Magnetospheric Multiscale (MMS) Mission
CDF File Format Guide

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Introduction

1.1 Purpose and Scope

This document is provided as a reference for construction of MMS standard CDF files. It is intended to complement information available from the Space Physics Data Facility (listed in Sec. 1.2). It lays down REQUIREMENTS and RECOMMENDATIONS for Level 2 (and above) CDF files that are intended for public access, and should be taken as RECOMMENDATIONs for all other mission CDFs.

This document is based on discussions within the MMS Science Data Working Group (SDWG) and subsequently the Data Systems Working Group (DSWG) and personnel at NASA's Space Physics Data Facility (SPDF). It is intended to provide sufficient reference material to understand the CDF skeleton files and the requirements for creating MMS CDF files, and to understand the structure and contents of the resulting CDF files.

1.2 References

Relevant documents that provide background material and support details provided in this guide are listed below:

Title	Identifier
CDF User's Guide	Available from http://cdf.gsfc.nasa.gov/
SPDF CDF Guidelines	http://spdf.gsfc.nasa.gov/sp_use_of_cdf.html
SKTEditor	http://sscweb.gsfc.nasa.gov/skteditor/
ISTP Guidelines	http://spdf.gsfc.nasa.gov/istp_guide/istp_guide.html
SODAWG Units of Measure	https://lasp.colorado.edu/galaxy/display/mms/Units+of+Measure
MMS Science Data Products Guide	TBS

2. MMS Science Investigations

The SMART (Solving Magnetospheric Acceleration, Reconnection and Turbulence) Instrument Suite will make high-time resolution measurements of plasmas, electric fields and magnetic fields and provide supporting measurements of energetic particles and ion composition. The SMART Instrument Suite consists of the following complement of instruments:

- **The FIELDS investigation** includes a sensor suite consisting of axial and spin-plane double-probe electric-field sensors (ADP and SDP), two flux-gate magnetometers (AFG and DFG), a search-coil magnetometer (SCM), and an electron drift instrument (EDI). These instruments measure DC magnetic field with a resolution of 10 ms, DC electric field with a resolution of 1 ms, electric plasma waves to 100 kHz, and magnetic plasma waves to 6 kHz.
- **The Energetic Particle Detector (EPD)** includes an Energetic Ion Spectrometer (EIS) and an all-sky particle sampler called the Fly's Eye Energetic Particle Sensor (FEEPS). These instruments measure the energy-angle distribution and composition of ions (20 to 500 keV) at a time resolution of < 30 seconds, the energy-angle distribution of total ions (45 – 500 keV) at a time resolution of < 10 seconds, and the coarse and fine energy-angle distribution of energetic electrons (25 – 500 keV) at time resolutions of < 0.5 and < 10 seconds, respectively.
- **The Fast Plasma Instrument (FPI)** includes four dual electron spectrometers (DES) and four dual ion spectrometers (DIS). These instruments measure the velocity-space distribution of electrons from 10 eV to 30 keV and ions from 10 eV to 30 keV with time resolution of 30 ms, and 150 ms, respectively
- **The Hot Plasma Composition Analyzer (HPCA)** measures the composition-resolved velocity-space distribution of ions from 1 eV to 40 keV with time resolution of 10 – 15 seconds.
- **The Active Spacecraft Potential Control (ASPOC)** generates beams of indium ions to limit positive spacecraft potentials to +4V in order to improve the measurements obtained by FPI, HPCA, ADP, and SDP.

MMS-SMART Instrument Team Facilities (ITFs) are the principal institutions associated with each of the MMS-SMART science investigations. These facilities and their personnel provide support to the operation of their instruments and the overall data processing and distribution effort for MMS science data products. The institutions listed below have responsibility for each of the SMART investigations and their corresponding instruments:

MMS Investigation	Managing Institution	Principal Investigator
Fast Plasma Instrument (FPI)	Goddard Space Flight Center (GSFC)	C. Pollock
Hot Plasma Composition Analyzer (HPCA)	Southwest Research Institute (SwRI)	S. Fuselier
FIELDS	University of New Hampshire (UNH)	R. Torbert
Energetic Particle Detector System (EPD)	Johns Hopkins University (JHU) Applied Physics Laboratory (APL)	B. Mauk
Active Spacecraft Potential Control (ASPOC)	Space Research Institute of the Austrian Academy of Sciences	K. Torkar

Additionally, the Principal Investigator for the complete SMART Instrument Suite is J. Burch from the Southwest Research Institute (SWRI).

3. Conventions

All MMS scientific data products that will be shared between MMS entities (e.g. ITFs, IDS groups) or made available to the general research community will be stored as CDF data files and are expected to be compatible with CDF version 3.5. Data that will not be shared beyond an individual team may be stored in any format that is convenient for that team. Additionally, all MMS data files will be written using CDF's internal MD5 checksum. If using CDF software from the SPDF, this checksum is turned on by default.

3.1 Science Product Naming Conventions

CDF data files have names of the following form:

scId_instrumentId_mode_dataLevel_optionalDataProductDescriptor_startTime_vX.Y.Z.cdf

where…

- scId: "mms1", "mms2", "mms3", or "mms4"
- instrumentId: instrument or investigation identifier depending on product. The following are valid MMS values:
  - adp
  - afg
  - afg-dfg
  - asp1
  - asp2
  - aspoc
  - att-def
  - des
  - des-dis
  - dfg
  - dis
  - dsp
  - edi
  - edp
  - epd
  - epd-eis
  - epd-feeps
  - eph-def
  - fields
  - fgm
  - fpi
  - hpca
  - mec
  - scm
  - sdp
- mode: "fast", "slow", "brst", "srvy"
- dataLevel: "l1a", "l1b", "l2", "ql", "l2pre", l2plus, “sitl”

- optionalDataProductDescriptor: optional field that may not be needed for all products. Where it is used, identifiers should be short (e.g. 3-8 character) descriptors that are helpful to end-users. If a descriptor contains multiple components, hyphens are used to separate those components. For instance, an optional time span may be specified as "-2s" to represent a data file that spans two seconds. In this case, "10s" and "-5m" are other expected values that correspond with ten seconds and 5 minutes respectively.
- startTime: yyyymmddhhmmss. Irrelevant, least significant, fields can be dropped when files start on regular hourly or minute boundaries.
- vX.Y.Z: 3-part version number as described below. Note that the initial value is "v0.0.0" and each component is incremented in integer steps, as needed.
    - X is the interface number. Increments in this number represent a significant change to the processing software and/or to the contents of the file. These changes will likely break existing code that expects a specific file format (e.g. file reading software). Additionally, increments in this number may require code changes to analysis software that expects the data to have been created using specific processing algorithms. The user should consult the appropriate meta-data for or changelogs.
    - Y is the quality number. This number represents a change in the quality of the data in the file, such as change in calibration or increase in fidelity. Changes should not impact software, but may require consideration when processing data.
    - Z is the bug fix/revision number. This number changes to indicate minor changes to the contents of the file due to reprocessing of missing data. Any dependent data products should generally be reprocessed if this value changes.
- .cdf: file extension

Additionally, to ensure software compatibility between disparate systems, filenames will consist of all lowercase characters. Filenames are used as a system identifier for a logical grouping of data and are also stored in the Logical_file_id global attribute field (see Section 4.1.7). Note that it is expected that filenames will be created dynamically from the attributes identified in Section 4 of this document.

4. Global Attributes

Global attributes are used to provide information about the data set as an entity. Together with variables and variable attributes, the global attributes make the data correctly and independently usable by someone not connected with the instrument team, and hence, a good archive product.

Global attributes that have been identified for use with MMS data products are listed below. Additional Global attributes can be defined but they must start with a letter and can otherwise contain letters, numbers and the underscore character (no other special characters allowed). Note that CDF attributes are case-sensitive and must exactly follow what is shown here.

Detailed descriptions of the attributes listed below are available at the ISTP/IACG Global Attributes webpage: http://spdf.gsfc.nasa.gov/istp_guide/gattributes.html.

4.1 Required

The following global attributes are required with MMS data products. MMS-specific values are provided where applicable.

4.1.1 Data_type

This attribute is used by CDF file writing software to create a filename. It is a combination of the following filename components: mode, data level, and optional data product descriptor, as described in Section 3.1.

4.1.2 Data_version

This attribute identifies the version (vX.Y.Z) of a particular CDF data file as described in Section 3.1.

4.1.3 Descriptor

This attribute identifies the name of the instrument or sensor that collected the data. Both a long name and a short name are given. For any data file, only a single value is allowed. For MMS, the following are valid values:

FIELDS>Electric and Magnetic Fields Investigation
ADP>Axial Double Probe
SDP>Spin-plane Double Probe
EDP->Electric Double Probe
AFG>Analog Flux Gate Magnetometer
DFG>Digital Flux Gate Magnetometer
AFG-DFG
AFG-DFG-SCM
SCM>Search Coil Magnetometer
EDI>Electron Drift Instrument

FPI>Fast Plasma Instrument
DIS>Dual Ion Spectrometers
DES>Dual Electron Spectrometers

HPCA> Hot Plasma Composition Analyzer

EPD>Energetic Particle Detector
EIS>Energetic Ion Spectrometer
FEEPS>Fly's Eye Energetic Particle Sensor
EIS-FEEPS

ASP1>Active Spacecraft Potential Control - sensor 1
ASP2>Active Spacecraft Potential Control - sensor 2
ASP>Active Spacecraft Potential Control – sensors 1 and 2

EPH>Ephemeris
ATT>Attitude

MEC>Magnetic Ephemeris and Coordinates

4.1.4 Discipline

This attribute describes both the science discipline and sub discipline. For MMS, this value should always be "Space Physics>Magnetospheric Science."

4.1.5 Generation_date

Date stamps the creation of the file using the syntax yyyymmdd, e.g., "20150923". This is distinct from the date in "validate" below which records the times of later validation processes.

4.1.6 Instrument_type

This attribute is used to facilitate making choices of instrument type. More than one entry is allowed. Valid values for MMS include:

- Electric Fields (space)
- Magnetic Fields (space)
- Particles (space)
- Plasma and Solar Wind
- Spacecraft Potential Control
- Ephemeris

4.1.7 Logical_file_id

This attribute stores the name of the CDF file as described in Section 3.1 but without the file extension (e.g. ".cdf"). This attribute is required to avoid loss of the original source in the case of accidental (or intentional) renaming. This attribute must be manually set by the user during creation.

4.1.8 Logical_source

This attribute determines the file naming convention in the SKT Editor and is used by CDA Web. It is composed of the following values:

- source_name - (e.g. spacecraft identifier - see Section 4.1.14)
- descriptor - (e.g. instrument identifier - see Section 4.1.3)

- data_type - (e.g. mode, data level, and optional data product descriptor - value come from attribute in Section 4.1.1, which is described in Section 3.1)

For instance, the following examples are valid "Logical_source" attributes:

mms1_edi_slow_ql_ambient
mms2_edi_brst_l2_ambient
mms3_edi_fast_l2_efield
mms4_dsp_slow_ql_lfe
mms1_dsp_fast_ql_mfe
mms2_dsp_slow_ql_lfb
mms3_sdp_fast_ql_swd
mms4_brst_l2_efield
mms1_brst_l2_bfield
mms1_fpi_fast_sitl_1h
mms1_des_slow_l1A_cnts-1h
mms1_dis_slow_l1A_cnts-1h

4.1.9 Logical_source_description

This attribute writes out the full words associated with the encrypted Logical_source above, e.g., "Level 1 Dual Electron Spectrometer Survey Data". Users on CDAWeb see this value on their website.

4.1.10 Mission_group

This attribute has a single value and is used to facilitate making choices of source through CDAWeb. This value should be “MMS.”

4.1.11 PI_affiliation

This attribute value should include the MMS mission PI affiliation followed by a comma-separated list of any Co-I affiliations that are responsible for this particular dataset. The following are valid MMS values, of which the abbreviations should be used exclusively within this attribute value, and the full text of the affiliation included in the general text attribute (4.1.15) as it is used solely in plot labels.

JHU/APL – Applied Physics Laboratory
GSFC – Goddard Space Flight Center
IRFU - Institutet för rymdfysik, Uppsala
IWF - Institut für Weltraumforschung
KTH - Kungliga Tekniska Högskolan (Swedish Royal Institute of Technology)
LANL - Los Alamos National Laboratory
LASP - Laboratory for Atmospheric and Space Physics
LPP - Laboratoire de Physique des Plasmas
SWRI – Southwest Research Institute
UCLA - University of California Los Angeles
UNH – University of New Hampshire

4.1.12 PI_name

This attribute value should include first initial and last name of the MMS mission PI followed by a comma-separated list of any Co-Is that are responsible for this particular dataset. For example, a single PI entry in this attribute would be: J. Burch. The attribute inclusive of Co-Is would be: J. Burch, C. Pollock, S. Fuselier, R. Torbert, B. Mauk, K.Torkar.

4.1.13 Project

This attribute identifies the name of the project and indicates ownership. For MMS, this value should be “STP>Solar-Terrestrial Physics”.

4.1.14 Source_name

This attribute identifies the observatory where the data originated. The following are valid values for MMS:

- MMS1>MMS Satellite Number 1
- MMS2>MMS Satellite Number 2
- MMS3>MMS Satellite Number 3
- MMS4>MMS Satellite Number 4
- MMS>MMS Constellation

4.1.15 TEXT

This attribute is an SPDF standard global attribute, which is a text description of the experiment whose data is included in the CDF. A reference to a journal article(s) or to a World Wide Web page describing the experiment is essential, and constitutes the minimum requirement. A written description of the data set is also desirable. This attribute can have as many entries as necessary to contain the desired information. Typically, this attribute is about a paragraph in length and is not shown on CDAWeb.

4.1.16 HTTP_LINK

This attribute stores the URL for with a description of this dataset at the SDC. This attribute is used in conjunction with "LINK_TEXT" and "LINK_TITLE". There can be up to 5 entries for each - there MUST be a corresponding entry of "LINK_TEXT" and "LINK_TITLE" for each "HTTP_LINK" entry. CDAWeb will then link to the URL given by "HTTP_LINK" using the "LINK_TITLE" and the description in "LINK_TEXT", on the CDAWeb Data Explorer page. For example:

- "LINK_TEXT" = 5-minute dual electron fast spectrometer data starting at 1 Feb 2015 13:15 available at
- "LINK_TITLE" = MMS1 DES
- "HTTP_LINK" = http://lasp.colorado.edu/mms1/des/fast/l2/

will create the following link:

5-minute dual electron fast spectrometer data starting at 1 Feb 2015 13:15 available at MMS1 DES

Multiple HTTP_LINK (as well as LINK_TEXT and LINK_TITLE) attributes may be included. It is suggested that each data set includes links to the MMS project web page, the relevant instrument page, and finally the web-services link to the data product itself. Thus the HTTP_LINK, LINK_TEXT, and LINK_TITLE attributes would read as follows:

"HTTP_LINK"	1: CDF_CHAR	{" http://mms.gsfc.nasa.gov/"}
	2: CDF_CHAR	{" http://mms.space.swri.edu/index.html"}
	3: CDF_CHAR	{" https://lasp.colorado.edu/mms/sdc/" }
"LINK_TEXT"	1: CDF_CHAR	{"MMS home page"}
	2: CDF_CHAR	{"SMART package home page"}
	3: CDF_CHAR	{"Science Data Center"}
"LINK_TITLE"	1: CDF_CHAR	{"At GSFC"}
	2: CDF_CHAR	{"AT SWRI"}
	3: CDF_CHAR	{"LASP SDC"}

4.1.17 LINK_TEXT

Usage described in Section 4.1.16. If text is not needed, use: ""

4.1.18 LINK_TITLE

Usage described in Section 4.1.16.

4.1.19 MODS

This attribute is an SPDF standard global attribute, which is used to denote the history of modifications made to the CDF data set. The MODS attribute should contain a description of all significant changes to the data set, essentially capturing a log of high-level release notes. This attribute can have as many entries as necessary and should be updated if the "X" value of the version number changes.

4.2 Recommended

The following global attributes are recommended but not required with MMS data products. MMS-specific values are provided where applicable.

4.2.1 Acknowledgement

This field indicates how the data should be cited.

4.2.2 Generated_by

This attribute indicates where users can get more information about this data and/or check for new versions.

4.3 Optional

4.3.1 Parents

This attribute lists the parent data files for files of derived and merged data sets. The syntax for a CDF parent is: "CDF>logical_file_id". Multiple entry values are used for multiple parents. This attribute is required for any MMS data products that are derived from 2 or more data sources and the file names of parent data should be clearly identified. CDF parents may include source files with non-cdf extensions.

4.3.2 Skeleton_version

This is a text attribute containing the skeleton file version number.

4.3.3 Rules_of_use

Text containing information on citability and/or PI access restrictions. This may point to a World Wide Web page specifying the rules of use. Rules of Use are determined on both a mission and instrument basis, at the discretion of the PI.

4.3.4 Time_resolution

Specifies time resolution of the file, e.g., "3 seconds".

5. Variables

There are three types of variables that should be included in CDF files: data, support data, and metadata. Additionally, required attributes are listed with each variable type listed below.

To facilitate data exchange and software development, variable names should be consistent across the MMS instruments and four spacecraft. Additionally, it is preferable that data types are consistent throughout all MMS data products (e.g. all real variables are CDF_REAL4, all integer variables are CDF_INT2, and flag/status variables are UINT2). This is not to imply that only these data types are allowable within MMS CDF files. All CDF supported data types are available for use by MMS.

For detailed information and examples, please see the following ISTP/IACG webpage: http://spdf.gsfc.nasa.gov/istp_guide/variables.html

5.1 Data

These are variables of primary importance (e.g., density, magnetic field, particle flux). Data is always time (record) varying, but can be of any dimensionality or CDF supported data type. Real or Integer data are always defined as having one element.

5.1.1 Naming

MMS data variables must adhere to the following naming convention

scId_instrumentId_paramName

An underscore is used to separate different fields in the variable name. It is strongly recommended that variable names employ further fields, qualifiers and information designed to identify unambiguously the nature of the variable, instrument mode and data processing level, with sufficient detail to lead the user to the unique source file which contains the variable. It is recommended that these follow the order shown below.

scId_instrumentId_paramName[_coordSys][_paramQualifier][_subModeLevel][_mode][_dataLevel]

where…

REQUIRED FIELDS

scId	See section 3.1
instrumentId	See section 3.1 and caveat below
paramName	data parameter identifier, a short (a few letters) representation of the physical parameter held in the variable

OPTIONAL FIELDS

coordSys	an acronym for the coordinate system in which the parameter is cast
paramQualifier	parameter descriptor, which may include multiple components separated by a "_" as needed (e.g. "pa_0" indicates a pitch angle of 0)
subModeLevel	Qualifier(s) to include mode and data level information supplementary to the following two fields
mode	See section 3.1
dataLevel	See section 3.1

For example: mms2_afg_b_gse_brst_l2

Note the following caveats:

- CDF variable names must begin with a letter and can contain numbers and underscores, but no other special characters.
- In general, the instrumentId field follows the convention used for file names as defined in Section 3.1. However, since variable names cannot contain a hyphen, an underscore should be used instead of a hyphen when needing to separate

instrument components. For instance, "afg-dfg" is a valid instrumentId in a filename but when used in a variable name, "afg_dfg" should be used instead.

- To ensure software compatibility between disparate systems, parameter names will consist of all lowercase characters.

5.1.2 Required Epoch Variable

All MMS CDF data files must contain at least one variable of data type CDF_TIME_TT2000, typically named "Epoch". This variable should normally be the first variable in each CDF data set. All time varying variables in the CDF data set will depend on either this "Epoch" variable or on another variable of type CDF_TIME_TT2000 (e.g. mms1_afg_epoch). More than one CDF_TIME_TT2000 type variable is allowed in a data set to allow for more than one time resolution, using the required DEPEND_0 attribute (5.1.3.2) to associate a time variable to a given data variable. It is recommended that all such time variables use “epoch” within their variable name.

For ISTP, but not necessarily for all MMS data, the time value of a record refers to the center of the accumulation period for the record if the measurement is not an instantaneous one. All MMS time variables used as DEPEND_0 are strongly recommended to have DELTA_PLUS_VAR and DELTA_MINUS_VAR attributes (see section 5.1.4.3 below) which delineate the time interval over which the data was sampled, integrated, or otherwise representative of. This also locates the timetag within that interval.

The datatype, CDF_TIME_TT2000, is defined as an 8-byte signed integer with the following characteristics:

Time_Base=J2000 (Julian date 2451545.0 TT or 2000 January 1, 12h TT)
Resolution=nanoseconds
Time_Scale=Terrestrial Time (TT)
Units=nanoseconds
Reference_Position=rotating Earth Geoid

Given a current list of leap seconds, conversion between TT and UTC is straightforward (TT = TAI + 32.184s; TT = UTC + deltaAT + 32.184s, where deltaAT is the sum of the leap seconds since 1960; for example, for 2009, deltaAT = 34s). Pad values of -9223372036854775808 (0x8000000000000000) which corresponds to 1707-09-22T12:13:15.145224192; recommended FILLVAL is same.

It is proposed that the required data variables VALIDMIN and VALIDMAX (5.1.3.14 and 5.1.3.15, respectively) are given values corresponding to the dates 1990-01-01T00:00:00 and 2100-01-01T00:00:00 as these are well outside any expected valid times.

5.1.3 Attributes: Data Variables

Data variables require the following attributes – see sections 5.1.3.1-5.1.3.16 for individual descriptions and usage:

- CATDESC
- DEPEND_0
- DEPEND_i [for dimensional data variables]
- DISPLAY_TYPE
- FIELDNAM
- FILLVAL
- FORMAT or FORM_PTR
- LABLAXIS or LABL_PTR_i
- SI_CONVERSION
- UNITS or UNIT_PTR
- VALIDMIN and VALIDMAX
- VAR_TYPE

In addition, the following attributes are strongly recommended for vectors, tensors and quaternions which are held in or relate to a particular coordinate system (see sections 5.1.3.17-5.1.3.20):

- COORDINATE_SYSTEM
- TENSOR_ORDER
- REPRESENTATION_i
- OPERATOR_TYPE [for quaternions]

5.1.3.1 CATDESC

This is a human readable description of the data variable. Generally, this is an 80-character string which describes the variable and what it depends on.

5.1.3.2 DEPEND_0

Explicitly ties a data variable to the time variable on which it depends. All variables which change with time must have a DEPEND_0 attribute defined. See section 5.2.1 which specifies the MMS usage of DEPEND_0.

5.1.3.3 DEPEND_i

Ties a dimensional data variable to a SUPPORT_DATA variable on which the i-th dimension of the data variable depends. The number of DEPEND attributes must match the dimensionality of the variable, i.e., a one-dimensional variable must have a DEPEND_1, a two-dimensional variable must have a DEPEND_1 and a DEPEND_2 attribute, etc. The value of the attribute must be a variable in the same CDF data set. It is strongly recommended that DEPEND_i variables hold values in physical units. DEPEND_i variables also require their own attributes, as described in section 5.1.4.

5.1.3.4 DISPLAY_TYPE (e.g. time_series, spectrogram, stack_plot,image)

This tells automated software, such as CDAWEB, how the data should be displayed. Examples of valid values include:

- time_series
- spectrogram
- stack_plot
- image

5.1.3.5 FIELDNAM

A shortened version of CATDESC which can be used to label a plot axis or as a data listing heading. This is a string, up to ~30 characters in length.

5.1.3.6 FILLVAL

Identifies the fill value used where data values are known to be bad or missing. FILLVAL is required for time-varying variables. Fill data are always non-valid data. The ISTP standard fill values are listed below:

- BYTE ---- -128
- INTEGER*2 ---- -32768
- INTEGER*4 ---- -2147483648
- INTEGER*8 ---- -9223372036854775808
- Unsigned INTEGER*1 ---- 255
- Unsigned INTEGER*2 ---- 65535
- Unsigned INTEGER*4 ---- 4294967295
- REAL*4 ---- -1.0E31
- REAL*8 ---- -1.0E31
- EPOCH ---- -1.0E31 (9999-12-31:23:59:59.999)
- EPOCH16 ---- -1.0E31 (9999-12-31:23:59:59.999999999999)
- TT2000 ---- -9223372036854775808LL (9999-12-31:23:59:59.999999999999)

5.1.3.7 FORMAT - required if not using FORM_PTR

This field allows software to properly format the associated data when displayed on a screen or output to a file. Format can be specified using either Fortran or C format codes. For instance, "F10.3" indicates that the data should be displayed across 10 characters where 3 of those characters are to the right of the decimal.

5.1.3.8 FORM_PTR - required if not using FORMAT

The value of this field is a variable which stores the character string that represents the desired output format for the associated data.

5.1.3.9 LABLAXIS (required if not using LABL_PTR_i)

Used to label a plot axis or to provide a heading for a data listing. This field is generally 6-10 characters. Only one of LABLAXIS or LABL_PTR_i should be present.

5.1.3.10 LABL_PTR_i (required if not using LABLAXIS)

Used to label a dimensional variable when one value of LABLAXIS is not sufficient to describe the variable or to label all the axes. LABL_PTR_i is used instead of LABLAXIS, where i can take on any value from 1 to n where n is the total number of dimensions of the original variable. The value of LABL_PTR_1 is a variable which will contain the short character strings which describe the first dimension of the original variable. The value of the attribute must be a variable in the same CDF data set and is generally 6-10 characters. Only one of LABLAXIS or LABL_PTR_i should be present.

5.1.3.11 SI_CONVERSION

The conversion factor to SI units. This is the factor that the variable must be multiplied by in order to convert it to generic SI units. This parameter contains two text fields separated by the ">" delimiter. The first component is the conversion factor and the second is the standard SI unit. Units are defined according to their standard SI symbols (ie. Tesla = T, Newtons = N, Meters = m, etc.) For data variables that are inherently unitless, and thus lack a conversion factor, this data attribute will be "□>□" where □ is a blank space and the quotation marks are not included. Units which are not conveniently transformed into SI should follow the blank syntax "□>□" described above.

For example, the magnetic field for FGM will be in nT, and to convert to Tesla the value of SI_CONVERSION will be "1.0e-9>T". The use of text allows this attribute to be parsed and the value must be extracted in software.

An active list of MMS standard UNITS and their SI_CONVERSIONs is maintained on the mission web-pages at https://lasp.colorado.edu/galaxy/display/mms/Units+of+Measure, accessible via the MMS Science Working Team pages. SI_CONVERSION strings must adhere to a strict, machine-parseable format that is fully described on the "Units of Measure" web page found by following the above link.

5.1.3.12 UNITS - required if not using UNIT_PTR

A 6-20 character string that identifies the units of the variable (e.g. nT for magnetic field). Use a blank character, rather than "None" or "unitless", for variables that have no units (e.g., a ratio or a direction cosine). An active list of MMS standard UNITS and their SI_CONVERSIONs is maintained on the mission web-pages at https://lasp.colorado.edu/galaxy/display/mms/Units+of+Measure, accessible via the MMS Science Working Team pages. Those pages also lay out the rules for formatting the UNITS string.

5.1.3.13 UNIT_PTR - required if not using UNITS

The value of this field is a variable which stores short character strings which identify the units of the variable. Use a blank character, rather than "None" or "unitless", for variables that have no units (e.g., a ratio or a direction cosine). The value of this attribute must be a variable in the same CDF data set.

5.1.3.14 VALIDMIN

The minimum value for a particular variable that is expected over the lifetime of the mission. Used by application software to filter out values that are out of range. The value must match the data type of the variable.

5.1.3.15 VALIDMAX

The maximum value for a particular variable that is expected over the lifetime of the mission. Used by application software to filter out values that are out of range. The value must match the data type of the variable.

5.1.3.16 VAR_TYPE

Used in CDAWeb to indicate if the data should be used directly by users. Possible values:

- "data" - integer or real numbers that are plottable
- "support_data" - integer or real "attached" or secondary data variables
- "metadata" - labels or character variables
- "ignore_data" - placeholders

5.1.3.17 COORDINATE_SYSTEM

All variables for which the values are dependent on the system of coordinates are strongly recommended to have this attribute. This includes both full vectors, tensors, etc. or individual values, e.g. of an angle with respect to some axis. The attribute is a text string which takes the form:

XXX[>optional long name]

where XXX is a recognised acronym, e.g., GSE, GSM, SM, GEI, BCS, DBCS, DSL, DMPA, etc. and the optional long name is an expansion of that acronym, e.g.

GSE
or
GSE>Geocentric Solar Ecliptic

5.1.3.18 TENSOR_ORDER

All variables which hold physical vectors, tensors, etc., or sub-parts thereof, are strongly recommended to have their tensorial properties held by this numerical value. Vectors have TENSOR_ORDER=1, pressure tensors have TENSOR_ORDER=2, etc. Variables which hold single components or sub-parts of a vector or tensor, e.g., the x-component of velocity or the three diagonal elements of a tensor, use this attribute to establish the underlying object from which they are extracted. TENSOR_ORDER is a number, usually held as a CDF_INT4, rather than a character string.

5.1.3.19 REPRESENTATION_i

This strongly recommended attribute holds the way vector or tensor variables are held, e.g., as Cartesian or polar forms, and their sequence order in the dimension i in which they are held. Cartesians are indicated by x,y,z; polar coordinates by r (magnitude), t (theta – from z-axis), p (phi – longitude or azimuth around z-axis from x axis), l (lambda = latitude). Examples follow.

NOTE: CDF variable attributes can NOT take multiple entries the way global attributes can. Accordingly, attributes such as REPRESENTATION_1 = "x", "y", "z" as shown below can only be held in a CDF file through the intermediary of a non-record-varying variable of the appropriate size, in a manner exactly parallel to the LABL_PTR_1 construct. Accordingly, the CDF file will have an attribute of the form:

REPRESENTATIOIN_1 = rep_1_variable

and rep_1_variable will be a variable in the file holding values, e.g., in the skeleton file, of the form:
[1] = {"x"}
[2] = {"y"}
[3] = {"z"}

In the examples that follow, REPRESENTATION_1 = "x", "y", "z" is used as a shorthand notation for this pointer to a representation variable.

Cartesian vector has REPRESENTATION_1 = "x", "y", "z"
Vector in spherical polars has REPRESENTATION_1 = "r", "t", "p"
x-component of a vector has REPRESENTATION_1 = "x"

Pressure tensor stored as a 3x3 array has:
REPRESENTATION_1 = "x", "y", "z"
REPRESENTATION_2 = "x", "y", "z"

Pressure tensor for which the 6 independent numbers are stored in a 1x6 array:
REPRESENTATION_1 = "xx", "xy", "xz", "yy", "yz", "zz" [permuted into the correct sequence order]

Diagonal components of a pressure tensor
REPRESENTATION_1 = "xx", "yy", "zz"

3D velocity distribution function stored as a 3D array
Each DEPEND_i variable corresponds to values in some coordinate system. Accordingly, each of these DEPEND_i variables should have its own COORDINATE_SYSTEM and

REPRESENTATION_1. For example, if the DEPEND_2 corresponds to the polar angle in DBCS coordinates, then the structure would be:

PSD_variable:
…
DEPEND_2 = Polar_var
…

Polar_var
…
COORDINATE_SYSTEM = “DBCS”
REPRESENTATION_1 = Polar_rep_var
…

Polar_rep_var
CDF_CHAR …
[] = “t”
…

The Energy DEPEND_i variable is the magnitude (“r”) component; its SI_CONVERSION and UNITS provide the necessary information to interpret it as energy rather than velocity or some other quantity. NOTE that as the representation for all the elements in a single DEPEND_i variable are the same, it is not necessary to repeat it; the single value is taken to be applicable to all elements.

5.1.3.20 OPERATOR_TYPE

This has been introduced to describe MMS quaternions (see Section 5.2 below). It has allowed values “UNIT_QUATERNION” or “ROTATION_MATRIX” although other values could be added. Unit quaternions correspond to pure spatial rotations.

5.1.4 Attributes for DEPEND_i Variables

5.1.4.1 Standard SUPPORT_DATA Attributes

Variables appearing in a data variable’s DEPEND_i attribute require a minimal set of their own attributes to fulfill their role in supporting the data variable. The standard SUPPORT_DATA variable attributes are listed in Section 5.3.2.
Other standard variable attributes are optional.

5.1.4.2 COORDINATE_SYSTEM; REPRESENTATION_i

As described in the final example shown in section 5.1.3.19, DEPEND_i variables are sometimes/often related to components in a particular coordinate system. In such cases, it is strongly recommended that they have their own COORDINATE_SYSTEM and REPRESENTATION_i attributes to specify the coordinate system and particular component to which the DEPEND_i variable corresponds.

5.1.4.3 DELTA_PLUS_VAR and DELTA_MINUS_VAR

DEPEND_i variables are typically physical values along the corresponding i-th dimension of the parent data variable, such as energy levels or spectral frequencies. The discreet set of values are located with respect to the sampling bin by DELTA_PLUS_VAR and DELTA_MINUS_VAR, which hold the variable name containing the distance from the value to the bin edge. It is strongly recommended that MMS DEPEND_i variables include DELTA_PLUS_VAR and DELTA_MINUS_VAR attributes that point to the appropriate variable(s) located elsewhere in the CDF file.

For example, for a variable energy_level that is the DEPEND_i of a particle distribution, if energy_dplus and energy_dminus are two variables pointed to by energy_level's DELTA_PLUS_VAR and DELTA_MINUS_VAR, then element [n] corresponds to the energy bin (energy_level[n]-energy_dminus[n]) to (energy_level[n]+energy_dplus[n]). DELTA_PLUS_VAR and DELTA_MINUS_VAR can point to the same variable which implies that energy_level[n] is in the center of the bin. DELTA_PLUS_VAR and DELTA_MINUS_VAR must have the same number of values as the size of the corresponding dimension of the parent variable, or hold a single constant value which applies for all bins. They can be record-varying, in which case they require a DEPEND_0 attribute.

In the case of the DEPEND_0 timetag variable, DELTA_PLUS_VAR and DELTA_MINUS_VAR together with the timetag identify the time interval over which the data was sampled, integrated, or otherwise regarded as representative of. DELTA_PLUS_VAR and DELTA_MINUS_VAR variables require FIELDNAM, UNITS and SI_CONVERSION attributes; in principle, these could differ from those of the DEPEND_i parent. They also require VAR_TYPE=SUPPORT_DATA. Other standard attributes might be helpful.

5.2 Quaternions

MMS mec files contain unit quaternions which can be employed to rotate from one coordinate system to the other. For an arbitrary rotation, that rotational information can expressed as a rotation through an angle θ about a unit vector **u**. The Wikipedia page on "Quaternions and Spatial Rotation" provides details and the relationship between the quaternion and a 3x3 rotation matrix. In the mec files, quaternions are represented by:

q = (qx, qy, qz, qw)

in which qw (also known elsewhere as qc) = cos (θ/2) and (qx, qy, qz) = **u** sin (θ/2). Extensions of existing attribute standards are strongly recommended to be used to describe such quaternions. The following attributes serve this purpose:

OPERATOR_TYPE=UNIT_QUATERNION
REPRESENTATION_1 = "x", "y", "z", "c" [in the right order; the "c" denotes the cosine term]
COORDINATE_SYSTEM=XXX [standard syntax, as for vectors; the FROM frame]
TO_COORDINATE_SYSTEM=YYY [same syntax; the TO frame]

Such a quaternion will take a vector given in the XXX coordinate system and generate its components in the YYY coordinate system.

5.3 Support Data

These are variables of secondary importance employed as DEPEND_i variables as described in section 5.1.3.3 (e.g., time, energy_bands associated with particle flux), but they may also be used for housekeeping or other information not normally used for scientific analysis.

5.3.1 Naming

Support data variable names must begin with a letter and can contain numbers and underscores, but no other special characters. Support data variable names need not follow the same naming convention as Data Variables (5.1.1) but may be shortened for convenience.

5.3.2 Required Attributes

CATDESC
DEPEND_0 (if time varying)
FIELDNAM
FILLVAL (if time varying)
FORMAT/FORM_PTR
SI_CONVERSION
UNITS/UNIT_PTR
VALIDMIN (if time varying)
VALIDMAX (if time varying)
VAR_TYPE = “support_data”

Other attributes may also be present.

5.4 Metadata

These are variables of secondary importance (e.g. a variable holding "Bx”, “By”, “Bz" to label magnetic field). Metadata are usually text strings as opposed to the numerical values held in DEPEND_i support data.

5.4.1 Naming

Metadata variable names must begin with a letter and can contain numbers and underscores, but no other special characters. Metadata variable names need not follow the same naming convention as Data Variables (5.1.1) but may be shortened for convenience.

5.4.2 Required Attributes

The following variable attributes are required.

CATDESC
DEPEND_0 (if time varying, this value must be “Epoch”)
FIELDNAM

FILLVAL (if time varying)
FORMAT/FORM_PTR
VAR_TYPE = metadata

Appendix A - Table of Acronyms

Acronym	Description
ADP	Axial Double Probe electric field instrument, part of FIELDS investigation
AFG	Analog Flux Gate Magnetometer, part of FIELDS investigation
APL	Applied Physics Laboratory
ASPOC	Active Spacecraft Potential Control
CDAWeb	Coordinated Data Analysis Web (part of the SPDF)
CDF	Common Data Format
DES	Dual Electron Spectrometer, part of FPI investigation
DFG	Digital Flux Gate Magnetometer, part of FIELDS investigation
DIS	Dual Ion Spectrometer, part of FPI investigation
EDI	Electron Drift Instrument, part of FIELDS investigation
EIS	Energetic Ion Spectrometer, part of EPD investigation
EPD	Energetic Particle Detector System
FEEPS	Fly's Eye Energetic Particle Sensor, part of EPD investigation
FPI	Fast Plasma Instrument
GSFC	Goddard Spaceflight Center
HPCA	Hot Plasma Composition Analyzer
IACG	Inter-Agency Consultative Group
IDS	Interdisciplinary Scientists
ISTP	International Solar-Terrestrial Physics
ITF	Instrument Team Facility
IRFU	Institutet för rymdfysik, Uppsala
IWF	Institut für Weltraumforschung (Space Research Institute of the Austrian Academy of Sciences)
JHU	Johns Hopkins University
KTH	Kungliga Tekniska Högskolan (Swedish Royal Institute of Technology)
LANL	Los Alamos National Laboratory
LASP	Laboratory for Atmospheric and Space Physics
LPP	Laboratoire de Physique des Plasmas
MMS	Magnetospheric Multiscale
SCM	Search Coil Magnetometer, part of FIELDS investigation
MEC	Magnetic Ephemeris and Coordinates
SDP	Spin-plane Double Probe (part of FIELDS investigation)
SDWG	MMS Science Data Working Group
SFDU	Standard Formatted Data Unit

SMART	Solving Magnetospheric Acceleration Reconnection and Turbulence
SPDF	Space Physics Data Facility
SwRI	Southwest Research Institute
UCLA	University of California Los Angeles
UNH	University of New Hampshire