A Standard for Exchangeable Magnetotelluric Metadata

Working Group for Data Handling and Software - PASSCAL Magnetotelluric Program

**Version 0.0.16 – July 2020**[[1]](#footnote-20)

# Introduction

Researchers using magnetotelluric (MT) methods lack a standardized format for storing time series data and metadata. Commercially available MT instruments produce data in formats that range from proprietary binary to ASCII, whereas recent datasets from the U.S. MT community have utilized institutional formats or heavily adapted formats like miniSEED. In many cases, the available metadata for MT time series are incomplete and loosely standardized; and overall, these datasets are not "user friendly". This lack of a standardized resource impedes the exchange and broader use of these data beyond a small community of specialists.

The [IRIS PASSCAL MT facility](https://www.iris.edu/hq/programs/passcal/magnetotelluric_instrumentation) maintains a pool of MT instruments that are freely available to U.S. Principal Investigators (PIs). Datasets collected with these instruments are subject to data sharing requirements, and an IRIS [working group](https://www.iris.edu/hq/about_iris/governance/mt_soft) advises the development of sustainable data formats and workflows for this facility. Following in the spirit of the standard created for [MT transfer function](https://library.seg.org/doi/10.1190/geo2018-0679.1) datasets, this document outlines a new metadata standard for level 0,1,and 2 MT time series data ([Data Levels](https://earthdata.nasa.gov/collaborate/open-data-services-and-software/data-information-policy/data-levels)). Following community approval of these standards, MTH5 (an HDF5 MT specific format) will be developed later in 2020.

The Python 3 module written for these standards and MTH5 is being developed at <https://github.com/kujaku11/MTarchive/tree/tables>.

# General Structure

The metadata for a full MT dataset are structured to cover details from single channel time series to a full survey. For simplicity, each of the different scales of an MT survey and measurements have been categorized starting from largest to smallest (Figure [1](#fig:example)). These categories are: Survey, Station, Run, DataLogger, Electric Channel, Magnetic Channel, and Auxiliary Channel. Each category is described in subsequent sections. Required keywords are labeled as and suggested keywords are labeled as . A user should use as much of the suggested metadata as possible for a full description of the data.

Schematic of a MT time series file structure with appropriate metadata. The top level is the *Survey* that contains general information about who, what, when, where, and how the data were collected. Underneath *Survey* are the *Station* and *Filter*. *Filter* contains information about different filters that need to be applied to the raw data to get appropriate units and calibrated measurements. Underneath *Station* are *Run*, which contain data that were collected at a single sampling rate with common start and end time at a single station. Finally, *Channel* describes each channel of data collected and can be an *Auxiliary*, *Electric*, or *Magnetic*. Metadata is attributed based on the type of data collected in the channel.

Schematic of a MT time series file structure with appropriate metadata. The top level is the *Survey* that contains general information about who, what, when, where, and how the data were collected. Underneath *Survey* are the *Station* and *Filter*. *Filter* contains information about different filters that need to be applied to the raw data to get appropriate units and calibrated measurements. Underneath *Station* are *Run*, which contain data that were collected at a single sampling rate with common start and end time at a single station. Finally, *Channel* describes each channel of data collected and can be an *Auxiliary*, *Electric*, or *Magnetic*. Metadata is attributed based on the type of data collected in the channel.

## Metadata Keyword Format

The metadata key names should be self-explanatory and are structured as follows:  
{category}.{name}, or can be nested {category1}.{categroy2}.{name} where:

* category refers to a metadata category or level that has common parameters, such as location, which will have a latitude, longitude, and elevation location.latitude, location.longitude, and location.elevation. These can be nested, for example, station.location.latitude
* name is a descriptive name, where words should be separated by an underscore. Note that only whole words should be used and abbreviations should be avoided, e.g. data\_quality.

A ‘.’ represents the separator between different categories. The metadata can be stored in many different forms. Common forms are XML or JSON formats. See examples below for various ways to represent the metadata.

## Formatting Standards

Specific and required formatting standards for location, time and date, and angles are defined below and should be adhered to.

### Time and Date Format

All time and dates are given as an ISO formatted date-time String in the UTC time zone. The ISO Date Time format is YYYY-MM-DDThh:mm:ss.ms+00:00, where the UTC time zone is represented by +00:00. UTC can also be denoted by Z at the end of the date-time string YYYY-MM-DDThh:mm:ss.msZ. Note that Z can also represent Greenwich Mean Time (GMT) but is an acceptable representation of UTC time. If the data requires a different time zone, this can be accommodated but it is recommended that UTC be used whenever possible to avoid confusion of local time and local daylight savings. Milliseconds can be accurate to 9 decimal places. ISO dates are formatted YYYY-MM-DD. Hours are given as a 24 hour number or military time, e.g. 4:00 PM is 16:00.

### Location

All latitude and longitude locations are given in decimal degrees in the well known datum specified at the Survey level. **NOTE: The entire survey should use only one datum that is specified at the Survey level.**

* All latitude values must be and all longitude values must be .
* Elevation and other distance values are given in meters.
* Datum should be one of the well known datums, WGS84 is preferred, but others are acceptable.

### Angles

All angles of orientation are given in decimal degrees. Orientation of channels should be given in a geographic or a geomagnetic reference frame where the right-hand coordinates are assumed to be North = 0, East = 90, and vertical is positive downward (Figure [2](#fig:reference)). The coordinate reference frame is given at the station level station.orientation.reference\_frame. Two angles to describe the orientation of a sensor is given by channel.measurement\_azimuth and channel.measurement\_tilt. In a geographic or geomagnetic reference frame, the azimuth refers to the horizontal angle relative to north positive clockwise, and the tilt refers to the vertical angle with respect to the horizontal plane. In this reference frame, a tilt angle of 90 points downward, 0 is parallel with the surface, and -90 points upwards.

Archived data should remain in measurement coordinates. Any transformation of coordinates for derived products can store the transformation angles at the channel level in  
channel.transformed\_azimuth and channel.transformed\_tilt, the transformed reference frame can then be recorded in station.orientation.transformed\_reference\_frame.

Diagram showing a right-handed geographic coordinate system. The azimuth is measured positive clockwise along the horizontal axis and tilt is measured from the vertical axis with positive down = 0, positive up = 180, and horizontal = 90.

Diagram showing a right-handed geographic coordinate system. The azimuth is measured positive clockwise along the horizontal axis and tilt is measured from the vertical axis with positive down = 0, positive up = 180, and horizontal = 90.

## Units

Acceptable units are only those from the International System of Units (SI). Only long names in all lower case are acceptable. Units with multiple dimensions should be separated by a dash (-) if multiplictive or per if divided. For example velocity would be meters per second and resistivity would be ohm-meter. Table [1](#tab:units) summarizes common acceptable units.

Acceptable Units

|  |  |
| --- | --- |
| **Measurement Type** | **Unit Name** |
| Angles | decimal degrees |
| Distance | meter |
| Electric Field | millivolt per kilometer |
| Latitude/Longitude | decimal degrees |
| Magnetic Field | nanotesla |
| Resistance | ohms |
| Resistivity | ohm-meter |
| Temperature | celsius |
| Time | second |
| Voltage | volt |

[tab:units]

## String Formats

Each metadata keyword can have a specific string style, such as date and time or alpha-numeric. These are described in Table [2](#tab:values). Note that any list should be comma separated.

Acceptable String Formats

|  |  |  |
| --- | --- | --- |
| **Style** | **Description** | **Example** |
| Free Form | An unregulated string that can contain {a-z, A-Z, 0-9} and special characters | This is Free Form! |
| Alpha Numeric | A string that contains no spaces and only characters {a-z, A-Z, 0-9, -, /, \_} | WGS84 or GEOMAG-USGS |
| Controlled Vocabulary | Only certain names or words are allowed. In this case, examples of acceptable values are provided in the documentation as [ option01 option02 ... ]. The ... indicates that other options are possible but have not been defined in the standards yet | reference\_frame = geographic |
| List | List of entries using a comma separator | Ex, Ey, Hx, Hy, Hz, T |
| Number | A number according to the data type; number of decimal places has not been implemented yet | 10.0 (float) or 10 (integer) |
| Date | ISO formatted date YYYY-MM-DD in UTC | 2020-02-02 |
| Date Time | ISO formatted date time YYYY-MM-DDThh:mm:ss.ms+00:00 in UTC | 2020-02-02T12:20:45.123456+00:00 |
| Email | A valid email address | <person@mt.org> |
| URL | A full URL that a user can view in a web browser | <https://www.passcal.nmt.edu/> |

[tab:values]

# Survey

A survey describes an entire data set that covers a specific time span and region. This may include multiple PIs in multiple data collection episodes but should be confined to a specific experiment or project. The Survey metadata category describes the general parameters of the survey.

p.275>p.5>>p.2 **Metadata Key** & **Description** & **Example**

**acquired\_by.author**

None

String

Free Form

& Name of the person or persons who acquired the data. This can be different from the project lead if a contractor or different group collected the data. & person name

**acquired\_by.comments**

None

String

Free Form

& Any comments about aspects of how the data were collected or any inconsistencies in the data. & Lightning strike caused a time skip at 8 am UTC.

**archive\_id**

None

String

Alpha Numeric

& Alphanumeric name provided by the archive. For IRIS this will be the FDSN providing a code. & YKN20

**archive\_network**

None

String

Alpha Numeric

& Network code given by PASSCAL/IRIS/FDSN. This will be a two character String that describes who and where the network operates. & EM

**citation\_dataset.doi**

None

String

URL

& The full URL of the doi Number provided by the archive that describes the raw data & <http://doi.10.adfabe>

**citation\_journal.doi**

None

String

URL

& The full URL of the doi Number for a journal article(s) that uses these data. If multiple journal articles use these data provide as a comma separated String of urls. & <http://doi.10.xbsfs>, or <http://doi.10.xbsfs>, <http://doi.10.xbsfs2>

[tab:survey]

Attributes for Survey Continued

|  |  |  |
| --- | --- | --- |
| **Metadata Key** | **Description** | **Example** |
| **comments**  None  String  Free Form | Any comments about the survey that are important for any user to know. | Solar activity low. |
| **country**  None  String  Free Form | Country or countries that the survey is located in. If multiple input as comma separated names. | USA, Canada |
| **datum**  None  String  Controlled Vocabulary | The reference datum for all geographic coordinates throughout the survey. It is up to the user to be sure that all coordinates are projected into this datum. Should be a well-known datum: [ WGS84 NAD83 OSGB36 GDA94 ETRS89 PZ-90.11 ... ] | WGS84 |
| **geographic\_name**  None  String  Free Form | Geographic names that encompass the survey. These should be broad geographic names. Further information can be found at <https://www.usgs.gov/core-science-systems/ngp/board-on-geographic-names> | Eastern Mojave, Southwestern USA |
| **name**  None  String  Free Form | Descriptive name of the survey, similar to the title of a journal article. | MT Characterization of Yukon Terrane |
| **northwest\_corner.latitude**  decimal degrees  Float  Number | Latitude of the northwest corner of the survey in the datum specified. |  |
| **northwest\_corner.longitude**  decimal degrees  Float  Number | Longitude of the northwest corner of the survey in the datum specified. |  |

[tab:survey2]

Attributes for Survey Continued

|  |  |  |
| --- | --- | --- |
| **Metadata Key** | **Description** | **Example** |
| **project**  None  String  Free Form | Alphanumeric name for the project. This is different than the archive\_id in that it describes a project as having a common project lead and source of funding. There may be multiple surveys within a project. For example if the project is to estimate geomagnetic hazards that project = GEOMAG but the archive\_id = YKN20. | GEOMAG |
| **project\_lead.author**  None  String  Free Form | Name of the project lead. This should be a person who is responsible for the data. | Magneto |
| **project\_lead.email**  None  String  Email | Email of the project lead. This is in case there are any questions about data. | mt.guru@em.org |
| **project\_lead.organization**  None  String  Free Form | Organization name of the project lead. | MT Gurus |
| **release\_license**  None  String  Controlled Vocabulary | How the data can be used. The options are based on Creative Commons licenses. Options: [ CC 0 CC BY CC BY-SA CC BY-ND CC BY-NC-SA CC BY-NC-ND]. For details visit <https://creativecommons.org/licenses/> | CC 0 |
| **southeast\_corner.latitude**  decimal degrees  Float  Number | Latitude of the southeast corner of the survey in the datum specified. |  |
| **southeast\_corner.longitude**  decimal degrees  Float  Number | Longitude of the southeast corner of the survey in the datum specified. |  |

[tab:survey3]

Attributes for Survey Continued

|  |  |  |
| --- | --- | --- |
| **Metadata Key** | **Description** | **Example** |
| **summary**  None  String  Free Form | Summary paragraph of the survey including the purpose; difficulties; data quality; summary of outcomes if the data have been processed and modeled. | Long project of characterizing mineral resources in Yukon |
| **time\_period.end\_date**  None  String  Date | End date of the survey in UTC. | -02-01 |
| **time\_period.start\_date**  None  String  Date | Start date of the survey in UTC. | -06-21 |

[tab:survey4]

## Example Survey XML Element

<?xml version="1.0" ?>  
<survey>  
 <acquired\_by>  
 <author>MT Graduate Students</author>  
 <comments>Multiple over 5 years</comments>  
 </acquired\_by>  
 <archive\_id>SAM1990</archive\_id>  
 <archive\_network>EM</archive\_network>  
 <citation\_dataset>  
 <doi>https://doi.###</doi>  
 </citation\_dataset>  
 <citation\_journal>  
 <doi>https://doi.###</doi>  
 </citation\_journal>  
 <comments>None</comments>  
 <country>USA, Canada</country>  
 <datum>WGS84</datum>  
 <geographic\_name>Yukon</geographic\_name>  
 <name>Imaging Gold Deposits of the Yukon Province</name>  
 <northwest\_corner>  
 <latitude type="Float" units="decimal degrees">-130</latitude>  
 <longitude type="Float" units="decimal degrees">75.9</longitude>  
 </northwest\_corner>  
 <project>AURORA</project>  
 <project\_lead>  
 <Email>m.tee@mt.org</Email>  
 <organization>EM Ltd.</organization>  
 <author>M. Tee</author>  
 </project\_lead>  
 <release\_license>CC0</release\_license>  
 <southeast\_corner>  
 <latitude type="Float" units="decimal degrees">-110.0</latitude>  
 <longitude type="Float" units="decimal degrees">65.12</longitude>  
 </southeast\_corner>  
 <summary>This survey spanned multiple years with graduate students  
 collecting the data. Lots of curious bears and moose,  
 some interesting signal from the aurora. Modeled data  
 image large scale crustal features like the   
 "fingers of god" that suggest large mineral deposits.  
 </summary>  
 <time\_period>  
 <end\_date>2020-01-01</end\_date>  
 <start\_date>1995-01-01</start\_date>  
 </time\_period>  
</survey>

# Station

A station encompasses a single site where data are collected. If the location changes during a run, then a new station should be created and subsequently a new run under the new station. If the sensors, cables, data logger, battery, etc. are replaced during a run but the station remains in the same location, then this can be recorded in the Run metadata but does not require a new station entry.

Attributes for Station

|  |  |  |
| --- | --- | --- |
| **Metadata Key** | **Description** | **Example** |
| **acquired\_by.author**  None  String  Free Form | Name of person or group that collected the station data and will be the point of contact if any questions arise about the data. | person name |
| **acquired\_by.comments**  None  String  Free Form | Any comments about who acquired the data. | Expert diggers. |
| **archive\_id**  None  String  Alpha Numeric | Station name that is archived a-z;A-Z;0-9. For IRIS this is a 5 character String. | MT201 |
| **channel\_layout**  None  String  Controlled Vocabulary | How the dipoles and magnetic channels of the station were laid out. Options: [ L + ... ] | + |
| **channels\_recorded**  None  String  Controlled Vocabulary | List of components recorded by the station. Should be a summary of all channels recorded dropped channels will be recorded in Run. Options: [ Ex Ey Hx Hy Hz T Battery ... ] | Ex, Ey, Hx, Hy, Hz, T |
| **comments**  None  String  Free Form | Any comments on the station that would be important for a user. | Pipeline near by. |

[tab:station]

Attributes for Station Continued

|  |  |  |
| --- | --- | --- |
| **Metadata Key** | **Description** | **Example** |
| **data\_type**  None  String  Controlled Vocabulary | All types of data recorded by the station. If multiple types input as a comma separated list. Options: [ RMT AMT BBMT LPMT ULPMT ... ] | BBMT |
| **geographic\_name**  None  String  Free Form | Closest geographic name to the station, should be rather general. For further details about geographic names see <https://www.usgs.gov/core-science-systems/ngp/board-on-geographic-names> | "Whitehorse, YK" |
| **id**  None  String  Free Form | Station name. This can be a longer name than the archive\_id name and be a more explanatory name. | bear hallabaloo |
| **location.declination.comments**  None  String  Free Form | Any comments on declination that are important to an end user. | Different than recorded declination from data logger. |
| **location.declination.model**  None  String  Controlled Vocabulary | Name of the geomagnetic reference model as {model\_name}{-}{YYYY}. Model options: | WMM-2016 |
| **location.declination.value**  decimal degrees  Float  Number | Declination angle relative to geographic north positive clockwise estimated from location and geomagnetic model. |  |
| **location.elevation**  meters  Float  Number | Elevation of station location in datum specified at survey level. |  |

Attributes for Station Continued

|  |  |  |
| --- | --- | --- |
| **Metadata Key** | **Description** | **Example** |
| **location.latitude**  decimal degrees  Float  Number | Latitude of station location in datum specified at survey level. |  |
| **location.longitude**  decimal degrees  Float  Number | Longitude of station location in datum specified at survey level. |  |
| **orientation.method**  None  String  Controlled Vocabulary | Method for orienting station channels. Options: [ compass GPS theodolite electric\_compass ... ] | compass |
| **orientation.reference\_frame**  None  String  Controlled Vocabulary | Reference frame for station layout. There are only 2 options geographic and geomagnetic. Both assume a right-handed coordinate system with North=0, E=90 and vertical positive downward. Options: [ geographic geomagnetic ] | geomagnetic |
| **orientation.transformed\_reference\_frame**  None  Float  Number | Reference frame rotation angel relative to orientation.reference\_frame assuming positive clockwise. Should only be used if data are rotated. |  |
| **provenance.comments**  None  String  Free Form | Any comments on provenance of the data. | From a graduated graduate student. |
| **provenance.creation\_time**  None  String  Date Time | Date and time the file was created. | -02-08 T12:23:40.324600 +00:00 |

Attributes for Station Continued

|  |  |  |
| --- | --- | --- |
| **Metadata Key** | **Description** | **Example** |
| **provenance.log**  None  String  Free Form | A history of any changes made to the data. | -02-10 T14:24:45+00:00 updated station metadata. |
| **provenance.software.author**  None  String  Free Form | Author of the software used to create the data files. | programmer 01 |
| **provenance.software.name**  None  String  Free Form | Name of the software used to create data files | mtrules |
| **provenance.software.version**  None  String  Free Form | Version of the software used to create data files | 12.01a |
| **provenance.submitter.author**  None  String  Free Form | Name of the person submitting the data to the archive. | person name |
| **provenance.submitter.email**  None  String  Email | Email of the person submitting the data to the archive. | mt.guru@em.org |
| **provenance.submitter.organization**  None  String  Free Form | Name of the organization that is submitting data to the archive. | MT Gurus |

Attributes for Station Continued

|  |  |  |
| --- | --- | --- |
| **Metadata Key** | **Description** | **Example** |
| **time\_period.end**  None  String  Date Time | End date and time of collection in UTC. | -02-04 T16:23:45.453670 +00:00 |
| **time\_period.start**  None  String  Date Time | Start date and time of collection in UTC. | -02-01 T09:23:45.453670 +00:00 |

## Example Station JSON

{ "station": {  
 "acquired\_by": {  
 "author": "mt",  
 "comments": null},  
 "archive\_id": "MT012",  
 "channel\_layout": "L",  
 "channels\_recorded": "Ex, Ey, Hx, Hy",  
 "comments": null,  
 "data\_type": "MT",  
 "geographic\_name": "Whitehorse, Yukon",  
 "id": "Curious Bears Hallabaloo",  
 "location": {  
 "latitude": 10.0,  
 "longitude": -112.98,  
 "elevation": 1234.0,  
 "declination": {  
 "value": 12.3,  
 "comments": null,  
 "model": "WMM-2016"}},  
 "orientation": {  
 "method": "compass",  
 "reference\_frame": "geomagnetic"},  
 "provenance": {  
 "comments": null,  
 "creation\_time": "1980-01-01T00:00:00+00:00",  
 "log": null,  
 "software": {  
 "author": "test",  
 "version": "1.0a",  
 "name": "name"},  
 "submitter": {  
 "author": "name",  
 "organization": null,  
 "email": "test@here.org"}},  
 "time\_period": {  
 "end": "1980-01-01T00:00:00+00:00",  
 "start": "1982-01-01T16:45:15+00:00"}  
 }  
}

# Run

A run represents data collected at a single station with a single sampling rate. If the dipole length or other such station parameters are changed between runs, this would require adding a new run. If the station is relocated then a new station should be created. If a run has channels that drop out, the start and end period will be the minimum time and maximum time for all channels recorded.

Attributes for Run

|  |  |  |
| --- | --- | --- |
| **Metadata Key** | **Description** | **Example** |
| **acquired\_by.author**  None  String  Free Form | Name of the person or persons who acquired the run data. This can be different from the station.acquired\_by and survey.acquired\_by. | M.T. Nubee |
| **acquired\_by.comments**  None  String  Free Form | Any comments about who acquired the data. | Group of undergraduates. |
| **channels\_recorded\_auxiliary**  None  String  name list | List of auxiliary channels recorded. | T, battery |
| **channels\_recorded\_electric**  None  String  name list | List of electric channels recorded. | Ex, Ey |
| **channels\_recorded\_magnetic**  None  String  name list | List of magnetic channels recorded. | Hx, Hy, Hz |
| **comments**  None  String  Free Form | Any comments on the run that would be important for a user. | Badger attacked Ex. |

[tab:run]

Attributes for Run Continued

|  |  |  |
| --- | --- | --- |
| **Metadata Key** | **Description** | **Example** |
| **comments**  None  String  Free Form | Any comments on the run that would be important for a user. | cows chewed cables at 9am local time. |
| **data\_logger.firmware.author**  None  String  Free Form | Author of the firmware that runs the data logger. | instrument engineer |
| **data\_logger.firmware.name**  None  String  Free Form | Name of the firmware the data logger runs. | mtrules |
| **data\_logger.firmware.version**  None  String  Free Form | Version of the firmware that runs the data logger. | 12.01a |
| **data\_logger.id**  None  String  Free Form | Instrument ID Number can be serial Number or a designated ID. | mt01 |
| **data\_logger.manufacturer**  None  String  Free Form | Name of person or company that manufactured the data logger. | MT Gurus |
| **data\_logger.model**  None  String  Free Form | Model version of the data logger. | falcon5 |

Attributes for Run Continued

|  |  |  |
| --- | --- | --- |
| **Metadata Key** | **Description** | **Example** |
| **data\_logger.power\_source.comments**  None  String  Name | Any comment about the power source. | Used a solar panel and it was cloudy. |
| **data\_logger.power\_source.id**  None  String  name | Battery ID or name | battery01 |
| **data\_logger.power\_source.type**  None  String  name | Battery type | pb-acid gel cell |
| **data\_logger.power\_source.voltage.end**  volts  Float  Number | End voltage |  |
| **data\_logger.power\_source.voltage.start**  volts  Float  Number | Starting voltage |  |
| **data\_logger.timing\_system.comments**  None  String  Free Form | Any comment on timing system that might be useful for the user. | GPS locked with internal quartz clock |
| **data\_logger.timing\_system.drift**  seconds  Float  Number | Estimated drift of the timing system. |  |

Attributes for Run Continued

|  |  |  |
| --- | --- | --- |
| **Metadata Key** | **Description** | **Example** |
| **data\_logger.timing\_system.type**  None  String  Free Form | Type of timing system used in the data logger. | GPS |
| **data\_logger.timing\_system.uncertainty**  seconds  Float  Number | Estimated uncertainty of the timing system. |  |
| **data\_logger.type**  None  String  Free Form | Type of data logger, this should specify the bit rate and any other parameters of the data logger. | broadband 32-bit |
| **data\_type**  None  String  Controlled Vocabulary | Type of data recorded for this run. Options: [ RMT AMT BBMT LPMT ULPMT ... ] | BBMT |
| **id**  None  String  Alpha Numeric | Name of the run. Should be station name followed by an alphabet letter for the run. | MT302b |
| **metadata\_by.author**  None  String  Free Form | Person who input the metadata. | Metadata Zen |
| **metadata\_by.comments**  None  String  Free Form | Any comments about the metadata that would be useful for the user. | Undergraduate did the input. |

Attributes for Run

|  |  |  |
| --- | --- | --- |
| **Metadata Key** | **Description** | **Example** |
| **provenance.comments**  None  String  Free Form | Any comments on provenance of the data that would be useful to users. | all good |
| **provenance.log**  None  String  Free Form | A history of changes made to the data. | -02-10 T14:24:45 +00:00 updated metadata |
| **sampling\_rate**  samples per second  Float  Number | Sampling rate for the recorded run. |  |
| **time\_period.end**  None  String  Date Time | End date and time of collection in UTC. | -02-04 T16:23:45.453670 +00:00 |
| **time\_period.start**  None  String  Date Time | Start date and time of collection in UTC. | -02-01 T09:23:45.453670 +00:00 |

[tab:]

## Example Run JSON

{  
 "run": {  
 "acquired\_by.author": "Magneto",  
 "acquired\_by.comments": "No hands all telekinesis.",  
 "channels\_recorded\_auxiliary": ["temperature", "battery"],  
 "channels\_recorded\_electric": ["Ex", "Ey"],  
 "channels\_recorded\_magnetic": ["Hx", "Hy", "Hz"],  
 "comments": "Good solar activity",  
 "data\_logger.firmware.author": "Engineer 01",  
 "data\_logger.firmware.name": "MTDL",  
 "data\_logger.firmware.version": "12.23a",  
 "data\_logger.id": "DL01",  
 "data\_logger.manufacturer": "MT Gurus",  
 "data\_logger.model": "Falcon 7",  
 "data\_logger.power\_source.comments": "Used solar panel but cloudy",  
 "data\_logger.power\_source.id": "Battery\_07",  
 "data\_logger.power\_source.type": "Pb-acid gel cell 72 Amp-hr",  
 "data\_logger.power\_source.voltage.end": 14.1,  
 "data\_logger.power\_source.voltage.start": 13.7,  
 "data\_logger.timing\_system.comments": null,  
 "data\_logger.timing\_system.drift": 0.000001,  
 "data\_logger.timing\_system.type": "GPS + internal clock",  
 "data\_logger.timing\_system.uncertainty": 0.0000001,  
 "data\_logger.type": "Broadband 32-bit 5 channels",  
 "data\_type": "BBMT",  
 "id": "YKN201b",  
 "metadata\_by.author": "Graduate Student",  
 "metadata\_by.comments": "Lazy",  
 "provenance.comments": "Data found on old hard drive",  
 "provenance.log": "2020-01-02 Updated metadata from old records",  
 "sampling\_rate": 256,  
 "time\_period.end": "1999-06-01T15:30:00+00:00",  
 "time\_period.start": "1999-06-5T20:45:00+00:00"  
 }  
}

# Electric Channel

Electric channel refers to a dipole measurement of the electric field for a single station for a single run.

Attributes for Electric

|  |  |  |
| --- | --- | --- |
| **Metadata Key** | **Description** | **Example** |
| **ac.end**  volts  Float  Number | Ending AC value; if more than one measurement input as a list of Number [1 2 ...] | , 49.5 |
| **ac.start**  volts  Float  Number | Starting AC value; if more than one measurement input as a list of Number [1 2 ...] | , 55.8 |
| **channel\_number**  None  Integer  Number | Channel number on the data logger of the recorded channel. |  |
| **comments**  None  String  Free Form | Any comments about the channel that would be useful to a user. | Lightning storm at 6pm local time |
| **component**  None  String  Controlled Vocabulary | Name of the component measured. Options: | Ex |
| **contact\_resistance.end**  ohms  Float  Number list | Starting contact resistance; if more than one measurement input as a list [1, 2, ... ] | , 1.8 |

[tab:electric]

Attributes for Electric Continued

|  |  |  |
| --- | --- | --- |
| **Metadata Key** | **Description** | **Example** |
| **contact\_resistance.start**  ohms  Float  Number list | Starting contact resistance; if more than one measurement input as a list [1, 2, ... ] | , 1.4 |
| **data\_quality.rating.author**  None  String  Free Form | Name of person or organization who rated the data. | graduate student ace |
| **data\_quality.rating.method**  None  String  Free Form | The method used to rate the data. Should be a descriptive name and not just the name of a software package. If a rating is provided, the method should be recorded. | standard deviation |
| **data\_quality.rating.value**  None  Integer  Number | Rating from 1-5 where 1 is bad, 5 is good, and 0 is unrated. Options: [ 0 1 2 3 4 5 ] |  |
| **data\_quality.warning**  None  String  Free Form | Any warnings about the data that should be noted for users. | periodic pipeline noise |
| **dc.end**  volts  Float  Number | Ending DC value; if more than one measurement input as a list [1, 2, ... ] |  |
| **dc.start**  volts  Float  Number | Starting DC value; if more than one measurement input as a list [1, 2, ... ] |  |

Attributes for Electric Continued

|  |  |  |
| --- | --- | --- |
| **Metadata Key** | **Description** | **Example** |
| **dipole\_length**  meters  Float  Number | Length of the dipole |  |
| **filter.applied**  None  Boolean  List | Boolean if filter has been applied or not. If more than one filter, input as a comma separated list. Needs to be the same length as filter.name. If only one entry is given, it is assumed to apply to all filters listed. | True, True |
| **filter.comments**  None  String  Free Form | Any comments on filters that is important for users. | low pass is not calibrated |
| **filter.name**  None  String  List | Name of filter applied or to be applied. If more than one filter, input as a comma separated list. | counts2mv, lowpass\_electric |
| **measurement\_azimuth**  decimal degrees  Float  Number | Azimuth angle of the channel in the specified survey.orientation.reference\_frame. |  |
| **measurement\_tilt**  decimal degrees  Float  Number | Tilt angle of channel in survey.orientation.reference\_frame. |  |
| **negative.elevation**  meters  Float  Number | Elevation of negative electrode in datum specified at survey level. |  |

Attributes for Electric Continued

|  |  |  |
| --- | --- | --- |
| **Metadata Key** | **Description** | **Example** |
| **negative.id**  None  String  Free Form | Negative electrode ID Number, can be serial number or a designated ID. | electrode01 |
| **negative.latitude**  decimal degrees  Float  Number | Latitude of negative electrode in datum specified at survey level. |  |
| **negative.longitude**  decimal degrees  Float  Number | Longitude of negative electrode in datum specified at survey level. |  |
| **negative.manufacturer**  None  String  Free Form | Person or organization that manufactured the electrode. | Electro-Dudes |
| **negative.model**  None  String  Free Form | Model version of the electrode. | falcon5 |
| **negative.type**  None  String  Free Form | Type of electrode, should specify the chemistry. | Ag-AgCl |
| **positive.elevation**  meters  Float  Number | Elevation of the positive electrode in datum specified at survey level. |  |

Attributes for Electric Continued

|  |  |  |
| --- | --- | --- |
| **Metadata Key** | **Description** | **Example** |
| **positive.id**  None  String  Free Form | Positive electrode ID Number, can be serial Number or a designated ID. | electrode02 |
| **positive.latitude**  decimal degrees  Float  Number | Latitude of positive electrode in datum specified at survey level. |  |
| **positive.longitude**  decimal degrees  Float  Number | Longitude of positive electrode in datum specified at survey level. |  |
| **positive.manufacturer**  None  String  Free Form | Name of group or person that manufactured the electrode. | Electro-Dudes |
| **positive.model**  None  String  Free Form | Model version of the electrode. | falcon5 |
| **positive.type**  None  String  Free Form | Type of electrode, should include chemistry of the electrode. | Pb-PbCl |
| **sample\_rate**  samples per second  Float  Number | Sample rate of the channel. |  |

Attributes for Electric Continued

|  |  |  |
| --- | --- | --- |
| **Metadata Key** | **Description** | **Example** |
| **time\_period.end**  None  String  Date Time | End date and time of collection in UTC | -02-04 T16:23:45.453670 +00:00 |
| **time\_period.start**  None  String  Date Time | Start date and time of collection in UTC. | -02-01T 09:23:45.453670 +00:00 |
| **transformed\_azimuth**  decimal degrees  Float  Number | Azimuth angle of channel that has been transformed into a specified coordinate system. Note this value is only for derivative products from the archived data. |  |
| **transformed\_tilt**  decimal degrees  Float  Number | Tilt angle of channel that has been transformed into a specified coordinate system. Note this value is only for derivative products from the archived data. |  |
| **type**  None  String  Free Form | Data type for the channel. | electric |
| **units**  None  String  Controlled Vocabulary | Units of the data, if archived data should always be in counts. Options: [ counts millivolts ] | counts |

## Example Electric Channel JSON

{  
 "electric": {  
 "ac.end": 10.2,  
 "ac.start": 12.1,  
 "channel\_number": 2,  
 "comments": null,  
 "component": "EX",  
 "contact\_resistance.end": [1.2, 1.3],  
 "contact\_resistance.start": [1.1, 1.4],  
 "data\_quality.rating.author": "mt",  
 "data\_quality.rating.method": "ml",  
 "data\_quality.rating.value": 4,  
 "data\_quality.warning": null,  
 "dc.end": 1.0,  
 "dc.start": 2.0,  
 "dipole\_length": 100.0,  
 "filter.applied": [false],  
 "filter.comments": null,  
 "filter.name": [ "counts2mv", "lowpass"],  
 "measurement\_azimuth": 90.0,  
 "measurement\_tilt": 20.0,  
 "negative.elevation": 100.0,  
 "negative.id": "a",  
 "negative.latitude": 12.12,  
 "negative.longitude": -111.12,  
 "negative.manufacturer": "test",  
 "negative.model": "fats",  
 "negative.type": "pb-pbcl",  
 "positive.elevation": 101.0,  
 "positive.id": "b",  
 "positive.latitude": 12.123,  
 "positive.longitude": -111.14,  
 "positive.manufacturer": "test",  
 "positive.model": "fats",  
 "positive.type": "ag-agcl",  
 "sample\_rate": 256.0,  
 "time\_period.end": "1980-01-01T00:00:00+00:00",  
 "time\_period.start": "2020-01-01T00:00:00+00:00",  
 "type": "electric",  
 "units": "counts"  
 }  
}

# Magnetic Channel

A magnetic channel is a recording of one component of the magnetic field at a single station for a single run.

Attributes for Magnetic

|  |  |  |
| --- | --- | --- |
| **Metadata Key** | **Description** | **Example** |
| **channel\_number**  None  Integer  Number | Channel Number on the data logger. |  |
| **comments**  None  String  Free Form | Any comments about the channel that would be useful to a user. | Pc1 at 6pm local time. |
| **component**  None  String  Controlled Vocabulary | Name of the component measured. Options: | Hx |
| **data\_quality.rating.author**  None  String  Free Form | Name of person or organization who rated the data. | graduate student ace |
| **data\_quality.rating.method**  None  String  Free Form | The method used to rate the data. Should be a descriptive name and not just the name of a software package. If a rating is provided, the method should be recorded. | standard deviation |
| **data\_quality.rating.value**  None  Integer  Number | Rating from 1-5 where 1 is bad, 5 is good, and 0 is unrated. Options: [ 0 1 2 3 4 5 ] |  |

[tab:magnetic]

Attributes for Magnetic Continued

|  |  |  |
| --- | --- | --- |
| **Metadata Key** | **Description** | **Example** |
| **data\_quality.warning**  None  String  Free Form | Any warnings about the data that should be noted for users. | periodic pipeline noise |
| **filter.applied**  None  Boolean  List | Boolean if filter has been applied or not. If more than one filter, input as a comma separated list. Needs to be the same length as filter.name. If only one entry is given, it is assumed to apply to all filters listed. | True, True |
| **filter.comments**  None  String  Free Form | Any comments on filters that is important for users. | low pass is not calibrated |
| **filter.name**  None  String  List | Name of filter applied or to be applied. If more than one filter, input as a comma separated list. | counts2mv, lowpass\_electric |
| **h\_field\_max.end**  nanotesla  Float  Number | Maximum magnetic field strength at end of measurement. |  |
| **h\_field\_max.start**  nanotesla  Float  Number | Maximum magnetic field strength at beginning of measurement. |  |
| **h\_field\_min.end**  nanotesla  Float  Number | Minimum magnetic field strength at end of measurement. |  |

Attributes for Magnetic Continued

|  |  |  |
| --- | --- | --- |
| **Metadata Key** | **Description** | **Example** |
| **h\_field\_min.start**  nt  Float  Number | Minimum magnetic field strength at beginning of measurement. |  |
| **location.elevation**  meters  Float  Number | elevation of magnetometer in datum specified at survey level. |  |
| **location.latitude**  decimal degrees  Float  Number | Latitude of magnetometer in datum specified at survey level. |  |
| **location.longitude**  decimal degrees  Float  Number | Longitude of magnetometer in datum specified at survey level. |  |
| **measurement\_azimuth**  decimal degrees  Float  Number | Azimuth of channel in the specified survey.orientation.reference\_frame. |  |
| **measurement\_tilt**  decimal degrees  Float  Number | Tilt of channel in survey.orientation.reference\_frame. |  |
| **sample\_rate**  samples per second  Float  Number | Sample rate of the channel. |  |

Attributes for Magnetic Continued

|  |  |  |
| --- | --- | --- |
| **Metadata Key** | **Description** | **Example** |
| **sensor.id**  None  String  Free Form | Sensor ID Number or serial Number. | mag01 |
| **sensor.manufacturer**  None  String  Free Form | Person or organization that manufactured the magnetic sensor. | Magnets |
| **sensor.model**  None  String  Free Form | Model version of the magnetic sensor. | falcon5 |
| **sensor.type**  None  String  Free Form | Type of magnetic sensor, should describe the type of magnetic field measurement. | induction coil |
| **time\_period.end**  None  String  Date Time | End date and time of collection in UTC. | -02-04 T16:23:45.453670 +00:00 |
| **time\_period.start**  None  String  Date Time | Start date and time of collection in UTC. | -02-01 T09:23:45.453670 +00:00 |
| **transformed\_azimuth**  decimal degrees  Float  Number | Azimuth angle of channel that has been transformed into a specified coordinate system. Note this value is only for derivative products from the archived data. |  |

Attributes for Magnetic Continued

|  |  |  |
| --- | --- | --- |
| **Metadata Key** | **Description** | **Example** |
| **transformed\_tilt**  decimal degrees  Float  Number | Tilt angle of channel that has been transformed into a specified coordinate system. Note this value is only for derivative products from the archived data. |  |
| **type**  None  String  Free Form | Data type for the channel | magnetic |
| **units**  None  String  Controlled Vocabulary | Units of the data. if archiving should always be counts. Options: [ counts nanotesla ] | counts |

## Example Magnetic Channel JSON

{ "magnetic": {  
 "comments": null,  
 "component": "Hz",  
 "data\_logger": {  
 "channel\_number": 2},  
 "data\_quality": {  
 "warning": "periodic pipeline",  
 "rating": {  
 "author": "M. Tee",  
 "method": "Machine Learning",  
 "value": 3}},  
 "filter": {  
 "name": ["counts2nT", "lowpass\_mag"],  
 "applied": [true, false],  
 "comments": null},  
 "h\_field\_max": {  
 "start": 40000.,  
 "end": 420000.},  
 "h\_field\_min": {  
 "start": 38000.,  
 "end": 39500.},  
 "location": {  
 "latitude": 25.89,  
 "longitude": -110.98,  
 "elevation": 1234.5},  
 "measurement\_azimuth": 0.0,  
 "measurement\_tilt": 180.0,  
 "sample\_rate": 64.0,  
 "sensor": {  
 "id": 'spud',  
 "manufacturer": "F. McAraday",  
 "type": "tri-axial fluxgate",  
 "model": "top hat"},  
 "time\_period": {  
 "end": "2010-01-01T00:00:00+00:00",  
 "start": "2020-01-01T00:00:00+00:00"},  
 "type": "magnetic",  
 "units": "nT"  
 }  
}

# Filters

Filters is a table that holds information on any filters that need to be applied to get physical units, and/or filters that were applied to the data to analyze the signal. This includes calibrations, notch filters, conversion of counts to units, etc. The actual filter will be an array of numbers contained within an array named name and formatted according to type. The preferred format for a filter is a look-up table which programatically can be converted to other formats.

It is important to note that filters will be identified by name and must be consistent throughout the file. Names should be descriptive and self evident. Examples:

* coil\_2284 induction coil Number 2284
* counts2mv conversion from counts to mV
* e\_gain electric field gain
* datalogger\_response\_024 data logger Number 24 response
* notch\_60hz notch filter for 60 Hz and harmonics
* lowpass\_10hz low pass filter below 10 Hz

In each channel there are keys to identify filters that can or have been applied to the data to get an appropriate signal. This can be a list of filter names or a single filter name. An applied key also exists for the user to input whether that filter has been applied. A single Boolean can be provided True if all filters have been applied, or False if none of the filters have been applied. Or applied can be a list the same length as names identifying if the filter has been applied. For example name: "[counts2mv, notch\_60hz, e\_gain]" and applied: "[True, False, True] would indicate that counts2mv and e\_gain have been applied but noth\_60hz has not.

Attributes for Filter

|  |  |  |
| --- | --- | --- |
| **Metadata Key** | **Description** | **Example** |
| **type**  None  String  Controlled Vocabulary | Filter type. Options: [look up poles zeros converter FIR ...] | lookup |
| **name**  None  String  Alpha Numeric | Unique name for the filter such that it is easy to query. See above for some examples. | counts2mv |
| **units\_in**  None  String  Controlled Vocabulary | The input units for the filter. Should be SI units or counts. | counts |
| **units\_out**  None  String  Controlled Vocabulary | The output units for the filter. Should be SI units or counts. | millivolts |
| **calibration\_date**  None  String  Date Time | If the filter is a calibration, include the calibration date. | -01-01 T00:00:00 +00:00 |

[tab:filter]

## Example Filter JSON

{  
 "filter":{  
 "type": "look up",  
 "name": "counts2mv",  
 "units\_in": "counts",  
 "units\_out": "mV",  
 "calibration\_date": "2015-07-01",  
 "comments": "Accurate to 0.001 mV"  
 }  
}

# Auxiliary Channels

Auxiliary channels include state of health channels, temperature, etc.

Attributes for Auxiliary

|  |  |  |
| --- | --- | --- |
| **Metadata Key** | **Description** | **Example** |
| **channel\_number**  None  Integer  Number | Channel Number on the data logger. |  |
| **comments**  None  String  Free Form | Any comments about the channel that would be useful to a user. | Pc1 at 6pm local time. |
| **component**  None  String  Controlled Vocabulary | Name of the component measured. Options: [ temperature battery ... ] | temperature |
| **data\_quality.rating.author**  None  String  Free Form | Name of person or organization who rated the data. | graduate student ace |
| **data\_quality.rating.method**  None  String  Free Form | The method used to rate the data. Should be a descriptive name and not just the name of a software package. If a rating is provided, the method should be recorded. | standard deviation |
| **data\_quality.rating.value**  None  Integer  Number | Rating from 1-5 where 1 is bad, 5 is good, and 0 is unrated. Options: [ 0 1 2 3 4 5 ] |  |

[tab:auxiliary]

Attributes for Auxiliary Continued

|  |  |  |
| --- | --- | --- |
| **Metadata Key** | **Description** | **Example** |
| **data\_quality.warning**  None  String  Free Form | Any warnings about the data that should be noted for users. | periodic pipeline noise |
| **filter.applied**  None  Boolean  List | Boolean if filter has been applied or not. If more than one filter, input as a comma separated list. Needs to be the same length as filter.name. If only one entry is given, it is assumed to apply to all filters listed. | True, True |
| **filter.comments**  None  String  Free Form | Any comments on filters that is important for users. | low pass is not calibrated |
| **filter.name**  None  String  List | Name of filter applied or to be applied. If more than one filter, input as a comma separated list. | counts2mv, lowpass\_auxiliary |
| **location.elevation**  meters  Float  Number | Elevation of channel location in datum specified at survey level. |  |
| **location.latitude**  decimal degrees  Float  Number | Latitude of channel location in datum specified at survey level. |  |
| **location.longitude**  decimal degrees  Float  Number | Longitude of channel location in datum specified at survey level. |  |

Attributes for Auxiliary Continued

|  |  |  |
| --- | --- | --- |
| **Metadata Key** | **Description** | **Example** |
| **measurement\_azimuth**  decimal degrees  Float  Number | Azimuth of channel in the specified survey.orientation.reference\_frame. |  |
| **measurement\_tilt**  decimal degrees  Float  Number | Tilt of channel in survey.orientation.reference\_frame. |  |
| **sample\_rate**  samples per second  Float  Number | Sample rate of the channel. |  |
| **time\_period.end**  None  String  time | End date and time of collection in UTC. | -02-04 T16:23:45.453670 +00:00 |
| **time\_period.start**  None  String  time | Start date and time of collection in UTC. | -02-01 T09:23:45.453670 +00:00 |
| **transformed\_azimuth**  decimal degrees  Float  Number | Azimuth angle of channel that has been transformed into a specified coordinate system. Note this value is only for derivative products from the archived data. |  |
| **transformed\_tilt**  decimal degrees  Float  Number | Tilt angle of channel that has been transformed into a specified coordinate system. Note this value is only for derivative products from the archived data. |  |

Attributes for Auxiliary Continued

|  |  |  |
| --- | --- | --- |
| **Metadata Key** | **Description** | **Example** |
| **type**  None  String  Free Form | Data type for the channel. | temperature |
| **units**  None  String  Controlled Vocabulary | Units of the data. Options: SI units or counts. | celsius |

## Example Auxiliary XML

<auxiliary>  
 <comments>great</comments>  
 <component>Temperature</component>  
 <data\_logger>  
 <channel\_number type="Integer">1</channel\_number>  
 </data\_logger>  
 <data\_quality>  
 <warning>None</warning>  
 <rating>  
 <author>mt</author>  
 <method>ml</method>  
 <value type="Integer">4</value>  
 </rating>  
 </data\_quality>  
 <filter>  
 <name>  
 <i>lowpass</i>  
 <i>counts2mv</i>  
 </name>  
 <applied type="boolean">  
 <i type="boolean">True</i>  
 </applied>  
 <comments>test</comments>  
 </filter>  
 <location>  
 <latitude type="Float" units="degrees">12.324</latitude>  
 <longitude type="Float" units="degrees">-112.03</longitude>  
 <elevation type="Float" units="degrees">1234.0</elevation>  
 </location>  
 <measurement\_azimuth type="Float" units="degrees">0.0</measurement\_azimuth>  
 <measurement\_tilt type="Float" units="degrees">90.0</measurement\_tilt>  
 <sample\_rate type="Float" units="samples per second">8.0</sample\_rate>  
 <time\_period>  
 <end>2020-01-01T00:00:00+00:00</end>  
 <start>2020-01-04T00:00:00+00:00</start>  
 </time\_period>  
 <type>auxiliary</type>  
 <units>celsius</units>  
</auxiliary>

# Option Definitions

Generalized electromagnetic period bands. Some overlap, use the closest definition.

|  |  |  |
| --- | --- | --- |
| **Data Type** | **Definition** | **Sample Rate [samples/s]** |
| AMT | radio magnetotellurics |  |
| BBMT | broadband magnetotellurics | – |
| LPMT | long-period magnetotellurics |  |

[tab:em]

These are the common channel components. More can be added.

|  |  |
| --- | --- |
| **Channel Type** | **Definition** |
| E | electric field measurement |
| H | magnetic field measurement |
| T | temperature |
| Battery | battery |
| SOH | state-of-health |

[tab:channel\_types]

The convention for many MT setups follows the right-hand-rule (Figure [2](#fig:reference)) with X in the northern direction, Y in the eastern direction, and Z positive down. If the setup has multiple channels in the same direction, they can be labeled with a Number. For instance, if you measure multiple electric fields Ex01, Ey01, Ex02, Ey02.

|  |  |
| --- | --- |
| **Direction** | **Definition** |
| x | north direction |
| y | east direction |
| z | vertical direction |
| # {0–9} | variable directions |

[tab:diretions]

1. ***Corresponding Authors:***

   Jared Peacock (<jpeacock@usgs.gov>)

   Andy Frassetto (<andy.frassetto@iris.edu>) [↑](#footnote-ref-20)