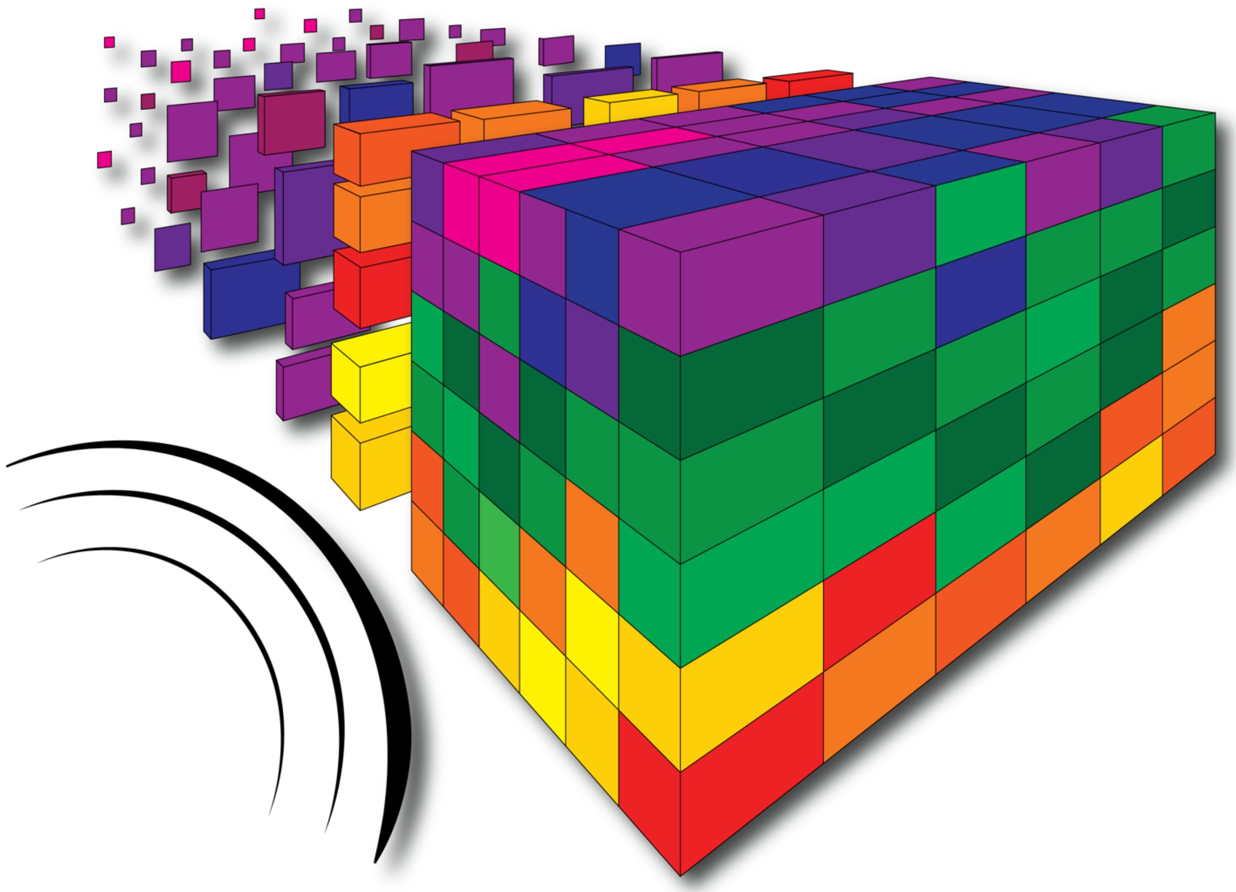
Geophysical Survey (GS) Data Standard and Conventions



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Contents

1. Introduction

The Geophysical Survey (GS) data convention is an open format for the storage and archiving of geophysical datasets and related models. The standard is based on the established NetCDF Climate and Forecast (CF) conventions (http://cfconventions.org/), incorporating specific data structures and best practices pertinent to geophysical surveys. The GS convention is organized in a way to be as generic as possible, accommodating a wide range of geophysical datatypes and survey designs, while adhering to specific data and metadata structures that provide a common architecture regardless of datatype. Our goal is to evolve the GS convention over time based on community input and needs to maximize the impact of a common open data standard.

The GS data convention (James et al., 2022) stores data and metadata in three fundamental group types based on content and data geometry, with groups organized in a hierarchical NetCDF structure (Figure 1A-B). The *Survey* group is at the root of the hierarchical structure for all datasets and contains metadata and other general information about the survey, instrumentation, and datasets within the file. The *Survey* group also contains information about the coordinate reference system, which defines the coordinate system for all child groups and ensures values can be displayed accurately in space. Unstructured data, such as scattered point data typically contained in CSV or ASCII-TXT files, are stored in *Tabular* groups. Data in *Tabular* groups often contain information in a column-row structure, with one or more regularly or irregularly spaced independent variables. *Tabular* datasets have the primary dimension of index, corresponding to the rows of individual measurements. Variables are contained in one or more columns; one-dimensional variables occupy a single column, or variables may have secondary or tertiary dimensions, such as depth or sample time, that occupy multiple columns. Common coordinates of *Tabular* data are defined as the x and y locations of each measurement location and share the dimension of “index”. Structured, or gridded datasets are stored in *Raster* groups. Structured *Raster* data are defined by their regular geometry, with coordinates that describe a regular grid in space, depth, or time. Data variables in a *Raster* group have dimensions that align with two or more coordinates. For both *Tabular* and *Raster* groups, attributes are attached to all variables, as well as the overall dataset group, that provide additional metadata information about the content within the group.

The hierarchical structure is intended to be flexible for storing a wide variety of geophysical datasets within these three groups (*Survey*, *Tabular*, *Raster*). While not required to create or read GS-structured NetCDF files, we have also developed an open-source Python tool, GSPy, to facilitate the use of this standard (Foks et al., 2022; https://doi.org/10.5066/P9XNQVGQ). GSPy provides functions for reading several standard data formats into the GS structure, along with metadata imported through structured JSON files. Once imported, datasets can be viewed, manipulated, and re-exported into standardized NetCDF files, as well as other common file formats.

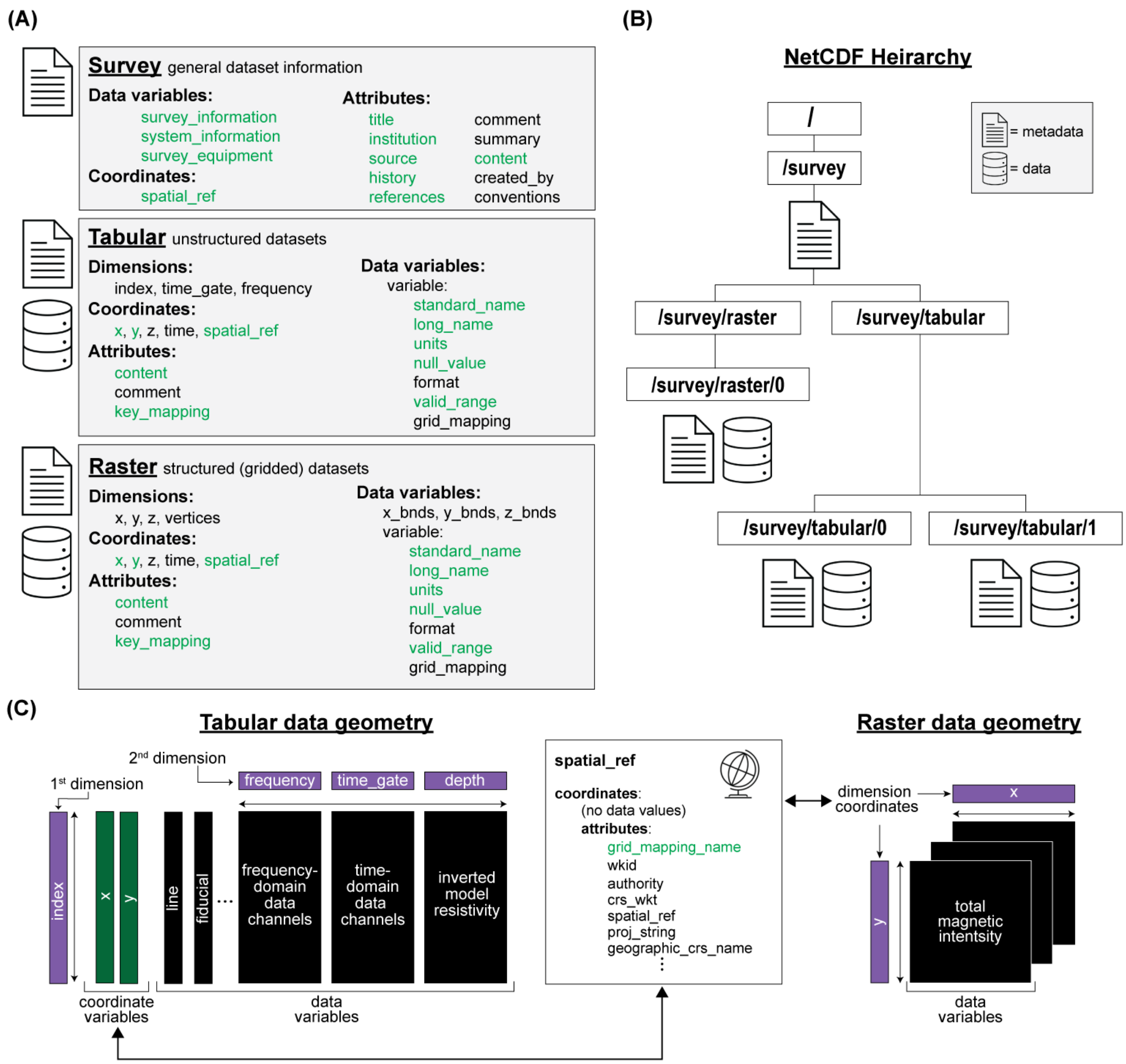

Figure 1. GS data convention (James et al., 2022). (A) Datasets are structured into three fundamental group types based on content and data geometry. The Survey group contains general metadata about the dataset. Unstructured datasets, such as from CSV or TXT files, form Tabular groups, whereas structured (gridded) datasets are categorized under the Raster group. Metadata is attached to all groups, with various required attributes (green text) that expands on the CF-1.8 convention. (B) Groups follow a strict hierarchy in the NetCDF file, with a single Survey group at the top to which all data groups are attached. Datasets are indexed within their respective group type. (C) Tabular and Raster data groups must contain clearly defined dimensions, such as index or x, y, z, as well as coordinate variables. Raster groups are distinct in that dimensions are also coordinates, whereas Tabular datasets are assigned spatial coordinates that align with the index dimension. Lastly, the coordinate variable "spatial_ref" is required for all datasets and is passed from the Survey to all data groups.

2. Survey

Survey is the root group in the GS data standard and must be the top level of any NetCDF file, with the location of /survey. The survey group contains general dataset information—i.e., who, what, where, when, and why—but does not contain data values. Basic survey information is stored as required and optional dataset attributes following the CF conventions, as well as in several dictionaries that contain additional details about the survey, instrumentation, and equipment used. An additional coordinate variable includes information about the coordinate reference system for the survey.

2.1. Dimensions

There are no dimensions within the Survey group because it contains no data variables.

2.2. Coordinates

The Survey group contains a single required coordinate variable, “spatial_ref”, that contains information about the coordinate system of the survey. This coordinate variable is duplicated within individual Tabular (Section 3.2.6) or Raster (Section 4.2.6) groups.

2.2.1. spatial_ref

In the GS standard, the spatial_ref variable serves as the “grid mapping” variable detailed by the CF conventions. The basic requirements of the spatial_ref variable include a grid mapping name together with attributes of the datum and projection parameters (if applicable). For complete details on grid mappings, including required parameters, please see Appendix F of the CF conventions: https://cfconventions.org/cf-conventions/cf-conventions.html#appendix-grid-mappings.

In addition to the requirement of single-property CF grid mapping attributes, a coordinate reference system (CRS) can be represented using several different structured formats, i.e., a well-known identification number (WKID; ESRI, 2016), a well-known text string (WKT; https://www.ogc.org/standards/wkt-crs), and/or a PROJ string (PROJ contributors, 2020). Since different software rely on different CRS representations, the GS standard recommends all variations to be included in the survey’s spatial_ref variable for maximum compatibility. If using the GSPy software, all necessary CRS attributes can be generated from any one of these three formats (WKID, WKT, PROJ string). Therefore, only one input CRS format is required when initializing a survey through GSPy. Further details on required and common spatial_ref attributes are listed below. See Appendix A for a summary of required and recommended coordinate attributes. Note that a copy of the spatial_ref variable is required as a coordinate variable within all data groups to ensure portability.

2.2.1.1. Single-property grid mapping attributes

Each grid mapping contains specific attributes that describe the map parameters. The “grid_mapping_name” attribute is required. Examples of other common attributes associated with the grid mapping are documented in Appendix F and Table F.1 in the CF conventions, https://cfconventions.org/cf-conventions/cf-conventions.html#appendix-grid-mappings. The specific attributes needed will depend on the details of the datum and projection used to define the coordinate system of the survey.

2.2.1.1.1. grid_mapping_name

Character string containing the name of the mapping system, all lowercase with no punctuation other than underscores. The value of “grid_mapping_name” is limited to a set of recognized names. See Appendix F in the CF convention documentation for details on each recognized grid mapping: https://cfconventions.org/cf-conventions/cf-conventions.html#appendix-grid-mappings.

2.2.1.2. crs_wkt

Character string containing the well-known text string for the coordinate reference system, https://www.ogc.org/standards/wkt-crs. The CRS well-known text format is recognized as an optional grid mapping attribute that may be used to specify multiple coordinate system properties. To improve compatibility with software that can interpret well-known text strings, the crs_wkt attribute is intended to act as a supplement, not a replacement, to single-property CF grid mapping attributes (Section 2.2.1.1).

2.2.1.3. wkid

Alphanumeric string containing the well-known ID for the horizontal coordinate system.

2.2.1.3.1. authority

Text string defining the authority of the wkid number, e.g., “EPSG” or “ESRI”.

2.2.1.4. proj_string

Text string of the projection information from PROJ (PROJ contributors, 2020).

2.2.1.5. vertical_crs

Text string with name of the vertical datum, e.g., “NAVD88” or “GRS80”. Vertical datum information is not covered by existing CF grid mapping attributes, but can also be included using VERT_DATUM in a CRS well-known text string (**Error! Reference source not found.**).

2.2.1.6. spatial_ref

Some software may require a “spatial_ref” key within the “spatial_ref” variable which contains a duplicate of the well-known text string from **Error! Reference source not found.**. This field may alternatively be called “esri_pe_string” if working specifically with Esri software.

```
survey.spatial_ref.attrs
```


```
{'crs_wkt': 'PROJCRS["NAD83(HARN) / Wisconsin Transverse Mercator",BASEGEOGCRS["NAD83(HARN)",DATUM["NAD83 (High Accuracy Refere
nce Network)",ELLIPSOID["GRS 1980",6378137,298.257222101,LENGTHUNIT["metre",1]]],PRIMEM["Greenwich",0,ANGLEUNIT["degree",0.0174
532925199433]],ID["EPSG",4152]],CONVERSION["Wisconsin Transverse Mercator 83",METHOD["Transverse Mercator",ID["EPSG",9807]],PAR
AMETER["Latitude of natural origin",0,ANGLEUNIT["degree",0.0174532925199433],ID["EPSG",8801]],PARAMETER["Longitude of natural o
rigin",-90,ANGLEUNIT["degree",0.0174532925199433],ID["EPSG",8802]],PARAMETER["Scale factor at natural origin",0.9996,SCALEUNIT
["unity",1],ID["EPSG",8805]],PARAMETER["False easting",520000,LENGTHUNIT["metre",1],ID["EPSG",8806]],PARAMETER["False northin
g",-4480000,LENGTHUNIT["metre",1],ID["EPSG",8807]]],CS[Cartesian,2],AXIS["easting (X)",east,ORDER[1],LENGTHUNIT["metre",1]],AXI
S["northing (Y)",north,ORDER[2],LENGTHUNIT["metre",1]],USAGE[SCOPE["unknown"],AREA["USA - Wisconsin"],BBOX[42.48,-92.89,47.31,-
86.25]],ID["EPSG",3071]]',
 'semi_major_axis': 6378137.0,
 'semi_minor_axis': 6356752.314140356,
 'inverse_flattening': 298.257222101,
 'reference_ellipsoid_name': 'GRS 1980',
 'longitude_of_prime_meridian': 0.0,
 'prime_meridian_name': 'Greenwich',
 'geographic_crs_name': 'NAD83(HARN)',
 'horizontal_datum_name': 'NAD83 (High Accuracy Reference Network)',
 'projected_crs_name': 'NAD83(HARN) / Wisconsin Transverse Mercator',
 'grid_mapping_name': 'transverse_mercator',
 'latitude_of_projection_origin': 0.0,
 'longitude_of_central_meridian': -90.0,
 'false_easting': 520000.0,
 'false_northing': -4480000.0,
 'scale_factor_at_central_meridian': 0.9996,
 'wkid': '3071',
 'authority': 'EPSG'}
```


2.3. Attributes

Attributes of the root group follow NetCDF Climate and Forecast (CF) Metadata Conventions v1.10 (https://cfconventions.org/Data/cf-conventions/cf-conventions-1.10/cf-conventions.pdf).

"The following attributes are intended to provide information about where the data came from and what has been done to it. This information is mainly for the benefit of human readers. The attribute values are all character strings."

2.3.1. title

A succinct description of what is in the dataset.

```
survey.title
```

```
'SkyTEM Airborne Electromagnetic (AEM) Survey, Northeast Wisconsin Bedrock Mapping'
```

2.3.2. institution

Specifies where the original data was produced.

```
survey.institution
```

```
'USGS Geology, Geophysics, and Geochemistry Science Center'
```

2.3.3. source

The method of production of the original data. If it was model-generated, source should name the model and its version, as specifically as could be useful. If it is observational, source should characterize it (e.g., "surface observation" or "radiosonde").

```
survey.source
```

```
'SkyTEM raw data, USGS processed data and inverted resistivity models, and depth to bedrock surface'
```

2.3.4. history

Provides an audit trail for modifications to the original data. Well-behaved generic NetCDF filters will automatically append their name and the parameters with which they were invoked to the global history attribute of an input NetCDF file. We recommend that each line begin with a timestamp indicating the date and time of day that the program was executed.

```
survey.history
```

```
'(1) Data acquisition 01/2021 - 02/2021 by SkyTEM Canada Inc.; (2) AEM and magnetic data processing by SkyTEM Canada Inc. 02/20
21 - 03/2021; raw and minimally processed AEM data, and processed magnetic data, received by USGS from SkyTEM Canada Inc 03/202
1; Minimally processed AEM data exported to netCDF /linedata/0 group 11/2021; (3) Minimally processed binary data and system re
sponse information received from the contractor were imported into the Aarhus Workbench software (v 6.0.1.0) where data were pr
ocessed by USGS 03/2021 - 06/2021. Processed AEM data exported to netCDF /linedata/1 group 11/2021; (4) Processed data were inv
erted in Aarhus Workbench software using laterally constrained inversion to recover 40-layer fixed depth blocky resistivity mod
els by USGS 03/2021 - 06/2021; Inverted resistivity models exported to netCDF /linemodel/0 group 11/2021. (5) Resistivity model
s were imported into the Geoscene3D software (v. 12.0.0.680) and points were generated at the first depth where resistivity exc
eeded 325 ohm-meters. These points were visually inspected and manually adjusted in selected areas to produce an AEM-derived es
tmiate of the elevation of the top of bedrock by USGS together with WGNHS 06/2021 - 07/2021. Points were exported to netCDF /li
nedata/2 group 11/2021. (6) Bedrock elevation points were interpolated using kriging in Geoscene3D software to produce a regula
r bedrock elevation grid 07/2021. (7) A bedrock depth grid was calculated in QGIS software (v. 3.14.1-Pi) by subtracting the be
drock elevation from land surface elevation. (8) Bedrock elevation, bedrock depth, and SkyTEM-provided magnetic grids were alig
ned to a common 100m x 100m grid and exported to netCDF /griddata/0 group 11/2021.'
```

2.3.5. references

Published or web-based references that describe the data or methods used to produce it. May also include reference to citation of the published version of this dataset.

```
survey.references
```

```
'Minsley, B.J, Bloss, B.R., Hart, D.J., Fitzpatrick, W., Muldoon, M.A., Stewart, E.K., Hunt, R.J., James, S.R., Foks, N.L., and
Komiskey, M.J., 2022, Airborne electromagnetic and magnetic survey data, northeast Wisconsin (ver. 1.1, June 2022): U.S. Geolog
ical Survey data release, https://doi.org/10.5066/P93SY9LI.'
```

2.3.6. comment

Miscellaneous information about the data or methods used to produce it.

```
survey.comment
```

```
'This dataset includes minimally processed (raw) AEM and raw/processed magnetic data provided by SkyTEM, fully processed data u
sed as input to inversion, laterally constrained inverted resistivity models, and derived estimates of bedrock depth.'
```

2.3.7. abstract

Additional details or ancillary information, for example short abstract or summary describing the data.

```
survey.summary
```

```
'Airborne electromagnetic (AEM) and magnetic survey data were collected during January and February 2021 over a distance of 3,1
70 line kilometers in northeast Wisconsin. These data were collected in support of an effort to improve estimates of depth to b
edrock through a collaborative project between the U.S. Geological Survey (USGS), Wisconsin Department of Agriculture, Trade, a
nd Consumer Protection (DATCP), and Wisconsin Geological and Natural History Survey (WGNHS). Data were acquired by SkyTEM Canad
a Inc. with the SkyTEM 304M time-domain helicopter-borne electromagnetic system together with a Geometrics G822A cesium vapor m
agnetometer. The survey was acquired at a nominal flight height of 30 - 40 m above terrain along parallel flight lines oriented
northwest-southeast with nominal line spacing of 0.5 miles (800 m). AEM data were inverted to produce models of electrical resi
stivity along flight paths, with typical depth of investigation up to about 300 m and 1 - 2 m near-surface resolution. Shallow
resistivity transitions were used to estimate depth to bedrock across the survey area.'
```

2.3.8. content

Description of what is in the NetCDF file. For example, "survey information (/survey), raw data (/survey/tabular/0), processed data (/survey/tabular/1)"

```
survey.content
```

```
'survey information (group /survey), raw data (group /survey/tabular/0), processed data (group /survey/tabular/1), inverted res
istivity models (group /survey/tabular/2), bedrock elevation points (group /survey/tabular/3), gridded magnetic and bedrock map
s (group /survey/raster/0)'
```

2.3.9. created_by

Software version or other methods used to produce the NetCDF file. For example, "gspy==0.1.0"

```
survey.created_by
```

```
'gspy==0.1.0'
```

2.3.10. conventions

Conventions of the data. For example, "CF-1.8, GS-0.1.0"

```
survey.conventions
```

```
'CF-1.8, GS-0.0'
```

2.4. Data variables

Auxiliary information about a survey and the equipment used are documented using data variables, described below, where each data variable is a dictionary that contains multiple key:value pairs. The first several dictionaries are required (**Error! Reference source not found.** - 2.4.3) to conform with the GS standard and ensure basic information about the survey is contained. Flightline information (2.4.4) is recommended for airborne geophysical surveys. Example dictionaries with keys for different survey types are documented in

Appendix B- System information standard templates, Appendix C- Survey equipment standard templates, and Appendix D- Flightline information standard names. The specific contents and key names for these dictionaries can be customized; however, the provided key names are recommended for consistency across common datasets. Additional dictionaries can be specified by the user to record supplementary metadata information pertinent to the survey as data variables within the *Survey* group. Other supplementary metadata specific to a single dataset group should be attached at that level (see Sections 3.3.3 and 4.3.3).

2.4.1. survey_information

This is a dictionary with required and optional keys that describe the basic details of the survey (i.e. who, what, when, where).

2.4.1.1. acquired_for

Text string with name of the institution survey was acquired for.

2.4.1.2. acquired_by

Text string with name of the group who acquired the data. For surveys acquired by a third-party contractor. Text string with name of contractor.

2.4.1.3. contractor_project_number

For surveys acquired by a third-party contractor. Alphanumeric string with contractor-defined project number.

2.4.1.4. survey_type

Text string or list of strings that describes datatype(s) acquired in the survey.

2.4.1.5. survey_area_name

Text string describing the name of the survey area.

2.4.1.6. location

Text string or list of strings with locations where survey was acquired. For example, State, County, Territory, or other geographical description.

2.4.1.7. country

Text string with name of country where survey was acquired.

2.4.1.8. acquisition_start

Text string with acquisition start date in YYYYMMDD format.

2.4.1.9. acquisition_end

Text string with acquisition end date in YYYYMMDD format.

2.4.1.10. survey_attributes_units

Text string with units for numeric values described in the Survey group. Default is “SI”. For example, a time-domain electromagnetic transmitter waveform specified in the system_information dictionary (2.4.2) would have units of seconds for ‘time’ and Amperes for ‘current’.

```
survey.survey_information.attrs
```

```
{'contractor_project_number': '20022',
 'contractor': 'SkyTEM Canada Inc',
 'client': 'U.S. Geological Survey',
 'survey_type': 'EM/Mag',
 'survey_area_name': 'Northeast Wisconsin Bedrock Mapping',
 'state': 'WI',
 'country': 'USA',
 'acquisition_start': '20210117',
 'acquisition_end': '20210207',
 'survey_attributes_units': 'SI'}
```

2.4.2. system_information

This is a dictionary with required and optional keys that describe the specifications of the geophysical instruments used in the survey. At a minimum, these details should capture the information a user would need to process or interpret the data stored within this file.

One or more geophysical systems that comprise a survey can be included here. Users may configure this dictionary in a way that meets the specific requirements of an instrument. Standard instrument attribute names for specific types of surveys are included in

Appendix B- System information standard templates

```
1  survey.system_information.attrs
```


```
{'electromagnetic_system.instrument_type': 'skytem 304M',
 'electromagnetic_system.data_normalized': 'True',
 'electromagnetic_system.number_of_transmitters': 2,
 'electromagnetic_system.number_of_receivers': 2,
 'electromagnetic_system.number_of_components': 4,
 'electromagnetic_system.skytem_skb_gex_available': 'True',
 'electromagnetic_system.reference_frame': 'right-handed positive down',
 'electromagnetic_system.coil_orientations': 'X,Z',
 'electromagnetic_system.sample_rate': '0.1 s',
 'electromagnetic_system.transmitter_0_label': 'LM',
 'electromagnetic_system.transmitter_0_number_of_turns': 1,
 'electromagnetic_system.transmitter_0_coordinates': '[[-12.64, -2.1, 0.0], [-6.14, -8.58, 0.0], [6.14, -8.58, 0.0], [11.41, -
3.31, 0.0], [11.41, 3.31, 0.0], [6.14, 8.58, 0.0], [-6.14, 8.58, 0.0], [-12.64, 2.1, 0.0]]',
 'electromagnetic_system.tranmitter_0_area': 342,
 'electromagnetic_system.transmitter_0_waveform_type': 'trapezoid',
 'electromagnetic_system.transmitter_0_waveform_time': array([-3.1810e-03, -3.1019e-03, -2.9844e-03, -2.3810e-03, -2.3781e-03,
       -2.3779e-03, -2.3776e-03, -2.3763e-03, -8.0000e-04, -7.2093e-04,
       -6.0345e-04,  0.0000e+00,  3.0000e-08,  7.0000e-08,  2.7200e-06,
        2.8000e-06,  2.9000e-06,  3.0100e-06,  3.1300e-06,  3.4100e-06,
        4.7400e-06]),
 'electromagnetic_system.transmitter_0_waveform_current': array([-0.        , -0.14067   , -0.30174   , -1.        , -0.0075094,
        0.022879 ,  0.037669 , -0.       ,  0.       ,  0.14063  ,
        0.30168  ,  1.       ,  0.99851  ,  0.98817  ,  0.05926  ,
        0.032392 ,  0.0075094, -0.012284 , -0.026411 , -0.038086 ,
        0.       ]),
 'electromagnetic_system.transmitter_0_current_scale_factor': 1.0,
 'electromagnetic_system.transmitter_0_peak_current': 9.0,
 'electromagnetic_system.transmitter_0_base_frequency': 210.0,
 'electromagnetic_system.transmitter_0_on_time': 0.0008,
 'electromagnetic_system.transmitter_0_off_time': 0.001581,
 'electromagnetic_system.transmitter_0_orientation': 'z',
 'electromagnetic_system.transmitter_1_label': 'HM',
 'electromagnetic_system.transmitter_1_number_of_turns': 4,
```


2.4.3. survey_equipment

This is a dictionary with required and optional keys that document the physical equipment and instrumentation used in the survey.

Multiple components of equipment and instrumentation that comprise a survey can be included here. Users may configure this dictionary in a way that meets the specific requirements of an instrument. Standard instrument attribute names for specific types of surveys are included in Appendix C- Survey equipment standard templates.

```
1  survey.survey_equipment.attrs
```


```
{'aircraft': 'Eurocopter Astar 350 B3',
 'magnetometer': 'Geometrics G822A, Kroum KMAG4 counter',
 'magnetometer_installation': 'Front of transmitter frame',
 'electromagnetic_system': 'SkyTEM 304M',
 'electromagnetic_installation': 'Rigid transmitter frame 40m beneath helicopter, Receiver coils at rear of transmitter frame 2
m vertical offset',
 'spectrometer_system': 'n/a',
 'spectrometer_installation': 'n/a',
 'spectrometer_sample_rate': 'n/a',
 'radar_altimeter_system': 'n/a',
 'radar_altimeter_sample_rate': 'n/a',
 'laser_altimeter_system': 'MDL ILM 300R (2)',
 'laser_altimeter_sample_rate': '0.033 s',
 'inclinometer_system': 'n/a',
 'inclinometer_sample_rate': 'n/a',
 'navigation_system': 'Real-time differential GPS Trimble Bullet III',
 'navigation_sample_rate': '1.0 s',
 'acquisition_system': 'skytem'}
```


2.4.4. flightline_information

This is a dictionary with optional keys that document information about flight lines and survey design. This basic information is intended to summarize basic survey design parameters.

Recommended standard field names are summarized in Appendix D- Flightline information standard names, though users may include other keys where needed to document survey information.

```
survey.flightline_information.attrs
```


```
{'traverse_line_spacing': '800 m',
 'traverse_line_direction': 'nw-se',
 'tie_line_spacing': 'n/a',
 'tie_line_direction': 'n/a',
 'nominal_terrain_clearance': '30 m',
 'final_line_kilometers': '3170 km',
 'traverse_line_numbers': '100101 - 115201',
 'repeat_line_numbers': '920001 - 920006',
 'pre_zero_line_numbers': 'n/a',
 'post_zero_line_numbers': 'n/a'}
```

3. Tabular

Data in a tabular group contain one or more variables of information typically originating from column-based CSV or TXT files, or similar formats. Each row in a tabular dataset typically represents a measurement or value at one coordinate (location, depth, or time), with values associated with that location listed in columns. Values are stored in data variables, which are typically one-dimensional (a single column of information) or two-dimensional (information in two or more columns). Data variables can be described by more than two dimensions but would need to be manipulated or read-in from a more complex input structure than a column-based table.

Data variables can be organized by several different dimensions and coordinates depending on data type, but at least one dimension and coordinate should be "index", representing the number of rows (or independent measurements) in the input dataset. Additional dimensions and coordinates are needed to describe multi-dimensional variables. For example, a 30-layer resistivity model could be described by a coordinate "layer_depths", which is an array of 30 depths that represent the center of each layer, and the dimension of layer_depths is 30. All resistivity models could then be contained in a two-dimensional data variable "resistivity" with dimensions (index, layer_depths), for example. Likewise, a time-domain electromagnetic dataset with 25 recorded time-gates per sounding location could have a coordinate "gate_times", an array of 25 electromagnetic time gate centers of dimension 25.

The horizontal coordinates of the dataset, if applicable, are specified by the required "x" and "y" coordinate variables. These variables have the dimension of index and contain the latitude and longitude (or easting and northing) coordinate values for each measurement location. When using GSPy, the x and y coordinates are duplicates of the latitude and longitude data variables included in the input dataset. These coordinate variables contain specific attributes and allow tabular datasets to be accurately represented in geospatial software.

In addition to being described by one or more coordinates and dimensions, each coordinate and data variable has attributes attached to it containing metadata about the variable. Some attributes are required, but users may choose to include any additional attributes as desired. Finally, a dataset within a *Tabular* group contains several general attributes that describe the group content and any additional metadata relevant to the dataset.

```
1  tabular[0].keys()
```

```
KeysView(<xarray.Dataset>
Dimensions:            (HM_gate_times: 32, LM_gate_times: 28, nv: 2, index: 1356892)
Coordinates:
  * HM_gate_times      (HM_gate_times) float64 2.886e-05 3.037e-05 ... 0.003544
  * LM_gate_times      (LM_gate_times) float64 -1.135e-06 3.65e-07 ... 0.001394
  * nv                 (nv) int64 0 1
    x                  (index) float64 7.243e+05 7.243e+05 ... 6.602e+05
    y                  (index) float64 4.916e+05 4.916e+05 ... 3.866e+05
    spatial_ref        float64 0.0
    DateTime           (index) float64 4.422e+04 4.422e+04 ... 4.424e+04
  * index              (index) int64 0 1 2 3 ... 1356889 1356890 1356891
Data variables: (12/35)
    LM_gate_times_bnds  (LM_gate_times, nv) float64 -1.42e-06 ... 0.001555
    HM_gate_times_bnds  (HM_gate_times, nv) float64 2.858e-05 ... 0.00394
    E_Nad83            (index) float64 7.243e+05 7.243e+05 ... 6.602e+05
    N_Nad83            (index) float64 4.916e+05 4.916e+05 ... 3.866e+05
    Line               (index) int64 100101 100101 100101 ... 115201 115201
    LM_X               (index, LM_gate_times) float64 -1e+04 -1e+04 ... 0.5186
    ...                 ...
    Mag_Filt           (index) float64 5.481e+04 5.481e+04 ... 5.414e+04
    Mag_Raw            (index) float64 5.481e+04 5.481e+04 ... 5.414e+04
    N_WGS84            (index) float64 4.968e+06 4.968e+06 ... 4.866e+06
    RMF                (index) float64 210.6 210.6 210.6 ... -109.0 -108.9
    Time               (index) object '17:14:42' '17:14:42' ... '15:01:23'
    TMI                (index) float64 5.482e+04 5.482e+04 ... 5.414e+04
Attributes:
    content:  raw data
    comment:  This dataset includes minimally processed (raw) AEM and raw/pro...)
```

3.1. Dimensions

Dimensions are scalar values that contain the length of a coordinate (Section 3.2). Note, in the NetCDF format, dimensions are simply a named pointer to coordinates variables of the same name. Tabular datasets have a required dimension of index, or the number of measurements (rows) in the data. Some examples of other common dimensions and their associated coordinates are also given below.

3.1.1.index

Integer value representing the number of rows, or primary dimension length of each variable, in the tabular dataset.

3.1.2. layer_depths

Integer value describes the number of model layers in a layered-earth model, where each layer may have one or more physical properties assigned (e.g., resistivity, density, etc.).

3.1.3. time_gates

Integer value describing the number of electromagnetic receiver gate times for a single data component. For datasets with multiple components of data (i.e. low-moment and high-moment or X and Z receivers), separate entries can be used for different components documented in Section 7.2.30.

3.1.4. frequencies

Integer value describing the number of transmitter-receiver frequency pairs in a frequency-domain electromagnetic system (Section 7.1.4).

3.1.5.spectra

Integer value describing the number of radiometric spectral bins.

3.1.6. nv

Integer value representing the number of vertices (nv) or bounds of a coordinate value. For example, when one-dimensional models consistent of layers defined by the depth to their center, the layer bounds would be described by a coordinate with dimensions (layer_depths, nv); where the nv dimension would be 2, denoting the top and bottom of each layer.

```
tabular[0].dims.mapping
{'HM_gate_times': 32, 'LM_gate_times': 28, 'nv': 2, 'index': 1356892}
```

3.2. Coordinates

Coordinate variables describe the dimensions of tabular data variables, including any spatial or temporal positioning of each data point. When applicable, x and y coordinate variables are used to document the coordinate locations of the data, and share the dimension of index when each measurement location is in a separate row of data. Coordinates may also describe other dimensions not directly linked to the dimension of data variables; for example, the number and positions of electrodes used in a galvanic resistivity survey. Coordinates are typically one-dimensional arrays of values. Coordinates that are linked to the dimension of a data variable are referred to as "dimension coordinates."

One additional required coordinate variable is included, spatial_ref, and contains details on the coordinate reference system of the dataset (see Section 2.2.1).

3.2.1.index

Array of integer values representing the primary dimension of the tabular data. Typically zero-based index array (0 to N).

3.2.2. x

Array of x-axis coordinates for each data location, has dimension of index.

3.2.3. y

Array of y-axis coordinates for each data location, has dimension of index.

3.2.4.z

Array of z-axis coordinates for each data location, has dimension of index.

3.2.5.time

Array of times for each data location, has dimension of index.

3.2.6. spatial_ref

Coordinate reference system variable. Duplicate of *Survey* spatial ref (see Section 2.2.1).

The coordinates below are examples of recommended names for particular datasets, where appropriate. Additional user-defined names can be used as-needed.

3.2.7. layer_depths

Array of real values that contains the depth to the center of each model layer in a layered-earth model, where each layer may have one or more physical properties assigned (e.g., resistivity, density, etc.).

3.2.8. gate_times

Array of real values that contains the electromagnetic receiver gate times for a single data component. For datasets with multiple components of data (i.e. low-moment and high-moment or X and Z receivers), separate entries can be used for different components documented in 7.2.30.

3.2.9. frequencies

Array of real values that contains the operating frequencies in a frequency-domain electromagnetic system, representing transmitter-receiver frequency pairs (7.1.4).

3.2.10. spectra

Array of real values that contains the center energy for each radiometric spectra channel.

3.2.11. nv

Array of integer values, typically [0,1], that describe the vertices for bounding variables of a coordinate value. For example, when one-dimensional models consistent of layers defined by the depth to their center, the layer bounds would be described by a coordinate with dimensions (layer_depths, nv); where the nv dimension would be 2, denoting the top and bottom of each layer.

```
tabular[0].coords
```

```
Coordinates:
  * HM_gate_times  (HM_gate_times) float64 2.886e-05 3.037e-05 ... 0.003544
  * LM_gate_times  (LM_gate_times) float64 -1.135e-06 3.65e-07 ... 0.001394
  * nv             (nv) int64 0 1
    x              (index) float64 7.243e+05 7.243e+05 ... 6.602e+05 6.602e+05
    y              (index) float64 4.916e+05 4.916e+05 ... 3.866e+05 3.866e+05
    spatial_ref    float64 0.0
    DateTime       (index) float64 4.422e+04 4.422e+04 ... 4.424e+04 4.424e+04
  * index          (index) int64 0 1 2 3 4 ... 1356888 1356889 1356890 1356891
```

3.3. Attributes

3.3.1. Coordinate attributes

3.3.1.1. standard_name

Text string with a short name of coordinate variable. Typically the same as the coordinate variable. Per CF conventions, there are restrictions on the string format: all lower-case, with no spaces or punctuation other than underscores. For a projected coordinate system, the spatial coordinate variables, “x” and “y”, should have the standard name “projection_x_coordinate” and “projection_y_coordinate”, respectively.

3.3.1.2. long_name

Text string with a more descriptive name of the coordinate variable. There are no restrictions on format, i.e., spaces and uppercase letters are allowed.

3.3.1.3. units

Text string describing the units of the coordinate variable.

3.3.1.4. null_value

Integer or real value, or "not_defined", describing null values (or "no data" values) within the coordinate variable array.

3.3.1.5. bounds

Text string of the data variable name that contains vertices of the coordinate boundaries. For example, if a layered earth model has the dimension coordinate "layer_depths", the associated layer bounds (top and bottom), are defined in a data variable called "layer_depth_bnds" named in the bounds attribute of the coordinate variable. See the CF conventions documentation for a complete description of bounds: https://cfconventions.org/cf-conventions/cf-conventions.html#cell-boundaries.

3.3.1.6. valid_range

List of integer or real values recording the minimum and maximum range of valid (not null) data values in the coordinate variable.

3.3.1.7. axis

Text string containing the generic axis of the coordinate variable: X, Y, Z, or T which represent the longitude, latitude, vertical, and time axis, respectively.

3.3.1.8. positive

Text string of "up" or "down" representing the positive direction for the vertical coordinate variable, "z". The "positive" attribute should be consistent with the sign convention implied by the standard_name, e.g., "depth" is defined as vertical distance below ground surface so a coordinate variable with a standard_name including depth should have the positive attribute with value "down".

3.3.1.9. vertical_datum

Text string describing the vertical datum, including either absolute datums or relative reference points, for the vertical (z) coordinate. For example, if the z coordinate is depth then the "vertical_datum" describes the reference for depth=0, e.g., ground surface or water surface. If using elevation, then this field contains the datum of the vertical coordinate system, e.g., "NAVD88".

3.3.1.10. time_datum

Text string describing the time datum, including either absolute datums or relative reference points, for the time (T) coordinate axis. For example, 'January 1, 1900' could be the time_datum value for a time coordinate variable given in decimal days. For absolute time coordinates, ‘UTC’ or other local time zone can be specified.

```
[tabular[0].index.attrs, tabular[0].x.attrs, tabular[0].DateTime.attrs]
```

```
[{'standard_name': 'index',
  'long_name': 'Index of individual data points',
  'units': 'not_defined',
  'null_value': 'not_defined',
  'valid_range': [0, 1356891]},
 {'standard_name': 'projection_x_coordinate',
  'long_name': 'Easting, Wisconsin Transverse Mercator (WTM), North American Datum of 1983 (NAD83)',
  'units': 'meter',
  'null_value': 'not_defined',
  'axis': 'X',
  'valid_range': [655026.626343047, 732295.562636796]},
 {'standard_name': 'time',
  'long_name': 'Time, decimal days',
  'units': 'day',
  'null_value': 'not_defined',
  'valid_range': array([44216.71854282, 44235.63582523]),
  'axis': 'T',
  'time_datum': 'January 1, 1900'}]
```

3.3.2. Data variable attributes

3.3.2.1. standard_name

Text string with a short name of data variable. Typically the same as the data variable. Must be all lower-case with no spaces or symbols other than underscores.

3.3.2.2. long_name

Text string with descriptive name of the data variable. There are no restrictions on the format.

3.3.2.3. units

Text string describing the units of the data value.

3.3.2.4. null_value

Integer or real value, or “not_defined”, describing missing or undefined data values within the data variable. Must be outside the valid_range.

3.3.2.5. valid_range

List of integer or real values representing the minimum and maximum range of valid values (not null) in the data variable.

3.3.2.6. grid_mapping

The name of the grid mapping coordinate variable, associating the coordinate reference system with the data variable. Should typically be “spatial_ref”, see Section 2.2.1.

3.3.2.7. coordinates

Text string containing a list of coordinate variable names. For a horizontal coordinate system with no grid mapping coordinate variable (i.e., the “spatial_ref” variable), then the coordinates attribute is used to associate the coordinate system with the data variable.

Since the “spatial_ref” coordinate variable is required per GS standards, this attribute is optional.

3.3.2.8. _FillValue

Optional. Integer or real value representing missing data or undefined values within the data variable. Must be outside of the valid_range of the data variable (3.3.2.5). Should match the “null_value” attribute. The “_FillValue” attribute can be used to automatically apply masking of null values in certain software.

```
tabular[0].HM_Z.attrs
```

```
{'_FillValue': nan,
 'standard_name': 'em_data_hmz',
 'long_name': 'EM data, high moment z-component',
 'units': 'picoVolt per Ampere per meter^4',
 'null_value': -9999.99,
 'valid_range': array([-330.80997323, 5833.12915615]),
 'grid_mapping': 'spatial_ref',
 'coordinates': 'spatial_ref x y'}
```

3.3.3. General attributes

3.3.3.1. content

Character string describing the content of the tabular group. For example, “raw electromagnetic data” or “inverted resistivity models”.

3.3.3.2. comment

Character string with additional details about the dataset, source, or processing used to produce the tabular group.

3.4. Data variables

A tabular group may contain many data variables. Typically, each data variable is defined by a single column (one-dimensional variable) or multiple columns (two-dimensional data) from the input data file (e.g., a CSV or ASCII text file). Each data variable is associated with one or more dimensions (Section 3.1) and has data variable attributes attached to it (Section 3.3.2). The spatial coordinates of the data variables, such as individual measurement locations, are defined by the x, y, and z coordinate variables and associated coordinate reference system described by the spatial_ref coordinate variable (Section 3.2).

4. Raster

Data in a *Raster* group contain one or more data variables that represent information typically originating from a gridded data structure such as GeoTIFF, Surfer grid, or GXF, for example. In contrast to data in a *Tabular* group, data in a *Raster* group are characterized as being structured on a regular grid in one or more dimensions. The most common structure for data variables in a Raster group are two dimensional, for example values that can be visualized on a map. Raster variables could also have additional dimensions, such as values that are measured over multiple depths, over multiple times, or within multiple spectral bands. Another distinction of Raster data are that the dimensions and coordinate variables should fully describe the axes that variables can be displayed against. This contrasts with Tabular data which have a primary dimension of index. Multiple data variables can be contained within the same Raster group; variables must share common coordinates, though don't need to have identical coordinates. For example, a group can contain a two-dimensional raster with coordinates "x" and "y" together with a three-dimensional raster that has coordinates "x", "y", and "z". In this case the "x" and "y" coordinates must match across the two variables.

The horizontal spatial coordinates of Raster data, if applicable, are specified by the required "x" and "y" coordinate variables defining the latitude and longitude (or easting and northing) coordinate values for the cell center locations of each gridded value. If the data have a vertical component, then the "z" coordinate variable is required. This vertical variable can represent either elevation or depth, and in either case the vertical datum should be defined in the variable attributes by the "vertical_datum" key, e.g., "NAVD88" or "ground surface". Likewise, if data are a series of images captured over time, then a "time" coordinate variable is required. All coordinate variables should match the dimension of the data. Since Raster data are gridded (not point values), each spatial coordinate variable and dimension require accompanying bounding variables that contain the border locations for each gridded cell value. However, some instances do not require bounding variables such as discrete time snapshots, or multi-band images.

In addition to being described by one or more coordinates and dimensions, each coordinate and data variable has attributes attached to it. Finally, the Raster group contains several general attributes that describe the group content and mapping of variable names to standard variables used for displaying information.

```
raster[0].keys()
```

```
<bound method Mapping.keys of <xarray.Dataset>
Dimensions:               (x: 799, y: 1155, nv: 2)
Coordinates:
  * x                     (x) float64 6.551e+05 6.552e+05 ... 7.349e+05
  * y                     (y) float64 4.953e+05 4.952e+05 ... 3.8e+05 3.799e+05
    spatial_ref           float64 0.0
  * nv                    (nv) int64 0 1
Data variables:
    magnetic_tmi          (y, x) float64 nan nan nan nan ... nan nan nan nan
    x_bnds                (x, nv) float64 6.55e+05 6.551e+05 ... 7.349e+05
    y_bnds                (y, nv) float64 4.954e+05 4.953e+05 ... 3.799e+05
    magnetic_rmf          (y, x) float64 nan nan nan nan ... nan nan nan nan
    bedrock_top_elevation (y, x) float32 nan nan nan nan ... nan nan nan nan
    bedrock_depth         (y, x) float32 nan nan nan nan ... nan nan nan nan
Attributes:
    dataset_attrs.content:  gridded magnetic and bedrock maps
    dataset_attrs.comment:  This dataset includes AEM-derived estimates of th...>
```

4.1. Dimensions

4.1.1. x

Integer value describing the number of grid cells in the x-direction.

4.1.2. y

Integer value describing the number of grid cells in the y-direction.

4.1.3. z

Integer value describing the number of grid cells in the z-direction.

4.1.4. time

Integer value describing the number of times represented in a gridded dataset.

4.1.5.bands

Integer value describing the number of bands (e.g. spectral bands) in a gridded dataset.

4.1.6. nv

Integer value representing the number of vertices or bounds of a coordinate value. For example, each grid cell in the x-direction has a left- and right-edge. The array of x-grid boundaries would have dimension (x, nv); where the nv dimension would be 2, denoting the left and right of each cell

```
raster[0].dims.mapping
{'x': 799, 'y': 1155, 'nv': 2}
```

4.2. Coordinates

4.2.1.x

Array of real values containing the cell center coordinates in the x-direction.

4.2.2. y

Array of real values containing the cell center coordinates in the y-direction.

4.2.3. z

Array of real values containing the cell center coordinates in the z-direction.

4.2.4. time

Array of real values containing the times represented by the data.

4.2.5. nv

Array of integer values, typically [0,1], that describe the vertices for bounding variables

4.2.6.spatial_ref

Dictionary with coordinate reference system variable. Duplicate of *Survey* spatial ref (see Section 2.2.1).

```
raster[0].coords
Coordinates:
  * x            (x) float64 6.551e+05 6.552e+05 ... 7.348e+05 7.349e+05
  * y            (y) float64 4.953e+05 4.952e+05 4.951e+05 ... 3.8e+05 3.799e+05
    spatial_ref  float64 0.0
  * nv           (nv) int64 0 1
```

4.3. Attributes

4.3.1. Coordinate attributes

4.3.1.1. standard_name

Text string with short name of data variable. Typically the same as the data variable. Must be all lower-case with no spaces or symbols.

4.3.1.2. long_name

Text string with description of the data variable

4.3.1.3. units

text string describing the units of the data value

4.3.1.4. null_value

Integer or real value, or “not_defined”, describing null values within the data variable

4.3.1.5. bounds

Character string of the data variable name containing the vertices of the coordinate cell boundaries. See the CF conventions for a complete description of bounds: https://cfconventions.org/cf-conventions/cf-conventions.html#cell-boundaries.

4.3.1.6. valid_range

List of integer or real values describing the valid range of values in the data variable

4.3.1.7. axis

Text string containing the generic axis of the coordinate variable: X, Y, Z, or T which represent the longitude, latitude, vertical, and time axis, respectively.

4.3.1.8. positive

Text string of “up” or “down” representing the positive direction for the vertical coordinate variable, “z”. The “positive” attribute should be consistent with the sign convention implied by the standard_name, e.g., “depth” is defined as vertical distance below ground surface so a coordinate variable with a standard_name including depth should have the positive attribute with value “down”.

4.3.1.9. vertical_datum

Text string describing the vertical datum, including either absolute datums or relative reference points, for the vertical (z) coordinate. For example, if the z coordinate is depth then the “vertical_datum” describes the reference for depth=0, e.g., ground surface or water surface. If using elevation, then this field contains the datum of the vertical coordinate system, e.g., “NAVD88”.

4.3.1.10. time_datum

Text string describing the time datum, including either absolute datums or relative reference points, for the time (T) coordinate axis. For example, ‘January 1, 1900’ could be the time_datum value for a time coordinate variable given in decimal days. For absolute time coordinates, ‘UTC’ or other local time zone can be specified.

```
raster[0].x.attrs
```


```
{'standard_name': 'projection_x_coordinate',
 'long_name': 'Easting, Wisconsin Transverse Mercator (WTM), North American Datum of 1983 (NAD83), cell centers',
 'units': 'meter',
 'null_value': 'not_defined',
 'bounds': 'x_bnds',
 'axis': 'X',
 'valid_range': array([655072.0482, 734872.0482])}
```


4.3.2. Data variable attributes

4.3.2.1. standard_name

Text string with short name of data variable. Typically the same as the data variable. Must be all lower-case with no spaces or symbols other than underscores.

4.3.2.2. long_name

Text string with descriptive name of the data variable. There are no restrictions on format.

4.3.2.3. units

Text string representing the units of the data variable.

4.3.2.4. null_value

Integer or real value, or “not_defined”, describing missing or undefined data values within the data variable. Must be outside the valid_range.

4.3.2.5. valid_range

List of integer or real values representing the minimum and maximum range of valid values in the data variable

4.3.2.6. grid_mapping

The name of the grid mapping coordinate variable, associating the coordinate reference system with the data variable. Should most often be “spatial_ref”, see Section 2.2.1.

4.3.2.7. coordinates

Text string containing a list of coordinate variable names. For a horizontal coordinate system with no grid mapping coordinate variable (i.e., the “spatial_ref” variable), then the coordinates attribute is used to associate the coordinate system with the data variable. Since the “spatial_ref” coordinate variable is required per GS standards, this attribute is optional.

4.3.2.8. _FillValue

Optional. Integer or real value representing missing data or undefined values within the data variable. Must be outside of the valid_range of the data variable (4.3.2.5). Should match the “null_value” attribute. The “_FillValue” attribute can be used to automatically apply masking of null values in certain software.

```
raster[0].magnetic_rmf.attrs
```

```
{'standard_name': 'residual_magnetic_field',
 'long_name': 'Residual magnetic field, IGRF corrected from 2015 model',
 'units': 'nanoTesla',
 'null_value': -9999.99,
 'valid_range': array([-478.36932373,  815.26867676]),
 'grid_mapping': 'spatial_ref'}
```

4.3.3. General attributes

4.3.3.1. content

Character string describing the content of the raster group. For example, "three-dimensional interpolated resistivity model".

4.3.3.2. comment

Character string with additional details about the content, source, or processing used to produce the raster group

4.4. Data variables

A Raster group may contain many data variables. Typically, each data variable is defined by a single two-dimensional gridded dataset from the input data file (e.g., GeoTIF or Surfer Grid); however, multiple two-dimensional grids may also be stacked into a three-dimensional or four-dimensional variable (e.g., x-y grids stacked along the z and/or time axis). Each data variable is associated with one or more dimensions (Section 4.1) and has data variable attributes attached to it (Section 4.3.2). The spatial coordinates of the data variables are typically defined by the x and y coordinate variables (Section 4.2) and associated coordinate reference system described by the spatial_ref coordinate variable (Section 2.2.1); however, other coordinates may be appropriate depending on the organization of the data variables.

When dimensions of data variables do not align, we recommend separating into multiple Raster groups with common coordinates within each group. This way, each dataset has a single set of dimension coordinates (x,y,z, and/or time) and the standard coordinates are not indexed, i.e., we advise against having multiple x or multiple y coordinates (x_0, x_1, etc.) within a group.

5. References

ESRI. (2016). *FAQ: What does "authority: EPSG" mean in an ArcGIS desktop .prj file?* (Esri Tech. Support). Retrieved from https://support.esri.com/en/technical-article/000011199

Foks, N. L., James, S. R., & Minsley, B. J. (2022). GSPy: Geophysical Data Standard in Python. U.S. Geological Survey software release. Retrieved from https://doi.org/10.5066/P9XNQVGQ

IAEA. (2003). *Guidelines for Radioelement Mapping Using Gamma Ray Spectrometry Data*. Vienna: International Atomic Energy Agency. Retrieved from https://www.iaea.org/publications/6746/guidelines-for-radioelement-mapping-using-gamma-ray-spectrometry-data

James, S. R., Foks, N. L., & Minsley, B. J. (2022). GSPy: A new toolbox and data standard for Geophysical Datasets. *Frontiers in Earth Science*, *10*. Retrieved from https://www.frontiersin.org/articles/10.3389/feart.2022.907614

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6. Appendix A- Summary of Attribute and Data Variable Requirements

Table of required, recommended, and optional attributes and data variables. We advise user discretion regarding when required and recommended elements are applicable, given the wide variety in geophysical surveys and datasets.

Group	**Variable**	**Attribute**	**Designation**	**Comment**
Survey				
Coordinates				
	spatial_ref		required	
	spatial_ref	grid_mapping_name	required	
	spatial_ref	crs_wkt	recommended	
	spatial_ref	wkid	recommended	
	spatial_ref	authority	recommended	
	spatial_ref	proj_string	recommended	
	spatial_ref	vertical_crs	required	For data with vertical coordinates
	spatial_ref	spatial_ref	recommended	
Attributes				
		title	required	
		institution	required	
		source	required	
		history	required	
		references	required	
		comment	required	
		abstract	recommended	
		content	recommended	
		created_by	recommended	
		conventions	recommended	
Data variables				
	survey_information		required	
	survey_information	acquired_for	recommended	For surveys supporting another entity or collaborator
	survey_information	acquired_by	recommended	For surveys supporting another entity or collaborator
	survey_information	contractor_project_number	optional	
	survey_information	survey_type	recommended	
	survey_information	survey_area_name	recommended	
	survey_information	location	required	
	survey_information	country	required	
	survey_information	acquisition_start	required	
	survey_information	acquisition_end	required	
	survey_information	survey_attributes_units	recommended	
	system_information		recommended / required	Required for airborne surveys
	survey_equipment		required	
	flightline_information		recommended	For airborne surveys
Tabular				

Group	Variable	Attribute	Designation	Comment
Dimensions				
	index		required	
	layer_depths		recommended	Standardized name for model layer depths dimension
	time_gates		recommended	Standardized name for time-domain electromagnetic time gates dimension
	frequencies		recommended	Standardized name for frequency dimension
	spectra		recommended	Standardized name for radiometric spectra dimension
	nv		required	For multidimensional data
Coordinates				
	index		required	
	x		required	For data with a spatial X coordinate axis
	y		required	For data with a spatial Y coordinate axis
	z		required	For data with a spatial Z coordinate axis
	time		required	For data with a temporal coordinate axis
	spatial_ref		required	
	layer_depths		recommended	
	gate_times		recommended	
	frequencies		recommended	
	spectra		recommended	
	nv		required	For multidimensional data
Attributes				
		content	required	
		comment	optional	
Coordinate attributes				
		standard_name	required	
		long_name	required	
		units	required	
		null_value	required	
		bounds	required	For coordinates with bounds
		valid_range	required	
		axis	required	For spatial or temporal coordinates
		positive	required	For data with a spatial Z coordinate axis

Group	Variable	Attribute	Designation	Comment
		vertical_datum	required	For data with a spatial Z coordinate axis
		time_datum	required	For data with a temporal coordinate axis
Data variable attributes				
		standard_name	required	
		long_name	required	
		units	required	
		null_value	required	
		valid_range	required	
		grid_mapping	required	
		coordinates	optional	
		_FillValue	optional	
Raster				
Dimensions				
	x		required	For data with a spatial X coordinate axis
	y		required	For data with a spatial Y coordinate axis
	z		required	For data with a spatial Z coordinate axis
	time		required	For data with a temporal coordinate axis
	bands		required	For data with discrete bands such as multispectral images
	nv		required	For multidimensional data
Coordinates				
	x		required	For data with a spatial X coordinate axis
	y		required	For data with a spatial Y coordinate axis
	z		required	For data with a spatial Z coordinate axis
	nv		required	For multidimensional data
	spatial_ref		required	
Attributes				
		content	required	
		comment	optional	
Coordinate attributes				
		standard_name	required	
		long_name	required	
		units	required	

Group	Variable	Attribute	Designation	Comment
		null_value	required	
		bounds	required	For coordinates with bounds
		valid_range	required	
		axis	required	For spatial or temporal coordinates
		positive	required	For vertical coordinate
		vertical_datum	required	For vertical coordinate
		time_datum	required	For temporal coordinate
Data variable attributes				
		standard_name	required	
		long_name	required	
		units	required	
		null_value	required	
		valid_range	required	
		grid_mapping	required	
		coordinates	optional	
		_FillValue	optional	

7. Appendix B- System information standard templates

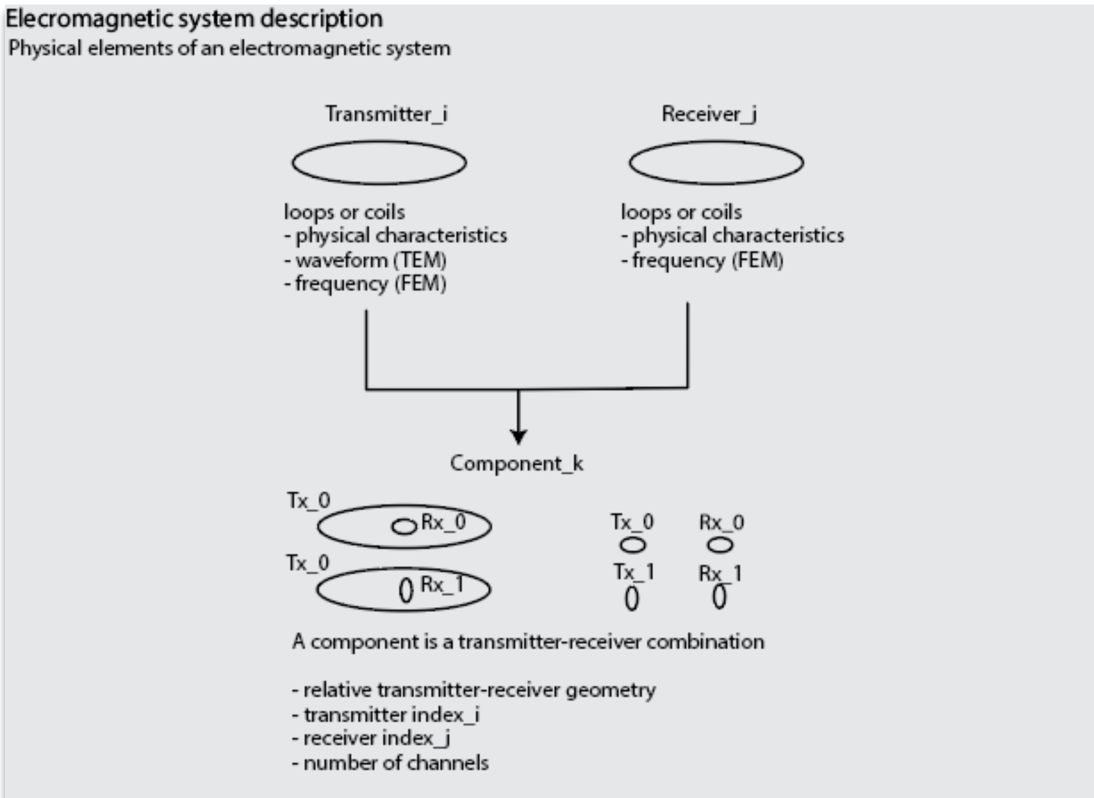
A generalized geophysical system comprises of one or more of the following elements:

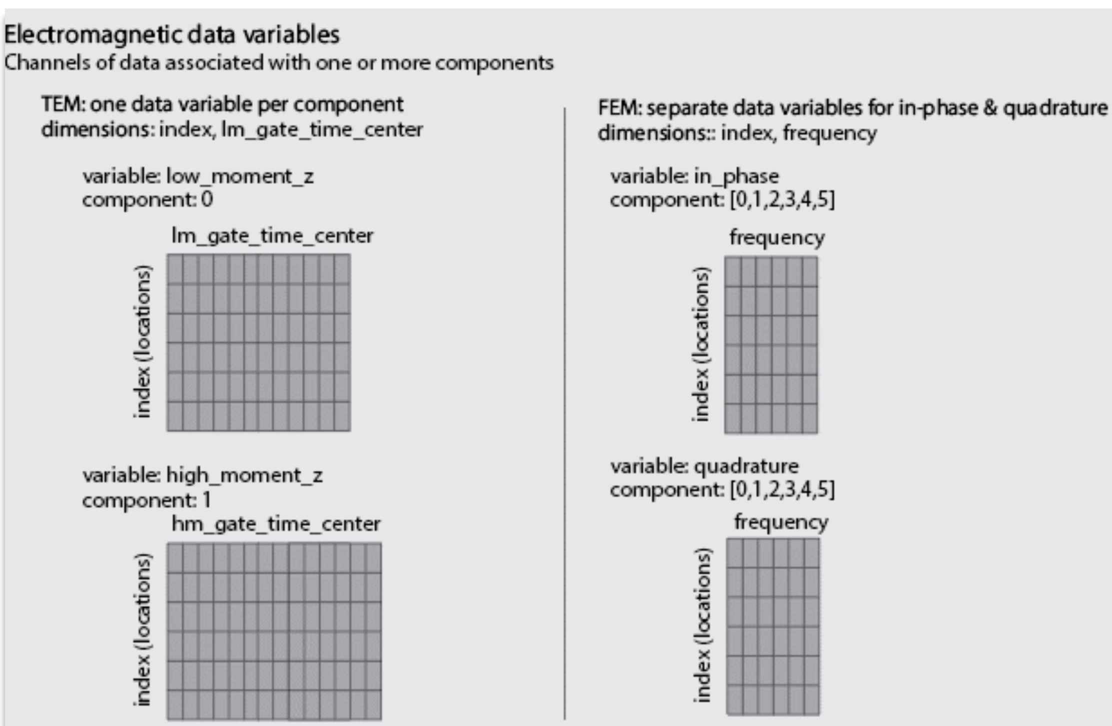
- Source(s) or transmitter(s), TX, that send energy into the earth
- Receiver(s), RX, that record natural or induced signals from the earth
- Component(s) that represent one or more specific transmitter-receiver combinations
- Channel(s) that represent discrete values recorded by a receiver. Channels typically match a data variable dimension (Section 3.1), but are flexible in their composition from sources, receivers, and components. For example, a data variable may have channels associated with a single component, or channels that result from the combination of multiple components.

Where possible, attributes should describe these elements of a system, and any other system characteristics. As an example, the characteristics of an electromagnetic system (frequency-domain or time-domain) could be described with the following elements:

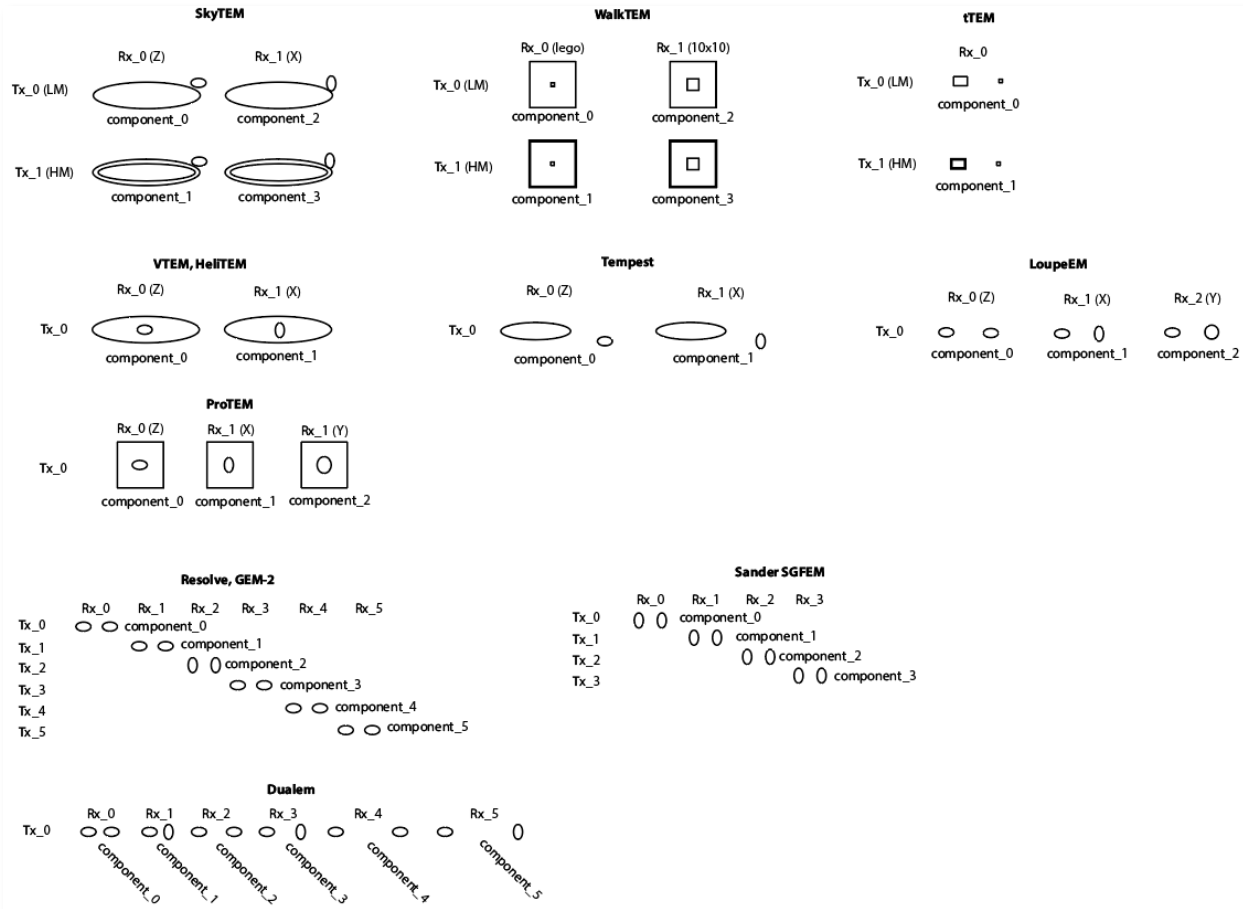
- Transmitter: physical coil or loop, index = i
- Receiver: physical coil or loop, index = j
- Component: a unique TX-RX combination, index = k
- Channel: one or more datapoints associated with a component (e.g. time gates, in-phase/quadrature), index = l

The examples below show how physical transmitters and receivers are paired into one or more components for a system. For time-domain electromagnetic data, there are typically many channels that describe the time-gates of a decay curve for each component of an instrument, where each component is linked to a data variable and each variable may have a different number of channels. For frequency-domain data, there are typically two data variables, in-phase and quadrature, where each variable has one channel per frequency. In this case, each channel in the data variable is linked to a separate component (i.e. transmitter-receiver pair).


Elecromagnetic system description
Physical elements of an electromagnetic system
Transmitter_i
Receiver_j
loops or coils
- physical characteristics
- waveform (TEM)
- frequency (FEM)
loops or coils
- physical characteristics
- frequency (FEM)
Component_k
Tx_0
Rx_0
Tx_0
Rx_1
Tx_0
Rx_0
Tx_1
Rx_1
A component is a transmitter-receiver combination
- relative transmitter-receiver geometry
- transmitter index_i
- receiver index_j
- number of channels


Electromagnetic data variables
Channels of data associated with one or more components
TEM: one data variable per component
dimensions: index, lm_gate_time_center
variable: low_moment_z
component: 0
lm_gate_time_center
index (locations)
variable: high_moment_z
component: 1
hm_gate_time_center
index (locations)
FEM: separate data variables for in-phase & quadrature
dimensions:: index, frequency
variable: in_phase
component: [0,1,2,3,4,5]
frequency
index (locations)
variable: quadrature
component: [0,1,2,3,4,5]
frequency
index (locations)

Some common electromagnetic instruments are described below, showing how individual transmitters and receivers combine to unique components:



7.1. Electromagnetic system (frequency-domain)

7.1.1. electromagnetic_system.instrument_type

Character string of electromagnetic instrument name or type

7.1.2. electromagnetic_system.data_normalized

Boolean flag indicating whether data are normalized or not. For frequency-domain EM, secondary normalized to the primary have data units ppm

7.1.3. electromagnetic_system.number_of_transmitters

Integer number of electromagnetic system transmitters

7.1.4. electromagnetic_system.number_of_receivers

Integer number of electromagnetic system receivers

7.1.5. electromagnetic_system.number_of_components

Integer number of electromagnetic components

7.1.6. electromagnetic_system.reference_frame

Character string describing electromagnetic system reference frame. For example, "right-handed positive down"

7.1.7. electromagnetic_system.sample_rate

Real number describing electromagnetic system sampling rate

7.1.8. electromagnetic_system.transmitter_[i]_frequency

Real number describing i^{th} transmitter frequency.

7.1.9. electromagnetic_system.transmitter_[i]_orientation

Character string describing the orientation of the i^{th} transmitter. For example, a "Z" for vertical magnetic dipole, "X" for a horizontal magnetic dipole aligned in the direction of

7.1.10. electromagnetic_system.transmitter_[i]_moment

Real number describing the moment of the i^{th} transmitter

7.1.11. electromagnetic_system.receiver_[j]_frequency

Real number describing j^{th} receiver frequency.

7.1.12. electromagnetic_system.receiver_[j]_orientation

Character string describing the orientation of the j^{th} receiver.

7.1.13. electromagnetic_system.receiver_[j]_moment

Real number describing j^{th} receiver moment

7.1.14. electromagnetic_system.component_[k]_name

Character string describing the name of the k^{th} system component. For example, 140k for 140kHz transmitter-receiver pair

7.1.15. electromagnetic_system.component_[k]_transmitter_index

Integer value with the transmitter index [i] for the k^{th} system component

7.1.16. electromagnetic_system.component_[k]_receiver_index

Integer value with the receiver index [j] for the k^{th} system component

7.1.17. electromagnetic_system.component_[k]_nchannels

Integer number describing the number of data channels for the k^{th} component. For frequency domain data, typically equals 2 (inphase + quadrature)

7.1.18. electromagnetic_system.component_[k]_txrx_dx

Real number describing the inline (x-direction) offset between k^{th} transmitter and receiver pair

7.1.19. electromagnetic_system.component_[k]_txrx_dy

Real number describing the crossline (y-direction) offset between k^{th} transmitter and receiver pair

7.1.20. electromagnetic_system.component_[k]_txrx_dz

Real number describing the vertical (z-direction) offset between k^{th} transmitter and receiver pair

7.2. Electromagnetic system (time-domain)

7.2.1. electromagnetic_system.instrument_type

Character string of electromagnetic instrument name or type

7.2.2. electromagnetic_system.data_normalized

Boolean flag indicating whether data are normalized or not. For time-domain EM, data normalized by transmitter and receiver moment (data units V/A*m^4).

7.2.3. electromagnetic_system.number_of_transmitters

Integer number of electromagnetic system transmitters

7.2.4. electromagnetic_system.number_of_receivers

Integer number of electromagnetic system receivers

7.2.5.electromagnetic_system.number_of_components

Integer number of electromagnetic components

7.2.6.electromagnetic_system.reference_frame

Character string describing electromagnetic system reference frame. For example, “right-handed positive down”

7.2.7. electromagnetic_system.sample_rate

Real number describing electromagnetic system sampling rate

7.2.8. electromagnetic_system.transmitter_[i]_name

Character string name for i^{th} transmitter. For example, “LM” for ‘low-moment’

7.2.9.electromagnetic_system.transmitter_[i]_number_of_turns

Integer number describing number of turns in the i^{th} transmitter.

7.2.10. electromagnetic_system.transmitter_[i]_coordinates :

Character string with x,y,z pairs of relative coordinates of the i^{th} transmitter. For example, "[[-12.64, -2.1, 0.0], [-6.14, -8.58, 0.0], [6.14, -8.58, 0.0], [11.41, -3.31, 0.0], [11.41, 3.31, 0.0], [6.14, 8.58, 0.0], [-6.14, 8.58, 0.0], [-12.64, 2.1, 0.0]]"

7.2.11. electromagnetic_system.tranmitter_[i]_area

Real number describing the area of the i^{th} transmitter loop

7.2.12. electromagnetic_system.transmitter_[i]_waveform_type

Character string describing the i^{th} transmitter waveform shape. For example, "trapezoid" or "triangular"

7.2.13. electromagnetic_system.transmitter_[i]_waveform_time :

List of real values that define the time values of the i^{th} transmitter waveform. Dimension must match the number of waveform current values in 7.2.14.

7.2.14. electromagnetic_system.transmitter_[i]_waveform_current

List of real values that define the current values of the i^{th} transmitter waveform. Dimension must match the number of waveform current values in 7.2.13. Current values typically normalized to the range of [-1.0, 1.0] when data are normalized to transmitter current.

7.2.15. electromagnetic_system.transmitter_[i]_current_scale_factor

Real number describing the scaling factor for the i^{th} transmitter current

7.2.16. electromagnetic_system.transmitter_[i]_peak_current

Real number describing the peak current of the i^{th} transmitter

7.2.17. electromagnetic_system.transmitter_[i]_base_frequency

Real number describing the base frequency for the i^{th} transmitter

7.2.18. electromagnetic_system.transmitter_[i]_on_time

Real number describing the on-time of the i^{th} transmitter waveform

7.2.19. electromagnetic_system.transmitter_[i]_off_time

Real number describing the off-time of the i^{th} transmitter waveform

7.2.20. electromagnetic_system.transmitter_[i]_orientation

Real number describing the orientation of the i^{th} transmitter. For example, "Z" refers to a horizontal loop or vertical magnetic dipole

7.2.21. electromagnetic_system.receiver_[j]_name

Character string name for j^{th} receiver. For example, "z" or "x" or "x1.1m'

7.2.22. electromagnetic_system.receiver_[j]_orientation

Character string describing the orientation of the j^{th} receiver.

7.2.23. electromagnetic_system.receiver_[j]_coil_low_pass_filter

Real number describing the cutoff frequency of the j^{th} receiver coil filter.

7.2.24. electromagnetic_system.receiver_[j]_instrument_low_pass_filter

Real number describing the cutoff frequency of the j^{th} receiver instrument filter.

7.2.25. electromagnetic_system.receiver_[j]_area

Real number describing the area of the j^{th} receiver.

7.2.26. electromagnetic_system.component_[k]_name

Character string describing the name of the k^{th} system component. For example, "LMz" for low-moment-z coil or just "z" for single moment

7.2.27. electromagnetic_system.component_[k]_transmitter_index

Integer value with the transmitter index [i] for the k^{th} system component

7.2.28. electromagnetic_system.component_[k]_receiver_index

Integer value with the receiver index [j] for the k^{th} system component

7.2.29. electromagnetic_system.component_[k]_number_of_gates

Integer number describing number of time gates for the k^{th} component.

7.2.30. electromagnetic_system.component_[k]_gate_center

List of real values describing the gate center times for the k^{th} component.

7.2.31. electromagnetic_system.component_[k]_gate_width

List of real values describing the width of each time gate for the k^{th} component.

7.2.32. electromagnetic_system.component_[k]_txrx_dx

Real number describing the inline (x-direction) offset between k^{th} transmitter and receiver pair

7.2.33. electromagnetic_system.component_[k]_txrx_dy

Real number describing the crossline (y-direction) offset between k^{th} transmitter and receiver pair

7.2.34. electromagnetic_system.component_[k]_txrx_dz

Real number describing the vertical (z-direction) offset between k^{th} transmitter and receiver pair

7.3. Magnetic system

7.3.1.magnetic_system.magnetometer_orientation

Text string describing orientation of the magnetometer

7.3.2. magnetic_system.acquisition_system

Text string describing the name ofmanufacturer/acquisition system

7.3.3.magnetic_system.base_magnetometer

Text string describing the make and model, along with other characteristics, of the base magnetometer

7.3.4.magnetic_system.sample_rate

Real number sampling rate of the magnetometer in seconds

7.3.5.magnetic_system.sensitivity

Real number sensitivity of the magnetometer in nT

7.3.6.magnetic_system.fom_pitch

Real number describing compensation test Figure of Merit (FOM) system effect of pitch in nanoteslas (nT).

7.3.7.magnetic_system.fom_roll

Real number describing compensation test Figure of Merit (FOM) system effect of roll in nT.

7.3.8.magnetic_system.fom_yaw

Real number describing compensation test Figure of Merit (FOM) system effect of yaw in nT.

7.3.9.magnetic_system.fom_sum

Real number describing sum of compensation test Figure of Merit (FOM) system effects in nT.

7.3.10. magnetic_system.lag_factor

Real number describing factor for lag (parallax) correction in seconds.

7.3.11. Magnetic_system.lag_correction

Text string describing lag (parallax) correction, use ‘none’ if not corrected

7.3.12. Magnetic_system.diurnal_correction

Text string describing diurnal correction, use ‘none’ if not corrected

7.3.13. Magnetic_system.tieline_levelling

Text string describing tie line levelling, use ‘none’ if not corrected

7.3.14. Magnetic_system.microlevelling

Text string describing micro-levelling procedure, use ‘none’ if not corrected

7.3.15. Magnetic_system.igrf_model_date

Text string describing International Geomagnetic Reference Field (IGRF) date used, use 'none' if not corrected

7.3.16. Magnetic_system.igrf_model_location

Text string describing International Geomagnetic Reference Field (IGRF) location used, use 'none' if not corrected

7.3.17. Magnetic_system.igrf_model_height

Text string describing International Geomagnetic Reference Field (IGRF) height or elevation used, use 'none' if not corrected

7.3.18. Magnetic_system.altitude_correction

Text string describing if an altitude correction was applied to data and method (such as "Taylor-series expansion"), use 'none' if not corrected.

7.4. Radiometric system

Specific parameters outlined below that are useful in documenting the acquisition and processing steps for radiometric data are described by the International Atomic Energy Agency (IAEA, 2003).

7.4.1. radiometric_system.crystal_type

Text string describing type of crystals in radiometric sensors, such as "NaI".

7.4.2. radiometric_system.sample_rate

Real number sample rate of spectrometer in Hz.

7.4.3. radiometric_system.downward_volume

Real number downward facing crystal volume in liters.

7.4.4. radiometric_system.upward_volume

Real number upward facing crystal volume in liters.

7.4.5. radiometric_system.spectrometer_TC_win

Text string describing Total Count energy window in keV.

7.4.6. radiometric_system.spectrometer_K_win

Text string describing Potassium energy window in keV.

7.4.7. radiometric_system.spectrometer_Th_win

Text string describing Thorium energy window in keV.

7.4.8.radiometric_system.spectrometer_U_win

Text string describing Uranium energy window in keV.

7.4.9.radiometric_system.spectrometer_cosmic_win

Text string describing Cosmic energy window in keV.

7.4.10. radiometric_system.K_index_start

Integer value of the array index for the start of the Potassium window.

7.4.11. radiometric_system.K_index_end

Integer value of the array index for the end of the Potassium window.

7.4.12. radiometric_system.Th_index_start

Integer value of the array index for the start of the Thorium window.

7.4.13. radiometric_system.Th_index_end

Integer value of the array index for the end of the Thorium window.

7.4.14. radiometric_system.U_index_start

Integer value of the array index for the start of the Uranium window.

7.4.15. radiometric_system.U_index_end

Integer value of the array index for the end of the Uranium window.

7.4.16. radiometric_system.TC_index_start

Integer value of the array index for the start of the Total Count window.

7.4.17. radiometric_system.TC_index_end

Integer value of the array index for the end of the Total Count window

7.4.18. radiometric_system.cosmic_index_start

Integer value of the array index for the start of the Cosmic window

7.4.19. radiometric_system.cosmic_index_end

Integer value of the array index for the end of the Cosmic window

7.4.20. radiometric_system.UU_index_start

Integer value of the array index for the start of the Upward Uranium window

7.4.21. radiometric_system.UU_index_end

Integer value of the array index for the end of the Upward Uranium window

7.4.22. radiometric_system.down_livetime_or_deadtime_corrected

Text string describing if either a livetime or deadtime correction was applied for downward looking crystals, use “none” if no correction applied.

7.4.23. radiometric_system.up_livetime_or_deadtime_corrected

Text string describing if either a livetime or deadtime correction was applied for upward looking crystals, use “none” if no correction applied.

7.4.24. radiometric_system.lowpass_filtering

Text string describing if any low pass filtering was applied to radiometric data, use “none” if no filtering applied.

7.4.25. radiometric_system.lowpass_filtering_fid_cutoff_cosmic

Integer value of lowpass filter width in fids applied to Cosmic window.

7.4.26. radiometric_system.lowpass_filtering_fid_cutoff_TC

Integer value of lowpass filter width in fids applied to Total Count window.

7.4.27. radiometric_system.lowpass_filtering_fid_cutoff_K

Integer value of lowpass filter width in fids applied to Potassium window

7.4.28. radiometric_system.lowpass_filtering_fid_cutoff_Th

Integer value of lowpass filter width in fids applied to Thorium window.

7.4.29. radiometric_system.lowpass_filtering_fid_cutoff_U

Integer value of lowpass filter width in fids applied to Uranium window.

7.4.30. radiometric_system.lowpass_filtering_fid_cutoff_altimeter

Integer value of lowpass filter width in fids applied to radar or laser altimeter data.

7.4.31. radiometric_system.background_parameter_aircraft_TC

Real number aircraft background correction parameter for Total Count data in cps (counts per second).

7.4.32. radiometric_system.background_parameter_aircraft_K

Real number aircraft background correction parameter for Potassium data in cps.

7.4.33. radiometric_system.background_parameter_aircraft_Th

Real number aircraft background correction parameter for Thorium data in cps.

7.4.34. radiometric_system.background_parameter_aircraft_U

Real number aircraft background correction parameter for Uranium data in cps.

7.4.35. radiometric_system.background_parameter_aircraft_UU

Real number aircraft background correction parameter for Upward Uranium data in cps.

7.4.36. radiometric_system.background_parameter_cosmic_TC

Real number background cosmic stripping parameter for Total Count data in cps per Cosmic cps.

7.4.37. radiometric_system.background_parameter_cosmic_K

Real number background cosmic stripping parameter for Potassium data in cps per Cosmic cps.

7.4.38. radiometric_system.background_parameter_cosmic_Th

Real number background cosmic stripping parameter for Thorium data in cps per Cosmic cps.

7.4.39. radiometric_system.background_parameter_cosmic_U

Real number background cosmic stripping parameter for Uranium data in cps per Cosmic cps.

7.4.40. radiometric_system.background_parameter_cosmic_UU

Real number background cosmic stripping parameter for Upward Uranium data in cps per Cosmic cps.

7.4.41. radiometric_system.radon_background_correction_method

Text string describing Radon background correction method, such as "Spectral-Ratio Method", "Full-Spectrum Method", "Upward Detector Method", "Lookup Table" or "Overwater".

7.4.42. radiometric_system.radon_background_correction_up_method_A1

Real number A1 ground coefficient (skyshine) for radon background correction using upward method.

7.4.43. radiometric_system.radon_backgroundcorrection_up_method_A2

Real number A2 ground coefficient (skyshine) for radon background correction using upward method.

7.4.44. radiometric_system.calibration_factor_a_TC

Real number calibration factor a, for Total Count data in cps for radon levelling using upward crystal method.

7.4.45. radiometric_system.calibration_factor_a_K

Real number calibration factor a, for Potassium data in cps for radon levelling using upward crystal method.

7.4.46. radiometric_system.calibration_factor_a_Th

Real number calibration factor a, for Thorium data in cps for radon levelling using upward crystal method.

7.4.47. radiometric_system.calibration_factor_a_U

Real number calibration factor a, for Uranium data in cps for radon levelling using upward crystal method.

7.4.48. radiometric_system.calibration_factor_b_TC

Real number calibration factor b, for Total Count data in cps for radon levelling using upward crystal method.

7.4.49. radiometric_system.calibration_factor_b_K

Real number calibration factor b, for Potassium data in cps for radon levelling using upward crystal method.

7.4.50. radiometric_system.calibration_factor_b_Th

Real number calibration factor b, for Thorium data in cps for radon levelling using upward crystal method.

7.4.51. radiometric_system.calibration_factor_b_U

Real number calibration factor b, for Uranium data in cps for radon levelling using upward crystal method.

7.4.52. radiometric_system.compton_stripping_ratio_alpha

Real number alpha stripping ratio, Uranium and Thorium

7.4.53. radiometric_system.compton_stripping_ratio_beta

Real number beta stripping ratio, Potassium and Thorium

7.4.54. radiometric_system.compton_stripping_ratio_gamma

Real number gamma stripping ratio, Potassium and Uranium

7.4.55. radiometric_system.compton_stripping_ratio_a

Real number a, Thorium stripping ratio (backscatter)

7.4.56. radiometric_system.compton_stripping_ratio_b

Real number b, if available

7.4.57. radiometric_system.compton_stripping_ratio_g

Real number g, if available

7.4.58. radiometric_system.compton_stripping_nominal_altitude

Real number nominal survey flight height above ground for stripping corrections in meters

7.4.59. radiometric_system.height_attenuation_coefficient_TC

Real number height correction coefficient for Total Count channel, per meter at Standard Temperature and Pressure (STP).

7.4.60. radiometric_system.height_attenuation_coefficient_K

Real number height correction coefficient for Potassium channel, per meter at STP.

7.4.61. radiometric_system.height_attenuation_coefficient_U

Real number height correction coefficient for Total Count channel, per meter at STP.

7.4.62. radiometric_system.height_attenuation_coefficient_Th

Real number height correction coefficient for Total Count channel, per meter at STP.

7.4.63. radiometric_system.source_sensitivity_factor_TC

Real number source sensitivity for Total Count, in /hr.

7.4.64. radiometric_system.source_sensitivity_factor_K

Real number source sensitivity for Potassium, in cps/% K.

7.4.65. radiometric_system.source_sensitivity_factor_Th

Real number source sensitivity for Thorium, in ppm eTh.

7.4.66. radiometric_system.source_sensitivity_factor_U

Real number source sensitivity for Uranium, in ppm eU

8. Appendix C- Survey equipment standard templates

8.1. survey_equipment.aircraft

Character string describing the make and model of survey aircraft for airborne surveys.

8.2. survey_equipment.aircraft_registration

Character string describing the registration of survey aircraft for airborne surveys

8.3. survey_equipment.magnetometer

Character string describing the make and model of magnetometer

8.4. survey_equipment.magnetometer_installation

Character string describing how the magnetometer is mounted. For example, “backpack”, “tail stinger”, or “on airborne electromagnetic system frame”

8.5. survey_equipment.electromagnetic_system

Character string describing the make and model of the electromagnetic system

8.6. survey_equipment.electromagnetic_installation

Character string describing how the electromagnetic system is mounted. For example, “ground loop”, “helicopter”, or “fixed-wing transmitter with receiver bird”

8.7. survey_equipment.spectrometer_system

Character string describing the make and model of the spectrometer system

8.8. survey_equipment.spectrometer_installation

Character string describing how the spectrometer is mounted. For example, “## NaI packs with X liter volume”

8.9. survey_equipment.radar_altimeter_system

Character string describing the make and model of the radar altimeter

8.10. survey_equipment.laser_altimeter_system

Character string describing the make and model of the laser altimeter

8.11. survey_equipment.inclinometer_system

Character string describing the make and model of the inclinometer

8.12. survey_equipment.navigation_system

Character string describing the make and model of the navigation system

8.13. survey_equipment.acquisition_system

Character string describing the make and model of the data acquisition recording system

9. Appendix D- Flightline information standard names

9.1. traverse_line_spacing

Real or integer value describing the distance between primary orientation traverse lines, or character string such as “variable” for irregular surveys

9.2. traverse_line_direction

Real or integer value describing the traverse line orientation in the range 0 (north) – 180

9.3. tie_line_spacing

Real or integer value describing the distance between tie- lines, or character string such as “variable” for irregular surveys, or “none”

9.4. tie_line_direction

Real or integer value describing the tie-line orientation in the range 0 (north) – 180

9.5. nominal_terrain_clearance

Real value describing the nominal instrument terrain clearance. May include multiple entries for different sensors with different clearance on the same survey platform (e.g electromagnetic, magnetic)

9.6. final_line_kilometers

Real value describing the total flight-line-kilometers surveyed

9.7. traverse_line_number_range

List of real or integer values containing the minimum and maximum traverse flight line numbers

9.8. tie_line_number_range

List of real or integer values containing the minimum and maximum tie- line numbers

9.9. repeat_line_number_range

List of real or integer values containing the minimum and maximum repeat line numbers. For example, lines that periodically repeat a pre-determined calibration profile

9.10. zero_line_number_range

List of real or integer values containing the minimum and maximum line numbers where high-altitude ‘zero’ data are recorded