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STORMER EQUATION IMPLEMENTATION USING OFFSET DIPOLE
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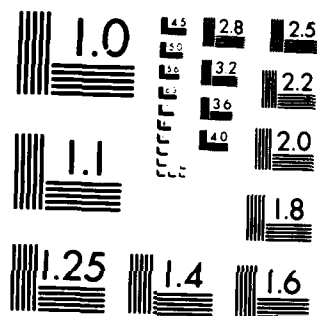
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OFFSET DIPOLE COORDINATES DERIVED FROM
SPECIFIED GEOGRAPHIC COORDINATES

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) -- For many purposes it is useful to have a fast means of estimating directional cosmic ray cutoffs pertaining to any specified direction and location. The Stormer equation offers a means of determining directional cutoffs to a precision suitable for use in non-critical applications, at a speed many orders of magnitude faster than the process of determining precise cutoffs by the "real" geomagnetic field trajectory tracing method. Use of offset dipole coordinates in the Stormer equation allows minimization of		

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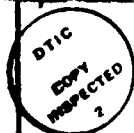
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-errors in the cutoff estimates arising from the non-inclusion of other than dipolar field terms.

A self contained procedure has been developed for computer use which, for any given location and direction expressed in geographic coordinates, first allows determination of the location and direction relative to the earth's equivalent magnetic dipole (whose location is determined from the lowest order harmonic field terms). The Stormer equation is then invoked, using these offset dipole coordinates, and a cutoff estimate so produced.

This report contains a printed copy of a FORTRAN computer program developed to carry out this task.

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STORMER EQUATION IMPLEMENTATION, USING OFFSET DIPOLE
COORDINATES DERIVED FROM SPECIFIED GEOGRAPHIC COORDINATES

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Introduction: For many purposes it is useful to have a fast means of estimating directional cosmic ray cutoffs pertaining to any specified direction and location. The derivation of "real" geomagnetic field cutoffs by means of computer calculations (see McCracken et al. 1962; Freon and McCracken, 1962; Shea et al, 1965; Cooke and Humble, 1979; for example) is a slow operation, and expensive in computer time. The Stormer cutoff function (Stormer (1930, 1955)), which expresses the dependence of the Stormer cutoff on location and direction in a dipole approximation to the earth's field, offers a means of determining cutoffs which is many orders of magnitude faster than the trajectory tracing method, and one which is sufficiently precise to produce useful estimates of cutoffs in non-critical applications.

The fundamental imprecision in the Stormer expression in representing the real field cutoffs, in particular due to failure to take into account higher order field harmonic terms, or the width and transparency of the penumbra, is normally exacerbated by the use of earth centered geographic or geomagnetic coordinates when invoking the expression (because the earth's equivalent dipole is not earth centered). It is possible to appreciably improve the accuracy of the cutoff estimates by using "magnetic" coordinates (i.e. offset dipole latitude, longitude, zenith, and azimuth) when employing

the expression, and in this way to take into account the offset and tilt of the earth's equivalent dipole. By this means, inherently, the effect of ignoring the higher order field terms is minimized. Smart and Shea (1977) have discussed the advantages of using offset dipole coordinates in conjunction with the Stormer expression, and the use of this expression for interpolating cosmic ray cutoffs over intervals within which precise calculated values do not exist.

A self contained system for transforming from geographic coordinates to offset dipole coordinates is described in this report. A printed copy of the computer program containing this procedure, which uses the calculated coordinates to derive cutoff estimates from the Stormer expression, is appended to the report.

Discussion: The coordinate transformation has a number of stages, which are individually described in the following:

1) A coordinate conversion is used to determine the offset dipole latitude, longitude, and radius from the nominated geographic latitude and longitude, and geocentric altitude. This conversion takes into account the offset and inclination of the earth's equivalent dipole for any required epoch, and assumes that the earth is an oblate spheroid of eccentricity 0.00674. The angle conversion equations are as follows:

$$\text{offset dipole longitude } \phi = \arctan \frac{(R \sin \psi \cos \lambda - y \cos b)}{C}$$

$$\text{offset dipole latitude } \theta = \arctan (\cos \phi \tan \alpha) \quad I$$

$$\text{offset dipole radius } R' = \frac{C}{\cos \theta \cos \phi}$$

where $\alpha = \arctan (F/G) + a$

$$C = \frac{G \cos a}{\cos(\alpha - a)}$$

and $F = R \sin \lambda - x$

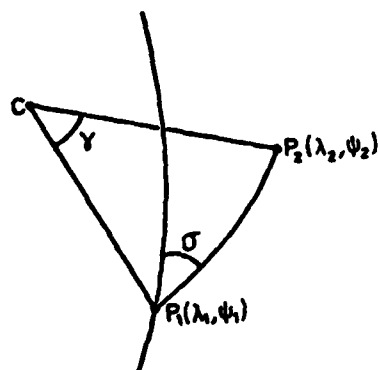
$$G = y \sin b + R \cos \lambda \cos (\psi - c)$$

λ and ψ are the geographic latitude and longitude respectively; R is the geographic radius at the specified location; x is the displacement of the equivalent earth dipole above the equatorial plane; y is the displacement of the dipole from the center of the earth in a direction parallel with the geographic equatorial plane; a is the inclination of the dipole axis from a direction parallel to the geographic N-S axis; b is related to the angle between the zero magnetic longitude and the geographic longitudinal direction towards which the dipole is displaced; and c is the geographic longitudinal direction parallel to which the direction zero offset dipole longitude lies.

A procedure for establishing the position of the equivalent dipole with respect to the geocentric coordinate system at any epoch is presented by Smart and Shea (1977). This procedure, which makes use of the low order terms in the spherical harmonic representation of the geomagnetic field, is discussed more fully by Roederer (1972), and Akasofu and Chapman (1975). The values of x , y , a , b and c used in the presently reported coordinate transformation can thus be determined as required. The equivalent dipole position determination is included as a subroutine in the computer program appended to this report.

2) The following steps rely on the use of a particular means of specifying the relative position of two points on the surface of a sphere. In particular, two angles are used, one (σ) defines the angle between the great circle connecting the two points and the meridian line intersecting one of them, and the other (γ) is the angle subtended at the center of the sphere by the two points (see figure 1).

Figure 1. Diagram defining the angles σ and γ used to express the relative position of the two points P_1 and P_2 on a spherical surface. C is the centre of the sphere.



If the two points are, as specified by latitude and longitude, (λ_1, ψ_1) and (λ_2, ψ_2) , then σ and γ are given by

$$\sigma = \arctan \left(\frac{\sin(\psi_2 - \psi_1) \cos \lambda_2}{\sin \lambda_1 \cos \lambda_2 - \sin \lambda_1 \cos \lambda_2 \cos(\psi_2 - \psi_1)} \right) \quad \text{II}$$

$$\gamma = \arccos(\cos(\psi_2 - \psi_1) \cos \lambda_1 \cos \lambda_2 + \sin \lambda_1 \sin \lambda_2)$$

Conversely, if the location of one point is known (λ_1, ψ_1) , say, then it is possible to determine the latitude and longitude of a second whose position is defined in terms of a specified σ and γ , by means of

$$\text{latitude} = \arcsin(\cos \sigma \sin \gamma \cos \lambda_1 + \cos \gamma \sin \lambda_1)$$

III

$$\text{longitude} = \psi_1 + \arccos \left(\frac{\cos \gamma - \sin \lambda_1 \sin \text{latitude}}{\cos \lambda_1 \cos \text{latitude}} \right)$$

3) The calculation of the magnetic zenith and azimuth uses the strategy of setting up a vector of known length (R'') pointing in the direction of interest. The position the tail of the vector, being the location of interest, is of course known in both geographic and magnetic coordinates (the latter determined by step 1), and similarly both geographic and offset dipole radius values pertaining to this point are known.

The geographic coordinates of the position of the head of the vector can be determined by using calculated σ and γ values, derived as follows (which values pertain to the projection of the vector onto a spherical surface).

$$\gamma = \arctan (R'' \sin ze / (R + R'' \cos ze))$$

IV

$$\sigma = az$$

Having evaluated these angles, the geographic latitude and longitude of the vector head can be calculated using the relationships III. The offset dipole latitude and longitude, and the distance R^* of the vector head from the dipole are then calculated using relationships I. Now, having the offset dipole coordinates of both ends of the vector, the angles σ and γ relating the two points (in the offset dipole frame of reference) can be calculated by means of the relationships II. The azimuth of the vector in the offset dipole frame of reference is simply the σ value, whilst the zenith angle is given by

$$ze = \arccos (R^* \cos \gamma - R')$$

where R' is the offset dipole radius of the vector tail (i.e. the distance of the vector tail from the offset dipole center).

Conclusion: By using the coordinate transformation procedure described, the position (latitude, longitude, and radius) of the site location relative to the offset dipole, and the zenith and azimuth pertaining to the direction of interest, may be calculated from the specified geographic coordinates and geocentric altitude. At each step during the derivation of these parameters tests are performed to ensure that calculated angle values lie in the correct quadrant, and appropriate corrections are made if they do not. Having thus determined the angles and distance relative to the equivalent dipole centered frame of reference the Stormer equation can be invoked with greatest possible precision.

The appropriately normalized Stormer expression is as follows:

$$\text{cutoff} = \frac{59.4 \cos^4 \theta}{R'^2 (1 + \sqrt{1 - \cos^3 \theta \sin az \sin ze})^2}$$

This expression takes in offset dipole latitude (θ), zenith (ze), azimuth (az , measured clockwise from magnetic north), and radial distance from the effective dipole center (R'); and produces cutoff rigidity values, in units of GV.

The appendix contains a printed copy of the computer program which carries out, in the way described, the entire task of producing a Stormer cutoff estimate from the specified input geographic position and direction parameters.

Acknowledgements

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References

- Akasofu, S., and S. Chapman, Solar-Terrestrial Physics (Chapter 2), Oxford University Press, London, 1972.
- Cooke, D.J., and J. E. Humble, J. Geophys. Res., 75, 5961, 1970.
- Freon, A., and K. G. McGracken, J. Geophys. Res., 67, 888, 1962.
- McGracken, K. G., U. R. Rao, and M. A. Shea, M.I.T. Technical Report 77, 1962.
- Roederer, J. G., Rev. Geophys. and Space Phys., 10, 599, 1972.
- Shea, M. A., D. F. Smart, and K. G. McGracken, J. Geophys. Res., 70, 4117, 1965.
- Smart, D. F., and M. A. Shea, 15th International Cosmic Ray Conference, Conference Papers, 11, 256, 1977.
- Stormer, C., Astrophys., 1, 237, 1930.
- Stormer, C., The Polar Aurora, Oxford University Press, London, 1955.

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00100      PROGRAM STORM
00110      DOUBLE PRECISION ZE, AZ, LAT, LON, ZER, AZR, LATR, LONR, ZERO, DTOR
00120      DOUBLE PRECISION MLATA, MLONA, ZEMA, AZMA, ZENEW, AZNEW, GAM, SIG
00130      DOUBLE PRECISION DSIN, DCOS, DTAN, DASIN, DACOS, DATAN, DABS, DSQRT
00140      DOUBLE PRECISION DFLAT, INCR, ERAD, DIFF, A, B, X, Y, R, RDEL, ALT
00150      DOUBLE PRECISION GAMVAL, MAGLAT, MAGLON, RMAG, CUTOFF, PI, PID2, PIB2
00160      COMMON /PIANG/PI, PID2, PIB2, ZERO
00170      COMMON /ANGLES/ SIG, GAM
00180      COMMON /POS/ X, Y, A, B, DIFF, ERAD
00190      COMMON /MAGIO/ ZENEW, AZNEW, R, RMAG, CUTOFF, MAGLAT, MAGLON, GAMVAL,
00200      X      RDEL, ALT
00210      C ANGLE CONVERSION FACTORS AND CONSTANTS ARE PRESET IN THE FOLLOWING.
00220      PI = 3.14159265359D+00
00230      PID2 = PI/2.0D+00
00240      PIB2 = PI*2.0D+00
00250      DTOR = PI/180.0D+00
00260      RDEL = 100.0D+00
00270      INCR = 1.0D-10
00280      ZERO = 0.0D+00
00290      C POSITION AND INCLINATION OF OFFSET DIPOLE NOW DEDUCED.
00300      CALL POSITN
00310      C IF DESIRED, INSERT OTHER VALUES OF A, B, X, Y, DIFF AND ERAD .E.
00320      A = A*DTOR
00330      B = B*DTOR
00340      DIFF = DIFF*DTOR
00350      C INPUT DATA ACCEPTED HERE.
00360      100 TYPE 1000
00370      ACCEPT *, LAT, LON, ZE, AZ, ALT
00380      C TERMINATE RUN IF LATITUDE VALUE ENTERED IS OUTSIDE THE POSSIBLE RANGE
00390      IF (DABS(LAT) .GT. 90.0D+00) GO TO 200
00400      ZER = ZE*DTOR+INCR
00410      AZR = AZ*DTOR+INCR
00420      CALL RANGE(AZR)
00430      LATR = LAT*DTOR+INCR
00440      LONR = LON*DTOR+INCR
00450      C NOW DEDUCE OFFSET DIPOLE COORDINATES OF DIRECTION.
00460      CALL MAGCO(LATR, LONR, ZER, AZR)
00470      C CALCULATED ANGLES ARE NOW CONVERTED FROM RADIANS TO DEGREES.
00480      MLATA = MAGLAT/DTOR
00490      MLONA = MAGLON/DTOR
00500      ZEMA = ZENEW/DTOR
00510      AZMA = AZNEW/DTOR
00520      C RESULTS ARE PRINTED OUT BY THE FOLLOWING INSTRUCTIONS.
00530      WRITE(6,2000)
00540      WRITE(6,4000)
00550      WRITE(6,5000) LAT, LON, ZE, AZ, ALT
00560      WRITE(6,6000) MLATA, MLONA, ZEMA, AZMA, RMAG, CUTOFF
00570      WRITE(6,3000)
00580      GO TO 100
00590      1000 FORMAT(' ENTER LAT, LON, ZE, AZ, AND ALT: ',*)
00600      2000 FORMAT(1X)
00610      3000 FORMAT(1X,/)
00620      4000 FORMAT(17X,45H LATITUDE      LONGITUDE      ZENITH      AZIMUTH,
00630      X      36H ALTITUDE      DIP. RAD.      CUTOFF)
00640      5000 FORMAT(13H GEOGRAPHIC: ,5F12.2)
00650      6000 FORMAT(13H OFFSET DIP. ,4F12.2,12X,2F12.2)
00660      200 STOP
00670      END
00680
00690
00700

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00710      SUBROUTINE RANGE(PARAM)
00720      C
00730      C THIS SUBROUTINE BRINGS ANGLE VALUES TO WITHIN 0-360 DEGREE RANGE
00740      C
00750      COMMON /PIANG/PI,PID2,PIB2,ZERO
00760      DOUBLE PRECISION PARAM,PI,PID2,PIB2,ZERO
00770      IF (PARAM .GE. PIB2) PARAM = PARAM-PIB2
00780      IF (PARAM .LT. ZERO) PARAM = PARAM+PIB2
00790      RETURN
00800      END
00810
00820
00830
00840      SUBROUTINE CHECK(PARAM)
00850      C
00860      C THIS SUBROUTINE PREVENTS EFFECT OF ROUND-OFF ERRORS ETC CAUSING
00870      C THE ARGUMENT OF AN ANGLE FUNCTION TO EXCEED 1.00 MAGNITUDE
00880      C
00890      DOUBLE PRECISION PARAM
00900      IF (PARAM .GT. +1.00+00) PARAM = 1.00+00
00910      IF (PARAM .LT. -1.00+00) PARAM = -1.00+00
00920      RETURN
00930      END
00940
00950
00960
00970      SUBROUTINE CONV(LAT1,LAT2,LON1,LON2)
00980      C
00990      C THIS SUBROUTINE CALCULATES THE GAMMA AND SIGMA ANGLES RELATING THE
01000      C TWO EARTH- OR DIPOLE-CENTERED VECTORS DIRECTED TOWARDS (LAT1,LON1)
01010      C AND (LAT2,LON2).
01020      C
01030      DOUBLE PRECISION CHVAL,GAM,SIG,DSIN,DASIN,DCOS,DACOS,PI,PID2,PIB2
01040      DOUBLE PRECISION LAT1,LAT2,LON1,LON2,VAL,DTCR,GAMD,SIGD,VALD,ZERO
01050      COMMON /PIANG/PI,PID2,PIB2,ZERO
01060      COMMON /ANGLES/ SIG,GAM
01070      CHVAL = DCOS(LON1-LON2)*DCOS(LAT1)*DCOS(LAT2)+DSIN(LAT1)*
01080      * DSIN(LAT2)
01090      CALL CHECK(CHVAL)
01100      GAM = DACOS(CHVAL)
01110      SIG = ZERO
01120      IF (GAM EQ ZERO) GO TO 100
01130      CHVAL = DSIN(LON2-LON1)*DCOS(LAT2)/DSIN(GAM)
01140      CALL CHECK(CHVAL)
01150      SIG = DASIN(CHVAL)
01160      100 CONTINUE
01170      CHVAL = DCOS(GAM)*DSIN(LAT1)
01180      CALL CHECK(CHVAL)
01190      VAL = DACOS(CHVAL)
01200      IF ((PID2-LAT2) .GE. VAL) SIG = PI-SIG
01210      CALL RANGE(SIG)
01220      RETURN
01230      END
01240
01250
01260
01270
01280
01290
01300
01310

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01320      SUBROUTINE CALC(LAT, LON, GAM, SIG, LATI, LONN)
01330      C
01340      C THIS SUBROUTINE DEDUCES THE LATITUDE AND LONGITUDE OF A DIRECTION
01350      C WHICH HAS A NOMINATED SIGMA AND GAMMA DEVIATION FROM A SPECIFIED
01360      C LATITUDE AND LONGITUDE
01370      C
01380      DOUBLE PRECISION SIG, GAM, LAT, LON, LATT, LONN, FUNC, PI, PID2, PIB2, ZERO
01390      DOUBLE PRECISION DSIN, DCOS, DASIN, DACOS, DABS, DFLOAT, VAL, CHVAL
01400      COMMON /PIANG/ PI, PID2, PIB2, ZERO
01410      CHVAL = DCOS(SIG)*DSIN(GAM)*DCOS(LAT)+DCOS(GAM)*DSIN(LAT)
01420      CALL CHECK(CHVAL)
01430      LATT = DASIN(CHVAL)
01440      FUNC = 1.0D+00
01450      IF (SIG .GT. PI) FUNC = -1.0D+00
01460      CHVAL = (DCOS(GAM)-DSIN(LAT)*DSIN(LATT))/DCOS(LAT)/DCOS(LATT)
01470      CALL CHECK(CHVAL)
01480      LONN = LON+FUNC*DACS(CHVAL)
01490      IF (LATT .LT. PIB2) GO TO 100
01500      LATT = PI-LATT
01510      LONN = LONN-PI
01520      100 IF (LATT .GT. -PIB2) GO TO 200
01530      LATT = -LATT-PI
01540      LONN = LONN-PI
01550      200 CALL RANGE(LONN)
01560      RETURN
01570      END
01580
01590
01600
01610      SUBROUTINE GETOMA(LAT, LON, RVEC)
01620      C
01630      C THIS SUBROUTINE TAKES IN GEOGRAPHIC LATITUDE & LONGITUDE AND
01640      C OUTPUTS OFFSET DIPOLE LATITUDE & LONGITUDE, LOCAL GEOGRAPHIC
01650      C RADIUS, AND DISTANCE FROM THE OFFSET DIPOLE.
01660      C
01670      DOUBLE PRECISION PI, PID2, PIB2, A, B, X, Y, DIFF, LAT, LON, ZENW, AZNEW, ALT
01680      DOUBLE PRECISION R, RMAG, CUTOFF, MAGLAT, MAGLON, GAMVAL, RVEC, RDEL, VAL
01690      DOUBLE PRECISION DSIN, DCOS, DTAN, DASIN, DACOS, DATAN, DSQRT, DABS, ZERO
01700      DOUBLE PRECISION ERAD
01710      COMMON /PIANG/ PI, PID2, PIB2, ZERO
01720      COMMON /POS/ X, Y, A, B, DIFF, ERAD
01730      COMMON /MAGIO/ ZENW, AZNEW, R, RMAG, CUTOFF, MAGLAT, MAGLON, GAMVAL,
01740      X      RDEL, ALT
01750      R = ALT+6356.7747D+00/DSQRT(1.0D+00-0.00673966D+00*
01760      X      DSIN(PID2-LAT)**2)
01770      IF (RVEC .GT. ZERO) R = RVEC
01780      AVAL = R*DSIN(LAT)-X
01790      VAL = Y*DSIN(B)+R*DCOS(LAT)*DCOS(LON-DIFF)
01800      GAMVAL = DATAN(AVAL/VAL)+A
01810      BVAL = VAL*DCOS(GAMVAL)/DCOS(GAMVAL-A)
01820      MAGLON = DATAN((R*DSIN(LON-DIFF)*DCOS(LAT)-Y*DCOS(B))/BVAL)
01830      IF (BVAL .LT. ZERO) MAGLON = MAGLON+PI
01840      CALL RANGE(MAGLON)
01850      MAGLAT = DATAN(DCOS(MAGLON)*DTAN(GAMVAL))
01860      RMAG = DABS(BVAL/DCOS(MAGLAT)/DCOS(MAGLON))
01870      RETURN
01880      END
01890
01900
01910
01920

```

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01930      SUBROUTINE MAGCO(LAT, LON, ZE, AZ)
01940      C
01950      C THIS SUBROUTINE TAKES A GIVEN SET OF GEOGRAPHIC COORDINATES
01960      C (LAT, LON, ZE, AZ) AND DEDUCES THE CORRESPONDING SET OF OFFSET
01970      C DIPOLE COORDINATES
01980      C
01990      DOUBLE PRECISION A, B, X, Y, ZENEW, AZNEW, R, RMAG, CUTOFF
02000      DOUBLE PRECISION ZEM, AZM, MAGLAT, MAGLON, GAMVAL, RDEL, RV, CHVAL
02010      DOUBLE PRECISION DSIN, DCOS, DTAN, DASIN, DACOS, DATAN, LAT, LON, ZE, AZ
02020      DOUBLE PRECISION MLAT, MLON, EP, RVEC, GAM, SIG, LATVEC, LONVEC, ALT
02030      COMMON /POS/ X, Y, A, B, DIFF, ERAD
02040      COMMON /MAGIO/ ZENEW, AZNEW, R, RMAG, CUTOFF,
02050      X      MAGLAT, MAGLON, GAMVAL, RDEL, ALT
02060      COMMON /ANGLES/ SIG, GAM
02070      C DEDUCE OFFSET DIPOLE LATITUDE AND LONGITUDE FROM GEOGRAPHIC VALUES
02080      CALL SETOMA(LAT, LON, -1.0D+00)
02090      RV = RMAG
02100      MLAT = MAGLAT
02110      MLON = MAGLON
02120      C DEDUCE GAMMA AND SIGMA APPLYING TO SAMPLE VECTOR.
02130      EPS = DATAN(RDEL*DSIN(ZE)/(R+RDEL*DCOS(ZE)))
02140      RVEC = (R+RDEL*DCOS(ZE))/DCOS(EPS)
02150      GAM = EPS
02160      SIG = AZ
02170      C CALCULATE GEOGRAPHIC LAT. & LON. OF VECTOR HEAD.
02180      CALL CALC(LAT, LON, GAM, SIG, LATVEC, LONVEC)
02190      C CONVERT THESE GEOGRAPHIC COORDINATES INTO OFFSET DIPOLE COORDINATES
02200      CALL SETOMA(LATVEC, LONVEC, RVEC)
02210      C CALCULATE GAM & SIG APPLYING TO OFFSET DIPOLE COORDINATE SYSTEM
02220      CALL CONV(MLAT, MAGLAT, MLON, MAGLON)
02230      C SO, DEDUCE OFFSET DIPOLE ZENITH AND AZIMUTH.
02240      AZNEW = SIG
02250      CHVAL = (RMAG*DCOS(GAM)-RV)/RDEL
02260      CALL CHECK(CHVAL)
02270      ZENEW = DACOS(CHVAL)
02280      C NOW COMPUTE CUTOFF VALUE FROM STORMER EXPRESSION.
02290      CALL CUTCAL(MLAT, MLON, ZENEW, AZNEW, RV, CUTOFF)
02300      MAGLAT = MLAT
02310      MAGLON = MLON
02320      RMAG = RV
02330      RETURN
02340      END
02350
02360
02370
02380      SUBROUTINE CUTCAL(LAT, LON, ZE, AZ, R, CUTOFF)
02390      C
02400      C THIS SUBROUTINE CALCULATES THE STORMER CUTOFF CORRESPONDING TO THE
02410      C SPECIFIED OFFSET DIPOLE LATITUDE, LONGITUDE, ZENITH AND AZIMUTH.
02420      C
02430      DOUBLE PRECISION LAT, LON, ZE, AZ, R, CUTOFF
02440      DOUBLE PRECISION DSIN, DCOS, DTAN, DASIN, DACOS, DATAN, DSQRT
02450      CUTOFF = 59.4D+00*(DCOS(LAT))**4/((R/6400.0D+00)**2+
02460      X      (1.0D+00+DSQRT(1.0D+00-(DCOS(LAT))**3*DSIN(AZ))*
02470      X      DSIN(ZE))**2)
02480      RETURN
02490      END
02500
02510
02520
02530

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02540      SUBROUTINE POSITN
02550      C
02560      C THIS SUBROUTINE DETERMINES THE POSITION OF THE EQUIVALENT DIPOLE
02570      C IN GEOGRAPHIC COORDINATES, AND RETURNS THE DEFINING PARAMETERS
02580      C X, Y, A, B, & DIFF.
02590      C
02600      DOUBLE PRECISION X, Y, A, B, DIFF, ERAD, PI, PID2, PIB2, ZERO
02610      DOUBLE PRECISION G01, G11, G02, G12, G22, H01, H11, H02, H12, H22
02620      DOUBLE PRECISION C11, PHI, PHID, H, L0, L1, L2, E, DENOM, XED, YED, ZED
02630      DOUBLE PRECISION DSQRT, DATAN, DFLOAT, CUBERT, THETA, THETAD, PSI, PSID
02640      COMMON /POS/ X, Y, A, B, DIFF, ERAD
02650      COMMON /PIANG/ PI, PID2, PIB2, ZERO
02660      C FIELD COEFFICIENTS FOR THE EPOCH OF INTEREST ARE INSERTED HERE.
02670      C THE FOLLOWING COEFFICIENTS ARE FOR THE IGRF65 FIELD
02680      ERAD = 6371.2D+00
02690      G01 = -0.30339D+00
02700      G11 = -0.02123D+00
02710      G02 = -0.01654D+00
02720      G12 = 0.02994D+00
02730      G22 = 0.01567D+00
02740      H01 = 0.0D+00
02750      H11 = 0.05758D+00
02760      H02 = 0.0D+00
02770      H12 = -0.02006D+00
02780      H22 = 0.00130D+00
02790      C11 = DSQRT(G11**2+H11**2)
02800      PHI = DATAN(H11/G11)
02810      THETA = DATAN(C11/G01)
02820      H = DSQRT(G01**2+G11**2+H11**2)
02830      CUBERT = 3.0D+00**((1.0D+00/DFLOAT(3)))
02840      L0 = 3.0D+00*G01+G02+CUBERT*(G11+G12+H11*H12)
02850      L1 = -G11*G02+CUBERT*(G01*G12+G11*G22+H11*H22)
02860      L2 = -H11*H02+CUBERT*(G01*H12-H11*G22+G11*H22)
02870      E = (L0*G01+L1*G11+L2*H11)/(4.0D+00*H*H)
02880      DENOM = 3.0D+00*H*H
02890      XED = (L1-G11*E)*ERAD/DENOM
02900      YED = (L2-H11*E)*ERAD/DENOM
02910      ZED = (L0-G01*E)*ERAD/DENOM
02920      DTOR = PI/180.0D+00
02930      PSI = DATAN(YED/XED)
02940      IF (THETA .GT. ZERO) GO TO 100
02950      THETA = -THETA
02960      PSI = PSI+PI
02970      CALL RANGE(PSI)
02980      100 A = THETA/DTOR
02990      DIFF = PHI/DTOR
03000      PSID = PSI/DTOR
03010      B = PSI-PHI-PID2
03020      CALL RANGE(B)
03030      CALL RANGE(PHI)
03040      E = B/DTOR
03050      DIFF = PHI/DTOR
03060      X = ZED
03070      Y = DSQRT(XED*XED+YED*YED)
03080      C CONSTANTS DEFINING THE POSITION AND ORIENTATION OF THE EQUIVALENT
03090      C DIPOLE ARE PRINTED HERE
03100      WRITE(6,1000) X, Y, A, B, DIFF
03110      1000 FORMAT(9F12.2)
03120      RETURN
03130      END

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