

# A Standard for Exchangeable Magnetotelluric Metadata

Working Group for Data Handling and Software - PASSCAL Magnetotelluric  
Program<sup>1</sup>

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Research Institutions for Seismology

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# 1 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, and 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 these time series are incomplete and only loosely standardized, and overall these datasets are not "user friendly". This lack of resources impedes the exchange and broader use of these data beyond a small community of specialists.

The [IRIS PASSCAL MT facility](#) 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](#) advises the development of sustainable data formats and workflows for this facility. Following in the spirit of the standard created for [MT transfer function](#) datasets, this document outlines a new metadata standard for MT time series. This standard is a key pillar of MTH5, a new data format which we propose for the international community of MT practitioners. Further information regarding MTH5 will be available later in 2020.

The Python 3 module written for these standards are found at <https://github.com/kujaku11/MTArchive/tree/tables>.

## 2 General Structure

The metadata for a full MT dataset are structured to cover details from single channel time series to the 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). These categories are: **Survey**, **Station**, **Run**, **DataLogger**, **Electric Channel**, **Magnetic Channel**, and **Auxiliary Channels**. Each of these are described in subsequent sections. Required keywords are labeled as **True** and suggested keywords are labeled as **False** a user should try to use as much of the suggested metadata as possible for a full description of the data.

### 2.1 Metadata Keyword Format

The metadata key names should be self explanatory and they are structured as follows: `{category}.{name}`, where:

- **category** refers to a metadata category 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 `positive.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`.

As described in this document a '.' represents the separator between different categories. The metadata can be stored in many different forms. Common are XML or JSON formats. See examples below for various ways to represent the metadata.

### 2.2 Formatting Standards

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

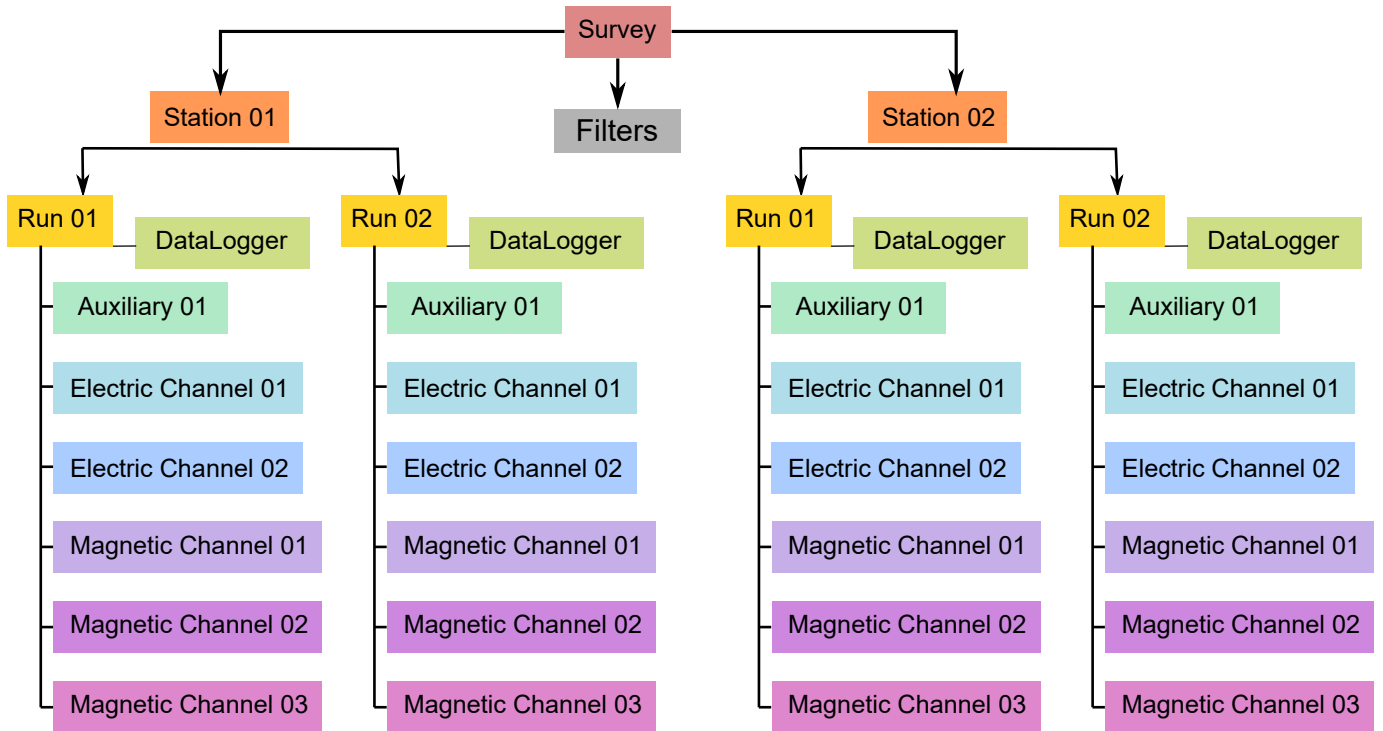


Figure 1: Schematic of a MT time series file structure with appropriate metadata. The top level is the *Survey* that contains general information about who, what, when, where, how the data were collected. Underneath *Survey* are the *Station* and *Filter*. *Filter* contains information about different filters that need to be applied to the raw data to get appropriate units and calibrated measurements. Underneath *Station* are *Run* which are blocks where data were collected at a single sampling rate with common start and end time. Finally *Channel* which describes each channel of data collected, this can be an *Auxiliary*, *Electric*, or *Magnetic*. Metadata is attributed based on the type of data collected in the channel.

### 2.2.1 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 UTC is represented by +00:00. If the data requires a different time zone this can be accommodated but it is recommended that UTC be used whenever possible. Milliseconds can be accurate to 6 decimal places. ISO dates are formatted YYYY-MM-DD.

### 2.2.2 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  $< |90|$  and all longitude values must be  $< |180|$ .
- 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.

### 2.2.3 Angles

All angles of orientation are given in decimal degrees. Orientation of channels should be given in geographic coordinates where angles are assumed to be clockwise positive from Geographic North = 0. If a station was collected not in geographic coordinates this needs to be specified in `station.orientation.option` and the `station.layout.rotation_angle` needs to be specified.

## 2.3 Units

Acceptable units are only those from the International System of Units (SI). Only long names in all lower case are acceptable. Table 1 summarizes common acceptable units:

Table 1: Acceptable units

Measurement Type	Unit Name
Angles	degrees
Distance	meters
Electric Field	millivolts
Latitude/Longitude	decimal degrees
Magnetic Field	nanotesla
Resistance	ohms
Resistivity	ohm-meters
Temperature	celsius
Time	seconds
Voltage	volts

## 2.4 String Formats

Each metadata level has a column that describes the style of the input. These are described in Table 2. Note that any list should be comma separated.

Table 2: 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 Vocabu- lary	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 yet.	station.orientation.option = geographic
list	List of entries using a comma separator	Ex, Ey, Hx, Hy, Hz, T'
Number	A Number in the form of the data type, Number of decimal places has not been implemented yet	10.0 for Float or 10 for int
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	<a href="mailto:person@mt.org">person@mt.org</a>
url	A full URL that a user could put into a web browser	<a href="https://www.passcal.nmt.edu/">https://www.passcal.nmt.edu/</a>

### 3 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. The **Survey** metadata category describes the general parameters of the survey.

Table 3: Attributes for Survey Category

Metadata Key	Description	Example
<b>acquired_by.author</b> Required: True Units: None Type: String Style: 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
<b>acquired_by.comments</b> Required: False Units: None Type: String Style: Email	Email of the contact person who acquired the data. This is in case there are any questions about aspects of how the data were collected or any inconsistencies in the data.	expert digger
<b>archive_id</b> Required: True Units: None Type: String Style: alpha numeric	Alphanumeric name provided by the archive. For IRIS this will be a 5 character String.	YKN20
<b>archive_network</b> Required: True Units: None Type: String Style: 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
<b>citation_dataset.doi</b> Required: True Units: None Type: String Style: url	The full url of the doi Number provided by the archive that describes the raw data	<a href="http://doi.10.adfabe">http://doi.10.adfabe</a>
<b>citation_journal.doi</b> Required: True Units: None Type: String Style: 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.	<a href="http://doi.10.xbsfs">http://doi.10.xbsfs</a> , or <a href="http://doi.10.xbsfs2">http://doi.10.xbsfs2</a>

## Attributes for Survey Category Continued

Metadata Key	Description	Example
<b>comments</b> Required: True Units: None Type: String Style: Free Form	Any comments about the survey that are important for any user to know.	Solar activity low.
<b>country</b> Required: True Units: None Type: String Style: Free Form	Country(s) countries that the survey is located in. If multiple input as comma separated names.	"USA, Canada"
<b>datum</b> Required: True Units: None Type: String Style: 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   other ].	WGS84
<b>geographic_name</b> Required: True Units: None Type: String Style: Free Form	Geographic names that encompass the survey. These should be broad geographic names. Further information can be found at <a href="https://www.usgs.gov/core-science-systems/ngp/board-on-geographic-names">https://www.usgs.gov/core-science-systems/ngp/board-on-geographic-names</a>	Yukon
<b>name</b> Required: True Units: None Type: String Style: Free Form	Descriptive name of the survey, similar to the title of a journal article.	MT      Characteri- zation of Yukon Terrane
<b>northwest_corner.latitude</b> Required: True Units: decimal degrees Type: Float Style: Number	Latitude of the northwest corner of the survey in the datum specified.	23.134
<b>northwest_corner.longitude</b> Required: True Units: decimal degrees Type: Float Style: Number	Longitude of the northwest corner of the survey in the datum specified.	14.23



## Attributes for Survey Category Continued

Metadata Key	Description	Example
<b>project</b> Required: True Units: None Type: String Style: Free Form	Alphanumeric name for the project. This is different than the <code>archive_id</code> in that it describes the overall project. For example if the project is to estimate geomagnetic hazards that project may be GEOMAG but the survey could be YKN20, which will be the <code>archive_id</code> .	GEOMAG
<b>project_lead.author</b> Required: True Units: None Type: String Style: Free Form	Name of the project lead. This should be a person who is responsible for the data.	Magneto
<b>project_lead.Email</b> Required: True Units: None Type: String Style: Email	Email of the project lead. This is in case there are any questions about data.	mt.guru@em.org
<b>project_lead.organization</b> Required: True Units: None Type: String Style: Free Form	Organization name of the project lead.	MT Gurus
<b>release_status</b> Required: True Units: None Type: String Style: Controlled Vocabulary	How the data can be used. The options are based on Creative Commons ( <a href="https://creativecommons.org/licenses/">https://creativecommons.org/licenses/</a> ). Options: [ CC 0   CC BY   CC BY-SA   CC BY-ND   CC BY-NC-SA   CC BY-NC-ND ]	CC 0
<b>southeast_corner.latitude</b> Required: True Units: decimal degrees Type: Float Style: Number	Latitude of the southeast corner of the survey in the datum specified.	23.134
<b>southeast_corner.longitude</b> Required: True Units: decimal degrees Type: Float Style: Number	Longitude of the southeast corner of the survey in the datum specified.	14.23

## Attributes for Survey Category Continued

Metadata Key	Description	Example
<b>summary</b> Required: True Units: None Type: String Style: 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
<b>time_period.end_date</b> Required: True Units: None Type: String Style: date	End date of the survey in UTC.	1995-02-01
<b>time_period.start_date</b> Required: True Units: None Type: String Style: date	Start date of the survey in UTC.	2020-06-21

### 3.1 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_status>CC0</release_status>
  <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>1995-01-01</end_date>
    <start_date>2020-01-01</start_date>
  </time_period>
</survey>
```

## 4 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 are replaced during a run but the station remains stations, then this can be recorded in the **Run** metadata but does not require a new station entry.

Table 4: Attributes for Station Category

Metadata Key	Description	Example
<b>acquired_by.author</b> Required: True Units: None Type: String Style: 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
<b>acquired_by.comments</b> Required: False Units: None Type: String Style: Email	Email of the contact person who collected the data for the station.	expert digger
<b>archive_id</b> Required: True Units: None Type: String Style: alpha numeric	Station name that is archived a-z;A-Z;0-9. For IRIS this is a 5 character String.	MT201
<b>channel_layout</b> Required: False Units: None Type: String Style: Controlled Vocabulary	How the dipoles and magnetic channels of the station were laid out. Options: [ L   +   other]	+
<b>channels_recorded</b> Required: True Units: None Type: String Style: 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   other ]	Ex, Ey, Hx, Hy, Hz, T
<b>comments</b> Required: False Units: None Type: String Style: Free Form	Any comments on the station that would be important for a user.	Pipeline near by.

## Attributes for Station Category Continued

Metadata Key	Description	Example
<b>data_type</b> Required: True Units: None Type: String Style: 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   other ]	BBMT
<b>geographic_name</b> Required: True Units: None Type: String Style: Free Form	Closest geographic name to the station, should be rather general. For further details about geographic names see <a href="https://www.usgs.gov/core-science-systems/ngp/board-on-geographic-names">https://www.usgs.gov/core-science-systems/ngp/board-on-geographic-names</a>	"Whitehorse, YK"
<b>id</b> Required: True Units: None Type: String Style: Free Form	Station name. This can be a longer name than the archive_id name and be a more explanatory name.	bear hallabaloo
<b>location.declination.comment</b> Required: True Units: None Type: String Style: Free Form	Any comments on declination that are important to an end user.	Different than recorded declination from data logger.
<b>location.declination.model</b> Required: True Units: None Type: String Style: Controlled Vocabulary	Name of the geomagnetic reference model as {model_name}{-}{YYYY}. Model options: [ EMAG2   EMM   HDGM   IGRF   WMM ]	WMM-2016
<b>location.declination.value</b> Required: True Units: degrees Type: Float Style: Number	Declination angle relative to geographic north positive clockwise estimated from location and geomagnetic model.	12.3
<b>location.elevation</b> Required: True Units: meters Type: Float Style: Number	Elevation of station location in datum specified at survey level.	123.4

## Attributes for Station Category Continued

Metadata Key	Description	Example
<b>location.latitude</b> Required: True Units: degrees Type: Float Style: Number	Latitude of station location in datum specified at survey level.	23.134
<b>location.longitude</b> Required: True Units: degrees Type: Float Style: Number	Longitude of station location in datum specified at survey level.	14.23
<b>orientation.layout_rotation</b> Required: False Units: degrees Type: Float Style: Number	If the data were collected in a coordinate system that is neither geomagnetic or geographic but still orthogonal this angle will specify the rotation of the layout. For example if you layout your x component N30W and your y component N60E, then the rotation angle would be N30E.	0
<b>orientation.method</b> Required: True Units: None Type: String Style: Controlled Vocabulary	Method for orienting station channels. Options: [ compass   GPS   theodolite   other ]	compass
<b>orientation.option</b> Required: True Units: None Type: String Style: Controlled Vocabulary	How the data are archived with respect to channel orientation. This will help a user orient the data into the proper coordinate system. Options: ['channel-measurement specific', 'geographic orthogonal', 'geomagnetic orthogonal', 'site-specific orthogonal']	geomagnetic-orthogonal
<b>provenance.comments</b> Required: False Units: None Type: String Style: Free Form	Any comments on provenance of the data	From a graduated graduate student.
<b>provenance.creation_time</b> Required: True Units: None Type: String Style: Date Time	date and time the file was created	2020-02-08 T12:23:40.324600 +00:00

# Attributes for Station Category Continued

Metadata Key	Description	Example
<b>provenance.log</b> Required: False Units: None Type: String Style: Free Form	A history of any changes made to the data	2020-02-10 T14:24:45+00:00 updated station metadata.
<b>provenance.software.author</b> Required: True Units: None Type: String Style: Free Form	Author of the software used to create the data files.	programmer 01
<b>provenance.software.name</b> Required: True Units: None Type: String Style: Free Form	Name of the software used to create data files	mtrules
<b>provenance.software.version</b> Required: True Units: None Type: String Style: Free Form	Version of the software used to create data files	12.01a
<b>provenance.submitter.autho</b> Required: True Units: None Type: String Style: Free Form	Name of the person submitting the data to the archive.	person name
<b>provenance.submitter.Email</b> Required: True Units: None Type: String Style: Email	Email of the person submitting the data to the archive.	mt.guru@em.org
<b>provenance.submitter.organ</b> Required: True Units: None Type: String Style: Free Form	Name of the organization that is submitting data to the archive.	MT Gurus

## Attributes for Station Category Continued

Metadata Key	Description	Example
<b>time_period.end</b> Required: True Units: None Type: String Style: Date Time	End date and time of collection in UTC	2020-02-04 T16:23:45.453670 +00:00
<b>time_period.start</b> Required: True Units: None Type: String Style: Date Time	Start date and time of collection in UTC	2020-02-01 T09:23:45.453670 +00:00



## 4.1 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",
    "id": "Curious Bears Hallabaloo",
    "location": {
      "latitude": 10.0,
      "longitude": -112.98,
      "elevation": 1234.0,
      "declination": {
        "value": 12.3,
        "comments": null,
        "model": "WMM"}}},
    "orientation": {
      "method": "compass",
      "option": "geographic",
      "layout_rotation_angle": 0.0},
    "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": "1980-01-01T00:00:00+00:00"}
  }
```

## 5 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. Note that run metadata should be derived from the data.

Table 5: Attributes for Run Category

Metadata Key	Description	Example
<b>acquired_by.author</b> Required: True Units: None Type: String Style: 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
<b>acquired_by.comments</b> Required: False Units: None Type: String Style: Email	Email of the contact person who collected the run.	<a href="mailto:mt@nubee.org">mt@nubee.org</a>
<b>channels_recorded_auxiliar</b> Required: True Units: None Type: String Style: name list	List of auxiliary channels recorded	T, battery
<b>channels_recorded_electric</b> Required: True Units: None Type: String Style: name list	List of electric channels recorded	Ex, Ey
<b>channels_recorded_magnet</b> Required: True Units: None Type: String Style: name list	List of magnetic channels recorded	Hx, Hy, Hz
<b>comments</b> Required: False Units: None Type: String Style: Free Form	Any comments on the run that would be important for a user.	Badger attacked Ex.

## Attributes for Run Category Continued

Metadata Key	Description	Example
<b>comments</b> Required: False Units: None Type: String Style: Free Form	Any comments on the run that would be important for a user.	cows chewed cables at 9am local time.
<b>data_logger.firmware.author</b> Required: True Units: None Type: String Style: Free Form	Author of the firmware that runs the data logger.	instrument engineer
<b>data_logger.firmware.name</b> Required: False Units: None Type: String Style: Free Form	Name of the firmware the data logger runs.	mtrules
<b>data_logger.firmware.version</b> Required: False Units: None Type: String Style: Free Form	Version of the firmware that runs the data logger.	12.01a
<b>data_logger.id</b> Required: False Units: None Type: String Style: Free Form	instrument ID Number can be serial Number or a designated ID	mt01
<b>data_logger.manufacturer</b> Required: True Units: None Type: String Style: Free Form	Name of person or company that manufactured the data logger.	MT Gurus
<b>data_logger.model</b> Required: False Units: None Type: String Style: Free Form	Model version of the data logger.	falcon5

# Attributes for Run Category Continued

Metadata Key	Description	Example
<b>data_logger.power_source.comments</b> Required: False Units: None Type: String Style: name	Any comment about the power source.	Used a solar panel and it was cloudy.
<b>data_logger.power_source.id</b> Required: False Units: None Type: String Style: name	Battery ID or name	battery01
<b>data_logger.power_source.type</b> Required: False Units: None Type: String Style: name	Battery type	pb-acid gel cell
<b>data_logger.power_source.voltage.end</b> Required: False Units: volts Type: Float Style: Number	End voltage	12.1
<b>data_logger.power_source.voltage.start</b> Required: False Units: volts Type: Float Style: Number	Starting voltage	14.3
<b>data_logger.timing_system.comments</b> Required: False Units: None Type: String Style: Free Form	any comment on timing system	GPS locked with internal quartz clock
<b>data_logger.timing_system.drift</b> Required: False Units: seconds Type: Float Style: Number	Estimated drift of the timing system	0.001

## Attributes for Run Category Continued

Metadata Key	Description	Example
<b>data_logger.timing_system.type</b> Required: False Units: None Type: String Style: Free Form	Type of timing system used in the data logger.	GPS
<b>data_logger.timing_system.uncertainty</b> Required: False Units: seconds Type: Float Style: Number	Estimated uncertainty of the timing system.	0.0002
<b>data_logger.type</b> Required: True Units: None Type: String Style: Free Form	Type of data logger, this should specify the bit rate and any other parameters of the data logger.	broadband 32-bit
<b>data_type</b> Required: True Units: None Type: String Style: Controlled Vocabulary	Type of data recorded for this run. Options: [ RMT   AMT   BBMT   LPMT   ULPMT   other]	BBMT
<b>id</b> Required: True Units: None Type: String Style: alpha numeric	Name of the run. Should be station name followed by an alphabet letter for the run.	MT302b
<b>metadata_by.author</b> Required: True Units: None Type: String Style: Free Form	author name	Person who input the metadata.
<b>metadata_by.comments</b> Required: False Units: None Type: String Style: Email	Email of the contact person who input the metadata.	undergraduate

## Attributes for Run Category

Metadata Key	Description	Example
<b>provenance.comments</b> Required: False Units: None Type: String Style: Free Form	Any comments on provenance of the data that would be useful to users.	all good
<b>provenance.log</b> Required: False Units: None Type: String Style: Free Form	A history of changes made to the data.	2020-02-10 T14:24:45 +00:00 updated metadata
<b>sampling_rate</b> Required: True Units: samples per second Type: Float Style: Number	Sampling rate for the recorded run.	100
<b>time_period.end</b> Required: True Units: None Type: String Style: Date Time	End date and time of collection in UTC.	2020-02-04 T16:23:45.453670 +00:00
<b>time_period.start</b> Required: True Units: None Type: String Style: Date Time	Start date and time of collection in UTC.	2020-02-01 T09:23:45.453670 +00:00

## 5.1 Example Run XML Element

```
<run>
  <acquired_by>
    <author>T. Lurric</author>
    <email>mt@mt.org</Email>
  </acquired_by>
  <channels_recorded_auxiliary>[Temperature]</channels_recorded_auxiliary>
  <channels_recorded_electric>[Ex, Ey]</channels_recorded_electric>
  <channels_recorded_magnetic>[Hx, Hy, Hz]</channels_recorded_magnetic>
  <comments>None</comments>
  <data_logger>
    <id>instrument01</id>
    <manufacturer>MT r' US</manufacturer>
    <type>32 bit digital</type>
    <model>best</model>
    <timing_system>
      <comments>Internal clock locked every 10 seconds</comments>
      <drift type="Float" units="seconds">0.00001</drift>
      <type>GPS</type>
      <uncertainty type="Float" units="seconds">0.0001</uncertainty>
    </timing_system>
    <firmware>
      <author>T. Lurric</author>
      <version>12.34c</version>
      <name>MTGDC</name>
    </firmware>
    <power_source>
      <type>Pb-acid gel cell</type>
      <id>10</id>
      <voltage>
        <start type="Float" units="volts">13.9</start>
        <end type="Float" units="volts">12.1</end>
      </voltage>
      <comments>connector cable chewed by rats</comments>
    </power_source>
  </data_logger>
  <data_type>BBMT</data_type>
  <id>mt01a</id>
  <metadata_by>
    <author>student</author>
    <comments>lazy</comments>
  </metadata_by>
  <provenance>
    <comments>redone by grad student</comments>
    <log>2020-01-01T00:00:00+00:00 updated metadata</log>
  </provenance>
  <sampling_rate type="Float" units="samples per second">256.0</sampling_rate>
```

```
<time_period>  
  <start>2020-01-01T00:00:00+00:00</start>  
  <end>2020-02-01T00:00:00+00:00</end>  
</time_period>  
</run>
```



## 6 Electric Channel

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

Table 6: Attributes for Electric Category

Metadata Key	Description	Example
<b>ac.end</b> Required: False Units: volts Type: Float Style: Number	Ending AC value; if more than one measurement input as a list of Number [1 2 ...]	45.3, 49.5
<b>ac.start</b> Required: False Units: volts Type: Float Style: Number	Starting AC value; if more than one measurement input as a list of Number [1 2 ...]	52.1, 55.8
<b>channel_number</b> Required: True Units: None Type: Integer Style: Number	Channel Number on the data logger of the recorded channel.	1
<b>comments</b> Required: False Units: None Type: String Style: Free Form	Any comments about the channel that would be useful to a user.	Lightning storm at 6pm local time
<b>component</b> Required: True Units: None Type: String Style: Controlled Vocabulary	Name of the component measured. Options: [ Ex   Ey   other]	Ex
<b>contact_resistance.end</b> Required: False Units: ohms Type: Float Style: Number list	Starting contact resistance; if more than one measurement input as a list of Number [1 2 ...]	1.5, 1.8

## Attributes for Electric Category Continued

Metadata Key	Description	Example
<b>contact_resistance.start</b> Required: False Units: ohms Type: Float Style: Number list	Starting contact resistance; if more than one measurement input as a list of Number [1 2 ...]	1.2, 1.4
<b>data_quality.rating.author</b> Required: False Units: None Type: String Style: Free Form	Name of person or organization who rated the data.	graduate student ace
<b>data_quality.rating.method</b> Required: False Units: None Type: String Style: Free Form	The method used to rate the data, should be a descriptive name and not just the name of a software package.	standard deviation
<b>data_quality.rating.value</b> Required: True Units: None Type: Integer Style: Number	Rating from 1-5 where 1 is bad and 5 is good and 0 if unrated. Options: [ 0   1   2   3   4   5 ]	4
<b>data_quality.warning</b> Required: False Units: None Type: String Style: Free Form	Any warnings about the data that should be noted for users.	periodic noise pipeline
<b>dc.end</b> Required: False Units: volts Type: Float Style: Number	Ending DC value; if more than one measurement input as a list of Number [1 2 ...]	1.5
<b>dc.start</b> Required: False Units: volts Type: Float Style: Number	Starting DC value; if more than one measurement input as a list of Number [1 2 ...]	1.1

## Attributes for Electric Category Continued

Metadata Key	Description	Example
<b>dipole_length</b> Required: True Units: meters Type: Float Style: Number	Length of the dipole	55.25
<b>filter.applied</b> Required: True Units: None Type: boolean Style: name 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 name or if only one entry is given it is assumed to apply to all filters listed.	True, False
<b>filter.comments</b> Required: False Units: None Type: String Style: name	Any comments on filters that is important for users.	low pass is not calibrated
<b>filter.name</b> Required: True Units: None Type: String Style: name list	Name of filter applied or to be applies. If more than one filter input as a comma separated list.	"counts2mv, low-pass_magnetic"
<b>measurement_azimuth</b> Required: True Units: degrees Type: Float Style: Number	Azimuth of channel in geographic coordinates. The submitter must insure that the azimuth is relative to geographic north clockwise positive.	0
<b>negative.elevation</b> Required: True Units: degrees Type: Float Style: Number	Elevation of negative electrode in datum specified at survey level	123.4
<b>negative.id</b> Required: True Units: None Type: String Style: Free Form	Negative electrode ID Number, can be serial number or a designated ID.	electrode01

## Attributes for Electric Category Continued

Metadata Key	Description	Example
<b>negative.latitude</b> Required: True Units: degrees Type: Float Style: Number	Latitude of negative electrode in datum specified at survey level.	23.134
<b>negative.longitude</b> Required: True Units: degrees Type: Float Style: Number	Longitude of negative electrode in datum specified at survey level.	14.23
<b>negative.manufacturer</b> Required: True Units: None Type: String Style: Free Form	Person or organization that manufactured the electrode.	Electro-Dudes
<b>negative.model</b> Required: False Units: None Type: String Style: Free Form	Model version of the electrode.	falcon5
<b>negative.type</b> Required: True Units: None Type: String Style: Free Form	Type of electrode, should specify the chemistry.	Ag-AgCl
<b>positive.elevation</b> Required: True Units: degrees Type: Float Style: Number	Elevation of the positive electrode in datum specified at survey level.	123.4
<b>positive.id</b> Required: True Units: None Type: String Style: Free Form	Positive electrode ID Number, can be serial Number or a designated ID.	electrode02

## Attributes for Electric Category Continued

Metadata Key	Description	Example
<b>positive.latitude</b> Required: True Units: degrees Type: Float Style: Number	Latitude of positive electrode in datum specified at survey level.	23.134
<b>positive.longitude</b> Required: True Units: degrees Type: Float Style: Number	Longitude of positive electrode in datum specified at survey level.	14.23
<b>positive.manufacturer</b> Required: True Units: None Type: String Style: Free Form	Name of group or person that manufactured the electrode.	Electro-Dudes
<b>positive.model</b> Required: False Units: None Type: String Style: Free Form	Model version of the electrode.	falcon5
<b>positive.type</b> Required: True Units: None Type: String Style: Free Form	Type of electrode, should include chemistry of the electrode.	Pb-PbCl
<b>sample_rate</b> Required: True Units: samples per second Type: Float Style: Number	Sample rate of the channel.	8
<b>time_period.end</b> Required: True Units: None Type: String Style: Date Time	End date and time of collection in UTC	2020-02-04 T16:23:45.453670 +00:00

## Attributes for Electric Category Continued

Metadata Key	Description	Example
<b>time_period.start</b> Required: True Units: None Type: String Style: Date Time	Start date and time of collection in UTC.	2020-02-01T 09:23:45.453670 +00:00
<b>type</b> Required: True Units: None Type: String Style: Free Form	Data type for the channel.	electric
<b>units</b> Required: True Units: None Type: String Style: Controlled Vocabulary	Units of the data, if archived data should always be in counts. Options: [ counts   millivolts ]	counts

## 6.1 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,
    "contact_resistance.start": 1.1,
    "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,
    "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"
  }
}
```

## 7 Magnetic Channel

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

Table 7: Attributes for Magnetic Category

Metadata Key	Description	Example
<b>channel_number</b> Required: True Units: None Type: Integer Style: Number	Channel Number on the data logger.	1
<b>comments</b> Required: False Units: None Type: String Style: Free Form	Any comments about the channel that would be useful to a user.	Pc1 at 6pm local time.
<b>component</b> Required: True Units: None Type: String Style: Controlled Vocabulary	Name of the component measured. Options: [ Hx   Hy   Hz   other]	Hx
<b>data_quality.rating.author</b> Required: False Units: None Type: String Style: Free Form	Name of person or organization who rated the data.	graduate student ace
<b>data_quality.rating.method</b> Required: False Units: None Type: String Style: Free Form	The method used to rate the data, should be a descriptive name and not just the name of a software package.	standard deviation
<b>data_quality.rating.value</b> Required: True Units: None Type: Integer Style: Number	Rating from 1-5 where 1 is bad and 5 is good and 0 if unrated. Options: [ 0   1   2   3   4   5 ]	4



## Attributes for Magnetic Category Continued

Metadata Key	Description	Example
<b>data_quality.warning</b> Required: False Units: None Type: String Style: Free Form	Any warnings about the data that should be noted for users.	periodic noise      pipeline
<b>filter.applied</b> Required: True Units: None Type: boolean Style: name 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 name or if only one entry is given it is assumed to apply to all filters listed.	True, False
<b>filter.comments</b> Required: False Units: None Type: String Style: name	Any comments on filters that is important for users.	low pass is not calibrated
<b>filter.name</b> Required: True Units: None Type: String Style: name list	Name of filter applied or to be applies. If more than one filter input as a comma separated list.	"counts2mv, low-pass_magnetic"
<b>h_field_max.end</b> Required: False Units: nanotesla Type: Float Style: Number	Maximum magnetic field strength at end of measurement.	34526.1
<b>h_field_max.start</b> Required: False Units: nanotesla Type: Float Style: Number	Maximum magnetic field strength at beginning of measurement.	34565.2
<b>h_field_min.end</b> Required: False Units: nanotesla Type: Float Style: Number	Minimum magnetic field strength at end of measurement.	50453.2

## Attributes for Magnetic Category Continued

Metadata Key	Description	Example
<b>h_field_min.start</b> Required: False Units: nt Type: Float Style: Number	Minimum magnetic field strength at beginning of measurement.	40345.1
<b>location.elevation</b> Required: False Units: degrees Type: Float Style: Number	elevation of magnetometer in datum specified at survey level.	123.4
<b>location.latitude</b> Required: False Units: degrees Type: Float Style: Number	Latitude of magnetometer in datum specified at survey level.	23.134
<b>location.longitude</b> Required: False Units: degrees Type: Float Style: Number	Longitude of magnetometer in datum specified at survey level.	14.23
<b>measurement_azimuth</b> Required: True Units: degrees Type: Float Style: Number	Azimuth of channel in geographic coordinates. The submitter must insure that the azimuth is relative to geographic north clockwise positive.	0
<b>sample_rate</b> Required: True Units: samples per second Type: Float Style: Number	Sample rate of the channel.	8
<b>sensor.id</b> Required: True Units: None Type: String Style: Free Form	Sensor ID Number or serial Number.	mag01

# Attributes for Magnetic Category Continued

Metadata Key	Description	Example
<b>sensor.manufacturer</b> Required: True Units: None Type: String Style: Free Form	Person or organization that manufactured the magnetic sensor.	Magnets
<b>sensor.model</b> Required: False Units: None Type: String Style: Free Form	Model version of the magnetic sensor.	falcon5
<b>sensor.type</b> Required: True Units: None Type: String Style: Free Form	Type of magnetic sensor, should describe the type of magnetic field measurement.	induction coil
<b>time_period.end</b> Required: True Units: None Type: String Style: Date Time	End date and time of collection in UTC.	2020-02-04 T16:23:45.453670 +00:00
<b>time_period.start</b> Required: True Units: None Type: String Style: Date Time	Start date and time of collection in UTC.	2020-02-01 T09:23:45.453670 +00:00
<b>type</b> Required: True Units: None Type: String Style: Free Form	Data type for the channel	magnetic
<b>units</b> Required: True Units: None Type: String Style: Controlled Vocabulary	units of the data. if archiving should always be counts. Options: [ counts   nanotesla ]	counts

## 7.1 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,
    "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"
  }
}
```

## 8 Filters

**Filters** is a table that holds information on any filters that need to be applied to get physical units, and 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 internally 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_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. Can be a single Boolean **True** if all filters have been applied, **False** if none of the filters have been applied. Or can be a list the same length and the filter list identifying if the filter has been applied. **name**: "[counts2mv, notch\_60hz, e\_gain]" and **applied**: "[True, False, True]".

### 8.1 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"
  }
}
```

Table 8: Attributes for Filter Category

Metadata Key	Description	Example
<b>type</b> Required: True Units: None Type: String Style: Controlled Vocabulary	Filter type. Options: [look up   poles zeros   converter   FIR   ...]	lookup
<b>name</b> Required: True Units: None Type: String Style: alpha numeric	Unique name for the filter such that it is easy to query. See above for some examples.	counts2mv
<b>units_in</b> Required: True Units: None Type: String Style: Controlled Vocabulary	The input units for the filter. Should be SI units or counts.	counts
<b>units_out</b> Required: True Units: None Type: String Style: Controlled Vocabulary	The output units for the filter. Should be SI units or counts.	millivolts
<b>calibration_date</b> Required: False Units: None Type: String Style: Date Time	If the filter is a calibration include the calibration date.	2010-01-01 T00:00:00 +00:00

## 9 Auxiliary Channels

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

Table 9: Attributes for Auxiliary Category

Metadata Key	Description	Example
<b>channel_number</b> Required: True Units: None Type: Integer Style: Number	Channel Number on the data logger.	1
<b>comments</b> Required: False Units: None Type: String Style: Free Form	Any comments about the channel that would be useful to a user	Pc1 at 6pm local time.
<b>component</b> Required: True Units: None Type: String Style: Controlled Vocabulary	Name of the component measured. Options: [ temperature   battery   other]	temperature
<b>data_quality.rating.author</b> Required: False Units: None Type: String Style: Free Form	Name of person or organization who rated the data	graduate student ace
<b>data_quality.rating.method</b> Required: False Units: None Type: String Style: Free Form	The method used to rate the data, should be a descriptive name and not just the name of a software package.	standard deviation
<b>data_quality.rating.value</b> Required: True Units: None Type: Integer Style: Number	Rating from 1-5 where 1 is bad and 5 is good and 0 if unrated. Options: [ 0   1   2   3   4   5 ]	4

## Attributes for Auxiliary Category Continued

Metadata Key	Description	Example
<b>data_quality.warning</b> Required: False Units: None Type: String Style: Free Form	Any warnings about the data that should be noted for users.	periodic noise      pipeline
<b>filter.applied</b> Required: True Units: None Type: boolean Style: name 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 name or if only one entry is given it is assumed to apply to all filters listed.	True, False
<b>filter.comments</b> Required: False Units: None Type: String Style: name	Any comments on filters that is important for users.	low pass is not calibrated
<b>filter.name</b> Required: True Units: None Type: String Style: name list	Name of filter applied or to be applies. If more than one filter input as a comma separated list	"counts2mv, low-pass"
<b>location.elevation</b> Required: False Units: degrees Type: Float Style: Number	Elevation of channel location in datum specified at survey level.	123.4
<b>location.latitude</b> Required: False Units: degrees Type: Float Style: Number	Latitude of channel location in datum specified at survey level.	23.134
<b>location.longitude</b> Required: False Units: degrees Type: Float Style: Number	Longitude of channel location in datum specified at survey level.	14.23



# Attributes for Auxiliary Category Continued

Metadata Key	Description	Example
<b>measurement_azimuth</b> Required: True Units: degrees Type: Float Style: Number	Azimuth of channel in geographic coordinates. The user must insure all azimuths are relative to geographic north positive clockwise for archiving.	0
<b>sample_rate</b> Required: True Units: samples per second Type: Float Style: Number	Sample rate of the channel.	8
<b>time_period.end</b> Required: True Units: None Type: String Style: time	End date and time of collection in UTC.	2020-02-04 T16:23:45.453670 +00:00
<b>time_period.start</b> Required: True Units: None Type: String Style: time	Start date and time of collection in UTC.	2020-02-01 T09:23:45.453670 +00:00
<b>type</b> Required: True Units: None Type: String Style: Free Form	Data type for the channel.	temperature
<b>units</b> Required: True Units: None Type: String Style: Controlled Vocabulary	Units of the data. Options: SI units or counts.	celsius

## 9.1 Example Auxiliary JSON

```
<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>
  <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>
```

## A Option Definitions

Table 10: Generalized electromagnetic period bands. Some overlap, use the closest definition.

Data Type	Definition	Period Range [s]
RMT	radio magnetotellurics	$10^{-6} - 10^{-4}$
AMT	audio magnetotellurics	$10^{-4} - 10^0$
BBMT	broadband magnetotellurics	$10^{-1} - 10^3$
LPMT	long period magnetotellurics	$10^2 - 10^5$
ULPMT	ultra long period magnetotellurics	$10^5 - 10^7$

Table 11: 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 channel

Table 12: Channel Direction. The convention for many MT setups follows the right-hand-rule 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