CYN
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DSC#767

72-012A-01K SPHE-00422
PIONEER 10
1-HR HVM INTERPL MAG FIELD

73-019A-01I SPHE-00421
PIONEER 11
1-HR HVM INTERPL MAG FIELD

Table of Contents



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**1. INTRODUCTION:**

The documentation for this data set was originally on paper, kept in NSSDC's Data Set Catalogs (DSCs). The paper documentation in the Data Set Catalogs have been made into digital images, and then collected into a single PDF file for each Data Set Catalog. The inventory information in these DSCs is current as of July 1, 2004. This inventory information is now no longer maintained in the DSCs, but is now managed in the inventory part of the NSSDC information system. The information existing in the DSCs is now not needed for locating the data files, but we did not remove that inventory information.

The offline tape datasets have now been migrated from the original magnetic tape to Archival Information Packages (AIP’s).

A prior restoration may have been done on data sets, if a requestor of this data set has questions; they should send an inquiry to the request office to see if additional information exists.

2. ERRATA/CHANGE LOG:

NOTE: Changes are made in a text box, and will show up that way when displayed on screen with a PDF reader.

***When printing, special settings may be required to make the text box appear on the printed output.***

| Version | Date | Person | Page | Description of Change |
| --- | --- | --- | --- | --- |
| 01 | | | | |
| 02 | | | | |

3 LINKS TO RELEVANT INFORMATION IN THE ONLINE NSSDC INFORMATION SYSTEM:

http://nssdc.gsfc.nasa.gov/nmc/

[NOTE: This link will take you to the main page of the NSSDC Master Catalog. There you will be able to perform searches to find additional information]

4. CATALOG MATERIALS:

a. Associated Documents — To find associated documents you will need to know the document ID number and then click here.
http://nssdcftp.gsfc.nasa.gov/miscellaneous/documents/

b. Core Catalog Materials

PIONEER 10

1-HR HVM INTERPLANETARY MAGNETIC FIELD DATA

72-012A-01K SPHE-00422

THIS DATA SET CONSISTS OF 1 MAGNETIC TAPE. THE TAPE IS 9-TRACK, 6250 BPI, CREATED ON A VAX COMPUTER, WRITTEN IN ASCII, WITH A LABEL NAME OF "P10HVM". A DIRECTORY OF THE TAPE AS WELL AS COPIES OF THE TEXT FILES, P10MAGHR.SFD,P10MAGHR.FMT AND MAGCOORD.DOC HAVE BEEN INCLUDED ALSO. THE D AND C NUMER ALONG WITH IT'S TIMESPAN IS LISTED BELOW.

| D# | C# | FILES | TIMESPAN |
|---|---|---|---|
| D-108357 | C-032392 | 8 | 03/03/72-11/17/75 |

***DATA WAS DOWNLOADED AND COPIED FROM ANON_DIR:[COHO.P10MAG.HOUR]***

==========================================================================

# PIONEER 10 INTERPLANETARY MAGNETIC FIELD DATA - 1 HOUR AVERAGES

Data Set Coverage (yyyy-mm-dd): 1972-03-03 to 1975-11-17

Experiment: Pioneer 10 Helium Vector Magnetometer (HVM)

Principal Investigator: Dr. Edward J. Smith, NASA JPL

Data Set Contact: Joyce Wolf, NASA JPL

Data Set Submission Date: 1993-09-16

Data Set Description:

The Helium Vector Magnetometer (HVM) measurements of interplanetary magnetic fields are averaged at one-hour intervals with respect to Spacecraft Event Time - UT. Data set parameters include the three orthogonal components of the magnetic field in RTN coordinates, where R is in the sun-s/c direction, T is the cross product of the solar rotation axis and R, and N is the cross product of R and T. The hourly field magnitude, averaged over scalar magnitudes at higher time resolution, is also provided. All field values are in nanotelsa. Data are available from launch through the time of instrument failure in 1975. This data set is also available on-line in the Coordinated Heliospheric Observations (COHO) data base at NSSDC's Anonymous FTP site and in the COHOWeb browse and retrieval service on the World Wide Web, both accessible via WWW at http://nssdc.gsfc.nasa.gov/space/space_physics_home.html, the NSSDC space physics page.

Data Set Files:

```
P10MAGHR.FMT    - this document
P10HVM_15M.SFD  - SFDU metadata extract from Pioneer 10 HVM 15-min. data set
P10MAGyy.DAT    - Hour average data files (ASCII) for year 19yy
MAGCOORD.DOC    - Document from JPL on Pioneer coordinate transformations
P10MAGHR.CAT    - VMS directory listing with file sizes in VMS blocks
```

Parameter Format for File P10MAGyy.DAT:

```
IY      - SCET-UT Year (yy)
IDOY    - SCET-UT Day of Year (ddd) , IDOY = 1 for Jan. 1
IHR     - SCET-UT Hour of day
BR      - Radial component (RTN system) of vector magnetic field in nT
BT      - Transverse component (RTN) of vector magnetic field in nT
BN      - Normal component (RTN) of vector magnetic field in nT
B       - Scaler magnetic field magnitude in nT
RAU     - Radial distance from Sun to spacecraft in AU
ELAT    - Ecliptic latitude of spacecraft in degrees
ELON    - Ecliptic longitude of spacecraft in degrees
```

The following FORTRAN read statement will read the hourly data records:

```
      READ(10,10) IY, IDOY, IHR, BR, BT, BN, B, RAU, ELAT, ELON
10    FORMAT(I3, I4.3, I3.2, 4F9.4, F9.5, F7.1, F8.1)
```

NSSDC Data Set ID: 72-012A-01K

NSSDC Data Set Location:

Off-line: ask for NSSDC data set 72-012A-01K from request@nssdca.gsfc.nasa.gov

On-line: COHO directory at nssdca::anon_dir:[coho.p10mag.hour]

Near-line: Pioneer project data set on NDADS (ingest in progress)

Acknowledgement:

Please acknowledge the National Space Science Data Center and the Principal Investigator, Dr. E. J. Smith of NASA's Jet Propulsion Laboratory, for use of this data in publications.

Related Information:

The file P10HVM_15M.SFD provides a detailed description of the Pioneer spacecraft, the HVM experiment, and the data. This ASCII document is written in Standard Formatted Data Unit (SFDU) format as part of NSSDC data set 72-012A-01I for 15-minute averaged data covering 1972-03-03 to 1975-11-17. Unlike the 1-hour data set here, the 15-min. data set gives times as Ground Received Time - UT.

Other information about the Pioneer mission, experiments, and data sets at NSSDC may be obtained via World Wide Web and NSSDC's space physics page at http://nssdc.gsfc.nasa.gov/space/space_physics_home.html. Non-WWW users may access NSSDC information in the NASA Master Directory and the NSSDC Master catalog via Internet login to the NSSDC On-Line Data Information Service (NODIS) at nodis@nssdca.gsfc.nasa.gov.

Pioneer data on NDADS (NASA's Data Archive and Distribution Service) may be located via WWW or an e-mail message to ARMS (Automated Retrieval Mail System) at archives@ndadsa.gsfc.nasa.gov with "HOLDINGS" on the subject line.

# PIONEER MAGNETOMETER COORDINATE SYSTEMS: DEFINITIONS AND TRANSFORMATIONS

by Joyce Wolf
Jet Propulsion Laboratory

Version: 9/13/91

TABLE OF CONTENTS



## 1.0 INTRODUCTION

There have been several different coordinate systems used for the Pioneer 10 and Pioneer 11 magnetometer data that have been deposited at the NSSDC. This document defines those coordinate systems, and gives instructions for calculating the matrices to transform the data from one system to another.

Section 2.0 describes the computation of a general transformation matrix and notes some properties of such matrices.

Section 3.0 lists the necessary parameters from the Trajectory Tape, and defines the angles that are used in the coordinate system descriptions.

Sections 4.1 through 4.8 describe eight coordinate systems and explain how they were used.

Section 5.0 outlines how a computer program to transform Pioneer

magnetometer data from one system to another might be constructed.

Section 6.0 details the transformation of averaged products of vector components from one coordinate system to another.

## 2.0 TRANSFORMATION MATRICES

In general, suppose V is a vector defined in a coordinate system S1, and we would like to calculate its components in a new coordinate system S2. Let U1 be the unit vector defined in S1 that specifies the direction of the X axis of S2. We set up a transformation matrix A, whose first row is the vector U1. Similarly, let U2 and U3 be the unit vectors in S1 that specify the Y and Z axes of S2. Let the second row of A be U2 and the third row be U3. Then W = A V; that is, multiplying the matrix A times the vector V gives the new vector W, which is the representation of V in S2.

In addition, the inverse transformation, from S2 to S1, is given by the transpose of A; that is, the matrix whose first column is U1, second column U2, and third column U3. This is true whenever the unit vectors are orthogonal (perpendicular) to each other.

Suppose we have a third coordinate system, S3, and we have computed B, the transformation matrix from S2 to S3. Then the transformation matrix from S1 to S3 is just the matrix product B A, where A is as defined above. Note that matrix multiplication is not commutative; that is, B times A does not equal A times B. It is, however, associative; that is, (A B) C = A (B C).

## 3.0 TRAJECTORY TAPE PARAMETERS

In order to compute the transformation matrices described below, certain parameters from the Trajectory Tapes are required. These tapes were distributed by the Pioneer Project at Ames, and contain values computed by the JPL Navigation Group's program DPTRAJ. NSSDC has copies of these tapes and the documentation necessary to read them. The following parameters from the Trajectory Tape are needed:

| | |
|---|---|
| VIGDAT | Gregorian calendar date and time |
| JULDAT | Julian Date |
| ETMUTC | Ephemeris Time minus Universal Time |
| REARPR | Distance from Pioneer to Earth |
| XPGSFF,YPGSFF,ZPGSFF | XYZ components of Earth-to-Pioneer vector, referred to mean ecliptic of 1950.0 |
| CELLTP, CELLNP | Celestial latitude and longitude of Pioneer, referred to ecliptic of date |
| XP1SFF,YP1SFF,ZP1SFF | XYZ components of Body1-to-Pioneer vector, referred to mean ecliptic of 1950.0, where Body1 is either Jupiter or Saturn |
| B1LATP,B1LONP | Latitude and longitude of Pioneer in body-fixed coordinate system (Jupiter or Saturn) |

From the above Trajectory Tape parameters, the following angles are calculated: (units are degrees; the FORTRAN function ATAN2D(Y,X) returns the angle whose tangent is Y/X and which is in the correct quadrant for the signs of Y and X).

```
1.  WLTAE = AE system latitude of Pioneer-to-Earth vector
          = -ATAN2D(ZPGSFF, SQRT(XPGSFF**2+YPGSFF**2))

2.  WLNAE = AE system longitude of Pioneer-to-Earth vector
          = 180 + ATAN2D(YPGSFF,XPGSFF)

3.  SLTAE = AE system latitude of Pioneer-to-Sun vector
          = -CELLTP

4.  SLNAE = AE system longitude of Pioneer-to-Sun vector
          = CELLNP - 180

5.  RLTAE = AE system latitude of Jupiter(or Saturn)-to-Pioneer vector
          = ATAN2D(ZP1SFF, SQRT(XP1SFF**2+YP1SFF**2))

6.  RLNAE = AE system longitude of Jupiter(or Saturn)-to-Pioneer vector
          = ATAN2D(YP1SFF, XP1SFF)

7.  RLTJG = JG system latitude of Jupiter-to-Pioneer vector
          = B1LATP

8.  RLNJG = JG system longitude of Jupiter-to-Pioneer vector
          = AMOD(B1LONP + 7.35568*(JULDAT-2435839.5) + 70.78, 360.)

9.  RLTKG = KG system latitude of Saturn-to-Pioneer vector
          = B1LATP (from Trajectory Tapes generated after 1976)

10. RLNKG = KG system longitude of Saturn-to-Pioneer vector
          = B1LONP (from Trajectory Tapes generated after 1976)
```

## 4.1 AE (CELESTIAL) COORDINATE SYSTEM:

This is a heliocentric system whose plane of reference is the true ecliptic of date. It is defined by the vectors A and E: A lies in the ecliptic and points from the Sun toward the Vernal Equinox (first point in Aries); E is the northward perpendicular to the ecliptic. The X axis is along A; the Z axis is along E, and the Y axis completes the right-hand orthogonal system.

The AE system is used for many of the Trajectory Tape parameters. It is also used an an intermediate system when transforming from PE to other systems. (When using AE as an intermediate system, all the trajectory tape parameters used in computation should be referred to the same epoch, either the ecliptic of date or of 1950.0. Longitudes in AE increase at approximately .01396 deg per year, and latitudes change up to .00013 deg -- see The Astronomical Almanac, 1983, p. B19)

## 4.2 PE (PIONEER INERTIAL) COORDINATE SYSTEM:

This system is Pioneer-centered. It is defined by the vectors P and E: P is the direction of the Pioneer spin axis, which nominally points

from Pioneer to Earth; E is the northward perpendicular to the ecliptic, which is just (0,0,1) in AE coordinates. The Z axis is along P; in AE coordinates, it is given by the unit vector U3 = (COS(WLTAE)*COS(WLNAE), COS(WLTAE)*SIN(WLNAE), SIN(WLNAE)). The X axis is the normalized cross product E x U3 / |E x U3|; it is parallel to the ecliptic plane, and is given in the AE system by U1 = (-SIN(WLNAE), COS(WLNAE), 0). The Y axis completes the right-hand orthogonal system, and is given by the cross product U2 = U3 x U1. The transformation matrix from PE to AE is composed of the three column vectors U1, U2, and U3.

The PE system is the basic system for despun, reduced high resolution data. This system was used for Pioneer 11 reduced high resolution data and minute average tapes after 1976.

## 4.3 SH (SOLAR INTERPLANETARY) COORDINATE SYSTEM:

This is a Pioneer-centered system, also called RTN (Radial-Tangential-Normal), which is defined by the vectors S and H: S is the direction from Pioneer to the Sun; H is the rotation axis of the Sun. The X axis in AE coordinates is the unit vector U1 = -S = (-COS(SLTAE)*COS(SLNAE), -COS(SLTAE)*SIN(SLNAE), -SIN(SLTAE)). The Y axis is parallel to the Sun's equatorial plane, and is given by the normalized cross-product U2 = (H x U1) / |H x U1|, where H in AE is (COS(HLTAE)*COS(HLNAE), COS(HLTAE)*SIN(HLNAE), SIN(HLTAE)). HLTAE = 82.75 deg; HLNAE = -14.6304 + .0139583*(t-1972.0), where t = year (see American Ephemeris, 1976, page 556). The Z axis completes the right-hand orthogonal system and is given by U3 = U1 x U2. The transformation matrix from AE to SH is composed of the row vectors U1, U2, and U3.

The SH system was used for Pioneer 10 and early Pioneer 11 reduced high resolution data and minute average tapes. It is also the coordinate system of choice for long-term analyses of hour and day averages, since the ideal spiral angle of the interplanetary field lies in the XY plane of the SH system.

## 4.4 SJ (SOLAR JUPITER) COORDINATE SYSTEM:

This system is defined by the vectors S and J: S is the direction from Pioneer to the Sun; J is Jupiter's rotation axis (the value used for J in the 1973 and 1974 encounters was -.01448,-0.03482,0.99929). The X axis is given in AE by U1 = S = (COS(SLTAE)*COS(SLNAE), COS(SLTAE)*SIN(SLNAE), SIN(SLTAE)). The Y axis is parallel to Jupiter's equatorial plane, and is given by the normalized cross-product U2 = (J x U1) / |J x U1|. The Z axis completes the right-hand orthogonal system and is given by U3 = U1 x U2. The transformation matrix from AE to SJ is composed of the row vectors U1, U2, and U3.

The SJ system was used for the minute, hour, and day averages sent to NSSDC for the Pioneer 10 Jupiter encounter (1973, days 329-349), and the Pioneer 11 Jupiter encounter (1974, days 328-348).

## 4.5 RJ (PIONEER JUPITER) COORDINATE SYSTEM:

This is a Jupiter-centered coordinate system, defined by the vectors R and J. R is the direction from the center of Jupiter to Pioneer; J is the rotation axis of Jupiter as above in Section 4.4. The X axis is given in AE by U1 = R = (COS(RLTAE)*COS(RLNAE), COS(RLTAE)*SIN(RLNAE), SIN(RLNAE)). The Y axis is parallel to Jupiter's equatorial plane, and is given by the normalized cross-product U2 = (J x U1) / |J x U1|. The Z axis completes the right-hand orthogonal system and is given by U3 = U1 x U2. The transformation matrix from AE to RJ coordinates is composed of the row vectors U1, U2, and U3.

The RJ system is an intermediate system used in transforming to the JG system.

## 4.6 JG (JOVIGRAPHIC) COORDINATE SYSTEM:

This is a Jupiter-fixed coordinate system, rotating with the planet. It is defined by the vectors J and G, where J is the direction of Jupiter's rotation axis as above in Section 4.4, and G lies in Jupiter's equatorial plane and is in the direction of the prime meridian, System III, epoch 1957.0 (see Ref. 3). The X axis is along G, the Z axis is along J, and the Y axis completes the orthogonal right hand system. One may compute the unit vectors of the RJ system in JG coordinates as follows: U1 is the direction from the center of Jupiter toward Pioneer, given by (COS(RLTJG)*COS(RLNJG), COS(RLTJG)*SIN(RLNJG), SIN(RLTJG)). U2 is the normalized cross-product (J x U1) / |J x U1|, where in JG coordinates J is just (0,0,1). U3 completes the right-hand orthogonal system and is given by U1 x U2. The transformation matrix from RJ to JG coordinates is composed of the column vectors U1, U2, and U3. (To transform to JG from other coordinate systems, first transform to AE, then to RJ.)

The JG system was used for data analysis for both the Pioneer 10 and Pioneer 11 Jupiter encounters, and for the two data sets sent to NSSDC that contain only data taken inside 7 Jupiter radii.

## 4.7 RK (PIONEER SATURN) COORDINATE SYSTEM:

This is a Saturn-centered coordinate system, defined by the vectors R and K. R is the direction from the center of Saturn to Pioneer; K is the direction of the rotation axis of Saturn (value used was .0912749927, .4615744529, .8823932798). The X axis is given in AE by the unit vector U1 = R = (COS(RLTAE)*COS(RLNAE), COS(RLTAE)*SIN(RLNAE), SIN(RLNAE)). The Y axis is parallel to Saturn's equatorial plane, and is given by the normalized cross-product U2 = (K x U1) / |K x U1|. The Z axis completes the right-hand orthogonal system and is given by U3 = U1 x U2. The transformation matrix from AE to RK coordinates is composed of the row vectors U1, U2, and U3.

The RK system was an intermediate system used in transforming to the KG system.

## 4.8 KG (KRONOGRAPHIC) COORDINATE SYSTEM:

This is a Saturn-fixed coordinate system, rotating with the planet, defined by the vectors K and G. K is the direction of Saturn's rotation axis, as above in Section 4.7, and G lies in Saturn's equatorial plane and in the direction of the prime meridian. The Z axis is along K, the X axis is along G, and the Y axis completes the orthogonal right hand system. One may compute the unit vectors of the RK system in KG coordinates as follows: U1 is the direction from the center of Saturn to Pioneer, given by (COS(RLTKG)*COS(RLNKG), COS(RLTKG)*SIN(RLNKG), SIN(RLTKG)). U2 is the normalized cross-product (K x U1) / |K x U1|, where in KG coordinates K is just (0,0,1). U3 completes the right-hand orthogonal system and is given by U1 x U2. The transformation matrix from RK to KG coordinates is composed of the column vectors U1, U2, and U3. (To transform to KG from other coordinate systems, first transform to AE, then to RK.)

The KG system was used in data analysis for the Pioneer 11 Saturn encounter. (Minute averages sent to the NSSDC were in the PE system, but a supplementary data set was also sent that included the parameters necessary to transform from PE to RK and KG.)

## 5.0 PROGRAMMING CONSIDERATIONS

The following outline may be helpful to anyone who needs to write a computer program to transform a set of Pioneer magnetometer data from one coordinate system into another.

1. Read N records, R(1) to R(N), from the Trajectory data set, which may be an actual Trajectory Tape, or a data set created from such a tape that contains only the parameters required for the coordinate transformation to be performed. N depends on the order of interpolation; if you are using linear interpolation, N = 2.

2. Assign times to these records, TIME(1) to TIME(N), converting the information in VIGDAT to whatever time units are convenient. For each time, subtract ETMUTC, the difference in seconds between Ephemeris Time and UTC, and if the magnetic field data is in Ground Received Time, add the one way light time delay, which is REARPR/299792.5 in seconds. (The minute, hour, and day average tapes submitted to NSSDC are in Ground Received Time.)

3. Read a magnetic field vector, and assign a time to it, BTIME, computed in the same units as TIME(1),...,TIME(N).

4. If BTIME > TIME(N), do the following:
```
          Do for I=2,N
          TIME(I-1) = TIME(I)
          R(I-1) = R(I)
          End do
     Read a record, R(N), from the Trajectory data set.
     Assign a time TIME(N) to this record as in Step 2.
Repeat Step 4 until BTIME < TIME(N) or BTIME = TIME(N).
```

5. Calculate trajectory parameters corresponding to BTIME by interpolation, using the values in R(1) through R(N). Linear interpolation is usually sufficient for interplanetary data, but for the Jupiter and Saturn encounters, higher order interpolation is required. We used a second-order Aitken method.

6. Use the trajectory parameters for BTIME calculated in Step 5 to calculate the desired transformation matrix. Multiply this matrix times the magnetic field vector, and write or store the resulting transformed vector and its time tag.

7. Repeat Steps 3-6 for the remaining magnetic field vectors.

Be sure to use double precision (REAL*8) for all the transformation computations. Matrix multiplication involves adding a lot of terms of the

same order of magnitude, which often have opposite signs, and it is very easy to lose precision.

Time averaging and transforming to a new coordinate system are both linear operations, so their order may be interchanged, as long as the transformation matrix does not change significantly during the averaging interval. We routinely transform interplanetary hour averages from one coordinate system to another. However, in the case of the Jupiter and Saturn encounter data, when the trajectory parameters vary rapidly and nonlinearly with time, it would be best to apply the coordinate transformations to the 1-minute averages (at most, 5-minute), and then do any time averaging that is desired.

## 6.0 TRANSFORMATIONS OF AVERAGES OF PRODUCTS OF FIELD COMPONENTS

The minute, hour, and day average tapes submitted to the NSSDC also contain averages of the squares and cross-products of the magnetic field components, from which variances and covariances of the components can be computed. If it is desired to compute variances and covariances of the field components in a new coordinate system, the averages of the products of the field components can easily be transformed into the new coordinate system.

Suppose A is the computed transformation matrix, with elements A(i,j), where i and j go from 1 to 3. Let P(k,m) be the time-averaged product of the k-th and m-th components of the field vector in the old coordinate system, where k and m range from 1 to 3 and represent X, Y, and Z. For example, P(1,2) is the average of the product (Bx By) over the given time interval in the old coordinate system. Let Q(i,k) be defined similarly, but for the new coordinate system. Then Q(i,k) = A(i,j) A(k,m) P(j,m), summed over j and m, as in the following fragment of code:

```
Q(I,K) = 0.
      DO J=1,3
            DO M=1,3
            Q(I,K) = Q(I,K) + A(I,J)*A(K,M)*P(J,M)
            END DO
      END DO
```

## 7.0 REFERENCES


1. Pioneer F/G Trajectory Data User Requirements, Pioneer Document PC-262.04, Ames Research Center, Dec. 20, 1971.

2. Tape Format Description, DPTRAJ Satellite Ephemeris Trajectory Tape, Pioneer Document PC-262.06, Ames Research Center, March 10, 1976.

3. Smith, E. J., et al., The Planetary Magnetic Field and Magnetosphere of Jupiter: Pioneer 10. J. Geophys. Res., Vol. 79, p. 3501, 1974.

4. Smith, E. J., et al., Saturn's Magnetosphere and Its Interaction with the Solar Wind. J. Geophys. Res., Vol. 85, p. 5655, 1980.

Directory ANON_DIR:[COHO.P10MAG.HOUR]

| | |
|---|---|
| MAGCOORD.DOC;3 | 38 |
| P10HVM_15M.SFD;1 | 16 |
| P10MAG72.DAT;3 | 937 |
| P10MAG73.DAT;3 | 1050 |
| P10MAG74.DAT;2 | 974 |
| P10MAG75.DAT;2 | 657 |
| P10MAGHR.CAT;1 | 0 |
| P10MAGHR.FMT;6 | 8 |

Total of 8 files, 3680 blocks.

PIONEER 11

1-HR HVM INTERPLANETARY MAGNETIC FIELD DATA

73-019A-01I SPHE-00421

THIS DATA SET CONSISTS OF 1 MAGNETIC TAPE. THE TAPE IS 9-TRACK, 6250 BPI, CREATED ON A VAX COMPUTER, WRITTEN IN ASCII, WITH A LABEL NAME OF "P11HVM". A DIRECTORY OF THE TAPE AS WELL AS COPIES OF THE TEXT FILES, P11MAGHR.SFD, P11MAGHR.FMT AND MAGCOORD.DOC HAVE BEEN INCLUDED ALSO. THE D AND C NUMBER ALONG WITH IT'S TIMESPAN IS LISTED BELOW.

| D# | C# | FILES | TIMESPAN |
|---|---|---|---|
| D-108356 | C-032391 | 24 | 04/06/72-08/01/92 |

***DATA WAS DOWNLOADED AND COPIED FROM ANON_DIR:[COHO.P11MAG.HOUR]***

DSC # 467

Directory ANON_DIR:[COHO.P10MAG.HOUR]

| | |
|---|---|
| MAGCOORD.DOC;3 | 38 |
| P10HVM_15M.SFD;1 | 16 |
| P10MAG72.DAT;3 | 937 |
| P10MAG73.DAT;3 | 1050 |
| P10MAG74.DAT;2 | 974 |
| P10MAG75.DAT;2 | 657 |
| P10MAGHR.CAT;1 | 0 |
| P10MAGHR.FMT;6 | 8 |

Total of 8 files, 3680 blocks.

=========================================================================

# PIONEER 10 INTERPLANETARY MAGNETIC FIELD DATA - 1 HOUR AVERAGES

Data Set Coverage (yyyy-mm-dd): 1972-03-03 to 1975-11-17

Experiment: Pioneer 10 Helium Vector Magnetometer (HVM)

Principal Investigator: Dr. Edward J. Smith, NASA JPL

Data Set Contact: Joyce Wolf, NASA JPL

Data Set Submission Date: 1993-09-16

Data Set Description:

The Helium Vector Magnetometer (HVM) measurements of interplanetary magnetic fields are averaged at one-hour intervals with respect to Spacecraft Event Time - UT. Data set parameters include the three orthogonal components of the magnetic field in RTN coordinates, where R is in the sun-s/c direction, T is the cross product of the solar rotation axis and R, and N is the cross product of R and T. The hourly field magnitude, averaged over scalar magnitudes at higher time resolution, is also provided. All field values are in nanotelsa. Data are available from launch through the time of instrument failure in 1975. This data set is also available on-line in the Coordinated Heliospheric Observations (COHO) data base at NSSDC's Anonymous FTP site and in the COHOWeb browse and retrieval service on the World Wide Web, both accessible via WWW at http://nssdc.gsfc.nasa.gov/space/space_physics_home.html, the NSSDC space physics page.

Data Set Files:

```
P10MAGHR.FMT     - this document
P10HVM_15M.SFD - SFDU metadata extract from Pioneer 10 HVM 15-min. data set
P10MAGyy.DAT     - Hour average data files (ASCII) for year 19yy
MAGCOORD.DOC     - Document from JPL on Pioneer coordinate transformations
P10MAGHR.CAT     - VMS directory listing with file sizes in VMS blocks
```

Parameter Format for File P10MAGyy.DAT:

```
IY      - SCET-UT Year (yy)
IDOY    - SCET-UT Day of Year (ddd) , IDOY = 1 for Jan. 1
IHR     - SCET-UT Hour of day
BR      - Radial component (RTN system) of vector magnetic field in nT
BT      - Transverse component (RTN) of vector magnetic field in nT
BN      - Normal component (RTN) of vector magnetic field in nT
B       - Scaler magnetic field magnitude in nT
RAU     - Radial distance from Sun to spacecraft in AU
ELAT    - Ecliptic latitude of spacecraft in degrees
ELON    - Ecliptic longitude of spacecraft in degrees
```

The following FORTRAN read statement will read the hourly data records:

```
      READ(10,10) IY, IDOY, IHR, BR, BT, BN, B, RAU, ELAT, ELON
10    FORMAT(I3, I4.3, I3.2, 4F9.4, F9.5, F7.1, F8.1)
```

NSSDC Data Set ID: 72-012A-01K

NSSDC Data Set Location:

Off-line: ask for NSSDC data set 72-012A-01K from request@nssdca.gsfc.nasa.gov

On-line: COHO directory at nssdca::anon_dir:[coho.p10mag.hour]

Near-line: Pioneer project data set on NDADS (ingest in progress)

Acknowledgement:

Please acknowledge the National Space Science Data Center and the Principal Investigator, Dr. E. J. Smith of NASA's Jet Propulsion Laboratory, for use of this data in publications.

Related Information:

The file P10HVM_15M.SFD provides a detailed description of the Pioneer spacecraft, the HVM experiment, and the data. This ASCII document is written in Standard Formatted Data Unit (SFDU) format as part of NSSDC data set 72-012A-01I for 15-minute averaged data covering 1972-03-03 to 1975-11-17. Unlike the 1-hour data set here, the 15-min. data set gives times as Ground Received Time - UT.

Other information about the Pioneer mission, experiments, and data sets at NSSDC may be obtained via World Wide Web and NSSDC's space physics page at http://nssdc.gsfc.nasa.gov/space/space_physics_home.html. Non-WWW users may access NSSDC information in the NASA Master Directory and the NSSDC Master catalog via Internet login to the NSSDC On-Line Data Information Service (NODIS) at nodis@nssdca.gsfc.nasa.gov.

Pioneer data on NDADS (NASA's Data Archive and Distribution Service) may be located via WWW or an e-mail message to ARMS (Automated Retrieval Mail System) at archives@ndadsa.gsfc.nasa.gov with "HOLDINGS" on the subject line.

NSSDCA::ANON_DIR:[COHO.P10MAG.MINUTE]P10HVM_15M.SFD

Note: this document is an extract from the SFDU metadata text for the 15-minute averaged IMF data in NSSDC data set 72-012A-01I. The mission, experiment, and data processing details also apply to the 1-minute data, except that the new one-minute data in 72-012A-01J have been supplied to NSSDC in RTN coordinates with SCET-UT times.

JFC 7/12/95

================================================================================
CCSD3ZF0000100000001CCSD3VS00002MRK**001

/* VOLDESC.SFD file */

Technical_Contact: Joyce Wolf
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CCSD$$MARKERMRK**001CCSD3SS00002MRK**002

Data_Set_Name: Pioneer 10 HVM Cruise Data Archive

Data_Source: Pioneer 10 Helium Vector Magnetometer

Scientific_Contact: Dr. Edward J. Smith
Jet Propulsion Laboratory
Mail Stop 169-506
4800 Oak Grove Drive
Pasadena, CA 91109

Electronic Mail: JPLSP::ESMITH
Telephone: 818-354-2248

Spacecraft_Characteristics: Launched on March 3, 1972, Pioneer 10 made its closest approach to Jupiter on Dec. 2, 1973. Since then, it has been heading out of the Solar System, downstream with respect to the direction of the interstellar wind. In 1990 it was 50 AU from the sun.

The spacecraft's spin axis is directed toward the Earth. On board are twelve instruments for measuring fields and particles. The spacecraft is powered by radioisotope thermal generators (RTG's).

Investigation_Objectives: The primary investigation objectives for the Pioneer 10 Helium Vector Magnetometer cruise data were to determine the large-scale structure and dynamics of the interplanetary magnetic field in the outer solar system and to study how they are influenced by changing solar activity.

Instrument_Attributes:

A. Instrument_Description: The Helium Vector Magnetometer produces measurements of the 3 orthogonal components of the ambient magnetic field in a

0-3 Hz passband. The instrument switches automatically among 8 ranges, plus or minus 4, 14, 42, 144, 640, 4000, 22000, and 140000 nT. The measurements are digitized to 8 bits and a sign bit, giving a sensitivity of 1/256 of full-scale in each range. For more information, refer to Smith, E. J., B. V. Connor, and G. T. Foster, Jr., "Measuring the magnetic fields of Jupiter and the outer solar system," IEEE Trans. Magn., vol. MAG-11, pp. 962-980, 1975.

B. Instrument_Performance: The instrument performed normally until its failure in December, 1975.

C. Measured_Parameters: 3 orthogonal components of magnetic field; third component is parallel to spacecraft spin axis.

D. Instrument_Accuracy: Two factors determine the accuracy with which each component of the field is determined. One is the scale factor relating the change in field to the corres-ponding change in output voltage. The straight line representing this scale factor intercepts the B axis (V = 0) at a non-zero value (the instrument "offset" or "zero level").

The HVM is operated in a feedback mode so that the scale factor is highly linear and very stable. An in-flight calibration (IFC) is incorporated into the instrument such that, on receipt of a command, carefully calibrated step field changes are applied to the sensor to produce an end-to-end calibration of all three axes. During the lifetime of Pioneer 10 and 11, we performed an in-flight calibration approximately every two weeks. No change in instrument response as large as one bit has ever been observed on either instrument. Thus, the scale factors are considered known to within 0.25 percent, and, accordingly, the errors are negligible.

Accurate estimates of the offsets must be determined in flight. Since Pioneer 10 is a spinning spacecraft with two magnetometer axes lying in the spin plane, two of the offsets can be continuously monitored by averaging the data on a given axis over a large number of revolutions. By analyzing the results over many long intervals, it is estimated that these two offsets are being determined to within 0.005 nT.

The offset on the sensor axis parallel to the spin axis is more difficult to determine. We use the method developed by Davis and Smith (also independently developed by Hedgecock), as improved upon by Belcher. The basis of this so-called variance method is to choose the BZ offset so as to reduce the variations in B-magnitude to a minimum in the least squares sense. Experience indicates that the method yields a relative accuracy of about 5 percent.

Data_Set_Quality: There are no significant known errors in the data.

Data_Processing_Overview: Data reduction was done on an IBM 7044 and a Univac 1108.

Raw data points consisted of Ground Received Time, triaxial magnetometer measurements in counts (0 to 511), and magnetometer range (0 to 7). Each measurement was converted into nanotesla using range-dependent scaling factors and offsets. Spin-plane offsets were calculated daily by averaging spinning data, and are estimated to have errors of less than .005 nT. The other offset (parallel to the spin axis) was estimated over periods of several weeks using either the Leverett Davis method of minimizing the variance of the square of the magnitude, or John Belcher's variation of that method; errors are estimated at less than .02 nT.

The magnetic field vectors were then despun into spacecraft inertial coordinates and rotated through the roll angle CKAH (Clock Angle of Sun, provided by Ames in File 3 on our EDR tapes). These field vectors were transformed from PE to SH (or SJ during Jupiter Encounter) before being written onto the RDR tapes. (In the PE system, Z is along the Pioneer spin axis, nominally toward Earth, and X lies in the plane containing the directions from Pioneer to the Earth and Sun and is orthogonal to the spin axis, Z. In SH, also known as Radial-Tangential-Normal, X is the Sun-to-Pioneer direction and Y is parallel to the Sun's equatorial plane. For a complete definition of these systems, see the description of COORDSYS in file FORMAT.SFD.)

From the RDR tapes, Ground Received Time 1-minute, 1-hour, and 1-day averages of the field components, crossproducts of components, squares of components, direction cosines of components, field magnitude, and square of field magnitude were calculated and submitted on tapes to NSSDC.

For this cruise data archive, each 15-minute (or 1 hour) Spacecraft Event Time parameter average has been constructed from those GRT 1-minute parameter averages whose midpoints (converted to SCET) lie within the SCET averaging interval. The number of seconds in each minute for which data existed was used as a weighting factor.

Lit_References:

Smith, E. J., B. V. Connor, and G. T. Foster, Jr., "Measuring the magnetic fields of Jupiter and the outer solar system," IEEE Trans. Magn., vol. MAG-11, pp. 962-980, 1975.

Other references may be found in these articles.

CCSD$$MARKERMRK**002

PIONEER MAGNETOMETER COORDINATE SYSTEMS: DEFINITIONS AND TRANSFORMATIONS

by Joyce Wolf
Jet Propulsion Laboratory

Version: 9/13/91

TABLE OF CONTENTS



## 1.0 INTRODUCTION

There have been several different coordinate systems used for the Pioneer 10 and Pioneer 11 magnetometer data that have been deposited at the NSSDC. This document defines those coordinate systems, and gives instructions for calculating the matrices to transform the data from one system to another.

Section 2.0 describes the computation of a general transformation matrix and notes some properties of such matrices.

Section 3.0 lists the necessary parameters from the Trajectory Tape, and defines the angles that are used in the coordinate system descriptions.

Sections 4.1 through 4.8 describe eight coordinate systems and explain how they were used.

Section 5.0 outlines how a computer program to transform Pioneer

From the above Trajectory Tape parameters, the following angles are calculated: (units are degrees; the FORTRAN function ATAN2D(Y,X) returns the angle whose tangent is Y/X and which is in the correct quadrant for the signs of Y and X).

```
1.  WLTAE = AE system latitude of Pioneer-to-Earth vector
          = -ATAN2D(ZPGSFF, SQRT(XPGSFF**2+YPGSFF**2))

2.  WLNAE = AE system longitude of Pioneer-to-Earth vector
          = 180 + ATAN2D(YPGSFF,XPGSFF)

3.  SLTAE = AE system latitude of Pioneer-to-Sun vector
          = -CELLTP

4.  SLNAE = AE system longitude of Pioneer-to-Sun vector
          = CELLNP - 180

5.  RLTAE = AE system latitude of Jupiter(or Saturn)-to-Pioneer vector
          = ATAN2D(ZP1SFF, SQRT(XP1SFF**2+YP1SFF**2))

6.  RLNAE = AE system longitude of Jupiter(or Saturn)-to-Pioneer vector
          = ATAN2D(YP1SFF, XP1SFF)

7.  RLTJG = JG system latitude of Jupiter-to-Pioneer vector
          = B1LATP

8.  RLNJG = JG system longitude of Jupiter-to-Pioneer vector
          = AMOD(B1LONP + 7.35568*(JULDAT-2435839.5) + 70.78, 360.)

9.  RLTKG = KG system latitude of Saturn-to-Pioneer vector
          = B1LATP (from Trajectory Tapes generated after 1976)

10. RLNKG = KG system longitude of Saturn-to-Pioneer vector
          = B1LONP (from Trajectory Tapes generated after 1976)
```

## 4.1 AE (CELESTIAL) COORDINATE SYSTEM:

This is a heliocentric system whose plane of reference is the true ecliptic of date. It is defined by the vectors A and E: A lies in the ecliptic and points from the Sun toward the Vernal Equinox (first point in Aries); E is the northward perpendicular to the ecliptic. The X axis is along A; the Z axis is along E, and the Y axis completes the right-hand orthogonal system.

The AE system is used for many of the Trajectory Tape parameters. It is also used an an intermediate system when transforming from PE to other systems. (When using AE as an intermediate system, all the trajectory tape parameters used in computation should be referred to the same epoch, either the ecliptic of date or of 1950.0. Longitudes in AE increase at approximately .01396 deg per year, and latitudes change up to .00013 deg -- see The Astronomical Almanac, 1983, p. B19)

## 4.2 PE (PIONEER INERTIAL) COORDINATE SYSTEM:

This system is Pioneer-centered. It is defined by the vectors P and E: P is the direction of the Pioneer spin axis, which nominally points

in AE by U1 = R = (COS(RLTAE)*COS(RLNAE), COS(RLTAE)*SIN(RLNAE), SIN(RLNAE)). The Y axis is parallel to Jupiter's equatorial plane, and is given by the normalized cross-product U2 = (J x U1) / |J x U1|. The Z axis completes the right-hand orthogonal system and is given by U3 = U1 x U2. The transformation matrix from AE to RJ coordinates is composed of the row vectors U1, U2, and U3.

The RJ system is an intermediate system used in transforming to the JG system.

## 4.6 JG (JOVIGRAPHIC) COORDINATE SYSTEM:

This is a Jupiter-fixed coordinate system, rotating with the planet. It is defined by the vectors J and G, where J is the direction of Jupiter's rotation axis as above in Section 4.4, and G lies in Jupiter's equatorial plane and is in the direction of the prime meridian, System III, epoch 1957.0 (see Ref. 3). The X axis is along G, the Z axis is along J, and the Y axis completes the orthogonal right hand system. One may compute the unit vectors of the RJ system in JG coordinates as follows: U1 is the direction from the center of Jupiter toward Pioneer, given by (COS(RLTJG)*COS(RLNJG), COS(RLTJG)*SIN(RLNJG), SIN(RLTJG)). U2 is the normalized cross-product (J x U1) / |J x U1|, where in JG coordinates J is just (0,0,1). U3 completes the right-hand orthogonal system and is given by U1 x U2. The transformation matrix from RJ to JG coordinates is composed of the column vectors U1, U2, and U3. (To transform to JG from other coordinate systems, first transform to AE, then to RJ.)

The JG system was used for data analysis for both the Pioneer 10 and Pioneer 11 Jupiter encounters, and for the two data sets sent to NSSDC that contain only data taken inside 7 Jupiter radii.

## 4.7 RK (PIONEER SATURN) COORDINATE SYSTEM:

This is a Saturn-centered coordinate system, defined by the vectors R and K. R is the direction from the center of Saturn to Pioneer; K is the direction of the rotation axis of Saturn (value used was .0912749927, .4615744529, .8823932798). The X axis is given in AE by the unit vector U1 = R = (COS(RLTAE)*COS(RLNAE), COS(RLTAE)*SIN(RLNAE), SIN(RLNAE)). The Y axis is parallel to Saturn's equatorial plane, and is given by the normalized cross-product U2 = (K x U1) / |K x U1|. The Z axis completes the right-hand orthogonal system and is given by U3 = U1 x U2. The transformation matrix from AE to RK coordinates is composed of the row vectors U1, U2, and U3.

The RK system was an intermediate system used in transforming to the KG system.

## 4.8 KG (KRONOGRAPHIC) COORDINATE SYSTEM:

This is a Saturn-fixed coordinate system, rotating with the planet, defined by the vectors K and G. K is the direction of Saturn's rotation axis, as above in Section 4.7, and G lies in Saturn's equatorial plane and in the direction of the prime meridian. The Z axis is along K, the X axis is along G, and the Y axis completes the orthogonal right hand system. One may compute the unit vectors of the RK system in KG coordinates as follows: U1 is the direction from the center of Saturn to Pioneer, given by (COS(RLTKG)*COS(RLNKG), COS(RLTKG)*SIN(RLNKG), SIN(RLTKG)). U2 is the normalized cross-product (K x U1) / |K x U1|, where in KG coordinates K is just (0,0,1). U3 completes the right-hand orthogonal

same order of magnitude, which often have opposite signs, and it is very easy to lose precision.

Time averaging and transforming to a new coordinate system are both linear operations, so their order may be interchanged, as long as the transformation matrix does not change significantly during the averaging interval. We routinely transform interplanetary hour averages from one coordinate system to another. However, in the case of the Jupiter and Saturn encounter data, when the trajectory parameters vary rapidly and nonlinearly with time, it would be best to apply the coordinate transformations to the 1-minute averages (at most, 5-minute), and then do any time averaging that is desired.

## 6.0 TRANSFORMATIONS OF AVERAGES OF PRODUCTS OF FIELD COMPONENTS

The minute, hour, and day average tapes submitted to the NSSDC also contain averages of the squares and cross-products of the magnetic field components, from which variances and covariances of the components can be computed. If it is desired to compute variances and covariances of the field components in a new coordinate system, the averages of the products of the field components can easily be transformed into the new coordinate system.

Suppose A is the computed transformation matrix, with elements A(i,j), where i and j go from 1 to 3. Let P(k,m) be the time-averaged product of the k-th and m-th components of the field vector in the old coordinate system, where k and m range from 1 to 3 and represent X, Y, and Z. For example, P(1,2) is the average of the product (Bx By) over the given time interval in the old coordinate system. Let Q(i,k) be defined similarly, but for the new coordinate system. Then Q(i,k) = A(i,j) A(k,m) P(j,m), summed over j and m, as in the following fragment of code:

```
Q(I,K) = 0.
     DO J=1,3
          DO M=1,3
          Q(I,K) = Q(I,K) + A(I,J)*A(K,M)*P(J,M)
          END DO
     END DO
```

## 7.0 REFERENCES


1. Pioneer F/G Trajectory Data User Requirements, Pioneer Document PC-262.04, Ames Research Center, Dec. 20, 1971.

2. Tape Format Description, DPTRAJ Satellite Ephemeris Trajectory Tape, Pioneer Document PC-262.06, Ames Research Center, March 10, 1976.

3. Smith, E. J., et al., The Planetary Magnetic Field and Magnetosphere of Jupiter: Pioneer 10. J. Geophys. Res., Vol. 79, p. 3501, 1974.

4. Smith, E. J., et al., Saturn's Magnetosphere and Its Interaction with the Solar Wind. J. Geophys. Res., Vol. 85, p. 5655, 1980.

PIONEER 11

Directory ANON_DIR:[COHO.P11MAG.HOUR]

| | |
|---|---|
| MAGCOORD.DOC;3 | 38 |
| P11HVM_15M.SFD;2 | 20 |
| P11MAG73.DAT;2 | 811 |
| P11MAG74.DAT;3 | 1024 |
| P11MAG75.DAT;2 | 895 |
| P11MAG76.DAT;2 | 490 |
| P11MAG77.DAT;2 | 812 |
| P11MAG78.DAT;2 | 486 |
| P11MAG79.DAT;2 | 743 |
| P11MAG80.DAT;2 | 618 |
| P11MAG81.DAT;2 | 683 |
| P11MAG82.DAT;2 | 520 |
| P11MAG83.DAT;2 | 418 |
| P11MAG84.DAT;2 | 442 |
| P11MAG85.DAT;2 | 340 |
| P11MAG86.DAT;2 | 534 |
| P11MAG87.DAT;1 | 519 |
| P11MAG88.DAT;1 | 450 |
| P11MAG89.DAT;1 | 310 |
| P11MAG90.DAT;1 | 183 |
| P11MAG91.DAT;1 | 166 |
| P11MAG92.DAT;1 | 93 |
| P11MAGHR.CAT;1 | 0 |
| P11MAGHR.FMT;4 | 9 |
| WOLF.DOC;2 | 5 |

Total of 25 files, 10609 blocks.

==========================================================================

PIONEER 11 INTERPLANETARY MAGNETIC FIELD DATA - 1 HOUR AVERAGES

---

Data Set Coverage (yyyy-mm-dd): 1973-04-06 to 1992-08-01

Experiment: Pioneer 11 Helium Vector Magnetometer (HVM)

Principal Investigator: Dr. Edward J. Smith, NASA JPL

Data Set Contact: Joyce Wolf, NASA JPL

Data Set Submission Date: 1993-09-16

Data Set Description:

The Helium Vector Magnetometer (HVM) measurements of interplanetary magnetic fields are averaged at one-hour intervals with respect to Spacecraft Event Time - UT. Data set parameters include the three orthogonal components of the magnetic field in RTN coordinates, where R is in the sun-s/c direction, T is the cross product of the solar rotation axis and R, and N is the cross product of R and T. The hourly field magnitude, averaged over scalar magnitudes at higher time resolution, is also provided. All field values are in nanotelsa. This data set is also available on-line in the Coordinated Heliospheric Observations (COHO) data base at NSSDC's Anonymous FTP site and in the COHOWeb browse and retrieval service on the World Wide Web, both accessible via WWW at http://nssdc.gsfc.nasa.gov/space/space_physics_home.html, the NSSDC space physics page.

Data Set Files:

```
P11MAGHR.FMT    - this document
P11HVM_15M.SFD  - SFDU metadata extract from Pioneer 11 HVM 15-min. data set
P11MAGyy.DAT    - Hour average data files (ASCII) for year 19yy
MAGCOORD.DOC    - Document from JPL on Pioneer coordinate transformations
P11MAGHR.CAT    - VMS directory listing with file sizes in VMS blocks
```

Parameter Format for File P11MAGyy.DAT:

```
IY      - SCET-UT Year (yy)
IDOY    - SCET-UT Day of Year (ddd) , IDOY = 1 for Jan. 1
IHR     - SCET-UT Hour of day
BR      - Radial component (RTN system) of vector magnetic field in nT
BT      - Transverse component (RTN) of vector magnetic field in nT
BN      - Normal component (RTN) of vector magnetic field in nT
B       - Scaler magnetic field magnitude in nT
RAU     - Radial distance from Sun to spacecraft in AU
ELAT    - Ecliptic latitude of spacecraft in degrees
ELON    - Ecliptic longitude of spacecraft in degrees
```

The following FORTRAN read statement will read the hourly data records:

```
      READ(10,10) IY, IDOY, IHR, BR, BT, BN, B, RAU, ELAT, ELON
10    FORMAT(I3, I4, I3, 4F9.4, F9.5, F7.1, F8.1)
```

NSSDC Data Set ID: 73-019A-01I

NSSDC Data Set Location:

Off-line: ask for NSSDC data set 73-019A-01I from request@nssdca.gsfc.nasa.gov

On-line: COHO directory at nssdca::anon_dir:[coho.p11mag.hour]

Near-line: Pioneer project data set on NDADS (ingest in progress)

Acknowledgement:

Please acknowledge the National Space Science Data Center and the Principal Investigator, Dr. E. J. Smith of NASA's Jet Propulsion Laboratory, for use of this data in publications.

Related Information:

The file P11HVM_15M.SFD provides a detailed description of the Pioneer spacecraft, the HVM experiment, and the data. This ASCII document is written in Standard Formatted Data Unit (SFDU) format as part of NSSDC data set 73-019A-01H for 15-minute averaged data covering the same time interval. Unlike the 1-hour data set here, the 15-min. data set gives times as Ground Received Time - UT and the coordinate system switches to Pioneer Ecliptic in 1976 and thereafter.

Other information about the Pioneer mission, experiments, and data sets at NSSDC may be obtained via World Wide Web and NSSDC's space physics page at http://nssdc.gsfc.nasa.gov/space/space_physics_home.html. Non-WWW users may access NSSDC information in the NASA Master Directory and the NSSDC Master catalog via Internet login to the NSSDC On-Line Data Information Service (NODIS) at nodis@nssdca.gsfc.nasa.gov.

Pioneer data on NDADS (NASA's Data Archive and Distribution Service) may be located via WWW or an e-mail message to ARMS (Automated Retrieval Mail System) at archives@ndadsa.gsfc.nasa.gov with "HOLDINGS" on the subject line.

P 11 HVM_15M.SFD

NSSDCA::ANON_DIR:[COHO.P11MAG]P11HVM_15M.SFD

Note: this document is an extract from the SFDU metadata text for the 15-minute averaged IMF data in NSSDC data set 73-019A-01H. The mission, experiment, and data processing details also apply to the 1-hour data, except that the one-hour data in 73-019A-01I have been supplied to NSSDC all in RTN coordinates with SCET-UT times.

JFC 7/17/95

```
================================================================================
CCSD3ZF0000100000001CCSD3VS00002MRK**001

/* VOLDESC.SFD file */

Technical_Contact:       Joyce Wolf
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                         Electronic Mail (SPAN):  JPLSP::JWOLF
                         Phone:  818-354-7361

Prev_Vols:               None
                         /* or USA_NASA_NSSD_P11A_0001
                               USA_NASA_NSSD_P11A_0002, etc.  */

CCSD$$MARKERMRK**001CCSD3SS00002MRK**002

Data_Set_Name:           Pioneer 11 HVM Cruise Data Archive

Data_Source:             Pioneer 11 Helium Vector Magnetometer

Scientific_Contact:      Dr. Edward J. Smith
                         Jet Propulsion Laboratory
                         Mail Stop 169-506
                         4800 Oak Grove Drive
                         Pasadena, CA 91109

                         Electronic Mail:  JPLSP::ESMITH
                         Telephone: 818-354-2248
```

Spacecraft_Characteristics: Launched in April of 1973, Pioneer 11 made its closest approach to Jupiter on Dec. 3, 1974. During late 1975 and early 1976, Pioneer 11 attained heliographic latitudes of 16 deg and higher; the sector structure of the IMF disappeared at these latitudes. On Sept. 1, 1979, Pioneer 11 made its closest approach to Saturn. Since then, it has been heading out of the Solar System, upstream with respect to the direction of the interstellar wind. It passed Neptune's orbit in 1990.

The spacecraft spins at about 7.8 rpm, with the spin axis directed toward the Earth. It carries 12 instruments for measuring fields and particles, and is powered by radioisotope thermal generators (RTG's).

Investigation_Objectives: The primary investigation objectives for the Pioneer 11 Helium Vector Magnetometer cruise data are to determine the large-scale structure and dynamics of the interplanetary magnetic field in the outer solar system and to study how they are influenced by changing solar activity, and the interaction of the solar wind with the interstellar medium.

Instrument_Attributes:

A. Instrument_Description: The Helium Vector Magnetometer produces measurements of the 3 orthogonal components of the ambient magnetic field in a 0-3 Hz passband. The instrument switches automatically among 8 ranges, plus or minus 4, 14, 42, 144, 640, 4000, 22000, and 140000 nT. The measurements are digitized to 8 bits and a sign bit, giving a sensitivity of 1/256 of full-scale in each range. For more information, refer to Smith, E. J., B. V. Connor, and G. T. Foster, Jr., "Measuring the magnetic fields of Jupiter and the outer solar system," IEEE Trans. Magn., vol. MAG-11, pp. 962-980, 1975.

B. Instrument_Performance: The instrument has functioned normally throughout the mission.

C. Measured_Parameters: Three orthogonal components of magnetic field; the third component is parallel to the spacecraft spin axis.

D. Instrument_Accuracy: Two factors determine the accuracy with which each component of the field is determined. One is the scale factor relating the change in field to the corres-ponding change in output voltage. The straight line representing this scale factor intercepts the B axis (V = 0) at a non-zero value (the instrument "offset" or "zero level").

The HVM is operated in a feedback mode so that the scale factor is highly linear and very stable. An in-flight calibration (IFC) is incorporated into the instrument such that, on receipt of a command, carefully calibrated step field changes are applied to the sensor to produce an end-to-end calibration of all three axes. During the lifetime of Pioneer 10 and 11, we performed an in-flight calibration approximately every two weeks. No change in instrument response as large as one bit has ever been observed on either instrument. Thus, the scale factors are considered known to within 0.25 percent, and, accordingly, the errors are negligible.

Accurate estimates of the offsets must be determined in flight. Since Pioneer 11 is a spinning spacecraft with two magnetometer axes lying in the spin plane, two of the offsets can be continuously monitored by averaging the data on a given axis over a large number of revolutions. By analyzing the results over many long intervals, it is estimated that these two offsets are being determined to within 0.005 nT. Since the spin axis is continuously oriented toward Earth and is very nearly radial at large distances (about 30 AU) the two transverse components (B-Theta and B-Phi) are extremely well known. At 30 AU, the field magnitude, B, is typically 0.2 nT and the relative accuracy is, therefore, about 2.5 percent.

The offset on the sensor axis parallel to the spin axis is more difficult to determine. We use the method developed by Davis and Smith (also independently developed by Hedgecock), as improved upon by Belcher. The basis of this so-called variance method is to choose the BZ offset so as to reduce the variations in B-magnitude to a minimum in the least squares sense. Experience indicates that the method yields a relative accuracy of greater than 5 percent. For Pioneer 11 we estimate that the offset is known to about 0.02 nT so that in a typical field of 0.2 nT, the offset is determined to within about 10 percent. This number is probably conservative and we may actually be doing slightly better.

Data_Set_Parameters: Averages of field components (BX, BY, BZ); averages of squares and crossproducts of components (BX2, BY2, BZ2 and BXBY, BXBZ, BYBZ); averages of field direction cosines (BXCOS, BYCOS, BZCOS); average of field magnitude (BMAG) and average of square of field magnitude (BMAG2). Heliocentric positions of the spacecraft and Earth, referred to the ecliptic and equinox of date, are also included.

Data_Set_Quality: There are no significant known errors in the data; however, in 1987 and afterward, the cyclic switching on and off of other instruments on Pioneer 11 caused random fluctuations of the instrument's Z axis zero levels. These fluctuations are of the order of 0.05 nT, with a period of several days. We have been able to remove most, but not all, of these fluctuations.

Data_Processing_Overview: Data reduction until 1976 was done on an IBM 7044 and a Univac 1108; after that time a SEL/32 was used.

Raw data points consisted of Ground Received Time, triaxial magnetometer measurements in counts (0 to 511), and magnetometer range (0 to 7). Each measurement was converted into nanotesla using range-dependent scaling factors and offsets. Spin-plane offsets were calculated daily by averaging spinning data. The other offset (parallel to the spin axis) was estimated over periods of several weeks using either the Leverett Davis method of minimizing the variance of the square of the magnitude, or John Belcher's variation of that method.

The magnetic field vectors were then despun into spacecraft inertial coordinates and rotated through the roll angle CKAH (Clock Angle of Sun, provided by Ames in File 3 on our EDR tapes). In this PE coordinate system, field vectors from 1976 and later were written onto RDR (Reduced Data Record) tapes. Prior to 1976, data were transformed from PE to SH (or SJ during Jupiter Encounter) before being written onto the RDR tapes. (In the PE system, Z is along the Pioneer spin axis, nominally toward Earth, and X lies in the plane containing the directions from Pioneer to the Earth and Sun and is orthogonal to the spin axis, Z. In SH, also known as Radial-Tangential-Normal, X is the Sun-to-Pioneer direction and Y is parallel to the Sun's equatorial plane. For a complete definition of these systems, see the description of COORDSYS in file FORMAT.SFD.)

From the RDR tapes, Ground Received Time 1-minute, 1-hour, and 1-day averages of the field components, crossproducts of components, squares of components, direction cosines of components, field magnitude, and square of field magnitude were calculated and submitted on tapes to NSSDC.

For this cruise data archive, each 15-minute (or 1 hour) Spacecraft Event Time parameter average has been constructed from those GRT 1-minute parameter averages whose midpoints (converted to SCET) lie within the SCET averaging interval. The number of seconds in each minute for which data existed was used as a weighting factor. Averages in PE coordinates have been converted to SH.

Lit_References: Smith, E. J., B. V. Connor, and G. T. Foster, Jr., "Measuring the magnetic fields of Jupiter and the outer solar system," IEEE Trans. Magn., vol. MAG-11, pp. 962-980, 1975.

Smith, E. J., et al., "Saturn's Magnetosphere and Its Interaction with the Solar Wind," J. Geophys. Res., vol. 85, pp. 5655-5674, 1980.

Smith, E.J., D. Winterhalter, and J. A. Slavin, "Recent Pioneer 11 observations of the distant heliospheric magnetic field," Solar Wind 6, eds. V.J. Pizzo, T.E. Holzer, and D.G. Sime, NCAR/TN-306, HAO/NCAR, Boulder, Colorado, 1988, p. 581.

Other references may be found in these articles.

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MAGCOOR.SYS

PIONEER MAGNETOMETER COORDINATE SYSTEMS: DEFINITIONS AND TRANSFORMATIONS

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## 1.0 INTRODUCTION

There have been several different coordinate systems used for the Pioneer 10 and Pioneer 11 magnetometer data that have been deposited at the NSSDC. This document defines those coordinate systems, and gives instructions for calculating the matrices to transform the data from one system to another.

Section 2.0 describes the computation of a general transformation matrix and notes some properties of such matrices.

Section 3.0 lists the necessary parameters from the Trajectory Tape, and defines the angles that are used in the coordinate system descriptions.

Sections 4.1 through 4.8 describe eight coordinate systems and explain how they were used.

Section 5.0 outlines how a computer program to transform Pioneer

magnetometer data from one system to another might be constructed.

Section 6.0 details the transformation of averaged products of vector components from one coordinate system to another.

## 2.0 TRANSFORMATION MATRICES

In general, suppose V is a vector defined in a coordinate system S1, and we would like to calculate its components in a new coordinate system S2. Let U1 be the unit vector defined in S1 that specifies the direction of the X axis of S2. We set up a transformation matrix A, whose first row is the vector U1. Similarly, let U2 and U3 be the unit vectors in S1 that specify the Y and Z axes of S2. Let the second row of A be U2 and the third row be U3. Then W = A V; that is, multiplying the matrix A times the vector V gives the new vector W, which is the representation of V in S2.

In addition, the inverse transformation, from S2 to S1, is given by the transpose of A; that is, the matrix whose first column is U1, second column U2, and third column U3. This is true whenever the unit vectors are orthogonal (perpendicular) to each other.

Suppose we have a third coordinate system, S3, and we have computed B, the transformation matrix from S2 to S3. Then the transformation matrix from S1 to S3 is just the matrix product B A, where A is as defined above. Note that matrix multiplication is not commutative; that is, B times A does not equal A times B. It is, however, associative; that is, (A B) C = A (B C).

## 3.0 TRAJECTORY TAPE PARAMETERS

In order to compute the transformation matrices described below, certain parameters from the Trajectory Tapes are required. These tapes were distributed by the Pioneer Project at Ames, and contain values computed by the JPL Navigation Group's program DPTRAJ. NSSDC has copies of these tapes and the documentation necessary to read them. The following parameters from the Trajectory Tape are needed:

| | |
|---|---|
| VIGDAT | Gregorian calendar date and time |
| JULDAT | Julian Date |
| ETMUTC | Ephemeris Time minus Universal Time |
| REARPR | Distance from Pioneer to Earth |
| XPGSFF,YPGSFF,ZPGSFF | XYZ components of Earth-to-Pioneer vector, referred to mean ecliptic of 1950.0 |
| CELLTP, CELLNP | Celestial latitude and longitude of Pioneer, referred to ecliptic of date |
| XP1SFF,YP1SFF,ZP1SFF | XYZ components of Body1-to-Pioneer vector, referred to mean ecliptic of 1950.0, where Body1 is either Jupiter or Saturn |
| B1LATP,B1LONP | Latitude and longitude of Pioneer in body-fixed coordinate system (Jupiter or Saturn) |

From the above Trajectory Tape parameters, the following angles are calculated: (units are degrees; the FORTRAN function ATAN2D(Y,X) returns the angle whose tangent is Y/X and which is in the correct quadrant for the signs of Y and X).

```
1.  WLTAE = AE system latitude of Pioneer-to-Earth vector
          = -ATAN2D(ZPGSFF, SQRT(XPGSFF**2+YPGSFF**2))

2.  WLNAE = AE system longitude of Pioneer-to-Earth vector
          = 180 + ATAN2D(YPGSFF,XPGSFF)

3.  SLTAE = AE system latitude of Pioneer-to-Sun vector
          = -CELLTP

4.  SLNAE = AE system longitude of Pioneer-to-Sun vector
          = CELLNP - 180

5.  RLTAE = AE system latitude of Jupiter(or Saturn)-to-Pioneer vector
          = ATAN2D(ZP1SFF, SQRT(XP1SFF**2+YP1SFF**2))

6.  RLNAE = AE system longitude of Jupiter(or Saturn)-to-Pioneer vector
          = ATAN2D(YP1SFF, XP1SFF)

7.  RLTJG = JG system latitude of Jupiter-to-Pioneer vector
          = B1LATP

8.  RLNJG = JG system longitude of Jupiter-to-Pioneer vector
          = AMOD(B1LONP + 7.35568*(JULDAT-2435839.5) + 70.78, 360.)

9.  RLTKG = KG system latitude of Saturn-to-Pioneer vector
          = B1LATP (from Trajectory Tapes generated after 1976)

10. RLNKG = KG system longitude of Saturn-to-Pioneer vector
          = B1LONP (from Trajectory Tapes generated after 1976)
```

## 4.1 AE (CELESTIAL) COORDINATE SYSTEM:

This is a heliocentric system whose plane of reference is the true ecliptic of date. It is defined by the vectors A and E: A lies in the ecliptic and points from the Sun toward the Vernal Equinox (first point in Aries); E is the northward perpendicular to the ecliptic. The X axis is along A; the Z axis is along E, and the Y axis completes the right-hand orthogonal system.

The AE system is used for many of the Trajectory Tape parameters. It is also used an an intermediate system when transforming from PE to other systems. (When using AE as an intermediate system, all the trajectory tape parameters used in computation should be referred to the same epoch, either the ecliptic of date or of 1950.0. Longitudes in AE increase at approximately .01396 deg per year, and latitudes change up to .00013 deg -- see The Astronomical Almanac, 1983, p. B19)

## 4.2 PE (PIONEER INERTIAL) COORDINATE SYSTEM:

This system is Pioneer-centered. It is defined by the vectors P and E: P is the direction of the Pioneer spin axis, which nominally points

from Pioneer to Earth; E is the northward perpendicular to the ecliptic, which is just (0,0,1) in AE coordinates. The Z axis is along P; in AE coordinates, it is given by the unit vector U3 = (COS(WLTAE)*COS(WLNAE), COS(WLTAE)*SIN(WLNAE), SIN(WLNAE)). The X axis is the normalized cross product E x U3 / |E x U3|; it is parallel to the ecliptic plane, and is given in the AE system by U1 = (-SIN(WLNAE), COS(WLNAE), 0). The Y axis completes the right-hand orthogonal system, and is given by the cross product U2 = U3 x U1. The transformation matrix from PE to AE is composed of the three column vectors U1, U2, and U3.

The PE system is the basic system for despun, reduced high resolution data. This system was used for Pioneer 11 reduced high resolution data and minute average tapes after 1976.

### 4.3 SH (SOLAR INTERPLANETARY) COORDINATE SYSTEM:

This is a Pioneer-centered system, also called RTN (Radial-Tangential-Normal), which is defined by the vectors S and H: S is the direction from Pioneer to the Sun; H is the rotation axis of the Sun. The X axis in AE coordinates is the unit vector U1 = -S = (-COS(SLTAE)*COS(SLNAE), -COS(SLTAE)*SIN(SLNAE), -SIN(SLTAE)). The Y axis is parallel to the Sun's equatorial plane, and is given by the normalized cross-product U2 = (H x U1) / |H x U1|, where H in AE is (COS(HLTAE)*COS(HLNAE), COS(HLTAE)*SIN(HLNAE), SIN(HLTAE)). HLTAE = 82.75 deg; HLNAE = -14.6304 + .0139583*(t-1972.0), where t = year (see American Ephemeris, 1976, page 556). The Z axis completes the right-hand orthogonal system and is given by U3 = U1 x U2. The transformation matrix from AE to SH is composed of the row vectors U1, U2, and U3.

The SH system was used for Pioneer 10 and early Pioneer 11 reduced high resolution data and minute average tapes. It is also the coordinate system of choice for long-term analyses of hour and day averages, since the ideal spiral angle of the interplanetary field lies in the XY plane of the SH system.

### 4.4 SJ (SOLAR JUPITER) COORDINATE SYSTEM:

This system is defined by the vectors S and J: S is the direction from Pioneer to the Sun; J is Jupiter's rotation axis (the value used for J in the 1973 and 1974 encounters was -.01448,-0.03482,0.99929). The X axis is given in AE by U1 = S = (COS(SLTAE)*COS(SLNAE), COS(SLTAE)*SIN(SLNAE), SIN(SLTAE)). The Y axis is parallel to Jupiter's equatorial plane, and is given by the normalized cross-product U2 = (J x U1) / |J x U1|. The Z axis completes the right-hand orthogonal system and is given by U3 = U1 x U2. The transformation matrix from AE to SJ is composed of the row vectors U1, U2, and U3.

The SJ system was used for the minute, hour, and day averages sent to NSSDC for the Pioneer 10 Jupiter encounter (1973, days 329-349), and the Pioneer 11 Jupiter encounter (1974, days 328-348).

### 4.5 RJ (PIONEER JUPITER) COORDINATE SYSTEM:

This is a Jupiter-centered coordinate system, defined by the vectors R and J. R is the direction from the center of Jupiter to Pioneer; J is the rotation axis of Jupiter as above in Section 4.4. The X axis is given

same order of magnitude, which often have opposite signs, and it is very easy to lose precision.

Time averaging and transforming to a new coordinate system are both linear operations, so their order may be interchanged, as long as the transformation matrix does not change significantly during the averaging interval. We routinely transform interplanetary hour averages from one coordinate system to another. However, in the case of the Jupiter and Saturn encounter data, when the trajectory parameters vary rapidly and nonlinearly with time, it would be best to apply the coordinate transformations to the 1-minute averages (at most, 5-minute), and then do any time averaging that is desired.

## 6.0 TRANSFORMATIONS OF AVERAGES OF PRODUCTS OF FIELD COMPONENTS

The minute, hour, and day average tapes submitted to the NSSDC also contain averages of the squares and cross-products of the magnetic field components, from which variances and covariances of the components can be computed. If it is desired to compute variances and covariances of the field components in a new coordinate system, the averages of the products of the field components can easily be transformed into the new coordinate system.

Suppose A is the computed transformation matrix, with elements A(i,j), where i and j go from 1 to 3. Let P(k,m) be the time-averaged product of the k-th and m-th components of the field vector in the old coordinate system, where k and m range from 1 to 3 and represent X, Y, and Z. For example, P(1,2) is the average of the product (Bx By) over the given time interval in the old coordinate system. Let Q(i,k) be defined similarly, but for the new coordinate system. Then Q(i,k) = A(i,j) A(k,m) P(j,m), summed over j and m, as in the following fragment of code:

```
          Q(I,K) = 0.
               DO J=1,3
                    DO M=1,3
                    Q(I,K) = Q(I,K) + A(I,J)*A(K,M)*P(J,M)
                    END DO
               END DO
```

## 7.0 REFERENCES


1. Pioneer F/G Trajectory Data User Requirements, Pioneer Document PC-262.04, Ames Research Center, Dec. 20, 1971.

2. Tape Format Description, DPTRAJ Satellite Ephemeris Trajectory Tape, Pioneer Document PC-262.06, Ames Research Center, March 10, 1976.

3. Smith, E. J., et al., The Planetary Magnetic Field and Magnetosphere of Jupiter: Pioneer 10. J. Geophys. Res., Vol. 79, p. 3501, 1974.

4. Smith, E. J., et al., Saturn's Magnetosphere and Its Interaction with the Solar Wind. J. Geophys. Res., Vol. 85, p. 5655, 1980.

system and is given by U1 x U2. The transformation matrix from RK to KG coordinates is composed of the column vectors U1, U2, and U3. (To transform to KG from other coordinate systems, first transform to AE, then to RK.)

The KG system was used in data analysis for the Pioneer 11 Saturn encounter. (Minute averages sent to the NSSDC were in the PE system, but a supplementary data set was also sent that included the parameters necessary to transform from PE to RK and KG.)

## 5.0 PROGRAMMING CONSIDERATIONS

The following outline may be helpful to anyone who needs to write a computer program to transform a set of Pioneer magnetometer data from one coordinate system into another.

1. Read N records, R(1) to R(N), from the Trajectory data set, which may be an actual Trajectory Tape, or a data set created from such a tape that contains only the parameters required for the coordinate transformation to be performed. N depends on the order of interpolation; if you are using linear interpolation, N = 2.

2. Assign times to these records, TIME(1) to TIME(N), converting the information in VIGDAT to whatever time units are convenient. For each time, subtract ETMUTC, the difference in seconds between Ephemeris Time and UTC, and if the magnetic field data is in Ground Received Time, add the one way light time delay, which is REARPR/299792.5 in seconds. (The minute, hour, and day average tapes submitted to NSSDC are in Ground Received Time.)

3. Read a magnetic field vector, and assign a time to it, BTIME, computed in the same units as TIME(1),...,TIME(N).

4. If BTIME > TIME(N), do the following:

   ```
           Do for I=2,N
           TIME(I-1) = TIME(I)
           R(I-1) = R(I)
           End do
       Read a record, R(N), from the Trajectory data set.
       Assign a time TIME(N) to this record as in Step 2.
   Repeat Step 4 until BTIME < TIME(N) or BTIME = TIME(N).
   ```

5. Calculate trajectory parameters corresponding to BTIME by interpolation, using the values in R(1) through R(N). Linear interpolation is usually sufficient for interplanetary data, but for the Jupiter and Saturn encounters, higher order interpolation is required. We used a second-order Aitken method.

6. Use the trajectory parameters for BTIME calculated in Step 5 to calculate the desired transformation matrix. Multiply this matrix times the magnetic field vector, and write or store the resulting transformed vector and its time tag.

7. Repeat Steps 3-6 for the remaining magnetic field vectors.

Be sure to use double precision (REAL*8) for all the transformation computations. Matrix multiplication involves adding a lot of terms of the