A Standard for Exchangeable Magnetotelluric Metadata

Working Group for Data Handling and Software - PASSCAL Magnetotelluric Program[1]

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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.

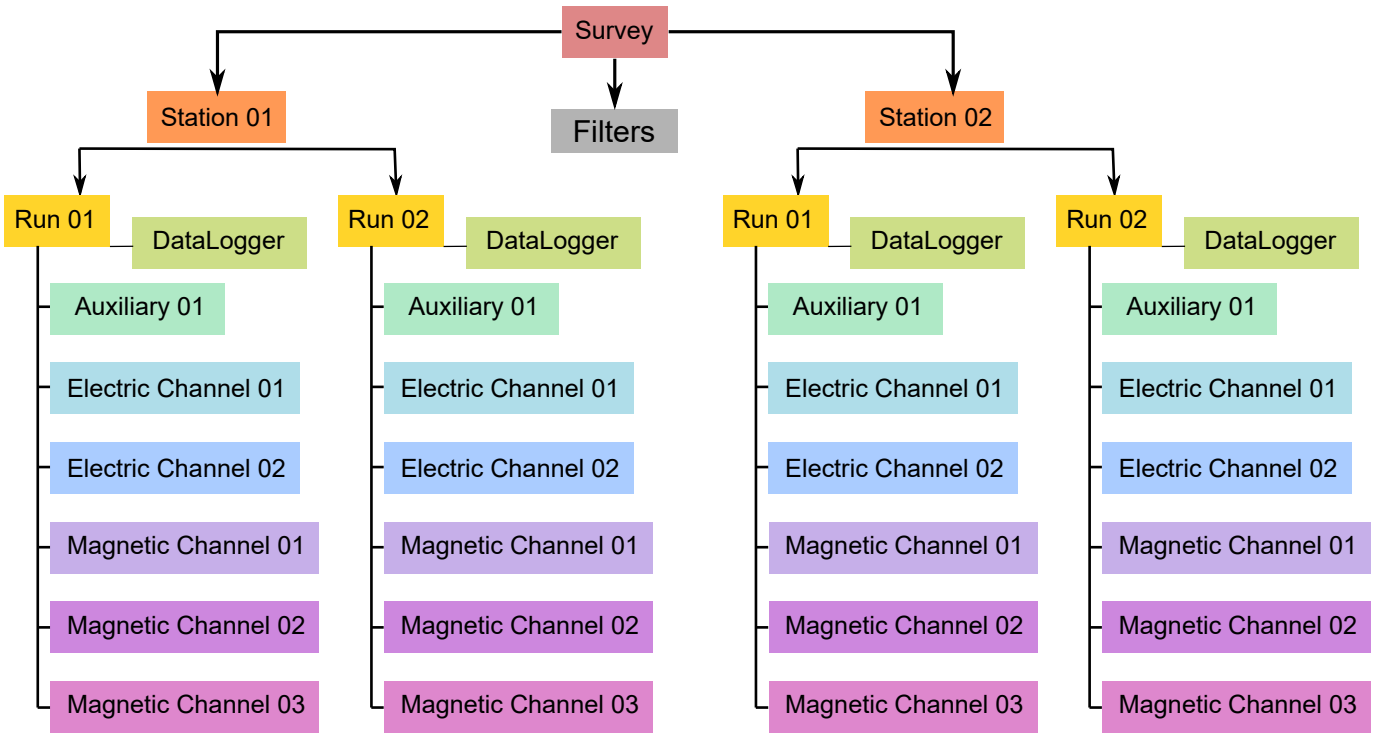

Figure 1: Schematic of a MT time series file structure with appropriate metadata. The top level is the *Survey* that contains general information about who, what, when, where, how the data were collected. Underneath *Survey* are the *Station* and *Filter*. *Filter* contains information about different 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.

2.1 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 $\longrightarrow$ `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.

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

Units should all be from the metric system. Abbreviations and full names are acceptable, for example `mV` and `millivolts`. Table 1 summarizes common acceptable units:

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 1: Acceptable units

Measurement Type	**Unit Long Name**	**Unit Short Name**
Angles	degrees	deg
Distance	meters	m
Latitude/Longitude	decimal degrees	deg
Resistance	Ohms	Ohms
Resistivity	Ohm-meters	Ohm-m, Ohmm
Temperature	Celsius	C
Time	seconds	s
Voltage	Volts	V

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 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 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	person@mt.org
url	a full URL that a user could put into a web browser	https://www.passcal.nmt.edu/

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	Type	Required	Style
acquired_by.author	who acquired the data, this can be different than the project_lead if a contractor was used	string	True	free form
acquired_by.comments	comments about who acquired the data, could include the various groups or contractors	string	False	free form
archive_id	alphanumeric name for the project e.g USGS-GEOMAG	string	True	alpha numeric
archive_network	network code given by PASSCAL/IRIS/FDSN	string	True	alpha numeric
citation_dataset.doi	citation dataset doi number	string	True	url
citation_journal.doi	citation journal doi	string	False	url
comments	comments about survey that are not in the summary	string	False	free form
country	country/countries survey located in, if multiple they should be comma separated	string	False	free form
datum	datum of latitude and longitude coordinates, should be a well-known datum [WGS84] and will be the reference datum for all location	string	True	alpha numeric
geographic_name	geographic location(s) of survey in general terms	string	True	free form
name	descriptive name of the survey	string	True	free form
northwest_corner.latitude	location of northwest corner of survey	float	True	number
northwest_corner.longitude	location of northwest corner of survey	float	True	number
project	alphanumeric name for the project e.g USGS-GEOMAG	string	True	alpha numeric
project_lead.email	email address of the project lead	string	True	email
project_lead.name	name of the project lead	string	True	free form
project_lead.organization	name of the organization for the project lead	string	True	free form
release_status	defined status of how the data can be used. Options are [Unrestricted Release | Paper Citation Required | Academic Use Only | Conditions Apply]	string	True	controlled vocabulary
southeast_corner.latitude	location of southeast corner of survey	float	True	number
southeast_corner.longitude	location of southeast corner of survey	float	True	number
summary	summary paragraph of survey including the purpose, difficulties, data quality, summary of outcomes if the data have been processed and modeled	string	True	free form
time_period.end_date	end date of survey in UTC	string	True	date
time_period.start_date	start date of survey in UTC	string	True	date

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>Unrestricted Release</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.
             Evidence for crustal shortening during the Miocene and
             multiple plutonic events. </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. 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	Type	Required	Style
acquired_by.author	person who acquired the station	string	True	free form
acquired_by.comments	comments about who acquired the data, could include the various groups or contractors	string	True	free form
archive_id	5 char name {A-Z; 1-9} for station	string	True	alpha numeric
channel_layout	how the station was laid out. Options [X | L | ...]	string	True	controlled vocabulary
channels_recorded	list of channels recorded e.g. 'Ex, Ey, Hx, Hy'	string	True	list
comments	any comments about station	string	False	free form
data_type	type of data collected, options: [BBMT | LPMT | AMT | Combo | ...] see Table 11	string	True	controlled vocabulary
geographic_name	closest geographic reference name to station	string	True	free form
id	name of the station	string	True	free form
location.declination.comments	comments on the declination	string	True	
location.declination.model	name of the declination model. Options: [EMAG2 | EMM | HDGM | IGRF | WMM] see https://www.ngdc.noaa.gov/geomag/ for definitions	string	True	controlled vocabulary
location.declination.value	declination value	float	True	number
location.latitude	longitude location for station	float	True	number
location.longitude	latitude location for station	float	True	number
location.elevation	elevation of station	float	True	number
orientation.option	orientation coordinate system [geographic | geomagnetic | channel-measurement specific | ...]	string	True	controlled vocabulary
orientation.method	method of orienting the channels [compass | differential GPS | gyroscope |...]	string	False	controlled vocabulary
orientation.layout_rotation_angle	if the data were collected in a coordinate system not geographic, this will specify the angle at which all channels were rotated by.	float	False	number
provenance.creation_time	creation time of time series data for storing	string	True	date time
provenance.comments	any comments on the history of the data	string	False	free form
provenance.log	log of any changes made to time series data	string	False	free form
provenance.software.author	author of software used to store time series	string	True	free form
provenance.software.name	name of software used to store time series	string	True	free form
provenance.software.version	version of software used to store time series	string	True	free form
provenance.submitter.author	name of person or group archive data	string	True	free form
provenance.submitter.email	email of person or group archiving	string	True	email
provenance.submitter.organization	name of organization or institution archiving	string	True	free form
time_period.start	start time and date of data logging in UTC	string	True	date time
time_period.end	stop time and date of data logging in UTC	string	True	date time

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.

Table 5: Attributes for Run category

Metadata Key	Description	Type	Required	Style
acquired_by.author	author name	string	True	free form
acquired_by.comments	email of the contact person	string	False	email
channels_recorded_auxiliary	list of auxiliary channels recorded	string	True	list
channels_recorded_electric	list of electric channels recorded. See Table 12 and Table 13	string	True	list
channels_recorded_magnetic	list of magnetic channels recorded. See Table 12 and Table 13	string	True	list
comments	any comments on the run. See Table 12 and Table 13	string	False	free form
data_logger.firmware.author	author of the firmware	string	False	free form
data_logger.firmware.name	firmware name	string	False	free form
data_logger.firmware.version	firmware version	string	False	free form
data_logger.id	instrument ID number can be serial number or a designated ID	string	True	free form
data_logger.manufacturer	who manufactured the instrument	string	True	free form
data_logger.model	model version of the instrument	string	False	free form
data_logger.power_source.comments	any comment about the battery	string	False	free form
data_logger.power_source.id	battery id	string	False	free form
data_logger.power_source.type	battery type	string	True	free form
data_logger.power_source.voltage.end	end voltage	float	False	number
data_logger.power_source.voltage.start	starting voltage	float	False	number
data_logger.timing_system.comments	any comment on timing system	string	False	free form
data_logger.timing_system.drift	estimated drift of the timing system	float	False	number
data_logger.timing_system.type	type of timing system	string	False	free form
data_logger.timing_system.uncertainty	estimated uncertainty of the timing system	float	False	number
data_logger.type	instrument type	string	True	free form
data_type	type of data recoreded for this run. Options: [BBMT | LPMT | AMT | Combo | ...] see Table 11 for more details	string	True	controlled vocabulary
id	run ID should be station.archive_id{a-z}	string	True	alpha numeric
metadata_by.author	metadata author name	string	True	free form
metadata_by.comments	comments on metadata	string	False	free form
provenance.comments	any comments on provenance of the data	string	False	free form
provenance.log	a history of changes made to the data	string	False	free form
sampling_rate	rate of sampling renureded for this run	float	True	number
time_period.end	maximum end time of all run channels	string	True	date time
time_period.start	minimum start time of all run channels	string	True	date time

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	Type	Required	Style
ac.end	ending AC value; if more than one measurement input as a list of number [1, ...]	float	False	number
ac.start	starting AC value; if more than one measurement input as a list of number [1, ...]	float	False	number
comments	any comments about the channel	string	False	free form
component	name of the component measured. Options: [Ex | Ey | Ez | E#]	string	True	controlled vocabulary
contact_resistance.end	starting contact resistance; if more than one measurement input as a list of number [1, ...]	float	False	number list
contact_resistance.start	starting contact resistance; if more than one measurement input as a list of number [1, ...]	float	False	number list
data_logger.channel_number	channel number on the data logger	integer	True	number
data_quality.rating.author	author of who rated the data	string	False	free form
data_quality.rating.method	the method used to rate the data	string	False	free form
data_quality.rating.value	a rating from 1-5 where 1 is bad and 5 is good and 0 if unrated	integer	True	number
data_quality.warning	any warnings about the data that should be noted	string	False	free form
dc.end	ending DC value; if more than one measurement input as a list of number [1, ...]	float	False	number
dc.start	starting DC value; if more than one measurement input as a list of number [1, ...]	float	False	number
dipole_length	length of the dipole	float	True	number
filter.applied	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.	boolean	True	list
filter.comments	any comments on filters	string	False	name
filter.name	name of filter applied or to be applies. If more than one filter input as a comma separated list	string	True	list
measurement_azimuth	azimuth of channel in measurement coordinates	float	True	number

Table 7: Attributes for Electric category continued

Metadata Key	Description	Type	Required	Style
negative.elevation	elevation of location in datum specified at survey level	float	False	number
negative.id	instrument ID number can be serial number or a designated ID	string	False	free form
negative.latitude	latitude of location in datum specified at survey level	float	False	number
negative.longitude	longitude of location in datum specified at survey level	float	False	number
negative.manufacturer	who manufactured the instrument	string	False	free form
negative.model	model version of the instrument	string	False	free form
negative.type	instrument type	string	True	free form
positive.elevation	elevation of location in datum specified at survey level	float	False	number
positive.id	instrument ID number can be serial number or a designated ID	string	False	free form
positive.latitude	latitude of location in datum specified at survey level	float	False	number
positive.longitude	longitude of location in datum specified at survey level	float	False	number
positive.manufacturer	who manufactured the instrument	string	False	free form
positive.model	model version of the instrument	string	False	free form
positive.type	instrument type	string	True	free form
sample_rate	sample rate	float	True	number
time_period.end	end date and time of collection in UTC	string	True	date time
time_period.start	start date and time of collection in UTC	string	True	date time
type	data type for the channel [electric]	string	True	controlled vocabulary
units	units of the data [counts | V]	string	True	controlled vocabulary

6.1 Example Electric Channel JSON


```
{
 "electric": {
    "ac.end": 10.2,
    "ac.start": 12.1,
    "comments": null,
    "component": "EX",
    "contact_resistance.end": 1.2,
    "contact_resistance.start": 1.1,
    "data_logger.channel_number": 2,
    "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 8: Attributes for Magnetic category

Metadata Key	Description	Type	Required	Style
comments	any comments about the channel	string	False	free form
component	name of the magnetic component measured. Options: [Hx | Hy | Hz | H#]	string	True	controlled vocabulary
data_logger.channel_number	channel number on the data logger	integer	True	number
data_quality.rating.author	author of who rated the data	string	False	free form
data_quality.rating.method	the method used to rate the data	string	False	free form
data_quality.rating.value	a rating from 1-5 where 1 is bad and 5 is good and 0 if unrated	integer	True	number
data_quality.warning	any warnings about the data that should be noted	string	False	free form
filter.applied	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.	boolean	True	list
filter.comments	any comments on filters	string	False	name
filter.name	name of filter applied or to be applies. If more than one filter input as a comma separated list	string	True	list
h_field_max.end	maximum magnetic field strength at end	float	False	number
h_field_max.start	maximum magnetic field strength at beginning	float	False	number
h_field_min.end	minimum magnetic field strength at end	float	False	number
h_field_min.start	minimum magnetic field strength at beginning	float	False	number
location.elevation	elevation of location in datum specified at survey level	float	False	number
location.latitude	latitude of location in datum specified at survey level	float	False	number
location.longitude	longitude of location in datum specified at survey level	float	False	number
measurement_azimuth	azimuth of channel in measurement coordinates	float	True	number
sample_rate	sample rate	float	True	number
sensor.id	instrument ID number can be serial number or a designated ID	string	True	free form
sensor.manufacturer	who manufactured the instrument	string	True	free form
sensor.model	model version of the instrument	string	False	free form
sensor.type	instrument type	string	True	free form
time_period.end	end date and time of collection in UTC	string	True	date time
time_period.start	start date and time of collection in UTC	string	True	date time
type	data type for the channel	string	True	free form
units	units of the data. Options: [counts | nT]	string	True	controlled vocabulary

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` $\longrightarrow$ induction coil number 2284
- `counts2mv` $\longrightarrow$ conversion from counts to mV
- `e_gain` $\longrightarrow$ electric field gain
- `datalogger_024` $\longrightarrow$ data logger number 24 response
- `notch_60hz` $\longrightarrow$ notch filter for 60 Hz and harmonics
- `lowpass_10hz` $\longrightarrow$ 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]"`.

Table 9: Attributes for Filters

Metadata Key	Description	Type	Required	Style
type	type of filter [look up | poles-zeros | converter | FIR | ...]	string	True	controlled vocabulary
name	unique name for the filter such that it is easy to query	string	True	alpha numeric
units_in	units of data going in [counts | mV/km | ...]	string	True	free form
units_out	units of data coming out [counts | mV/km | ...]	string	True	free form
calibration_date	date of calibration	string	True	date time
comments	any comments on the filtering	string	False	free form

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"
    }
}
```

9 Auxiliary Channels

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

Table 10: Attributes for Auxiliary category

Metadata Key	Description	Type	Required	Style
comments	any comments about the channel	string	False	free form
component	name of the component measured. Options [Temperature | batter_voltage | state_of_health | ...]	string	True	controlled vocabulary
data_logger.channel_number	channel number on the data logger	integer	True	number
data_quality.rating.author	author of who rated the data	string	False	free form
data_quality.rating.method	the method used to rate the data	string	False	free form
data_quality.rating.value	a rating from 1-5 where 1 is bad and 5 is good and 0 if unrated	integer	True	number
data_quality.warning	any warnings about the data that should be noted	string	False	free form
filter.applied	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.	boolean	True	list
filter.comments	any comments on filters	string	False	name
filter.name	name of filter applied or to be applies. If more than one filter input as a comma separated list	string	True	list
location.elevation	elevation of location in datum specified at survey level	float	False	number
location.latitude	latitude of location in datum specified at survey level	float	False	number
location.longitude	longitude of location in datum specified at survey level	float	False	number
measurement_azimuth	azimuth of channel in measurement coordinates	float	True	number
sample_rate	sample rate	float	True	number
time_period.end	end date and time of collection in UTC	string	True	date time
time_period.start	start date and time of collection in UTC	string	True	date time
type	data type for the channel	string	True	free form
units	units of the data options are related to the data type [counts | ...]	string	True	controlled vocabulary

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 11: 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 12: 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 13: 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