MAGLIB

REFERENCE MANUAL OF MAGLIB LIBRARY:

GEOGRAPHIC, GEOPHYSICS AND GEOMAGNETIC CALCULATION

ROUTINES

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Version 4, Revision 0, 2010/12/09
Version 5, Revision 0, 2017/02/28
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MAGLIB

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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 eccentered-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 6.0

Internal magnetic fields:

IGRF 2020 is now available. As a consequence, DGRF 2010 and DGRF 2015 have now definitive coefficients and are called in the international standard DGRF 2010 and DGRF 2015. The spherical harmonics expansion has been extended to the 13th order since the DGRF 2000.
As the secular variations are only available for the last updated model, i.e., IGRF 2020, calculated secular variations have been introduced for the previous models DGRF 2010 and DGRF 2015. These were calculated using a linear interpolation.
A new interim geomagnetic field model has been introduced, the IGRF 2020. A new interpolation model for the time period between 1995 and 2020 has been introduced.
The routine DIPOL calculates the magnetic field of the dipole and the first harmonics using IGRF 2020 coefficients.

Orientation of the dipole:

The introduction of the new magnetic field models has immediate consequences on the calculation of the dipole parameters thetdip and phidip 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, SOLTER10 in the interval 2010-2015, SOLTER15 in the interval 2015-2020 and SOLTER20 in the interval 2020-2025.

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 – 2025.
The INIGEO1 routine used for the CLUSTER Project calculates all the rotation matrices for the interval 2000 – 2025. INIGEO1 is simply an extension of INIGEOM as it calculates three additional rotation matrices.

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	Status	Revision 5.0
Magnetic field: $1945 \leq T < 1970$	**chp45_70**	Unchanged	
	dgrf45_70	Unchanged	
Magnetic field: $1970 \leq T < 1995$	**chp70_95**	Unchanged	
	dgrf70_95	Unchanged	
Magnetic field: $1995 \leq T < 2020$	**chp95_20**	Updated	New set of coefficients for year 2020.
	igrf95_20	Updated	
Magnetic field: $1995 \leq T < 2000$	**chp95**	Unchanged	
	dgrf95	Unchanged	
Magnetic field: $2000 \leq T < 2005$	**chp00**	Unchanged	
	dgrf00	Unchanged	
Magnetic field: $2005 \leq T < 2010$	**chp05**	Unchanged	
	dgrf05	Unchanged	
Magnetic field: $2010 \leq T < 2015$	**chp10**	Updated	Definitive set of coefficients unchanged, definitive calculated secular variations.
	dgrf10	Updated	
Magnetic field: $2015 \leq T < 2020$	**chp15**	Updated	Definitive coefficients, interim calculated secular variations. igrf15 module renamed as dgrf15
	dgrf15	New	
Magnetic field: $2020 \leq T < 2025$	**chp20**	New	New CHP model, New IGRF model.
	igrf20	New	
Magnetic field gradients: $1995 \leq T < 2000$	**grad95**	Unchanged	
Magnetic field gradients: $2000 \leq T < 2005$	**grad00**	Unchanged	
Magnetic field gradients: $2005 \leq T < 2010$	**grad05**	Unchanged	
Magnetic field gradients: $2010 \leq T < 2015$	**grad10**	Updated	Definitive coefficients unchanged, definitive calculated secular variations.
Magnetic field gradients: $2015 \leq T < 2020$	**grad15**	Updated	Definitive coefficients, interim calculated secular variations.
Magnetic field gradients: $2020 \leq T < 2025$	**grad20**	New	Interim coefficients, interim secular variations.
Orientation of the dipole: $1945 \leq T < 1970$	**soltervo**	Unchanged	Unchanged
Orientation of the dipole: $1970 \leq T < 2000$	**solterv**	Unchanged	Unchanged
Orientation of the dipole: $2000 \leq T < 2005$	**solter00**	Unchanged	
Orientation of the dipole: $2005 \leq T < 2010$	**solter05**	Unchanged	

Orientation of the dipole: $2010 \le T < 2015$	**solter10**	Updated	Updated secular variations
Orientation of the dipole: $2015 \le T < 2020$	**solter15**	Updated	Updated coefficients.
Orientation of the dipole: $2020 \le T < 2025$	**solter20**	New	New coefficients.
Rotation matrices: $1945 \le T < 2000$	**inigeomv**	Unchanged	
Rotation matrices: $2000 \le T < 2025$	**inigeom**	Updated	New solter20 involved.
Rotation matrices: $2000 \le T < 2025$	**inigeo1**	Updated	New solter20 involved.
Transformation matrix from the geocentric coordinate system into the field coordinate system	**rovdh**	Updated	Call new igrf20 module.
Conjugate points: $2000 \le T < 2025$	**dconjr**	Updated	Updated internal field models
	pconjr	Updated	
Equatorial conjugate: $2000 \le T < 2025$	**econjr**	Updated	Updated internal field models
Galperin L parameter: $2000 \le T < 2025$	**dlgalp**	Updated	Updated internal field models
	flgalp	Updated	

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 1st to December 2024 the 31st.

inigeom: Calculations are done for all epochs from January 2000 the 1st to December 2024 the 31st.

inigeomv: These calculations are done for all epochs from January 1945 the 1st to December 1999 the 31st.

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 1st to December 2024 the 31st.

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), rgmgsm(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, rsmgsm, 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)
djulc	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	
rgsmsm	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
rosmgs	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 1st to December 2024 the 31st.

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 1st to December 1999 the 31st.

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	($1945 \leq$ 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 ≥ 2000

Called routines:

rogdip roggsm rogse rogsm roig roigsm solterv
soltervo

Used by:

users programs:
testinigv 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

$$pi = \pi = \cos^{-1}(-1.d0)$$
$$dpi = 2\pi$$
$$\deg = 180.d0/\pi$$
$$rad = \pi/180.d0$$
$$pid = \pi/2.d0$$
$$xmu = 398600.5 km^3/s^2$$
$$rayt = 6378.137 km$$

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.

rosmgs: 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 conjdip 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:

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

Output parameters:

rr	geocentric distance	(same unit as input)
dlatr	geocentric latitude	(radians)
dlonr	geocentric longitude	(radians)
ifail	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	outma1	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, rgsm(3,3)
double precision rggsm(3,3), rgsmg(3,3)
integer ifail
```

call roggsm (tilt, rgsm, rggsm, rgsmg, ifail)

Input parameters:

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	

Output parameters:

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
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, igrf20, 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: Kp = 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:

aberrm

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 tgls, xls
integer ichapp
integer ifail

call chapel (tgls, xls, ichapp, ifail)

Input parameters:

tgls	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	($1 \leq isw \leq 5$)
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 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:

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 plasmaspause.

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	y 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 Kp = 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

3.17 OLSDON

Author: CNES - JC KOSIK - October 2001

Purpose:

This routine returns the Olson's data corresponding to a given tilt angle.
When the tilt angle is greater than 30 degrees, the 30 degrees values are returned.

Specifications:

```
integer tiltd
double precision trc(13,12)
integer ifail
```

call olsdon (tiltd,trc, ifail)

Input parameters:

tiltd	tilt angle	(degrees)

Output parameters:

trc	Olson's data for the given point	(tens of earth radii)
ifail	return code	

Remarks:

ifail: useless

Called routines: none

Used by:

users programs:
testolsdon

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	msheath
oval	posnsh	pospsh	rbelt	spcar	tgml	

Used by:

users programs:
testrad testsph

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 $\geq$ y0, y0 = 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 IGRF20 model which contains coefficients defined for epoch 2020. The GSFC65 model contains the coefficients which were used by Mc Ilwain to calculate the B-L coordinate system.

This chapter describes 27 routines:

chp20:	calculates the magnetic field components for epochs ≥ 2020.
chp15:	calculates the magnetic field components for epochs ≥ 2015.
chp10:	calculates the magnetic field components for epochs ≥ 2010.
chp05:	calculates the magnetic field components for epochs ≥ 2005.
chp00:	calculates the magnetic field components for epochs ≥ 2000.
chp95:	calculates the magnetic field components for epochs ≥ 1995.
chp95_20:	calculates the magnetic field for all epochs between 1995 and 2020.
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.

igrf20:	calculates the internal magnetic field components of the IGRF20 model.
dgrf15:	calculates the internal magnetic field components of the DGRF15 model.
dgrf10:	calculates the internal magnetic field components of the DGRF10 model.
dgrf05:	calculates the internal magnetic field components of the DGRF05 model.
dgrf00:	calculates the internal magnetic field components of theDGRF00 model.
dgrf95:	calculates the internal magnetic field components of the DGRF95 model.
igrf95_20:	calculates the internal magnetic field components between 1995 and 2020.
dgrf70_95:	calculates the internal magnetic field components between 1970 and 1995.
dgrf45_70:	calculates the internal magnetic field components between 1945 and 1970.

grad20:	calculates the internal magnetic field components of the IGRF 20 model and the nine associated gradients.

grad15:	calculates the internal magnetic field components of the DGRF 15 model and the nine associated gradients.
grad10:	calculates the internal magnetic field components of the DGRF 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 IGRF20 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 CHP15 model
vs_igrf:	calculates the secular variations of the DGRF15 model

4.1 CHP20

Author: updated from CNES - JC KOSIK – July 2020

Purpose:

This routine calculates the magnetic field components from 2020 to 2025.

Specifications:

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

call chp20 (year, rre, thetr, phir, br, bt, bp, bb, ifail)

Input parameters:

year	real epoch (≥ 2020.)	(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:
testchp20

4.2 CHP15

Author: updated from CNES - JC KOSIK – February 2017

Purpose:

This routine calculates the magnetic field components from 2015 to 2020.

Specifications:

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

call chp15 (year, rre, thetr, phir, br, bt, bp, bb, ifail)

Input parameters:

year	real epoch (≥ 2015.)	(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:
testchp15

4.3 CHP10

Author: updated from CNES - JC KOSIK – February 2017

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 (≥ 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

4.4 CHP05

Author: updated from CNES - JC KOSIK – February 2017

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 (≥ 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

4.5 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 (≥ 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

4.6 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 (≥ 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

4.7 CHP95_20

Author: updated from CNES - JC KOSIK – July 2020

Purpose:

This routine calculates the magnetic field for all epochs between 1995 and 2020.

Specifications:

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

call chp95_20 (year, rre, thetr, phir, br, bt, bp, bb, ifail)

Input parameters:

year	epoch (1995 ≤ year < 2020)	(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_20

4.8 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 ≤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

4.9 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 ($1945 < year \leq 1970$)	(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

4.10 IGRF20

Author: updated from CNES - JC KOSIK – July 2020

Purpose:

This routine calculates the magnetic field components for epochs between 2020 to 2025.

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 (≥ 2020.)	(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:
testchp20 testgrad20

4.11 DGRF15

Author: updated from CNES - JC KOSIK – February 2017

Purpose:

This routine calculates the magnetic field components for epochs between 2015 to 2020.

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 (≥ 2015.)	(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:
testchp15 testgrad15

4.12 DGRF10

Author: updated from CNES - JC KOSIK – February 2017

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 dgrf10 (year, rre, thet, phi, br, bt, bp, bb, ifail)

Input parameters:

year	real epoch (≥ 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

4.13 DGRF05

Author: updated from CNES - JC KOSIK – February 2017

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 (≥ 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

4.14 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 (≥ 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

4.15 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

4.16 IGRF95_20

Author: from CNES - JC KOSIK – December 2010

Purpose:

This routine calculates the magnetic field for all epochs between 1995 and 2020.

Specifications:

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

call igrf95_20 (year, rre, thet, phi, br, bt, bp, bb, ifail)

Input parameters:

year	real epoch ($1995 \leq$ year < 2020)	(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 2π	(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_20

4.17 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 ($1970 < year \leq 1995$)	(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 2π	(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

4.18 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 ($1945 < year \leq 1970$)	(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 2π	(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

4.19 GRAD20

Author:updated from CNES - JC KOSIK – July 2020

Purpose:

This routine calculates the internal magnetic field components of the IGRF 20 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 grad20 (year, rre, thet, phi, br, bt, bp, bb, gradb,ifail)

Input parameters:

year	real epoch (≥ 2020.)	(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 π, 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:
testgrad20

4.20 GRAD15

Author:updated from CNES - JC KOSIK – February 2017

Purpose:

This routine calculates the internal magnetic field components of the IGRF 15 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 grad15 (year, rre, thet, phi, br, bt, bp, bb, gradb,ifail)

Input parameters:

year	real epoch (≥ 2015.)	(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 π, 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:

testgrad15

4.21 GRAD10

Author:updated from CNES - JC KOSIK – February 2017

Purpose:

This routine calculates the internal magnetic field components of the DGRF 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 (≥ 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 π, 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

4.22 GRAD05

Author: updated from CNES - JC KOSIK – February 2017

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 (≥ 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 π, 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

4.23 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 (≥ 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 π, 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

4.24 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 (≥ 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 π, 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

4.25 DIPOL

Author: updated from CNES - JC KOSIK – July 2020

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 IGRF20 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 ≥ 2020)	(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

4.26 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 coordinatein the geocentric system	(earth radii)
yg	y coordinatein 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

4.27 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 (≥ 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

4.28 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:

g10	spherical harmonic, dipole term	
g11	spherical harmonic, g11 coefficient	
h11	spherical harmonic, h11 coefficient	

Output parameters:

ginc10	tilted dipole component	
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: none

Used by:

users programs:
testdipex2

4.29 VS_CHP

Author: from CNES - JC KOSIK – December 2010

Purpose:

This routine calculates the secular variations of the CHP10 or CHP15 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 CHP10 are definitive (CHP15 and CHP10 have definitive coefficients). The secular variations for CHP15 are interim variations (CHP15 have definitive coefficients but CHP20 have interim coefficients).

ifail: useless

Called routines: none

Used by:

users programs:
testvs

4.30 VS_IGRF

Author: from CNES - JC KOSIK – December 2010

Purpose:

This routine calculates the secular variations of the DGRF10 or DGRF15 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 DGRF10 are definitive (DGRF05 and DGRF10 have definitive coefficients). The secular variations for DGRF15 are interim variations (DGRF15 have definitive coefficients but IGRF20 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 ΔB in the midday-midnight plane. ΔB 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 ΔB in the noon-midnight plane. The ΔB 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: Nikolaï 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 Ae.

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 Ae	(from 1 to 6)
tilt	tilt angle or geomagnetic latitude of the Sun	(radians)
xysm	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: Ae =0 - 50
indval: 2: Ae = 50 - 100
indval: 3: Ae =100 - 150
indval: 4: Ae =150 - 250
indval: 5: Ae =250 - 400
indval: 6: Ae $\geq$ 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: Nikolaï 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 Kp.

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 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:

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: 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

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:
    outma1
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 - Febuary 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: Nikolaï 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 Λ_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.

bgsm: calculates the total magnetic field as sum of the internal magnetic field (Dipole, DGRF00 or DGRF05 or DGRF10 or DGRF15 or IGRF20) 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.

conjdip: 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 DGRF10 or DGRF15 or IGRF20 magnetic field).

invar: calculates the Mac Ilwain L parameter value.

invlat: 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 DGRF10 or DGRF15 or IGRF20) 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 6)
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 = 4) epoch (> 2015 if magin = 5) epoch (> 2020 if magin = 1 or 6)	(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 = DGRF10 field
magin: 5 = DGRF15 field
magin: 6 = IGRF20 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 $1 \leq$ indval ≤ 5 and $1 \leq$ Kp ≤ 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 tgls, tlsat
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, tgls, tlsat,
>       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 coordinatein 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 coordinatein the inertial system	(earth radii)
yi	x coordinatein the inertial system	(earth radii)
zi	x coordinatein 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)
tgls	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 tgls
double precision xlchap
integer ifail
```

call chapp2 (tgls, xlchap ,ifail)

Input parameters:

tgls	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 DGRF10 or DGRF15 or IGRF20 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 6)
year	real epoch (≥ 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 = DGRF 2010 field
magin: 5 = DGRF 2015 field
magin: 6 = IGRF 2020 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 ≤ indval ≤ 5 and 1 ≤ Kp ≤ 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 6)
year	epoch (≥ 2000 if magin = 2) epoch (≥ 2005 if magin = 3) epoch (≥ 2010 if magin = 4) epoch (≥ 2015 if magin = 5) epoch (≥ 2020 if magin = 1 or 6)	(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 = DGRF10 field
magin: 5 = DGRF15 field
magin: 6 = IGRF20 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 ≤ indval ≤ 5 and 1 ≤ Kp ≤ 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) ≤ 0.01
ifail: 2 = getting out of the magnetopause

Called routines:

carsp magtot mpause spcar

Used by:

routines:

dlgalp 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 6)
magout	external magnetic field type	(from 1 to 3)
year	epoch (≥ 2000 if magin = 2) epoch (≥ 2005 if magin = 3) epoch (≥ 2010 if magin = 4) epoch (≥ 2015 if magin = 5) epoch (≥ 2020 if magin = 1 or 6)	(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 = DGRF 2010
magin: 5 = DGRF 2015
magin: 6 = IGRF 2020

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

xlamb: if colatitude > π /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 6)
year	epoch (≥ 2000 if magin = 2) epoch (≥ 2005 if magin = 3) epoch (≥ 2010 if magin = 4) epoch (≥ 2015 if magin = 5) epoch (≥ 2020 if magin = 1 or 6)	(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 = DGRF 2010 field
magin: 5 = DGRF 2015 field
magin: 6 = IGRF 2020 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 ≤ indval ≤ 5 and 1 ≤ Kp ≤ 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 rre > rmax or (rre - 1) ≤ 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 6)
magout	external magnetic field type	(from 1 to 3)
year	epoch (≥ 2000 if magin = 2) epoch (≥ 2005 if magin = 3) epoch (≥ 2010 if magin = 4) epoch (≥ 2015 if magin = 5) epoch (≥ 2020 if magin = 1 or 6)	(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 = DGRF 2010
magin: 5 = DGRF 2015
magin: 6 = IGRF 2020

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

xlamb: if colatitude > π /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), rgsmg(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, rgsmg, 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 (≥ 2020)	(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 componentalong 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, $1 \leq isw \leq 5$

magin: 6 = IGRF 2020
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 DGRF10 or DGRF15 or IGRF20 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 6)
year	epoch (≥ 2000 if magin = 2) epoch (≥ 2005 if magin = 3) epoch (≥ 2010 if magin = 4) epoch (≥ 2015 if magin = 5) epoch (≥ 2020 if magin = 1 or 6)	(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 = DGRF 2010 field
magin: 5 = DGRF 2015 field
magin: 6 = IGRF 2020 field

ifail: useless

Called routines:

dipol dgrf00 dgrf05 dgrf10 dgrf15 igrf20

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:
dlgalp 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 6)
year	epoch (≥ 2000 if magin = 2) epoch (≥ 2005 if magin = 3) epoch (≥ 2010 if magin = 4) epoch (≥ 2015 if magin = 5) epoch (≥ 2020 if magin = 1 or 6)	(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 = DGRF 2010
magin: 5 = DGRF 2015
magin: 6 = IGRF 2020

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 $1 \le$ indval ≤ 5 and $1 \le$ Kp ≤ 5

ifail: useless

Called routines:

inmag outma1

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 ≤ indval ≤ 5 and 1 ≤ Kp ≤ 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 6)
year	epoch (≥ 2000 if magin = 2) epoch (≥ 2005 if magin = 3) epoch (≥ 2010 if magin = 4) epoch (≥ 2015 if magin = 5) epoch (≥ 2020 if magin = 1 or 6)	(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 = DGRF 2010
magin: 5 = DGRF 2015
magin: 6 = IGRF 2020

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 ≤ indval ≤ 5 and 1 ≤ Kp ≤ 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 rre > rmax or (rre - 1) ≤ 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

6.22 TGML2

Author: CNES - JC KOSIK - June 1995

Purpose:

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

Specifications:

```
double precision xsm, ysm
double precision tgl
integer ifail
```

call tgml2 (xsm, ysm, tgl, ifail)

Input parameters:

xsm	x coordinate in the solar magnetic system
ysm	y coordinate in the solar magnetic system

Output parameters:

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

Remarks:

ifail: useless

If xsm = ysm = 0, time is set to 0.

Called routines:

angleg

Used by:

routines:
dchapp

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, tlsat
integer ifail

call tlocal (ihour, imin, isec, phir, tlsat, ifail)

Input parameters:

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

Output parameters:

tlsat	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 13 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.

solter20: 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 2020 the 1st to December 2024 the 31st.

solter15: 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 2015 the 1st to December 2019 the 31st.

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 1st to December 2014 the 31st.

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 1st to December 2009 the 31st.

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 1st to December 2004 the 31st.

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 1st to December 1999 the 31st.

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 1st to December 1969 the 31st.

sun: calculates the sideral 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 to small
ifail: 2 = julian date to 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:f12.6)
dayend	ending julian date	(real:f12.6)
epoch	reference julian date of state vector	(real:f15.9)
revepo	orbit number	(real:f11.3)
smaxis	half big axis (kilometers)	(real:f13.5)
omotin	mean inverse motion for a Keplerian orbit	(real:f13.5)

Third record:

nrec	record identifier (300 + number of polynomial components)	(integer:i3)
y(6)	state vector for Keplerian orbit (kilometers, kilometers/second)	(real:3f11.3, 3f11.7)
rdist	distance from Earth center at the current date (kilometers)	(real:f11.3)

Fourth record type:

nrec	record identifier (number of the Chebychev polynomial coefficients)	(integer:i3)
coeff	Chebychev polynomial coefficients	(real:3f11.3, 3f11.7)

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 -0.0000034 -0.0000046
 25     -0.084     -0.020     -0.034 -0.0001040 -0.0000215 -0.0000523
 36     -0.191     -0.040     -0.096 -0.0000043 -0.0000015  0.0000002
  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 -0.0000348 -0.0000572
 28      1.145     -1.007     -0.106 -0.0015970 -0.0004069 -0.0001684
 39    -23.101     -6.827     -2.707 -0.0000059 -0.0000364 -0.0001108
 50      0.046     -0.402     -0.523 -0.0000788  0.0000418  0.0000095
 61     -0.558      0.290      0.086 -0.0000104  0.0000032 -0.0000593
 72     -0.056      0.018     -0.310 -0.0000054  0.0000037 -0.0000018
  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	x component of the velocity in the inertial coordinate system	(kilometers/ second)
vzi	x component of the velocity in the inertial coordinate system	(kilometers/ second)
ifail	return code	

Remarks:

ifail: 0 = no problem
ifail: 1 = julian date to small
ifail: 2 = julian date to 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

7.3 PR2000

Author: ESOC - June 1995
ref: The astronomical almanac 1985 page 18

Purpose:

This routine calculates the precession matrix which transforms a vector in the inertial coordinate system J2000 into a vector in the inertial coordinate system of the Epoch. This calculation is used for Cluster spacecraft.

Specifications:

double precision day
double precision p(3,3)
integer ifail

call pr2000 (day, p, ifail)

Input parameters:

day	julian date (from 2000)	(> 0)

Output parameters:

p	precession matrix
ifail	return code

Remarks:

ifail: useless

Called routines: none

Used by:

routines:
posin

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 1st to December 2004 the 31st.

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	($2000 \leq$ 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 – February 2017

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 1st to December 2009 the 31st.

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 – February 2017

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 1st to December 2014 the 31st.

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 SOLTER15

Author: updated from CNES - JC KOSIK – February 2017

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 2015 the 1st to December 2019 the 31st.

Specifications:

```
      integer iyear, imonth, iday, ihour, imin, isec
      double precision year, alfag, alfas, deltas
      double precision obliq, tetdip, phidip
      integer ifail

      call solter15 (iyear, imonth, iday, ihour, imin, isec, year,
     >            alfag, alfas, deltas, obliq, tetdip, phidip, ifail)
```

Input parameters:

iyear	year	($2015 \leq$ year < 2020)
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:

testsolter15

7.9 SOLTER20

Author: updated from CNES - JC KOSIK – July 2020

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 2020 the 1st to December 2024 the 31st.

Specifications:

```
      integer iyear, imonth, iday, ihour, imin, isec
      double precision year, alfag, alfas, deltas
      double precision obliq, tetdip, phidip
      integer ifail

      call solter15 (iyear, imonth, iday, ihour, imin, isec, year,
     >          alfag, alfas, deltas, obliq, tetdip, phidip, ifail)
```

Input parameters:

iyear	year	(2020 ≤ year < 2025)
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:

testsolter20

7.10 SOLTERV

Author: CNES - JC KOSIK - January 1998

Purpose:

This routine calculates the right ascension of Greenwich, the right ascension of the Sun end 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 1st to December 1999 the 31st.

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 ≥ 2000

Called routines:

julg sun

Used by:

routines:
inigeomv
users programs:
testsoltv

7.11 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 1st to December 1969 the 31st.

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	($1945 \leq$ 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 ≥ 1970

Called routines:

julg sun

Used by:

routines:
inigeomv
users programs:
testsoltvo

7.12 SUN

Author: adapted from G. MEAD routine in Ref 1.

Purpose:

This routine calculates the sideral 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 sideral 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:

solter20 solter15 solter10 solter05 solter00 solterv soltervo

7.13 TSIDRG

Author: CNES

Purpose:

This function calculates the sideral time in radians with respect to the CNES vernal point, with a precision of 10^{-12} radians.

Specifications:

```
external tsidrg
double precision tsidrg
double precision sidt
double precision djd
integer ifail
```

sidt = tsidrg (djd, ifail)

Input parameters:

djd	CNES julian date

Output parameters:

"sidt"	sideral time	(radians)
ifail	return code	

Remarks:

ifail: useless

The CNES vernal point is the projection of the mean vernal point on the epoch equator (equator of date). The mean vernal point is defined as the intersection of the ecliptic with the mean equator the CNES vernal point is slightly different from the one obtained with routine "sun".

Called routines: none

Used by:

routines:
 pvig

8. MATHEMATICS

This chapter describes 15 routines:

angleg: calculates an angle between (0, 2π) 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 2π.

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 π 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 rfonc, rtab(*), ra, rb
double precision rh, repsi, rsol
integer inbr
integer ifail
```

call nuraci (rfonc, rtab, ra, rb, rh, repsi, rsol, inbr, ifail)

Input parameters:

rfonc	name of the function which calculates f(x)	(defined by caller routine)
rtab	array of parameters describing rfonc 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)

rfonc: has the following form:
rfonc = rtab(1) * f1(x) + rtab(2) * f2(x) +.......+ rtab(n) * fn(x)
where f1(x) ... fn(x) are functions of x such as e^x, log(x), cos(x) and sin(x) look for the solution of rfonc = rh

inbr: 0 = 0 or 2 roots on [a,b] (conventionally rsol = 0)
inbr: 1 = one root
inbr: 2 = a and b are roots (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:

$$\begin{bmatrix} xr \\ yr \\ zr \end{bmatrix} = \begin{bmatrix} & & \\ & ama & \\ & & \end{bmatrix} \begin{bmatrix} xp \\ yp \\ zp \end{bmatrix}$$

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
outma1 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:
outma1

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	($\geq$ 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	($\geq$ 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

9.4 DJGREG

Author: CNES - JC KOSIK - January 1991

Purpose:

This routine transforms a CNES julian date into a gregorian date.

Specifications:

double precision dxx
integer iyear, imonth, iday, ihour, imin, isec
integer ifail

call djgreg (dxx, iyear, imonth, iday, ihour, imin, isec, ifail)

Input parameters:

dxx	date in CNES julian days	> 0.

Output parameters:

iyear	year	($\geq$ 1950)
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)
ifail	return code	

Remarks:

ifail: useless

The CNES julian date begins on 1950/01/01 at 0 hours.

Called routines:

calendg datjhms

Used by:

routines:
ctrlpos

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 1st 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. $\leq$ sec < 60.)

Output parameters:

djuld	julian date (from 2000)	(> 0.)
ifail	return code	

Remarks:

ifail: useless

djuld(2000) = 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	($\geq$ 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 solter20 solter15 solter10 solter05 solter00 solterv soltervo

users programs:

testdate testgeog

10. CONTROL ROUTINES

This chapter describes 5 routines:

ctrldat: 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 ctrldat (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 ≥ 14610.0

calendar date validity:
- taking in account the bisextiles years
- iyear: ≥ 1995 for "gsfc65" routine 1995
- imonth: 1 ≤ month ≤ 12
- iday: 1 ≤ day ≤ 28 or 29 or 30 or 31 according to "month" value
- ihour: 0 ≤ hours ≤ 23
- imin: 0 ≤ minutes ≤ 59
- isec: 0 ≤ seconds ≤ 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 ($0 \leq \text{theta} \leq \pi$),

phi: validity ($0 \leq \text{phi} \leq 2\pi$))

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 6)
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 = DGRF10 field
magin: 5 = DGRF15 field
magin: 6 = IGRF20 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 1st to December 2024 the .31st.

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 6)
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 ≥ 14610.0

calendar date validity:
  taking in account the bisextiles years
  iyear: ≥ 1995
  imonth: 1 ≤ month ≤ 12
  iday: 1 ≤ day ≤ 28 or 29 or 30 or 31 according to month value
  ihour: 0 ≤ hours ≤ 23
  imin: 0 ≤ minutes ≤ 59
  isec: 0 ≤ seconds ≤ 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 =DGRF10 field
magin: 5 = DGRF15 field
magin: 6 = IGRF20 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

rr: ≥ 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:

ctrldat 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