CINDI Ion Velocity Meter Data Submission

R.A. Heelis, W.R. Coley and R.A. Stoneback

University of Texas at Dallas

October 2017

***1. Background***

The IVM instrument that is part of the Coupled Ion Neutral Dynamics Investigation (CINDI) consists of a retarding potential analyzer (RPA) and an ion drift meter (IDM). Table 1 describes the geophysical parameters derived from each of these sensors.

|  |  |  |
| --- | --- | --- |
| Sensor | Parameter | Range |
| RPA | Total Ion Number Density | 103 to 5x106 cm-3 |
| RPA | Major Constituent Ion Fraction | 0.0 to 1.0 |
| RPA | Common Ion Temperature | 500° K to 12000° K |
| RPA | Along Track Ion Drift (ram) | -1500 m/s to 1500 m/s |
| RPA | Aperture Plane Potential wrt Plasma | 0.5 V to -1.5 V |
| IDM | Total Ion Number Density | 103 to 5x106 cm-3 |
| IDM | Cross Track Vertical Ion Drift | -1500 m/s to 1500 m/s |
| IDM | Cross Track Horizontal Ion Drift | -1500 m/s to 1500 m/s |

**Table 1. Originally Retrieved Geophysical Parameters from the IVM instrument**

The data files also contain the spacecraft position in geographic and geomagnetic coordinates as well as rotation matrices and geomagnetic field unit vectors that allow the original ion drift components to be cast in geographic and geomagnetic coordinates.

A complete description of the contents of a data file are described in the document attached as an appendix entitled

CINDI IVM Post-Processed HDF file record description v3.3.doc

***2. IVM Data Quality***

The performance of the IVM is affected by the ambient conditions and by the electrostatic environment of the satellite. Thus, each data entry is assigned a data quality flag for the parameters derived from the RPA and the IDM.

The first three years of the CINDI mission were conducted during a period of extremely low solar activity, where throughout the altitude range of the satellite significant concentrations of both O+ and H+ were present. In this environment the RPA can successfully retrieve the plasma temperature and major ion composition. However derivation of the ram ion drift (parallel to the satellite track) is only possible when the O+ concentration is above 1 x 104 cm-3. This produces substantial regions of the satellite orbit in which the ram ion drift must be set to zero in order to successfully retrieve the ion temperature and ion composition. *These data are flagged in the RPA quality flag and should not be used as measures of the ram ion drift.*

In addition the low signal level associated with low plasma density and high H+ concentrations prevent a sensible measure of the ion arrival angle from which the cross-track ion drift is derived. *These data are flagged in the IDM quality flag and should not be used without significant robustness checks and appropriate smoothing to remove the accompanying noise.*

Finally, the originally retrieved ion drifts are additionally subject to offsets due to biases produced by the electrical and mechanical environment of the spacecraft and contamination due to asymmetric photoemission currents within the instrument. The ion drifts are subjected to a first order correction to remove these effects prior to rotation into geomagnetic coordinates. *The native corrected drifts in spacecraft coordinates represent the most complete data available to the user.*

**2.1 Effects of Photoemission**

Photoemission currents from the collectors may produce asymmetries in the ion current that would otherwise be interpreted as ambient ion drifts. Attempts to correct and/or remove this signal from the IDM drifts have been undertaken leaving abrupt gaps in the early morning local time hours. Strong local time gradients may exist near the edges of these gaps that are indicative of an extension of the photoemission current correction that is improperly applied in the data. Care should be taken to insure that no such gradients are incorporated into any interpretation of the drift data in these local time regions.

**2.2 Effects of Magnetic Torquers**

Ion drift data have been removed for most instances when the magnetic torquers are active on the spacecraft. This data is flagged in the IDM quality flag but neighboring points, which may be effected by the recently active torquer, should be checked for deviations more than 20 m/s from the median value in the same neighborhood

**2.3 Rotation into Magnetic Coordinates**

Before rotation of the native ion drift measurements to magnetic coordinates each time series is reviewed for quality and a first order smoothing is applied in order to minimize the convolution of different uncertainties from measurements made by the RPA and the DM. The procedure described below produces reasonably robust representations of the large-scale drifts in the equatorial ionosphere. Irregularity drift motions in nighttime plasma structures will be revealed, but the magnitudes can be significantly suppressed by the data smoothing. It is recommended that the native vertical plasma drift be utilized in studies requiring more accurate representations of deviations from a mean value.

**2.3.1 Data Smoothing**

Remove contributions for which the ram drift is identically zero.

Remove flyers in all drift components using a 113-point (~15 minutes in local time) median to remove any point that is more than 25 m/s away from the median value

Suppress variations at scale sizes less than 30 km using a 5-point boxcar average.

The user should be aware that a rotation to magnetic coordinates is very sensitive to small uncertainties in the vehicle inertial attitude and the magnetic field direction. In the topside ionosphere at dip angles larger than 20°, large field-aligned diffusive flows may inject some apparent component perpendicular to the magnetic field due to such uncertainties. Thus, caution should be exercised when using derived perpendicular drifts at large dip angles. Return to the original measurements in spacecraft coordinates will reveal any systematic deviations on a pass by pass basis.

**2.4 Anomalous Vertical (meridional) Drifts**

Continuous corrections for the vehicle attitude are applied in the data processing, but their remain days when the post analysis of the vehicle attitude is suspect and may produce erroneous offsets in the vehicle pitch angle. These data may be easily identified by noting the daily average of the vertical plasma drift, which should yield a value that is less than 20 m/s. Specific days when small biases in the vertical drift exist and where the vertical ion drift should be used with caution are:

9/28/08 – 11/24/08

Spacecraft attitude reported by alternative star tracker. A nominal bias correction (30 m/s) has been removed from this data prior to rotation to magnetic coordinates. However, these measures of vertical ion drift should be viewed with caution.

2009-02-17

2009-04-01

2009-04-29

2009-06-24

2009-08-17

2010-01-02

2010-02-19

2010-07-10

2011-01-04

2011-01-10

2011-02-25

2011-04-04

2011-04-27

2011-06-17

2011-08-18

2011-08-24

2011-09-29

2012-04-12

2012-06-18

2012-11-03

2012-11-20

2014-03-31

2014-05-03

2014-07-08

2014-12-21

2015-01-02

2015-01-20

2015-05-24

2015-07-01

2015-08-05

2015-08-06

2015-08-11

2015-08-31 to 2015-09-02

2015-09-17 to 2015-09-19

2015-09-21 to 2015-09-22

2015-09-28 to 2015-09-30

2015-10-03 to 2015-10-04

2015-10-10 to 2015-10-11

Toward the end of the mission from 2015-10-01 onward, control of the spacecraft through perigee was increasingly compromised and the vehicle attitude information must be viewed with some caution. During this period the vertical plasma drift should be examined carefully and any discontinuities in the drift exceeding 20 m/s over a continuous UT period of 1 hour or more should be viewed with caution.

September 24, 2017

**CINDI IVM Post-Processed HDF Record Description**

**Version 3.4**

This is a description of the post-processed (CS) version of the CINDI HDF IVM files. A record is written for every RPA sweep (normally every 0.5 or 1.0 seconds). Drift meter data is averaged to the RPA cadence. There are 119 words in a record. The parameter descriptions below are taken from the FORTRAN and IDL routines that create the HDF file. The HDF file will contain a single data array dimensioned 119 by the # of RPA sweeps in the TM file processed. The exact dimensions of the data array in a file may be determined using the appropriate HDF call.

* Version 2.0 removes the quaternions and replaces them with Bg in the IVM spacecraft coordinates (and a spare word).
* Version 2.1 includes the angle between ram and the sun in word 99.
* Version 2.2 adds sc velocity in absolute and relative coordinates.
* Version 3.0 adds 13 words to the data record that include Russell Stoneback’s drift offset corrections (where available), photoemission correction, conversion of drifts to magnetic coordinates, and a flag that indicates if the offset corrections have been performed or not.
* Version 3.1 adds the unit vectors of the magnetic coordinates axes in spacecraft coordinates.
* Version 3.2 corrects minor errors in the descriptions and adds clarification to certain parameters.
* Version 3.3 makes changes corresponding to Russell Stoneback’s reprocessing of the drift-offset corrections following the receipt of improved spacecraft attitude information. The number of words has been reduced to 122.
* Version 3.4 makes the record list more readable for archival purposes. The first column contains the word number within a given record. The second column(when present)contains the variable name in the original FORTRAN program. The final column contains a description of the word.

The post-processing is a two-stage process. The first 106 words are written by the FORTRAN routine (first stage), with the exception that the corrected ion velocities are inserted in words 62, 64, and 66 by the IDL routine (second stage). The XYZ coordinate system used is the spacecraft coordinate system (x positive ram, z positive nadir, y positive to right of s/c track). The coordinate rotation matrices are double precision and must be formed by equivalencing the two consecutive single precision words indicated. Absolute velocities are relative to ECI and relative velocities are relative to co-rotating atmosphere. The ion velocities in words 120-122 have not been corrected for attitude and/or photoemission problems and are included for archival completeness.

-----------------------------------------------------------------------

**RECORD VARIABLE PARAMETER DESCRIPTION**

**WORD # NAME**

Word(1) = idatec !date (YYYYDDD)

Word(2) = itimec !time (ms)

Word(3) = coadata(7) !geographic latitude

Word(4) = coadata(8) !geographic longitude

Word(5) = coadata(9) !altitude (km)

Word(6) = coadata(1) !spacecraft X Position (ECI)

Word(7) = coadata(2) !spacecraft Y Position (ECI)

Word(8) = coadata(3) !spacecraft Z Position (ECI)

Word(9) = coadata(4) !spacecraft X Velocity (ECI)

Word(10) = coadata(5) !spacecraft Y Velocity (ECI)

Word(11) = coadata(6) !spacecraft Z Velocity (ECI)

Word(12) = coadata(22) !Solar Zenith Angle (degree)

Word(13) = coadata(23) !Solar Local Time (hour)

Word(14) = coadata(31) !Apex Altitude

Word(15) = coadata(29) !Apex Latitude

Word(16) = coadata(30) !Apex Longitude

Word(17) = coadata(25) !Invariant Latitude

Word(18) = coadata(26) !Magnetic Inclination

Word(19) = coadata(27) !Corrected Magnetic Latitude

Word(20) = coadata(24) !Magnetic Local Time (hour)

Word(21) = coadata(10) !IGRF geomagnetic field North

Word(22) = coadata(11) !IGRF geomagnetic field East

Word(23) = coadata(12) !IGRF geomagnetic field Down

Word(24) = rrec(1) !ECI/SC Matrix 11 Double Precision

Word(25) = rrec(2) !ECI/SC Matrix 11 Double Precision

Word(26) = rrec(3) !ECI/SC Matrix 12 Double Precision

Word(27) = rrec(4) !ECI/SC Matrix 12 Double Precision

Word(28) = rrec(5) !ECI/SC Matrix 13 Double Precision

Word(29) = rrec(6) !ECI/SC Matrix 13 Double Precision

Word(30) = rrec(7) !ECI/SC Matrix 21 Double Precision

Word(31) = rrec(8) !ECI/SC Matrix 21 Double Precision

Word(32) = rrec(9) !ECI/SC Matrix 22 Double Precision

Word(33) = rrec(10) !ECI/SC Matrix 22 Double Precision

Word(34) = rrec(11) !ECI/SC Matrix 23 Double Precision

Word(35) = rrec(12) !ECI/SC Matrix 23 Double Precision

Word(36) = rrec(13) !ECI/SC Matrix 31 Double Precision

Word(37) = rrec(14) !ECI/SC Matrix 31 Double Precision

Word(38) = rrec(15) !ECI/SC Matrix 32 Double Precision

Word(39) = rrec(16) !ECI/SC Matrix 32 Double Precision

Word(40) = rrec(17) !ECI/SC Matrix 33 Double Precision

Word(41) = rrec(18) !ECI/SC Matrix 33 Double Precision

Word(42) = rrec(19) !LVLH/SC Matrix 11 Double Precision

Word(43) = rrec(20) !LVLH/SC Matrix 11 Double Precision

Word(44) = rrec(21) !LVLH/SC Matrix 12 Double Precision

Word(45) = rrec(22) !LVLH/SC Matrix 12 Double Precision

Word(46) = rrec(23) !LVLH/SC Matrix 13 Double Precision

Word(47) = rrec(24) !LVLH/SC Matrix 13 Double Precision

Word(48) = rrec(25) !LVLH/SC Matrix 21 Double Precision

Word(49) = rrec(26) !LVLH/SC Matrix 21 Double Precision

Word(50) = rrec(27) !LVLH/SC Matrix 22 Double Precision

Word(51) = rrec(28) !LVLH/SC Matrix 22 Double Precision

Word(52) = rrec(29) !LVLH/SC Matrix 23 Double Precision

Word(53) = rrec(30) !LVLH/SC Matrix 23 Double Precision

Word(54) = rrec(31) !LVLH/SC Matrix 31 Double Precision

Word(55) = rrec(32) !LVLH/SC Matrix 31 Double Precision

Word(56) = rrec(33) !LVLH/SC Matrix 32 Double Precision

Word(57) = rrec(34) !LVLH/SC Matrix 32 Double Precision

Word(58) = rrec(35) !LVLH/SC Matrix 33 Double Precision

Word(59) = rrec(36) !LVLH/SC Matrix 33 Double Precision

Word(60) = iquality(i) !RPA data quality flag

 (see description document)

Word(61) = iqualdm(i) !drift meter data quality flag for

 Vh and Vv

Word(62) = vx(i) !x-axis (ram)smoothed ion velocity,

 s/c coordinates (offset and photoemission corrected, if possible. Check flag: word 107)

Word(63) = vxsig(i) !Vx variance

Word(64) = vh(i) !y-axis (horizontal)smoothed ion velocity,

(s/c) coordinates (offset and photoemission corrected, if possible. Check flag: word 107)

Word(65) = vhsig(i) !Vh variance

Word(66) = vv(i) !z-axis (vertical)smoothed ion velocity,

(s/c)coordinates(offset and photoemission corrected, if possible. Check flag: word 107)

Word(67) = vvsig(i) !Vv variance

Word(68) = deni(i) !ion density (cm-3)

Word(69) = denisig(i) !ion density variance

Word(70) = ti(i) !ion temperature (K)

Word(71) = tisig(i) !Ti variance

Word(72) = massid(1) !atomic mass no. for ion #1 (normally H+)

Word(73) = rmassfrac(1) !fraction for ion #1

Word(74) = rmasssig(1) !fraction variance for ion #1

Word(75) = massid(2) !atomic mass no. for ion #2 (normally He+)

Word(76) = rmassfrac(2) !fraction for ion #2

Word(77) = rmasssig(2) !fraction variance

Word(78) = massid(3) !atomic mass no. for ion #3 (normally O+)

Word(79) = rmassfrac(3) !fraction for ion #3

Word(80) = rmasssig(3) !variance for ion #3

Word(81) = massid(4) !atomic mass no. for ion #4

Word(82) = rmassfrac(4) !fraction for ion #4

Word(83) = rmasssig(4) !fraction variance for ion #4

Word(84) = massid(5) !atomic mass no. for ion #5

Word(85) = rmassfrac(5) !fraction for ion #5

Word(86) = rmasssig(5) !fraction variance for ion #5

Word(87) = pot(i) !sensor plane potential (V)

Word(88) = potsig(i) !sensor plane potential variance

Word(89) = iqualdena(i) !dm a density data quality

Word(90) = dena(i) !dm a density

Word(91) = denasig(i) !dm a density variance

Word(92) = iqualdenb(i) !dm b density data quality

Word(93) = denb(i) !dm b density

Word(94) = denbsig(i) !dm b density variance

Word(95) = coadata(32) !Orbit Number

Word(96) = coadata(13)\*doadata(19)+

 coadata(14)\*doadata(22)+

 coadata(15)\*doadata(25) !Bgx in IVM coordinates.

Word(97) = -(coadata(13)\*doadata(20)+

 coadata(14)\*doadata(23)+

 coadata(15)\*doadata(26)) !Bgy in IVM coordinates.

Word(98) = -(coadata(13)\*doadata(21)+

 coadata(14)\*doadata(24)+

 coadata(15)\*doadata(27)) !Bgz in IVM coordinates.

Word(99) = coadata(40) !angle between ram and sun.

Word(100) = zni(i) !Ni from 0V RPA point (cm-3)

Word(101) = svelxsc !sc absolute velocity in sc coordinates

Word(102) = svelysc !sc absolute velocity in sc coordinates

Word(103) = svelzsc !sc absolute velocity in sc coordinates

Word(104) = rvelxsc !sc relative velocity in sc coordinates

Word(105) = rvelysc !sc relative velocity in sc coordinates

Word(106) = rvelzsc !sc relative velocity in sc coordinates

**The following ion parameters describe the ion drift rotation into magnetic coordinates**

Word(107) = offset\_flag ; f.nn f= 1 if offset corrected

 data is available, nn = # of dm points

 averaged for cross-track velocities.

Word(108) = zonal unit vector along s/c x-axis

Word(109) = zonal unit vector along s/c y-axis

Word(110) = zonal unit vector along s/c z-axis

Word(111) = parallel unit vector along s/c x-axis

Word(112) = parallel unit vector along s/c y-axis

Word(113) = parallel unit vector along s/c z-axis

Word(114) = meridional unit vector along s/c x-axis

Word(115) = meridional unit vector along s/c y-axis

Word(116) = meridional unit vector along s/c z-axis

Word(117) = ion velocity zonal (m/s, magnetic coordinates)

Word(118) = ion velocity parallel (m/s magnetic coordinates)

Word(119) = ion velocity meridional (m/s mag. coordinates)

Word(120) = vx(\*) ! Vx original uncorrected (m/s)

Word(121) = vy(\*) ! Vy original uncorrected (m/s)

Word(122) = vz(\*) ! Vz original uncorrected (m/s)

**CINDI IVM QUALITY FLAG DESCRIPTION**

**VERSION 2.1, October 10, 2017**

After the main CINDI IVM production program has been run UTD applies a quality control algorithm. The following description details the processes. **It is important to use these quality flags to ensure that only good quality data (quality flag ≤ 4) is used in any subsequent scientific analysis.**

**QUALITY CONTROL**

During the regular data processing each record of data from the retarding potential analyzer (RPA) and ion drift meter (DM) are separately given preliminary numerical quality flags in the range of 0-9 with 0 indicating the best quality data, 3 indicating “use with caution”, 5 indicating “undetermined”, 6 indicating torque flag (DM only), 8 TM limits flag (DM only), and 9 indicating “poor quality data, do not use”. Subsequently, the values of these quality flags may be adjusted by a post-processing quality control algorithm in order to further check and classify the geophysical parameters. Also, poor quality data or non-geophysically valid values of a parameter may be set to 0 or to fill data (-999999.). A description of the final RPA and DM flags follows:

**RPA Quality Flag**

 0. High quality data.

1. High quality data except for the ram velocity Vx and the spacecraft sensor plane potential. These two values are suspect and should be used with caution.
2. Not used.
3. Good quality data. The RMS fitting error is large and/or |Vx|>1000 m/s. The data may have more noise than quality flag = 0 data. Use Vx with caution.
4. Good quality data. The RMS fitting error may be large, leading to greater noise levels. The ram velocity Vx and the spacecraft sensor plane potential values are suspect and should not be used.
5. Undetermined. This value will only be seen if the quality control algorithm has failed.
6. Not used.
7. Ion temperature, composition, velocity, or density values are out of acceptable range and are untrustworthy. Data values have been set to fill data.
8. Not used.
9. Poor quality data. Do not use.

**DM Quality Flag**

 0. High quality data.

1. Not used.
2. Not used.
3. Good quality data.
4. Not used.
5. The angle between the ram direction and the sun is between 35° and 48° indicating possible sun glint into the instrument. Use data with caution.
6. Indicates Torquer Rod flag is set indicating that the torquer rods are firing within about 10 seconds of this time. Current and nearby drift data are suspect.
7. |Vy| > 1000 or |Vz| > 600 or DM ion density < 1000. As a result, the following geophysical quantities have been set to fill data: Vy, Vy variance, Vz, Vz variance, DM density, and DM density variance.
8. DM telemetry word has hit the positive or negative limit. The data is bad.
9. Poor quality data. Do not use.