer magin, magout  
double precision year, tilt  
double precision rggsm(3,3), rgsmg(3,3)  
double precision tetdip, phidip, rre, theto, phio  
double precision flg, xlamb  
integer ifail

**call flgalp (magin, magout, year, tilt, rggsm, rgsmg, tetdip, phidip,  
> rre, theto, phio, flg, xlamb, ifail)**

### **Input parameters:**

magin	internal magnetic field type	(from 1 to 4)
magout	external magnetic field type	(from 1 to 3)
year	epoch ( $\geq 2000$ if magin = 2) epoch ( $\geq 2005$ if magin = 3) epoch ( $\geq 2010$ if magin = 1 or 4)	(years and fractions)
tilt	tilt angle between the solar magnetic equator and the geomagnetic equator	(radians)
rggsm	transformation matrix (3,3) from the geocentric coordinate system into the solar magnetospheric coordinate system	
rgsmg	transformation matrix (3,3) from the solar magnetospheric coordinate system into the geocentric coordinate system	
tetdip	geocentric colatitude of the point where the dipole cuts the northern hemisphere	(radians)
phidip	geocentric longitude of the point where the dipole cuts the northern hemisphere	(radians)
rre	geocentric radial distance	(earth radii)
theto	geocentric colatitude	(radians)
phio	geocentric longitude	(radians)

**Output parameters:**

flg	Mac Ilwain L parameter	(Galperin's method)
xlamb	invariant latitude	(radians)
ifail	return code	

**Remarks:**

magin: 1 = Dipole + g11 + h11  
magin: 2 = DGRF 2000  
magin: 3 = DGRF 2005  
magin: 4 = IGRF 2010

magout: 1 = Tsyganenko 87 field  
magout: 2 = Tsyganenko 89 field  
magout: 3 = Kosik 1997

xlamb: if colatitude  $> \pi/2.$ , xlamb is set negative

ifail: 0 = no problem  
ifail: 1 = the conjugated point calculation failed  
ifail: 2 = L's value is zero and xlamb isn't calculated

**Called routines:**

invar    invlat    pconjr

**Used by:**

users programs:  
testflgalp

## 6.12 GEOPHYS

**Author:** CNES - JC KOSIK - June 1998

### **Purpose:**

This routine calculates the geophysical quantities and the non local geophysical parameters:

- the magnetic field components and the total field in the geocentric coordinate system,
- the x, y and z coordinates in the solar magnetic system,
- the x, y and z coordinates in the solar magnetospheric system,
- the x, y and z coordinates in the solar ecliptic system,
- the Mc Ilwain L parameter according to Galperin's method,
- the invariant altitude,
- the geographic position and the geomagnetic local time of the conjugate point.

### **Specifications:**

integer ignloc, isw  
double precision rre, thetr, phir  
double precision year, tilt  
double precision rgsm(3,3), rggsm(3,3), rgse(3,3), rgsng(3,3)  
double precision dismp, br, bt, bp, bb, bxsm, bysm, bzsm  
double precision btsm, bxgsm, bygsm, bzgsm, btgsm  
double precision bxse, byse, bzse, btse  
double precision fl, xlamb, rmagc, thetc, phic, tgmlc  
integer ifail

**call geophys (ignloc, isw, rre, thetr, phir, year, tilt,**  
> **rgsm, rggsm, rgsng, rgse, dismp, br, bt, bp, bb,**  
> **bxsm, bysm, bzsm, btsm, bxgsm, bygsm, bzgsm,**  
> **btgsm, bxse, byse, bzse, btse,**  
> **fl, xlamb, rmagc, thetc, phic, tgmlc, ifail)**

### Input parameters:

ignloc	non local parameters calculation indicator	(0 or 1)
isw	solar wind intensity indicator	( $1 \leq isw \leq 5$ )
rre	geocentric radial distance	(earth radii)
thetr	geocentric colatitude	(radians)
phir	geocentric longitude	(radians)
year	epoch ( $\geq 2010$ )	(years and fractions)
tilt	tilt angle or geomagnetic latitude of the Sun	(radians)
rgsm	transformation matrix (3,3) from the geocentric coordinate system into the solar magnetic coordinate system	
rggsm	transformation matrix (3,3) from the geocentric coordinate system into the solar magnetospheric coordinate system	
rgsmg	transformation matrix (3,3) from the solar magnetospheric coordinate system into the geocentric coordinate system	
rgse	transformation matrix (3,3) from the geocentric coordinate system into the solar ecliptic coordinate system	

### Output parameters:

dismp	distance to the magnetopause, negative inside, positive outside	(earth radii)
br	magnetic field radial component along the meridian, positive outwards	(gauss)
bt	magnetic field tangential component along the meridian, positive southwards	(gauss)
bp	magnetic field eastward component, positive eastwards	(gauss)
bb	magnetic field amplitude	(gauss)
bxsm	x solar magnetic component of the total magnetic field	(earth radii)
bysm	y solar magnetic component of the total magnetic field	(earth radii)
bzsm	z solar magnetic component of the total magnetic field	(earth radii)
btsm	magnetic field amplitude in the solar magnetic system	
bxgsm	x solar magnetospheric component of the total magnetic field	(gauss)
bygsm	y solar magnetospheric component of the total magnetic field	(gauss)
bzgsm	z solar magnetospheric component of the total magnetic field	(gauss)
btgsm	magnetic field amplitude in the solar magnetospheric system	
bxse	x solar ecliptic component of the total magnetic field	(gauss)
byse	y solar ecliptic component of the total magnetic field	(gauss)
bzse	z solar ecliptic component of the total magnetic field	(gauss)
btse	magnetic field amplitude in the solar ecliptic system	(gauss)
fl	Mac Ilwain L parameter	
xlamb	invariant latitude	(radians)
rmagc	radial distance of the conjugate point	(earth radii)
thetc	geocentric colatitude of the conjugate point	(radians)
phic	geocentric longitude of the conjugate point	(radians)
tgmlc	geomagnetic local time of the conjugated point in the same hemisphere	(hours and fractions)
ifail	return code	

**Remarks:**

ignloc: 0 = non local parameters are not calculated  
ignloc: 1 = non local parameters are calculated

isw: defines the subsolar distance value  
isw: 1: rb = 12.6 earth radii  
isw: 2: rb = 11.7 earth radii  
isw: 3: rb = 11. earth radii  
isw: 4: rb = 10. earth radii  
isw: 5: rb = 8.8 earth radii

ifail: 0 = no problem  
ifail: 1 = dismp < 0

The geomagnetic activity index is based on the solar wind activity.  
indval is at first set to: isw + 1,  $1 \leq \text{isw} \leq 5$

magin: 4 = IGRF 2010  
magout: 1 = Tsyganenko 87 field

**Called routines:**

dlgalp    geogsm    geose    geosm    magtot    tgml    vspvcar

**Used by:**

users programs:  
testclu



## 6.13 INMAG

**Author:** CNES - JC KOSIK - June 1995

### **Purpose:**

This routine calculates the three components of the internal geomagnetic field (dipole, DGRF00 or DGRF05 or IGRF10 magnetic field models).

### **Specifications:**

integer magin  
double precision year, rre, thet, phi  
double precision bri, bti, bpi, bbi  
integer ifail

**call inmag (magin, year, rre, thet, phi, bri, bti, bpi, bbi, ifail)**

### **Input parameters:**

magin	internal magnetic field type	(from 1 to 4)
year	epoch ( $\geq 2000$ if magin = 2) epoch ( $\geq 2005$ if magin = 3) epoch ( $\geq 2010$ if magin = 1 or 4)	(years and fractions)
rre	geocentric distance	(earth radii)
thet	geocentric colatitude	(radians)
phi	geocentric longitude	(radians)

### **Output parameters:**

bri	internal magnetic field radial component along the meridian, positive outwards	(gauss)
bti	internal magnetic field tangential component along the meridian, positive southwards	(gauss)
bpi	internal magnetic field eastward component, positive eastwards	(gauss)
bbi	internal magnetic field modulus	(gauss)
ifail	return code	

### **Remarks:**

magin: 1 = dipole + g11 + h11  
magin: 2 = DGRF 2000 field  
magin: 3 = DGRF 2005 field  
magin: 4 = IGRF 2010 field

ifail: useless

**Called routines:**

dipol    dgrf00    dgrf05    igrf10

**Used by:**

routines:

magtot

## 6.14 INVAR

**Author:** Mac Ilwain

adapt. CNES - JC KOSIK - January 1991

### **Purpose:**

This routine calculates the Mac Ilwain L parameter value with the internal field of Jenssen and Cain.

### **Specifications:**

double precision thet, phi, rre  
double precision flg  
integer ifail

**call invar (rre, thet, phi, flg, ifail)**

### **Input parameters:**

rre	geocentric radial distance	(earth radii)
thet	geocentric colatitude	(radians)
phi	geocentric longitude	(radians)

### **Output parameters:**

flg	Mac Ilwain L parameter
ifail	return code

### **Remarks:**

ifail: useless

This routine was established by Mac Ilwain in the early sixties and is valid only with a magnetic field of the early sixties.

Error on L is less than 0.1 earth radii.

**Called routines:** none

### **Used by:**

routines:  
    dlgalp    flgalp    posmag

## 6.15 *INVLAT*

**Author:** CNES - JC KOSIK - January 1991

**Purpose:**

This routine calculates the invariant latitude.

**Specifications:**

double precision flg  
double precision xlamb  
integer ifail

**call invlat (flg, xlamb, ifail)**

**Input parameters:**

flg	Mac Ilwain L parameter	(Galperin's method)
-----	------------------------	---------------------

**Output parameters:**

xlamb	invariant latitude	(radians)
ifail	return code	

**Remarks:**

ifail: 0 = no problem  
ifail: 1 = fl = 0.0

**Called routines:** none

**Used by:**

routines:  
    dldalp    flgalp    posmag

## 6.16 MAGTOT

**Author:** CNES - JC KOSIK - June 1995

### **Purpose:**

This routine calculates the total magnetic field at a point. This field is the possible combination of a dipole field or an IGRF model with an external field - in this case Tsyganenko, Kosik 97.

### **Specifications:**

integer magin  
double precision year  
integer magout, indgm, indval  
double precision tilt  
double precision rggsm(3,3), rgsmg(3,3)  
double precision rre, thet, phi  
double precision br, bt, bp, b  
integer ifail

**call magtot (magin, year, magout, indgm, indval, tilt, rggsm,  
> rgsmg, rre, thet, phi, br, bt, bp, b, ifail)**

### **Input parameters:**

magin	internal magnetic field type	(from 1 to 4)
year	epoch ( $\geq 2000$ if magin = 2) epoch ( $\geq 2005$ if magin = 3) epoch ( $\geq 2010$ if magin = 1 or 3)	(years and fractions)
magout	external magnetic field type	(from 0 to 3)
indgm	geomagnetic index type	(1 or 2)
indval	geomagnetic index value for Kp or Ae	(from 1 to 6)
tilt	tilt angle or geomagnetic latitude of Sun	(radians)
rggsm	transformation matrix (3,3) from the geocentric coordinate system into the solar magnetospheric coordinate system	
rgsmg	transformation matrix (3,3) from the solar magnetospheric coordinate system into the geocentric coordinate system	
rre	geocentric radial distance	(earth radii)
thet	geocentric colatitude	(radians)
phi	geocentric longitude	(radians)

### Output parameters:

br	magnetic field radial component	(gauss)
bt	magnetic field tangential component	(gauss)
bp	magnetic field eastward component	(gauss)
bb	magnetic field modulus	(gauss)
ifail	return code	

### Remarks:

magin: 1 = dipole + g11 + h11  
magin: 2 = DGRF 2000  
magin: 3 = DGRF 2005  
magin: 4 = IGRF 2010

magout: 0 = no external field  
magout: 1 = Tsyganenko 87  
magout: 2 = Tsyganenko 89  
magout: 3 = Kosik 1997

indgm: geomagnetic index: 1 = Kp, 2 = Ae

indval: geomagnetic index value for Kp or Ae

indval = 1: Kp = 0, 0+	Ae = 0 - 50
indval = 2: Kp = 1-, 1, 1+	Ae = 50 - 100
indval = 3: Kp = 2-, 2, 2+	Ae = 100 - 150
indval = 4: Kp = 3-, 3, 3+	Ae = 150 - 250
indval = 5: Kp = 4-, 4, 4+	Ae = 250 - 400
indval = 6: Kp > 5	Ae ≥ 400

for Kosik 97  $1 \leq \text{indval} \leq 5$  and  $1 \leq Kp \leq 5$

ifail: useless

### Called routines:

inmag outmal

### Used by:

routines:  
bgsm corgm dconjr econjr geophys pconjr

## 6.17 MCILWE

**Author:** CNES - JC KOSIK - January 1991

### **Purpose:**

This routine calculates the field electric potential depending on the equatorial radius and the local time.

### **Specifications:**

double precision req, tgmleq  
double precision phikv  
integer ifail

**call mcilwe (req, tgmleq, phikv, ifail)**

### **Input parameters:**

req	geocentric radial distance in the equatorial plane	(earth radii)
tgmleq	geomagnetic local time	(hours and fractions)

### **Output parameters:**

phikv	electric potential	(kilovolts)
ifail	return code	

### **Remarks:**

ifail: 0 = no problem  
ifail: 1 = tgmleq < 0.0  
ifail: 2 = req < 4.0 (earth radii)

**Called routines:** none

### **Used by:**

users programs:  
testilwe

## 6.18 OUTMA1

**Author:** CNES - JC KOSIK - June 1995

### **Purpose:**

This routine calculates the three components of the external magnetic field for any of the external models: Tsyganenko 1987 long version, Tsyganenko 1989 Kp, Tsyganenko 1989 Ae, Kosik 1997 Kp.

### **Specifications:**

integer magout, indgm, indval  
double precision tilt  
double precision rggsm(3,3), precision rgsmg(3,3)  
double precision rre, thet, phi  
double precision bre, bte, bpe  
integer ifail

**call outma1 (magout, indgm, indval, tilt, rggsm, rgsmg,  
> rre, thet, phi, bre, bte, bpe, ifail)**

### **Input parameters:**

magout	external magnetic field type	(from 0 to 3)
indgm	geomagnetic index type	(1 or 2)
indval	geomagnetic index value for Kp or Ae	(from 1 to 6)
tilt	tilt angle or geomagnetic latitude of the Sun	(radians)
rggsm	transformation matrix (3,3) from the geocentric coordinate system into the solar magnetospheric coordinate system	
rgsmg	transformation matrix (3,3) from the solar magnetospheric coordinate system into the geocentric coordinate system	
rr	geocentric distance	(earth radii)
thet	geocentric colatitude	(radians)
phi	geocentric longitude	(radians)

### **Output parameters:**

bre	external magnetic field radial component along the meridian, positive outwards	(gauss)
bte	external magnetic field tangential component along the meridian, positive southwards	(gauss)
bpe	external magnetic field eastward component, positive eastwards	(gauss)
ifail	return code	



**Remarks:**

magout: 0 = no external field  
magout: 1 = Tsyganenko 87 field  
magout: 2 = Tsyganenko 89 field  
magout: 3 = Kosik 97 Kp

indgm: geomagnetic index: 1 = Kp, 2 = Ae

indval: geomagnetic index value for Kp or Ae

indval = 1: Kp = 0, 0+	Ae = 0 - 50
indval = 2: Kp = 1-, 1, 1+	Ae = 50 - 100
indval = 3: Kp = 2-, 2, 2+	Ae = 100 - 150
indval = 4: Kp = 3-, 3, 3+	Ae = 150 - 250
indval = 5: Kp = 4-, 4, 4+	Ae = 250 - 400
indval = 6: Kp > 5	Ae ≥ 400

for Kosik 97  $1 \leq \text{indval} \leq 5$  and  $1 \leq \text{Kp} \leq 5$

ifail: useless

**Called routines:**

ex89ae   ex89kp   geogsm   gsmgeo   spcar   tsyg87   vcarvsp

**Used by:**

routines:  
    magtot

## 6.19 PCONJR

**Author:** CNES - JC KOSIK - January 1991

### **Purpose:**

This routine calculates the conjugate point of a spacecraft taking in account a combination of internal and external fields and the different values of the geomagnetic indexes if any. This algorithm is fast with an average precision.

### **Specifications:**

integer magin  
double precision year  
integer magout, indgm, indval  
double precision tilt, rb  
double precision rggsm(3,3), rgsmg(3,3)  
double precision tetdip, phidip, dir  
double precision rre, theto, phio, rfin, rmax  
integer np  
double precision tr(500), tthet(500), tphi(500)  
integer ifail

**call pconjr (magin, year, magout, indgm, indval, tilt, rb, rggsm,**  
> **rgsmg, tetdip, phidip, dir, rre, theto, phio, rfin,**  
> **rmax, np, tr, tthet, tphi, ifail)**

### Input parameters:

magin	internal magnetic field type	(from 1 to 3)
year	epoch ( $\geq 2000$ if magin = 2) epoch ( $\geq 2005$ if magin = 3) epoch ( $\geq 2010$ if magin = 1 or 4)	(years and fractions)
magout	external magnetic field type	(0, 1, 2 or 3)
indgm	geomagnetic index type	(1 or 2)
indval	geomagnetic index value for Kp or Ae	(from 1 to 6)
tilt	tilt angle or geomagnetic latitude of the Sun	(radians)
rb	subsolar distance of magnetopause	(earth radii)
rggsm	transformation matrix (3,3) from the geocentric coordinate system into the solar magnetospheric coordinate system	
rgsmg	transformation matrix (3,3) from the solar magnetospheric coordinate system into the geocentric coordinate system	
tetdip	geocentric colatitude of the point where the dipole cuts the northern hemisphere	(radians)
phidip	geocentric longitude of the point where the dipole cuts the northern hemisphere	(radians)
dir	field lines direction	
rre	geocentric distance	(earth radii)
theto	geocentric colatitude	(radians)
phio	geocentric longitude	(radians)
rfin	geocentric distance where the field line tracing is stopped	(earth radii)
rmax	maximum geocentric distance for the field line tracing	(earth radii)

### Output parameters:

np	number of calculated points	
tr	array of the geocentric distances of the field line points	(earth radii)
tthet	array of the colatitudes of the calculated points of the field line	(radians)
tphi	array of the longitudes of the calculated points of the field line	(radians)
ifail	return code	

**Remarks:**

magin: 1 = dipole  
magin: 2 = DGRF 2000  
magin: 3 = DGRF 2005  
magin: 4 = IGRF 2010

magout: 0 = no external field  
magout: 1 = Tsyganenko 87 field  
magout: 2 = Tsyganenko 89 field  
magout: 3 = Kosik 1997

indgm: geomagnetic index: 1 = Kp, 2 = Ae

indval: geomagnetic index value for Kp or Ae

indval = 1: Kp = 0, 0+	Ae = 0 - 50
indval = 2: Kp = 1-, 1, 1+	Ae = 50 - 100
indval = 3: Kp = 2-, 2, 2+	Ae = 100 - 150
indval = 4: Kp = 3-, 3, 3+	Ae = 150 - 250
indval = 5: Kp = 4-, 4, 4+	Ae = 250 - 400
indval = 6: Kp > 5	Ae ≥ 400

for Kosik 97  $1 \leq \text{indval} \leq 5$  and  $1 \leq Kp \leq 5$

dir: +1 = field line tracing goes towards the higher altitudes (from the surface towards the opposite hemisphere)  
dir: -1 = field line tracing goes towards the lower altitudes (towards the surface of the same hemisphere)

rfin: 1 = final point on the Earth

ieq: 1 = crossing the equator  
ieq: 0 = not crossing the equator

ifail: 0 = no problem  
ifail: 1 =  $L > 500$  or  $r_{re} > r_{max}$  or  $(r_{re} - 1) \leq 0.01$   
ifail: 2 = getting out of the magnetopause

**Called routines:**

magtot    mpause

**Used by:**

routines:  
    flgalp  
users programs:  
    testpconj

## 6.20 TGEOGR

**Author:** CNES - JC KOSIK - January 1991

### **Purpose:**

This routine calculates the geographic quantities and all the magnetospheric local parameters (except magnetic values) for a given set of orbital elements and a given epoch.

### **Specifications:**

integer norb  
double precision tvect(6), djd  
double precision rgdip(3,3), rgsm(3,3), rggsm(3,3), rgse(3,3)  
double precision tgraph(23)  
integer ifail

**call tgeogr (norb, tvect, djd, rgdip, rgsm,  
> rggsm, rgse, tgraph, ifail)**

### **Input parameters:**

norb	orbit number	
tvect	array of inertial coordinates	(kilometers and kilometers/ second)
djd	julian date	
rgdip	transformation matrix (3,3) from the geocentric coordinate system into the dipolar coordinate system	
rgsm	transformation matrix (3,3) from the geocentric coordinate system into the solar magnetic coordinate system	
rggsm	transformation matrix (3,3) from the geocentric coordinate system into the solar magnetospheric coordinate system	
rgse	transformation matrix (3,3) from the geocentric coordinate system into the solar ecliptic coordinate system	

### **Output parameters:**

tgraph	array of geographic quantities
ifail	return code

**Remarks:**

tvect: tvect(1)	x component of the position in the inertial coordinate system	(kilometers)
tvect: tvect(2)	y component of the position in the inertial coordinate system	(kilometers)
tvect: tvect(3)	z component of the position in the inertial coordinate system	(kilometers)
tvect: tvect(4)	x component of velocity in the inertial coordinate system	(kilometers/second)
tvect: tvect(5)	y component of velocity in the inertial coordinate system	(kilometers/second)
tvect: tvect(6)	z component of velocity in the inertial coordinate system	(kilometers/second)
tgraph: tgraph(01)	CNES julian date	
tgraph: tgraph(02)	orbit number	
tgraph: tgraph(03)	x component of the position in the geographic coordinate system	(kilometers)
tgraph: tgraph(04)	y component of the position in the geographic coordinate system	(kilometers)
tgraph: tgraph(05)	z component of the position in the geographic coordinate system	(kilometers)
tgraph: tgraph(06)	x component of the speed in the geographic coordinate system	(kilometers/second)
tgraph: tgraph(07)	y component of the speed in the geographic coordinate system	(kilometers/second)
tgraph: tgraph(08)	z component of the speed in the geographic coordinate system	(kilometers/second)
tgraph: tgraph(09)	geocentric (above geoid) altitude	(kilometers)
tgraph: tgraph(10)	geographic latitude	(radians)
tgraph: tgraph(11)	geographic longitude	(radians)
tgraph: tgraph(12)	geographic radial distance	(earth radii).
tgraph: tgraph(13)	geocentric colatitude	(radians)
tgraph: tgraph(14)	geocentric longitude	(radians)
tgraph: tgraph(15)	x coordinate in the solar ecliptic system	(earth radii)
tgraph: tgraph(16)	y coordinate in the solar ecliptic system	(earth radii)
tgraph: tgraph(17)	z coordinate in the solar ecliptic system	(earth radii)
tgraph: tgraph(18)	x coordinate in the solar magnetospheric system	(earth radii)
tgraph: tgraph(19)	y coordinate in the solar magnetospheric system	(earth radii)
tgraph: tgraph(20)	z coordinate in the solar magnetospheric system	(earth radii)
tgraph: tgraph(21)	geomagnetic latitude	(radians)
tgraph: tgraph(22)	geomagnetic longitude	(radians)
tgraph: tgraph(23)	geomagnetic local time	(hours and fractions)

ifail: useless

**Called routines:**

gcvgd    geogkm    geogsm    georre    geose    ggeom    pvig  
tgml

**Used by:**

users programs:  
testgeog

## 6.21 TGML

**Author:** CNES - JC KOSIK - January 1991

### **Purpose:**

This routine calculates the geomagnetic local time of the spacecraft in hours and fractions of hours using the spherical geocentric coordinates.

### **Specifications:**

double precision rgsm(3,3), thet, phi  
double precision tgl  
integer ifail

**call tgml (rgsm, thet, phi, tgl, ifail)**

### **Input parameters:**

rgsm	transformation matrix (3,3) from the geocentric coordinate system into the solar magnetic coordinate system	
thet	geocentric colatitude	(radians)
phi	geocentric longitude	(radians)

### **Output parameters:**

tgl	geomagnetic local time	(hours and fractions)
ifail	return code	

### **Remarks:**

ifail: useless

### **Called routines:**

angleg    geosm

### **Used by:**

routines:  
calpos    geophys    posmag    tgeogr





## 6.23 TLOCAL

**Author:** CNES - JC KOSIK - June 1995

### **Purpose:**

This routine calculates the local time in hours and fractions of hours.

### **Specifications:**

integer ihour, imin, isec  
double precision phir, tlat  
integer ifail

**call tlocal (ihour, imin, isec, phir, tlat, ifail)**

### **Input parameters:**

ihour	hours	(0 to 23)
imin	minutes	(0 to 23)
isec	seconds	(0 to 59)
phir	geocentric longitude	(radians)

### **Output parameters:**

tlat	local time	(hours and fractions)
ifail	return code	

### **Remarks:**

ifail: useless

**Called routines:** none

### **Used by:**

routines:  
calpos

## 7. ASTRONOMY AND CELESTIAL MECHANICS

The orientation of the dipole with respect to the solar wind is time dependent. Different astronomical routines are necessary to calculate the location of the Sun, the julian date and the gregorian date.

This chapter describes 11 routines:

- orbit:** calculates the state vector by solving Kepler's equation. Cluster data are given as input.
- posin:** calculates the state vector in the initial frame of the date. Cluster data are given as input.
- pr2000:** calculates the precession matrix from the geocentric mean coordinate system to the date mean coordinate system.
- pvig:** transforms the rectangular components in the inertial coordinate system into rectangular components in the geographic coordinate system.
- solter10:** calculates the right ascension of Greenwich, the right ascension of the Sun and the declination of the Sun. It calculates also the geographic position of the point where the dipole cuts the northern hemisphere. These calculations are done for all epochs from January 2010 the 1<sup>st</sup> to December 2014 the 31<sup>st</sup>.
- solter05:** calculates the right ascension of Greenwich, the right ascension of the Sun and the declination of the Sun. It calculates also the geographic position of the point where the dipole cuts the northern hemisphere. These calculations are done for all epochs from January 2005 the 1<sup>st</sup> to December 2009 the 31<sup>st</sup>.
- solter00:** calculates the right ascension of Greenwich, the right ascension of the Sun and the declination of the Sun. It calculates also the geographic position of the point where the dipole cuts the northern hemisphere. These calculations are done for all epochs from January 2000 the 1<sup>st</sup> to December 2004 the 31<sup>st</sup>.
- solterv:** calculates the right ascension of Greenwich, the right ascension of the Sun and the declination of the Sun. It calculates also the geographic position of the point where the dipole cuts the northern hemisphere. These calculations are done for all epochs from January 1970 the 1<sup>st</sup> to December 1999 the 31<sup>st</sup>.
- soltervo:** calculates the right ascension of Greenwich, the right ascension of the Sun and the declination of the Sun. It calculates also the geographic position of the point where the dipole cuts the northern hemisphere. These calculations are done for all epochs from January 1945 the 1<sup>st</sup> to December 1969 the 31<sup>st</sup>.
- sun:** calculates the sidereal time and the position of the Sun for all epochs from 1901 to 2099 with a precision of 0.006 degrees.

**tsidrg:** calculates the sideral time in radians with a precision is of  $10^{-12}$  radians.

## 7.1 ORBIT

**Author:** ESA - January 1991

### **Purpose:**

This routine calculates the state vector by solving Kepler's equation. A file giving the Chebychev polynomial components is required as input. This calculation is used for Cluster spacecraft.

### **Specifications:**

double precision day  
integer kode, lfile, nsat  
double precision x(kode), orbnum  
integer ifail

**call orbit (day, kode, lfile, nsat, x, orbnum, ifail)**

### **Input parameters:**

day	julian date (from 2000)	(> 0)
kode	size of the state vector	(3 or 6)
lfile	unit number of the input file	

### **Output parameters:**

nsat	spacecraft identifier	(1,2,3 or 4)
x	state vector of the spacecraft	(position: kilometers, velocity: kilometers/ seconds)
orbnum	orbit number	
ifail	return code	

### **Remarks:**

kode: 3 = position  
kode: 6 = position and velocity

ifail: 0 = no problem  
ifail: 1 = julian date too small  
ifail: 2 = julian date too high  
ifail: 3 = non continuous date between two subsequent records  
ifail: 4 = incorrect kode value (different from 3 or 6)  
ifail: 5 = invalid date in file  
ifail: 6 = file reading error

The file must be opened before calling this routine.

The records must have subsequent date:

beginning date of record i - ending date of record i-1 > gap with gap = 2.d-4)

*Contents of Cluster data file:*

*First record type:*

nspace	spacecraft number	(integer:i3)
date	elements	(unused in orbit routine)

*Second record type:*

nrec	record identifier (200 + spacecraft number)	(integer:i3)
daydeb	beginning julian date	(real:fl2.6)
dayend	ending julian date	(real:fl2.6)
epoch	reference julian date of state vector	(real:fl5.9)
revepo	orbit number	(real:fl1.3)
smaxis	half big axis (kilometers)	(real:fl3.5)
omotin	mean inverse motion for a Keplerian orbit	(real:fl3.5)

*Third record:*

nrec	record identifier (300 + number of polynomial components)	(integer:i3)
y(6)	state vector for Keplerian orbit (kilometers, kilometers/second)	(real:3fl1.3, 3fl1.7)
rdist	distance from Earth center at the current date (kilometers)	(real:fl1.3)

*Fourth record type:*

nrec	record identifier (number of the Chebychev polynomial coefficients)	(integer:i3)
coeff	Chebychev polynomial coefficients	(real:3fl1.3, 3fl1.7)

*Example of Cluster data file:*

```
1 P 1994-06-20T04:11:36Z 1996-09-27T12:08:21Z 1996-09-27T16:13:03Z
201-1190.494202-1190.324269-1190.416903086 0.170 75267.55030 32707.12094
303 -59934.248 430.416 57153.095 -2.0723618 0.0130835 -0.1879987 82817.725
14 -0.194 -0.040 -0.098 -0.0000137 -0.00000034 -0.00000046
25 -0.084 -0.020 -0.034 -0.0001040 -0.00000215 -0.00000523
36 -0.191 -0.040 -0.096 -0.0000043 -0.00000015 0.00000002
1 P 1994-06-20T04:11:36Z 1996-09-27T16:13:03Z 1996-09-29T02:01:50Z
201-1190.324269-1188.915399-1189.613510960 0.507 75310.61606 32735.19596
306-125169.968 789.226 1317.318 0.0138254 -0.0013232 -1.0370751 125179.388
17 -22.573 -7.102 -2.799 0.0000159 -0.00000348 -0.00000572
28 1.145 -1.007 -0.106 -0.0015970 -0.0004069 -0.0001684
39 -23.101 -6.827 -2.707 -0.0000059 -0.00000364 -0.00001108
50 0.046 -0.402 -0.523 -0.0000788 0.0000418 0.00000095
61 -0.558 0.290 0.086 -0.0000104 0.00000032 -0.00000593
72 -0.056 0.018 -0.310 -0.0000054 0.00000037 -0.00000018
1 P 1994-06-20T04:11:36Z 1996-09-29T02:01:50Z 1996-09-29T11:46:38Z
201-1188.915399-1188.509284-1188.713958110 0.885 75272.20764 32710.15672
```

304	-36328.006	141.417	-54519.180	2.6005894	-0.0162463	0.3311135	65514.006
15	-0.753	-0.396	0.104	0.0000408	0.0000219	-0.0000303	
26	0.229	0.170	-0.222	-0.0001390	-0.0000803	-0.0000074	
37	-0.721	-0.382	0.054	0.0000555	0.0000245	-0.0000354	
48	0.116	0.066	-0.096	0.0000255	0.0000069	-0.0000198	

**Called routines:** none

**Used by:**

routines:  
    posin

## 7.2 POSIN

**Author:** CNES - JC KOSIK - June 1995

### **Purpose:**

This routine calculates the state vector in the inertial reference frame. A file giving the Chebychev polynomial components is required as input. This calculation is used for Cluster spacecraft.

### **Specifications:**

integer lfile, nsat  
double precision day  
double precision orbnum  
double precision xikm, yikm, zikm  
double precision vxi, vyi, vzi  
integer ifail

**call posin (lfile, nsat, day, orbnum, xikm, yikm, zikm,  
> vxi, vyi, vzi, ifail)**

### **Input parameters:**

lfile	unit number of the input file	
day	julian date (from 2000)	(> 0)
nsat	spacecraft identifier	(1,2,3 or 4)

### **Output parameters:**

orbnum	orbit number	
xikm	x component of the position in the inertial coordinate system	(kilometers)
yikm	y component of the position in the inertial coordinate system	(kilometers)
zikm	z component of the position in the inertial coordinate system	(kilometers)
vxi	x component of the velocity in the inertial coordinate system	(kilometers/ second)
vyi	y component of the velocity in the inertial coordinate system	(kilometers/ second)
vzi	z component of the velocity in the inertial coordinate system	(kilometers/ second)
ifail	return code	

### **Remarks:**

ifail: 0 = no problem  
ifail: 1 = julian date too small  
ifail: 2 = julian date too high  
ifail: 3 = non continuous date between two subsequent records



ifail: 4 = incorrect kode value (different from 3 or 6)  
ifail: 5 = invalid date in file  
ifail: 6 = file reading error

xikm, yikm, zikm, vixi, vyi, vzi are obtained in the initial frame of reference of the epoch (corrected from precession).

The file must be opened before calling this routine.

The records must have subsequent date:

beginning date of record i - ending date of record i-1 > gap with gap = 2.d-4)

The Chebychev components data file is described in routine orbit (6.1).

**Called routines:**

orbit      pr2000      promal

**Used by:**

users programs:  
testclu



## 7.4 PVIG

**Author:** CNES - JC KOSIK - January 1991

### **Purpose:**

This routine transforms the rectangular components (position, velocity of a spacecraft) in the inertial coordinate system into rectangular components in the geographic coordinate system.

### **Specifications:**

double precision djd  
double precision xi, yi, zi, vxi, vyi, vzi  
double precision xg, yg, zg, vxg, vyg, vzg  
integer ifail

**call pvig (djd, xi, yi, zi, vxi, vyi, vzi,  
> xg, yg, zg, vxg, vyg, vzg, ifail)**

### **Input parameters:**

djd	CNES julian date	
xi	x component of the position in the inertial coordinate system	(kilometers)
yi	y component of the position in the inertial coordinate system	(kilometers)
zi	z component of the position in the inertial coordinate system	(kilometers)
vxi	x component of the velocity in the inertial coordinate system	(kilometers/ second)
vyi	y component of the velocity in the inertial coordinate system	(kilometers/ second)
vzi	z component of the velocity in the inertial coordinate system	(kilometers/ second)

### **Output parameters:**

xg	x component of the position in the geographic coordinate system	(kilometers)
yg	y component of the position in the geographic coordinate system	(kilometers)
zg	z component of the position in the geographic coordinate system	(kilometers)
vxg:	x component of the velocity in the geographic coordinate system	(kilometers/ second)
vyg	y component of the velocity in the geographic coordinate system	(kilometers/ second)
vzg	z component of the velocity in the geographic coordinate system	(kilometers/ second)
ifail	return code	

### **Remarks:**

ifail: useless

**Called routines:**

tsidrg

**Used by:**

routines:

tgeogr

## 7.5 SOLTER00

**Author:** updated from CNES - JC KOSIK – December 2010

### **Purpose:**

This routine calculates the right ascension of Greenwich, the right ascension of the Sun and the declination of the Sun. It calculates also the geographic position of the point where the dipole cuts the northern hemisphere.

These calculations are done for all epochs from January 2000 the 1<sup>st</sup> to December 2004 the 31<sup>st</sup>.

### **Specifications:**

integer iyear, imonth, iday, ihour, imin, isec  
double precision year, alfag, alfas, deltas  
double precision obliq, tetdip, phidip  
integer ifail

**call solter00 (iyear, imonth, iday, ihour, imin, isec, year,  
> alfag, alfas, deltas, obliq, tetdip, phidip, ifail)**

### **Input parameters:**

iyear	year	(2000 ≤ year < 2005)
imonth	month	(1 to 12)
iday	day	(1 to 31)
ihour	hours	(0 to 23)
imin	minutes	(0 to 23)
isec	seconds	(0 to 59)

### **Output parameters:**

year	epoch	(years and fractions)
alfag	right ascension of Greenwich	(radians)
alfas	right ascension of the Sun	(radians)
deltas	declination of the Sun	(radians)
obliq	inclination of the ecliptic over the equator	(radians)
tetdip	geocentric colatitude of the point where the dipole cuts the northern hemisphere	(radians)
phidip	geocentric longitude of the point where the dipole cuts the northern hemisphere	(radians)
ifail	return code	

**Remarks:**

ifail: useless

**Called routines:**

      julg      sun

**Used by:**

      routines:

          inigeo1  inigeom

      users programs:

          testsolter00

## 7.6 SOLTER05

**Author:** updated from CNES - JC KOSIK – December 2010

### **Purpose:**

This routine calculates the right ascension of Greenwich, the right ascension of the Sun and the declination of the Sun. It calculates also the geographic position of the point where the dipole cuts the northern hemisphere.

These calculations are done for all epochs from January 2005 the 1<sup>st</sup> to December 2009 the 31<sup>st</sup>.

### **Specifications:**

integer iyear, imonth, iday, ihour, imin, isec  
double precision year, alfag, alfas, deltas  
double precision obliq, tetdip, phidip  
integer ifail

**call solter05 (iyear, imonth, iday, ihour, imin, isec, year,  
> alfag, alfas, deltas, obliq, tetdip, phidip, ifail)**

### **Input parameters:**

iyear	year	(2005 ≤ year < 2010)
imonth	month	(1 to 12)
iday	day	(1 to 31)
ihour	hours	(0 to 23)
imin	minutes	(0 to 23)
isec	seconds	(0 to 59)

### **Output parameters:**

year	epoch	(years and fractions)
alfag	right ascension of Greenwich	(radians)
alfas	right ascension of the Sun	(radians)
deltas	declination of the Sun	(radians)
obliq	inclination of the ecliptic over the equator	(radians)
tetdip	geocentric colatitude of the point where the dipole cuts the northern hemisphere	(radians)
phidip	geocentric longitude of the point where the dipole cuts the northern hemisphere	(radians)
ifail	return code	

**Remarks:**

ifail: useless

**Called routines:**

      julg      sun

**Used by:**

      routines:

          inigeo1  inigeom

      users programs:

          testsolter05



## 7.7 SOLTER10

**Author:** updated from CNES - JC KOSIK – December 2010

### **Purpose:**

This routine calculates the right ascension of Greenwich, the right ascension of the Sun and the declination of the Sun. It calculates also the geographic position of the point where the dipole cuts the northern hemisphere.

These calculations are done for all epochs from January 2010 the 1<sup>st</sup> to December 2014 the 31<sup>st</sup>.

### **Specifications:**

integer iyear, imonth, iday, ihour, imin, isec  
double precision year, alfag, alfas, deltas  
double precision obliq, tetdip, phidip  
integer ifail

**call solter10 (iyear, imonth, iday, ihour, imin, isec, year,  
> alfag, alfas, deltas, obliq, tetdip, phidip, ifail)**

### **Input parameters:**

iyear	year	(2010 ≤ year < 2015)
imonth	month	(1 to 12)
iday	day	(1 to 31)
ihour	hours	(0 to 23)
imin	minutes	(0 to 23)
isec	seconds	(0 to 59)

### **Output parameters:**

year	epoch	(years and fractions)
alfag	right ascension of Greenwich	(radians)
alfas	right ascension of the Sun	(radians)
deltas	declination of the Sun	(radians)
obliq	inclination of the ecliptic over the equator	(radians)
tetdip	geocentric colatitude of the point where the dipole cuts the northern hemisphere	(radians)
phidip	geocentric longitude of the point where the dipole cuts the northern hemisphere	(radians)
ifail	return code	

**Remarks:**

ifail: useless

**Called routines:**

      julg      sun

**Used by:**

      routines:

          inigeo1  inigeom

      users programs:

          testsolter10

## 7.8 SOLTERV

**Author:** CNES - JC KOSIK - January 1998

### **Purpose:**

This routine calculates the right ascension of Greenwich, the right ascension of the Sun and the declination of the Sun. It calculates also the geographic position of the point where the dipole cuts the northern hemisphere.

These calculations are done for all epochs from January 1970 the 1<sup>st</sup> to December 1999 the 31<sup>st</sup>.

### **Specifications:**

integer iyear, imonth, iday, ihour, imin, isec  
double precision year, alfag, alfas, deltas  
double precision obliq, tetdip, phidip  
integer ifail

**call solterv (iyear, imonth, iday, ihour, imin, isec, year,  
> alfag, alfas, deltas, obliq, tetdip, phidip, ifail)**

### **Input parameters:**

iyear	year	(1970 ≤ year < 2000)
imonth	month	(1 to 12)
iday	day	(1 to 31)
ihour	hours	(0 to 23)
imin	minutes	(0 to 23)
isec	seconds	(0 to 59)

### **Output parameters:**

year	epoch	(years and fractions)
alfag	right ascension of Greenwich	(radians)
alfas	right ascension of the Sun	(radians)
deltas	declination of the Sun	(radians)
obliq	inclination of the ecliptic over the equator	(radians)
tetdip	geocentric colatitude of the point where the dipole cuts the northern hemisphere	(radians)
phidip	geocentric longitude of the point where the dipole cuts the northern hemisphere	(radians)
ifail	return code	

**Remarks:**

ifail: 0 = no problem

ifail: 1 = if  $iyear < 1970$  or  $iyear \geq 2000$

**Called routines:**

      julg      sun

**Used by:**

      routines:

          inigeomv

      users programs:

          testsolv

## 7.9 SOLTERVO

**Author:** CNES - JC KOSIK - January 1998

### **Purpose:**

This routine calculates the right ascension of Greenwich, the right ascension of the Sun and the declination of the Sun. It calculates also the geographic position of the point where the dipole cuts the northern hemisphere.

These calculations are done for all epochs from January 1945 the 1<sup>st</sup> to December 1969 the 31<sup>st</sup>.

### **Specifications:**

integer iyear, imonth, iday, ihour, imin, isec  
double precision year, alfag, alfas, deltas  
double precision obliq, tetdip, phidip  
integer ifail

**call soltervo (iyear, imonth, iday, ihour, imin, isec, year,  
> alfag, alfas, deltas, obliq, tetdip, phidip, ifail)**

### **Input parameters:**

iyear	year	(1945 ≤ year < 1970)
imonth	month	(1 to 12)
iday	day	(1 to 31)
ihour	hours	(0 to 23)
imin	minutes	(0 to 23)
isec	seconds	(0 to 59)

### **Output parameters:**

year	epoch	(years and fractions)
alfag	right ascension of Greenwich	(radians)
alfas	right ascension of the Sun	(radians)
deltas	declination of the Sun	(radians)
obliq	inclination of the ecliptic over the equator	(radians)
tetdip	geocentric colatitude of the point where the dipole cuts the northern hemisphere	(radians)
phidip	geocentric longitude of the point where the dipole cuts the northern hemisphere	(radians)
ifail	return code	

**Remarks:**

ifail: 0 = no problem

ifail: 1 = if iyear < 1945 or iyear  $\geq$  1970

**Called routines:**

      julg      sun

**Used by:**

      routines:

          inigeomv

      users programs:

          testsoltvo

## 7.10 SUN

**Author:** adapted from G. MEAD routine in Ref 1.

### **Purpose:**

This routine calculates the sidereal time and the position of the Sun for all epochs from 1901 to 2099 with a precision of 0.006 degrees.

### **Specifications:**

integer iyear, iday  
double precision fday  
double precision gst, alfas, deltas, obliq  
integer ifail

**call sun (iyear, iday, fday, gst, alfas, deltas, obliq, ifail)**

### **Input parameters:**

iyear	year	1901 ≤ year < 2100)
iday	number of the day in the year	(1 to 365)
fday	number of seconds in the day	

### **Output parameters:**

gst	middle sidereal Greenwich time	(radians)
alfas	right ascension of the Sun	(radians)
deltas	declination of the Sun	(radians)
obliq	inclination of the ecliptic over the equator	(radians)
fail	return code	

### **Remarks:**

ifail: useless

*Ref 1:* Geophysical coordinate transformations - G. Russel, in Cosmic Electrodynamics 2, 1971, Reidel 184 - 196.

**Called routines:** none

### **Used by:**

routines:  
solter10 solter05 solter00 solterv soltervo





## 8. MATHEMATICS

This chapter describes 15 routines:

- angleg:** calculates an angle between  $(0, 2\pi)$  using director cosines.
- bessel:** calculates the Bessel functions of any order.
- carsp:** transforms the geocentric cartesian coordinates of a point into spherical coordinates.
- fact:** calculates the factorial of a number.
- kardan:** calculates the real or imaginary roots of a third degree equation.
- norma:** normalizes a vector.
- nuraci:** resolves a non linear equation on  $[a,b]$ .
- parabn:** calculates the normal to a parabola.
- promal:** calculates the multiplication of a one column matrix (3) by a square matrix (3,3).
- promat:** calculates the multiplication of two square matrices (3,3) and gives the resulting matrix and its inverse matrix.
- spcar:** transforms the spherical coordinates of a point into geocentric cartesian coordinates.
- tradeg:** converts angular coordinates arrays from radians to degrees.
- tspcar:** transforms the spherical coordinates of all the points of a field line into cartesian coordinates.
- vcarvsp:** transforms the cartesian components of a vector into spherical components.
- vspvcar:** transforms the geocentric spherical components of a vector into cartesian components.

## 8.1 ANGLEG

**Author:** CNES - JC KOSIK - January 1991

### **Purpose:**

This function calculates an angle using its director cosines.  
The angle is given in radians between 0 and  $2\pi$ .

### **Specifications:**

external angleg  
double precision angleg  
double precision acosa, asina  
double precision angle  
integer ifail

**angle = angleg (acosa, asina, ifail)**

### **Input parameters:**

acosa      angle cosine arc  
asina      angle sin arc

### **Output parameters:**

"angle"      calculated angle      (radians)  
ifail      return code

### **Remarks:**

ifail: useless

If acosa = 0 and asina = 0 angle is set to 0.

**Called routines:** none

### **Used by:**

routines:  
calpos      carsp      geogkm      parabn      tgml      tgml2

## 8.2 BESSEL

**Author:** CNES - JC KOSIK - June 1995 - algorithm adapted from Ref(2)

**Purpose:**

This routine calculates the Bessel functions of any order.

**Specifications:**

double precision x  
integer kk  
double precision bess  
integer ifail

**call bessel (x, kk, bess, ifail)**

**Input parameters:**

x	radial coordinate	(0 to 10)
kk	function order	(1 to 6)

**Output parameters:**

bess	result of the function
ifail	return code

**Remarks:**

ifail: useless

kk: 0 to 6 = J0, J1, J2, J3, J4, J5.

Ref(2): Nelson M. Balckman, S. Honein Mousavineshad IEEE transactions on aerospace and Electronic systems, vol AES-22, N°1, Jan 1986.

**Called routines:** none

**Used by:** none

### 8.3 CARSP

**Author:** CNES - JC KOSIK - January 1997

**Purpose:**

This routine transforms the geocentric cartesian coordinates of a point into spherical coordinates.

**Specifications:**

double precision xx, yy, zz  
double precision rr, thet, phi  
integer ifail

**call carsp (xx, yy, zz, rr, thet, phi, ifail)**

**Input parameters:**

xx	x coordinate in the cartesian system	(earth radii or kilometers)
yy	y coordinate in the cartesian system	(earth radii or kilometers)
zz	z coordinate in the cartesian system	(earth radii or kilometers)

**Output parameters:**

rr	geocentric radial distance	(same unit as input)
thet	geocentric colatitude counted from z axis	(radians)
phi	geocentric longitude counted from x axis	(radians)
ifail	return code	

**Remarks:**

ifail: useless

If  $(xx^2 + yy^2) = 0$ , phi is set to zero,  
thet is set to zero if zz is positive or null, thet is set to  $\pi$  if zz is negative.

**Called routines:**

angleg

**Used by:**

routines:

angdip	calpos	conjdip	dchapp	dconjr	econjr
georre	ggeom	kk97kp			

users programs:

testclu	testdist2
---------	-----------

## **8.4 FACT**

**Author:** CNES

**Purpose:**

This function calculates the factorial of a number.

**Specifications:**

integer ival  
integer ifail  
double precision factor  
external factor

**factor = fact (ival, ifail)**

**Input parameters:**

ival          number

**Output parameters:**

"factor"      factorial value  
ifail          return code

**Remarks:**

ifail: useless

**Called routines:** none

**Used by:** none

## 8.5 KARDAN

**Author:** CNES - Mme Soubry  
CNES - JC KOSIK - January 1991

### **Purpose:**

This routine calculates the real or imaginary roots of a third degree equation.

### **Specifications:**

double precision a(4)  
double precision rr(3), ri(3)  
integer icode  
integer ifail

**call kardan (a, rr, ri, icode, ifail)**

### **Input parameters:**

a            array of the four equation coefficients

### **Output parameters:**

rr            array of the three real roots  
ri            array of the three imaginary roots  
icode        number of real roots encountered            (0 to 3)  
ifail        return code

### **Remarks:**

$$mx^3 + nx^2 + px + q = 0$$

coefficient m must be different from zero

$$a(1) = m, a(2) = n, a(3) = p, a(4) = q$$

ifail: useless

**Called routines:** none

### **Used by:**

routines:  
ddparab

## 8.6 NORMA

**Author:** CNES - JC KOSIK - June 1995

**Purpose:**

This routine normalizes a vector.

**Specifications:**

double precision vecx, vecy, vecz  
double precision xnorm, ynorm, znorm  
integer ifail

**call norma (vecx, vecy, vecz, xnorm, ynorm, znorm, ifail)**

**Input parameters:**

vecx	x component of the vector
vecy	y component of the vector
vecz	z component of the vector

**Output parameters:**

xnorm	x component of the normalized vector
ynorm	y component of the normalized vector
znorm	z component of the normalized vector
ifail	return code

**Remarks:**

ifail: useless

**Called routines:** none

**Used by:**

routines:  
parabn



## 8.7 NURACI

**Author:** CNES - BERGES - mars 1986  
(c) MSLIB 0029 24.09.87 v1.0

### Purpose:

This routine solves a non linear equation on  $[a,b]$ .  
It searches for a real root for the non linear equation  $f(x) = h$  on  $[a,b]$  interval using the secant method with a convergence acceleration by dichotomy.

### Specifications:

double precision rfunc, rtab(\*), ra, rb  
double precision rh, repsi, rsol  
integer inbr  
integer ifail

**call nuraci (rfunc, rtab, ra, rb, rh, repsi, rsol, inbr, ifail)**

### Input parameters:

rfunc	name of the function which calculates $f(x)$	(defined by caller routine)
rtab	array of parameters describing rfunc function	
ra	first boundary of $[a,b]$ interval	
rb	second boundary of $[a,b]$ interval	

### Output parameters:

rh	second member of the equation
repsi	precision needed
rsol	root
inbr	number of roots on $[a,b]$
ifail	return code

**Remarks:**

rtab: rtab(1): dipolar line parameter  
rtab: rtab(2): geocentric distance (earth radii)  
rtab: rtab(3): colatitude (radians)

rfunc: has the following form:

$$\text{rfunc} = \text{rtab}(1) * f_1(x) + \text{rtab}(2) * f_2(x) + \dots + \text{rtab}(n) * f_n(x)$$

where  $f_1(x) \dots f_n(x)$  are functions of  $x$  such as  $e^x$ ,  $\log(x)$ ,  $\cos(x)$  and  $\sin(x)$  look for the solution of  $\text{rfunc} = \text{rh}$

inbr: 0 = 0 or 2 roots on  $[a,b]$  (conventionally  $\text{rsol} = 0$ )

inbr: 1 = one root

inbr: 2 = a and b are roots ( $\text{rsol}$  is set to a)

ifail: useless

**Called routines:** none

**Used by:** none

## 8.8 PARABN

**Author:** CNES - JC KOSIK - June 1995

### **Purpose:**

This routine calculates the normal to the magnetopause parabola or the bow shock.

### **Specifications:**

double precision arond, drond  
double precision yy, zz  
double precision xnpar, ynpar, znpar  
integer ifail

**call parabn (arond, drond, yy, zz, xnpar, ynpar, znpar, ifail)**

### **Input parameters:**

arond	parameter modified by the quadratic transformation
drond	parameter modified by the quadratic transformation
yy	x coordinate in the axial symmetry system
zz	x coordinate in the axial symmetry system

### **Output parameters:**

xnpar	x component of the normal
ynpar	y component of the normal
znpar	z component of the normal
ifail	return code

### **Remarks:**

ifail: useless

### **Called routines:**

angleg	norma
--------	-------

**Used by:** none

## 8.9 PROMAL

**Author:** CNES - JC KOSIK - January 1991

### **Purpose:**

This routine calculates the multiplication of a one column matrix (3) by a square matrix (3,3).

### **Specifications:**

double precision ama(3,3)  
double precision xp, yp, zp  
double precision xr, yr, zr  
integer ifail

**call promal (ama, xp, yp, zp, xr, yr, zr, ifail)**

### **Input parameters:**

ama        matrix (3,3)  
xp        x component of the column matrix  
yp        y component of the column matrix  
zp        z component of the column matrix

### **Output parameters:**

xr        x component of the result matrix  
yr        y component of the result matrix  
zr        z component of the result matrix  
ifail     return code

### **Remarks:**

ifail: useless

The matrices product is performed as follows:

$$\begin{bmatrix} xr \\ yr \\ zr \end{bmatrix} = \begin{bmatrix} & & \\ & & \\ & & \end{bmatrix} \begin{bmatrix} xp \\ yp \\ zp \end{bmatrix}$$

**Called routines:** none

### **Used by:**

routines:  
calpos    dipgeo    geodip    geogsm    geose    geosm  
gsmgeo    posin     segeo    smgeo

## 8.10 PROMAT

**Author:** CNES - JC KOSIK - January 1991

### **Purpose:**

This routine calculates the multiplication of two square matrices (3,3) and gives the resulting matrix and its inverse matrix.

### **Specifications:**

double precision ama(3,3), bma(3,3)  
double precision cma(3,3), cmat(3,3)  
integer ifail

**call promat (ama, bma, cma, cmat, ifail)**

### **Input parameters:**

ama	matrix	(3,3)
bma	matrix multiplied by matrix ama	(3,3)

### **Output parameters:**

cma	resulting matrix (3,3) from the product of "ama" and "bma" matrices
cmat	inverse matrix (3,3) of "cma"
ifail	return code

### **Remarks:**

ifail: useless

The matrices product is performed in the following order: [ cma ] = [ ama ] \* [ bma ]

**Called routines:** none

### **Used by:**

routines:  
    roggsm    rogsm    roigsm  
users programs:  
    testinige    testinige1

## 8.11 SPCAR

**Author:** CNES - JC KOSIK - January 1991

### **Purpose:**

This routine transforms the spherical coordinates of a point into geocentric cartesian coordinates.

### **Specifications:**

double precision rr, thet, phi  
double precision xcar, ycar, zcar  
integer ifail

**call spcar (rr, thet, phi, xcar, ycar, zcar, ifail)**

### **Input parameters:**

rr	geocentric distance of the point	(any unit)
thet	geocentric colatitude of the point	(radians)
phi	geocentric longitude of the point	(radians)

### **Output parameters:**

xcar	x coordinate in the geocentric system	(same unit as input)
ycar	y coordinate in the geocentric system	(same unit as input)
zcar	z coordinate in the geocentric system	(same unit as input)
ifail	return code	

### **Remarks:**

thet:  $0 \leq \text{thet} \leq \pi$   
phi:  $0 \leq \text{phi} \leq 2\pi$

ifail: useless

**Called routines:** none

**Used by:**

routines:

angdip    conjdip    dconjr    econjr    ggeom    mpause  
outmal    posmag

users programs:

testmodel

## 8.12 TRADEG

**Author:** CNES - JC KOSIK - January 1991

### **Purpose:**

This routine converts two angular coordinates arrays from radians to degrees.

### **Specifications:**

integer np  
double precision tab1r(np), tab2r(np)  
double precision tab1d(np), tab2d(np)  
integer ifail

**call tradeg (np, tab1r, tab2r, tab1d, tab2d, ifail)**

### **Input parameters:**

np	number of elements of the arrays	
tab1r	first array of angular coordinates	(radians)
tab2r	second array of angular coordinates	(radians)

### **Output parameters:**

tab1d	first array of angular coordinates	(degrees)
tab2d	second array of angular coordinates	(degrees)
ifail	return code	

### **Remarks:**

ifail: useless

**Called routines:** none

### **Used by:**

users programs:  
testcorgm testdconj testeconj testpconj



## 8.13 TSPCAR

**Author:** CNES - JC KOSIK - January 1991

### **Purpose:**

This routine transforms the spherical coordinates of all the points of a field line into cartesian coordinates.

### **Specifications:**

integer np  
double precision tr(500), tthet(500), tphi(500)  
double precision tx(500), ty(500), tz(500)  
integer ifail

**call tspcar (np, tr, tthet, tphi, tx, ty, tz, ifail)**

### **Input parameters:**

np	number of points	
tr	array of radial distances	(earth radii or kilometers)
tthet	array of colatitudes	(radians)
tphi	array of longitudes	(radians)

### **Output parameters:**

tx	array of x coordinates in the cartesian system	(same unit as input)
ty	array of y coordinates in the cartesian system	(same unit as input)
tz	array of z coordinates in the cartesian system	(same unit as input)
ifail	return code	

### **Remarks:**

ifail: 0 = no problem  
ifail: 1 = number of points negative or null

**Called routines:** none

**Used by:** none

## 8.14 VCARVSP

**Author:** CNES - JC KOSIK - January 1991

### **Purpose:**

This routine transforms the cartesian components of a vector into spherical components.

### **Specifications:**

double precision thet, phi  
double precision vgx, vgy, vgz  
double precision vr, vt, vp  
integer ifail

**call vcarvsp (thet, phi, vgx, vgy, vgz, vr, vt, vp, ifail)**

### **Input parameters:**

thet	geocentric colatitude	(radians)
phi	geocentric longitude	(radians)
vgx	x component in the cartesian coordinate system	(any unit)
vgy	y component in the cartesian coordinate system	(any unit)
vgz	z component in the cartesian coordinate system	(any unit)

### **Output parameters:**

vr	geocentric radial distance	(same unit as input)
vt	geocentric colatitude	(radians)
vp	geocentric longitude	(radians)
ifail	return code	

### **Remarks:**

ifail: useless

**Called routines:** none

### **Used by:**

routines:  
outmal

## 8.15 VSPVCAR

**Author:** CNES - JC KOSIK - January 1991

### **Purpose:**

This routine transforms the geocentric spherical components of a vector into cartesian components.

### **Specifications:**

double precision thet, phi  
double precision vr, vt, vp  
double precision vgx, vgy, vgz  
integer ifail

**call vspvcar (thet, phi, vr, vt, vp, vgx, vgy, vgz, ifail)**

### **Input parameters:**

thet	geocentric colatitude	(radians)
phi	geocentric longitude	(radians)
vr	x component of the vector in the spherical coordinate system	(any unit)
vt	y component of the vector in the spherical coordinate system	(any unit)
vp	z component of the vector in the spherical coordinate system	(any unit)

### **Output parameters:**

vgx	x component in the cartesian coordinate system	(same unit as input)
vgy	y component in the cartesian coordinate system	(same unit as input)
vgz	z component in the cartesian coordinate system	(same unit as input)
ifail	return code	

### **Remarks:**

ifail: useless

**Called routines:** none

### **Used by:**

routines:  
    bgsm      geophys      kk97kp

## 9. DATE CALCULATIONS

This chapter describes 6 routines:

- caldaj:** calculates the time interval in seconds between two julian CNES dates or converts into seconds a julian CNES date established from an initial date.
- calendg:** transforms a CNES julian day into a calendar day.
- datjhms:** calculates the days, hours, minutes and seconds from a number of seconds.
- djgreg:** transforms a CNES julian date into a gregorian date.
- jd2000:** transforms a calendar date into a julian day with 2000 January 1st for reference.
- julg:** transforms a calendar day into a CNES julian day.

## 9.1 CALDAJ

**Author:** CISI - LAGARRIGUE  
prog. CISI (MSLIB code adaptation)

### Purpose:

This routine calculates the time interval in seconds between two julian CNES dates or adds a duration in seconds to a CNES julian date.

### Specifications:

integer iday2  
double precision rseco2  
integer iday1  
double precision rseco1, rtime  
integer iconve, idayd  
double precision rsecon, rduree  
integer ifail

**call caldaj (iday2, rseco2, iday1, rseco1, rtime, iconve,  
> idayd, rsecon, rduree, ifail)**

### Input parameters:

iday2	ending CNES julian day (if iconve = 0)	(> 0)
rseco2	number of seconds in "iday2" day (if iconve = 0)	(0. ≤ rseco2 < 86400.)
iday1	initial CNES julian day (if iconve = 0 or iconve = 1)	(> 0)
rseco1	number of seconds in "iday1" day (if iconve = 0 or iconve = 1)	(0. ≤ rseco1 < 86400.)
rtime	duration (if iconve = 1)	seconds
iconve	conversion type	(0 or 1)

### Output parameters:

idayd	CNES julian day (if iconve = 1)	(≥ 0)
rsecon	number of seconds in "idayd" day (if iconve = 1)	(0. ≤ rsecon < 86400.)
rduree	time interval (if iconve = 0)	seconds
ifail	return code	

**Remarks:**

iconve: 0 = calculation of the time interval between 2 CNES julian dates,  
iconve: 1 = adding a duration in seconds to a CNES julian date.

ifail: useless

The CNES julian dates begins on 1950/01/01 at 0 hours.

**Called routines:** none

**Used by:** none

## 9.2 CALENDG

**Author:** CNES - JC KOSIK - January 1991

**Purpose:**

This routine transforms a CNES julian day into a calendar day.

**Specifications:**

integer idatjul  
integer iday, imonth, iyear  
integer ifail

**call calendg (idatjul, iday, imonth, iyear, ifail)**

**Input parameters:**

idatjul      CNES julian day      (> 0)

**Output parameters:**

iday          day      (1 to 31)  
imonth       month     (1 to 12)  
iyear         year      (≥ 1950)  
ifail          return code

**Remarks:**

ifail: useless

The CNES julian date begins on 1950/01/01 at 0 hours.

**Called routines:** none

**Used by:**

routines:  
    djgreg  
users programs:  
    testdate

### 9.3 DATJHMS

**Author:** CNES - JC KOSIK - January 1991

**Purpose:**

This routine calculates the days, hours, minutes and seconds from a number of seconds.

**Specifications:**

double precision sec  
integer iday, ihour, imin, isec  
integer ifail

**call datjhms (sec, iday, ihour, imin, isec, ifail)**

**Input parameters:**

sec	number of seconds	(≥ 0.)
-----	-------------------	--------

**Output parameters:**

iday	day	(1 to 31)
ihour	hours	(0 to 23)
imin	minutes	(0 to 23)
isec	seconds	(0 to 59)
ifail	return code	

**Remarks:**

ifail: useless

**Called routines:** none

**Used by:**

routines:  
    djgreg  
users programs:  
    testdate





## 9.5 JD2000

**Author:** ESOC - June 1995

ref: The astronomical almanac 1985 page b18

### Purpose:

This routine transforms a calendar date into a julian date with 2000 January 1<sup>st</sup> for reference. The calendar date must be within 1950/01/01 and 2099/12/31.

### Specifications:

integer iyear, imonth, iday, ihour, imin  
double precision sec  
double precision djuld  
integer ifail

**call jd2000 (year, imonth, iday, ihour, imin, sec, djuld, ifail)**

### Input parameters:

iyear	year	(4 digits)
imonth	month	(1 to 12)
iday	day	(1 to 31)
ihour	hours	(1 to 31)
imin	minutes	(1 to 31)
sec	real seconds	(0. ≤ sec < 60.)

### Output parameters:

djuld	julian date (from 2000)	(> 0.)
ifail	return code	

### Remarks:

ifail: useless

$\text{djuld}(2000) = \text{djuld}(1950) - 18262.0$

**Called routines:** none

### Used by:

users programs:  
testclu

## 9.6 JULG

**Author:** CNES - JC KOSIK - June 1995

### **Purpose:**

This function transforms a calendar day into a CNES Julian day.

### **Specifications:**

external julg  
integer julg  
integer iday, imonth, iyear  
integer ifail

**juld = julg (iday, imonth, iyear, ifail)**

### **Input parameters:**

iday	day	(1 to 31)
imonth	month	(1 to 12)
iyear	year	(≥ 1950)

### **Output parameters:**

ifail	return code
"juld"	CNES julian day

### **Remarks:**

ifail: useless

The CNES julian date begins on 1950/01/01 at 0 hours.

**Called routines:** none

### **Used by:**

routines:  
    inigeo1    solter10    solter05    solter00    solterv    soltervo  
users programs:  
    testdate    testgeog

## 10. CONTROL ROUTINES

This chapter describes 5 routines:

- ctrlat:** controls the validity of a CNES julian date or a calendar date.
- ctrldis:** controls the spacecraft coordinates validity.
- ctrlind:** controls the indexes of field calculation type validity.
- ctrlpar:** controls the input data for the calculation routines.
- ctrlpos:** controls the position of the spacecraft relatively to the magnetosphere.

## 10.1 CTRLDAT

**Author:** CNES - JC KOSIK - January 1991

### **Purpose:**

This routine controls the CNES julian date or a calendar date.

### **Specifications:**

integer icalnd  
double precision datjul  
integer iyear, imonth, iday, ihour, imin, isec  
integer ifldat

**call ctrlдат (icalnd, datjul, iyear, imonth, iday, ihour, imin, isec, ifldat)**

### **Input parameters:**

icalnd	date type	(0 or 1)
datjul	CNES julian date	
iyear	year	
imonth	month	(1 to 12)
iday	day	(1 to 31)
ihour	hours	(0 to 23)
imin	minutes	(0 to 23)
isec	seconds	(0 to 59)

### **Output parameters:**

ifldat	date validity indicator
--------	-------------------------

**Remarks:**

icalnd: 0 = julian  
icalnd: 1 = calendar

datjul: julian date validity: date  $\geq$  14610.0

calendar date validity:

taking in account the bisextiles years

year:  $\geq$  1995 for "gsfc65" routine 1995

imonth:  $1 \leq$  month  $\leq$  12

iday:  $1 \leq$  day  $\leq$  28 or 29 or 30 or 31 according to "month" value

ihour:  $0 \leq$  hours  $\leq$  23

imin:  $0 \leq$  minutes  $\leq$  59

isec:  $0 \leq$  seconds  $\leq$  59

dates: if the date is julian, the parameters relative to the calendar date must be set to zero and vice versa.

ifldat: 0 = OK

ifldat: 1 = incorrect date

ifldat: 2 = warning: date  $<$  1995

**Called routines:** none

**Used by:**

routines:

ctrlpar

## 10.2 CTRLDIS

**Author:** CNES - JC KOSIK - January 1991

**Purpose:**

This routine controls the spacecraft coordinates.

**Specifications:**

integer iunitr  
double precision rr, theta, phi  
integer ifail1, ifail2, ifail3

**call ctrldis (iunitr, rr, theta, phi, ifail1, ifail2, ifail3)**

**Input parameters:**

iunitr	distance rr unit	(0 or 1)
rr	distance	(in iunitr unit)
theta	theta angle	(radians)
phi	phi angle	(radians)

**Output parameters:**

ifail1	rr validity indicator
ifail2	theta validity indicator
ifail3	phi validity indicator

**Remarks:**

iunitr: 0 = kilometers

iunitr: 1 = earth radii

rr:  $\geq 1$  earth radius with 1 earth radius = 6378.16 km

theta: validity ( $0 \leq \theta \leq \pi$ ),

phi: validity ( $0 \leq \phi \leq 2\pi$ )

ifail1: 0 = OK

ifail1: 1 = r incorrect

ifail2: 0 = OK

ifail2: 1 = theta incorrect

ifail3: 0 = OK

ifail3: 1 = phi incorrect

**Called routines:** none**Used by:**

routines:

ctrlpar



### 10.3 CTRLIND

**Author:** CNES - JC KOSIK - January 1991

**Purpose:**

This routine controls the indexes used in magnetic field calculation.

**Specifications:**

integer magin, magout, indgm, indval  
integer ifail1, ifail2, ifail3, ifail4

**call ctrlind (magin, magout, indgm, indval, ifail1, ifail2, ifail3, ifail4)**

**Input parameters:**

magin	internal magnetic field type	(from 1 to 4)
magout	external magnetic field type	(from 0 to 2)
indgm	geomagnetic index type	(1 or 2)
indval	geomagnetic index value for Kp or Ae	(from 1 to 6)

**Output parameters:**

ifail1	magin validity indicator
ifail2	magout validity indicator
ifail3	indgm validity indicator
ifail4	indgv validity indicator

**Remarks:**

magin: 1 = dipole + g11 + h11  
magin: 2 = DGRF00 field  
magin: 3 = DGRF05 field  
magin: 4 = IGRF10 field

magout: 0 = no external field  
magout: 1 = Tsyganenko 87 field  
magout: 2 = Tsyganenko 89 field  
magout: 3 = Kosik 97

indgm: geomagnetic index: 1 = Kp, 2 = Ae

indval: geomagnetic index value for Kp or Ae

indval = 1: Kp =0, 0+	Ae = 0 - 50
indval = 2: Kp =1- , 1 , 1+	Ae = 50 - 100
indval = 3: Kp =2- , 2 , 2+	Ae = 100 - 150
indval = 4: Kp =3- , 3 , 3+	Ae = 150 - 250
indval = 5: Kp =4- , 4 , 4+	Ae = 250 - 400
indval = 6: Kp > 5	Ae ≥ 400

ifail1: 0 = no problem  
ifail1: 1 = magin incorrect

ifail2: 0 = no problem  
ifail2: 1 = magout incorrect

ifail3: 0 = no problem  
ifail3: 1 = indgm incorrect

ifail4: 0 = no problem  
ifail4: 1 = indval incorrect

**Called routines:** none

**Used by:**

routines:  
ctrlpar

## 10.4 CTRLPAR

**Author:** CNES - JC KOSIK - January 1991

### **Purpose:**

This routine controls the input data for the calculations routines. These calculation are done for all epochs from January 1970 the 1<sup>st</sup> to December 2014 the .31<sup>st</sup>.

### **Specifications:**

integer itypda  
double precision datjul  
integer iyear, imonth, iday, ihour, imin, isec  
integer magin, magout, indgm, indval, iunitr  
double precision rr, theta, phi  
integer ifldat, iflind, iflcoo, iflpos

**call ctrlpar (itypda, datjul, iyear, imonth, iday, ihour, imin, isec,  
> magin, magout, indgm, indval, iunitr, rr, theta, phi,  
> ifldat, iflind, iflcoo, iflpos)**

### **Input parameters:**

itypda	date type	(0 or 1)
datjul	CNES julian date	
iyear	year	
imonth	month	(1 to 12)
iday	day	(1 to 31)
ihour	hours	(0 to 23)
imin	minutes	(0 to 23)
isec	seconds	(0 to 59)
magin	internal magnetic field type	(from 1 to 4)
magout	external magnetic field type	(from 0 to 2)
indgm	geomagnetic index type	(1 or 2)
indval	geomagnetic index value for Kp or Ae	(from 1 to 6)
iunitr	distance rr unit	(0 or 1)
rr	distance	(in iunitr unit)
theta	theta angle	(radians)
phi	phi angle	(radians)

### **Output parameters:**

ifldat	date validity indicator
iflind	magnetic field indicators validity indicators
iflcoo	spacecraft coordinates validity indicator
iflpos	spacecraft position validity indicator relatively to magnetopause

## Remarks:

itypda: 0 = julian  
itypda: 1 = calendar

datjul: julian date validity: date  $\geq 14610.0$

calendar date validity:

taking in account the bisextiles years

iyear:  $\geq 1995$

imonth:  $1 \leq \text{month} \leq 12$

iday:  $1 \leq \text{day} \leq 28$  or  $29$  or  $30$  or  $31$  according to month value

ihour:  $0 \leq \text{hours} \leq 23$

imin:  $0 \leq \text{minutes} \leq 59$

isec:  $0 \leq \text{seconds} \leq 59$

dates: if the date is julian, the parameters relative to the calendar date must be set to zero and vice versa.

magin: 1 = dipole + g11 + h11

magin: 2 = DGRF00 field

magin: 3 = DGRF05 field

magin: 4 = IGRF10 field

magout: 0 = no external field

magout: 1 = Tsyganenko 87 field

magout: 2 = Tsyganenko 89 field

magout: 3 = Kosik 97

indgm: geomagnetic index: 1 = Kp, 2 = Ae

indval: geomagnetic index value for Kp or Ae

indval = 1: Kp = 0, 0+                      Ae = 0 - 50

indval = 2: Kp = 1-, 1, 1+                Ae = 50 - 100

indval = 3: Kp = 2-, 2, 2+                Ae = 100 - 150

indval = 4: Kp = 3-, 3, 3+                Ae = 150 - 250

indval = 5: Kp = 4-, 4, 4+                Ae = 250 - 400

indval = 6: Kp > 5                        Ae  $\geq 400$

rr:  $\geq 1$  earth radius with 1 earth radius = 6378.16 km

theta: validity ( $0 \leq \text{theta} \leq \pi$ ),

phi: validity ( $0 \leq \text{phi} \leq 2\pi$ )

iunitr: 0 = kilometers

iunitr: 1 = earth radii

ifl(xxx): 0 = no problem

ifldat: 1 = incorrect date

ifldat: 2 = warning - date < 1995

iflind: 1 = incorrect indexes for field calculation

iflcoo: 1 = incorrect spacecraft coordinates (rr, theta, phi)

iflpos: 0 = spacecraft is inside the magnetosphere

iflpos: 1 = spacecraft is outside the magnetosphere

**Called routines:**

ctrlrat    ctrlind    ctrldis    ctrlpos

**Used by:**

users programs:

testctrl

## 10.5 CTRLPOS

**Author:** CNES - JC KOSIK - January 1991

### **Purpose:**

This routine controls the position of the spacecraft relatively to the magnetosphere.

### **Specifications:**

integer itypda  
double precision datjul  
integer iyear, imonth, iday, ihour, imin, isec  
integer iunitr  
double precision rr, theta, phi  
integer iflpos

**call ctrlpos (itypda, datjul, iyear, imonth, iday, ihour, imin, isec,  
> iunitr, rr, theta, phi, iflpos)**

### **Input parameters:**

itypda	date type	(0 or 1)
datjul	CNES julian date	
iyear	year	
imonth	month	(1 to 12)
iday	day	(1 to 31)
ihour	hours	(0 to 23)
imin	minutes	(0 to 23)
isec	seconds	(0 to 59)
iunitr	distance rr unit	(0 or 1)
rr	distance	(in iunitr unit)
theta	theta angle	(radians)
phi	phi angle	(radians)

### **Output parameters:**

iflpos	spacecraft position validity indicator relatively to the magnetopause
--------	---

**Remarks:**

itypda: 0 = julian date  
itypda: 1 = calendar date

iunitr: 0 = kilometers  
iunitr: 1 = earth radii

rr:  $\geq 1$  earth radius with 1 earth radius = 6371.2 km

theta: validity ( $0 \leq \theta \leq \pi$ ),

phi: validity ( $0 \leq \phi \leq 2\pi$ )

iflpos: 1 = spacecraft is inside the magnetosphere  
iflpos: 0 = spacecraft is outside the magnetosphere

**Called routines:**

djgreg    inigeom    mpause

**Used by:**

routines:  
    ctrlpar