ocbpy Documentation

Release 0.3.0-beta

Angeline G. Burrell; Gareth Chisham; Jone Reistad

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Contents

This documentation describes the Open Closed field line Boundary (OCB) gridding process and provides examples for usage.

CHAPTER 1

Overview

One of the challenges of working in the polar Magnetosphere-Ionosphere-Thermosphere (MIT) system is choosing an appropriate coordinate system. The ocbpy module converts between the Altitude Adjusted Corrected GeoMagnetic (AACGM) coordinates and a grid that is constructed relative to the Open Closed field line Boundary (OCB). This is particulary useful for statistical studies of the poles, where gridding relative to a fixed magnetic coordinate system would cause averaging of different physical regions, such as auroral and polar cap measurements. This coordinate system is described in the articles listed in *Citation Guide*

CHAPTER 2

Citation Guide

When publishing work that uses OCBpy, please cite both the package and the boundary data set. Specifying which version of OCBpy used will also improve the reproducibility of your presented results.

2.1 OCBpy

- Burrell, A. G., et al. (2022). aburrell/ocbpy: Version 0.3.0. Zenodo. doi:10.5281/zenodo.1217177.

```
@Misc{ocbpy,
      author = {Burrell, A. G. and Chisham, G. and Reistad, J. P.},
      title  = {aburrell/ocbpy: Version 0.3.0},
      year   = {2022},
      date   = {2022-10-21},
      doi    = {10.5281/zenodo.1179230},
      url    = {http://doi.org/10.5281/zenodo.1179230},
      }
```

This package was first described in the python in heliophysics over article, which may also be cited if a description of the package is desired.

- Burrell, A. G., et al. (2018). Snakes on a spaceship — An overview of Python in heliophysics. Journal of Geophysical Research: Space Physics, 123, 10,384–10,402. doi:10.1029/2018JA025877.

2.2 Authors

- Angeline G. Burrell - https://github.com/aburrell
- Gareth Chisham
- Jone P. Reistad - https://github.com/jpreistad

2.3 Contributors

- Dominic Jodoin - https://github.com/cotsog

2.4 IMAGE FUV Boundaries

Please cite both the papers discussing the instrument and the appropriate boundary retrieval method.

- **SI12/SI13**: Mende, S., et al. Space Science Reviews (2000) 91: 287-318. http://doi.org/10.1023/A:1005292301251.
- **WIC**: Mende, S., et al. Space Science Reviews (2000) 91: 271-285. http://doi.org/10.1023/A:1005227915363.
- **OCB**: Chisham, G. (2017) A new methodology for the development of high-latitude ionospheric climatologies and empirical models, J. Geophys. Res. Space Physics, 122, 932–947, http://doi.org/10.1002/2016JA023235.
- **OCB**: Chisham, G. et al. (2022) Ionospheric Boundaries Derived from Auroral Images. In Prep.
- **OCB**: Chisham, G. (2017) Auroral Boundary Derived from IMAGE Satellite Mission Data (May 2000 - Oct 2002), Version 1.1, Polar Data Centre, Natural Environment Research Council, UK. http://doi.org/10.5285/75aa66c1-47b4-4344-ab5d-52ff2913a61e.
- **OCB**: Chisham, G., et al. (2022) Ionospheric boundaries derived from auroral images. Journal of Geophysical Research: Space Physics, 127, e2022JA030622. https://doi.org/10.1029/2022JA030622.

2.5 AMPERE Boundaries

Please follow the AMPERE data usage requirements provided by APL and cite the R1/R2 FAC boundary retrieval method and the OCB correction method.

- **FAC**: Milan, S. E. (2019): AMPERE R1/R2 FAC radii. figshare. Dataset. https://doi.org/10.25392/leicester.data.11294861.v1
- **OCB**: Burrell, A. G., et al. (2020): AMPERE Polar Cap Boundaries, Ann. Geophys., 38, 481-490, http://doi.org/10.5194/angeo-38-481-2020

2.6 DMSP SSJ Boundaries

The DMSP SSJ boundaries are retrieved using ssj_auroral_boundary. Please follow the citation guidelines on their page. The general reference for the DMSP SSJ boundary data set is provided below.

- **SSJ Auroral Boundaries (2010-2014)**: Kilcommons, L., et al. (2019). Defense Meteorology Satellite Program (DMSP) Electron Precipitation (SSJ) Auroral Boundaries, 2010-2014 (Version 1.0.0) [Data set]. Zenodo. http://doi.org/10.5281/zenodo.3373812

CHAPTER 3

Boundary Data Sets

Poleward (OCB) and Equatorward Auroral Boundaries (EABs) must be obtained from observations or a model for this coordinate transformation. The standard OCB and EAB data sets can be found in `ocbpy/boundaries`, though this location may also found using *`ocbpy.boundaries.files.get_boundary_directory()`*. Currently, three different boundary data set types are available. Not all data sets include the locations of the EAB. Routines to retrieve boundary filenames from specific instruments, time periods, hemispheres, and boundary types are provided in the *`ocbpy.boundaries.files`* sub-module.

3.1 IMAGE

Data from three auroral instruments provide northern hemisphere poleward auroral boundary (PAB) and EAB locations for 3 May 2000 02:41:43 UT - 31 Oct 2002 20:05:16, though not all of the times included in these files contain high-quality estimations of the boundary locations. Recommended selection criteria are included as defaults in the `OCBoundary` class. There are also boundary files that combine the information from all instruments to obtain the OCB and EAB. These combined files are the default boundaries for the IMAGE time period. You can read more about the OCB determination, EAB determination, this selection criteria, and the three auroral instruments (IMAGE Wideband Imaging Camera (WIC) and FUV Spectrographic Imagers SI12 and SI13) in the articles listed in *IMAGE FUV Boundaries*.

The most recent corrects for each instrument that add the DMSP particle precipitation corrections to the PAB and EAB locations are included in *`ocbpy.ocb_correction`*. These corrections should be applied to the data used to obtain the circle fits included in the instrument files, not the circle fits themselves. These data sets may be obtained from the British Antarctic Survey.

3.2 AMPERE

OCB data sets can also be obtained from AMPERE (Active Magnetosphere and Planetary Electrodynamics Response Experiment) R1/R2 Field-Aligned Current (FAC) boundary data. This data is provided for both hemispheres between 2010-2016, inclusive. Because there is an offset between the R1/R2 FAC boundary and the OCB, a correction is required. This correction can be implemented using the routines in *`ocbpy.ocb_correction`*. More information

about the method behind the identification of these boundaries and their offset can be found in the articles listed in *AMPERE Boundaries*. Recommended selection criteria are included as defaults in the `OCBoundary` class.

3.3 DMSP SSJ

DMSP particle precipitation instruments make it possible to identify the poleward and equatorward boundaries of the auroral oval along the satellite orbit. Details about this identification process can be found in the references listed in *DMSP SSJ Boundaries*. Routines to download and proceess the DMSP boundary files are provided in the `ocbpy.boundaries.dmsp_ssj_files` sub-module.

3.4 Boundaries Module

Boundary file utilities.

3.4.1 Boundary Files

Functions that support boundary file selection.

`ocbpy.boundaries.files.`**`get_boundary_directory`**`()`
Get the OCBpy boundary directory.

Returns **boundary_dir** – Directory holding the boundary files included in OCBpy

Return type str

`ocbpy.boundaries.files.`**`get_boundary_files`**`(`*bound='ocb'*`)`
Get boundary filenames and their spatiotemporal ranges.

Parameters **bound** (*str*) – String specifying which boundary is desired (OCB or EAB) (default='ocb')

Returns **boundary_files** – Dict with keys of boundary files containing dicts specifying the hemisphere, instrument, file start time, and file end time

Return type dict

Notes

IMAGE instruments may be separated into WIC, SI12, and SI13. If IMAGE is desired, the combined file will be used.

Unknown instruments should have filenames of the format, instrument_hemisphere_%Y%m%d_%Y%m%d.boundary

`ocbpy.boundaries.files.`**`get_default_file`**`(`*stime*, *etime*, *hemisphere*, *instrument=''*, *bound='ocb'*`)`
Get the default file for a specified time and hemisphere.

Parameters

- **stime** (*dt.datetime or NoneType*) – Starting time for which the file is desired; if None, will prioritize IMAGE data for the northern and AMERE data for the southern hemisphere

- **etime** (*dt.datetime or NoneType*) – Ending time for which the file is desired; if None, will prioritize IMAGE data for the northern and AMPERE data for the southern hemisphere
- **hemisphere** (*int*) – Hemisphere for which the file is desired (1=north, -1=south)
- **instrument** (*str*) – Instrument that provides the data. This will override the starting and ending times. Accepts 'ampere', 'amp', 'image', 'si12', 'si13', 'wic', 'dmsp-ssj', and '' (to accept instrument defaults based on time range). Will also accept the instrument name for any instrument whose boundary file follows the naming convention INST_HEMI_YYYYMMDD_YYYYMMDD_*.BBB, where: INST = instrument name HEMI = north or south YYYYMMDD = starting and ending year, month, day BBB = ocb or eab (default='')
- **bound** (*str*) – String specifying which boundary is desired (OCB or EAB) (default='ocb')

Returns

- **default_file** (*str or NoneType*) – Default filename with full path defined or None if no file was available for the specified input constraints
- **instrument** (*str*) – Instrument for the default file (either 'ampere', 'image', or 'dmsp-ssj')

3.4.2 DMSP SSJ Files

CHAPTER 4

OCB Gridding

OCB and dual-boundary gridding is performed by matching observations and OCBs and/or EABs in Universal Time (UT) and then normalising the AACGM magnetic coordinates of the observation to boundary coordinates. This is done by determining the observation's location relative to the current boundary and placing it in the same location relative to a typical OCB and/or EAB. For the OCB, this defaults to 74 degrees, while for the EAB, this defaults to 64 degrees. Data matching is performed by *ocbpy.cycle_boundary.match_data_ocb()*. Coordinate normalisation, as well as boundary loading and data cycling is done within the appropriate boundary classes: *OCBoundary*, *EABoundary*, and *DualBoundary*.

For observations that depend on the cross polar cap potential, it is also important to scale the magnitude. This ensures that the magnitudes from different sized polar caps compare to the *typical* polar cap the OCB gridding produces. For vector data, the local polar north and east components may also change. Magnitude scaling is performed by *ocbpy.ocb_scaling.normal_evar()* or *ocbpy.ocb_scaling.normal_curl_evar()*. Vector scaling, re-orientation, and boundary coordinate normalisation are performed within the class *VectorData*. These classes and functions make up the *ocbpy.ocb_scaling* module.

4.1 Boundary Classes

Hold, manipulate, and load the OCB and EAB data.

References

class ocbpy._boundary.**DualBoundary**(*eab_filename='default'*, *ocb_filename='default'*, *eab_instrument=''*, *ocb_instrument=''*, *hemisphere=1*, *eab_lat=64.0*, *ocb_lat=74.0*, *stime=None*, *etime=None*, *eab_rfunc=None*, *eab_rfunc_kwargs=None*, *ocb_rfunc=None*, *ocb_rfunc_kwargs=None*, *eab=None*, *ocb=None*, *max_delta=60*)

Object containing EAB and OCB data for dual-boundary coordinates.

Parameters

- **eab_filename** (*str or NoneType*) – File containing the required equatorward auroral boundary data sorted by time. If NoneType, no file is loaded. If 'default', *ocbpy.boundaries.files.get_default_file* is called. (default='default')
- **ocb_filename** (*str or NoneType*) – File containing the required open-closed field line boundary data sorted by time. If NoneType, no file is loaded. If 'default', *ocbpy.boundaries.files.get_default_file* is called. (default='default')
- **eab_instrument** (*str*) – Instrument providing the EABoundaries. Requires 'image' or 'dmsp-ssj' if a file is provided. If using filename='default', also accepts 'si12', 'si13', 'wic', and ''. (default='')
- **ocb_instrument** (*str*) – Instrument providing the OCBoundaries. Requires 'image', 'ampere, or 'dmsp-ssj' if a file is provided. If using filename='default', also accepts 'si12', 'si13', 'wic', and ''. (default='')
- **hemisphere** (*int*) – Integer (+/- 1) denoting northern/southern hemisphere (default=1)
- **eab_lat** (*float*) – Typical EABoundary latitude in AACGM coordinates. Hemisphere will give this boundary the desired sign. (default=64.0)
- **ocb_lat** (*float*) – Typical OCBoundary latitude in AACGM coordinates. Hemisphere will give this boundary the desired sign. (default=74.0)
- **stime** (*dt.datetime or NoneType*) – First time to load data or beginning of file. If specifying time, be sure to start before the time of the data to allow the best match within the allowable time tolerance to be found. (default=None)
- **etime** (*dt.datetime or NoneType*) – Last time to load data or ending of file. If specifying time, be sure to end after the last data point you wish to match to, to ensure the best match within the allowable time tolerance is made. (default=None)
- **eab_rfunc** (*numpy.ndarray, function, or NoneType*) – EAB radius correction function. If None, will use the instrument default. Function must have AACGM MLT (in hours) as argument input. To allow the boundary shape to change with univeral time, each temporal instance may have a different function (array input). If a single function is provided, will recast as an array that specifies this function for all times. (default=None)
- **eab_rfunc_kwargs** (*numpy.ndarray, dict, or NoneType*) – Optional keyword arguements for *eab_rfunc*. If None is specified, uses function defaults. If dict is specified, recasts as an array of this dict for all times. Array must be an array of dicts. (default=None)
- **ocb_rfunc** (*numpy.ndarray, function, or NoneType*) – OCB radius correction function. If None, will use the instrument default. Function must have AACGM MLT (in hours) as argument input. To allow the boundary shape to change with univeral time, each temporal instance may have a different function (array input). If a single function is provided, will recast as an array that specifies this function for all times. (default=None)
- **ocb_rfunc_kwargs** (*numpy.ndarray, dict, or NoneType*) – Optional keyword arguements for *ocb_rfunc*. If None is specified, uses function defaults. If dict is specified, recasts as an array of this dict for all times. Array must be an array of dicts. (default=None)
- **eab** (*ocbpy.EABoundary or NoneType*) – Equatorward auroral boundary data object or None to initialize here (default=None)
- **ocb** (*ocbpy.OCBoundary*) – Open-closed field line boundary data oject or Noneto initialize here (default=None)

- **max_delta** (*int*) – Maximum number of seconds allowed between paired EAB and OCB records (default=60)

eab

ocb

max_delta

hemisphere

dtime
Numpy array of paired boundary datetimes

Type numpy.ndarray

eab_ind
Numpy array of EAB indices for a good quality paired boundary

Type numpy.ndarray

ocb_ind
Numpy array of OCB indices for a good quality paired boundary

Type numpy.ndarray

rec_ind
Current OCB record index (default=0; initialised=-1)

Type int

records
Maximum number of paired boundary records

Type int

set_good_ind()
Pair the good indices for the quality EABs and OCBs.

get_next_good_ind()
Cycle to the the next quality paired boundary record.

normal_coord()
Convert data position(s) to normalised co-ordinates relative to the OCB.

revert_coord()
Convert the position of a measurement in OCB into AACGM co-ordinates.

get_aacgm_boundary_lats()
Calculate the EAB and OCB latitude in AACGM coordinates.

calc_r()
Calculate the scaled and unscaled radius at a normalised co-ordinates.

Raises ValueError – Incorrect or incompatible input, mismatched hemisphere assignment

calc_r(*bound_lat*, *bound_mlt*, *aacgm_mlt*, *r_corr*, *overwrite=False*)
Calculate the scaled and unscaled radius at a normalised co-ordinate.

Parameters

- **bound_lat** (*array-like or float*) – Normalised dual-boundary latitude in degrees
- **bound_mlt** (*array-like or float*) – Normalised dual-boundary MLT in hours

- **aacgm_mlt** (*array-like or float*) – MLT in AACGM coordinates in hours
- **r_corr** (*array-like or float*) – OCB radial correction in degrees
- **overwrite** (*bool*) – Overwrite previous boundary locations if this time already has calculated boundary latitudes for a different set of input longitudes (default=False).

Returns

- **scaled_r** (*array-like*) – Scaled radius for the region (OCB, EAB, Sub-auroral) in degrees
- **unscaled_r** (*array-like*) – Unscaled radius for the region (OCB, EAB, Sub-auroral) in degrees

get_aacgm_boundary_lats(*aacgm_mlt*, *rec_ind=None*, *overwrite=False*, *set_lon=True*)

Calculate the OCB latitude in AACGM coordinates at specified MLTs.

Parameters

- **aacgm_mlt** (*int, float, or array-like*) – AACGM longitude location(s) (in degrees) for which the OCB latitude will be calculated.
- **rec_ind** (*int, array-like, or NoneType*) – Record index for which the OCB AACGM latitude will be calculated, or None to calculate all boundary locations (default=None).
- **overwrite** (*bool*) – Overwrite previous boundary locations if this time already has calculated boundary latitudes for a different set of input longitudes (default=False).
- **set_lon** (*bool*) – Calculate the AACGM longitude of the OCB alongside the MLT (default=True).

See also:

`ocbpy.OCBoundary.get_aacgm_boundary_lat()`

get_next_good_ind()

Cycle the boundary attributes to the next good paired index.

normal_coord(*lat*, *lt*, *coords='magnetic'*, *height=350.0*, *method='ALLOWTRACE'*, *overwrite=False*)

Convert coordinates to be normalised relative to the EAB and OCB.

Parameters

- **lat** (*float or array-like*) – Input latitude (degrees), must be geographic, geodetic, or AACGMV2
- **lt** (*float or array-like*) – Input local time (hours), must be solar or AACGMV2 magnetic
- **coords** (*str*) – Input coordiate system. Accepts 'magnetic', 'geocentric', or 'geodetic' (default='magnetic')
- **height** (*float or array-like*) – Height (km) at which AACGMV2 coordinates will be calculated, if geographic coordinates are provided (default=350.0)
- **method** (*str*) – String denoting which type(s) of conversion to perform, if geographic coordinates are provided. Expects either 'TRACE' or 'ALLOWTRACE'. See AACGMV2 for details[2]. (default='ALLOWTRACE')
- **overwrite** (*bool*) – Allow the OCB and EAB AACGM boundary locations to be overwritten (default=False)

[2] Angeline Burrell, Christer van der Meeren, & Karl M. Laundal. (2020). aburrell/aacgmv2 (All Versions). Zenodo. doi:10.5281/zenodo.1212694.

Returns

- **bound_lat** (*float or array-like*) – Magnetic latitude relative to EAB and OCB (degrees)
- **bound_mlt** (*float or array-like*) – Magnetic local time relative to EAB and OCB (hours)
- **ocb_lat** (*float or array-like*) – Magnetic latitude relative to only the OCB (degrees)
- **r_corr** (*float or array-like*) – Radius correction to OCB (degrees)

Notes

Approximation - Conversion assumes a planar surface

Defines *bound_mlt* relative to only the OCB.

See also:

`aacgmv2()`, `ocbpy.OCBoundary.normal_coord()`

rec_ind
Record index that identifies the current good EAB/OCB pair.

revert_coord(*ocb_lat*, *ocb_mlt*, *r_corr=0.0*, *is_ocb=True*, *aacgm_mlt=None*, *coords='magnetic'*, *height=350.0*, *method='ALLOWTRACE'*, *overwrite=False*)
Convert from OCB or dual-boundary into AACGM co-ordinates.

Parameters

- **ocb_lat** (*float or array-like*) – Input OCB or dual-boundary latitude in degrees
- **ocb_mlt** (*float or array-like*) – Input OCB/dual-boundary local time in hours
- **r_corr** (*float or array-like*) – Input OCB radial correction in degrees, may be a function of AACGM MLT (default=0.0)
- **is_ocb** (*bool*) – Specifies that the input of *ocb_lat* is in OCB coordinates if True or in dual-boundary coordinates if False. If False, *aacgm_mlt* must be provided (default=True)
- **aacgm_mlt** (*float, array-like, or NoneType*) – Output AACGM MLT of the dual-boundary data, only used if *is_ocb* is False (default=None)
- **coords** (*str*) – Output coordiate system. Accepts 'magnetic', 'geocentric', or 'geodetic' (default='magnetic')
- **height** (*float or array-like*) – Geocentric height above sea level (km) at which AACGMV2 coordinates will be calculated, if geographic coordinates are desired (default=350.0)
- **method** (*str*) – String denoting which type(s) of conversion to perform, if geographic coordinates are provided. Expects either 'TRACE' or 'ALLOWTRACE'. See AACGMV2 for details[2]. (default='ALLOWTRACE')
- **overwrite** (*bool*) – Allow the OCB and EAB AACGM boundary locations to be overwritten (default=False)

Returns

- **lat** (*float or array-like*) – latitude (degrees)
- **lt** (*float or array-like*) – local time (hours)

Raises `ValueError` – When necessary inputs are not fully supplied

Notes

Approximation - Conversion assumes a planar surface

See also:

`aacgmv2()`, `ocbpy.OCBoundary.revert_coord()`

set_good_ind(*ocb_min_merit=None*, *ocb_max_merit=None*, *ocb_kwargs=None*, *eab_min_merit=None*, *eab_max_merit=None*, *eab_kwargs=None*)

Pair the good indices for the quality EABs and OCBs.

Parameters

- **ocb_min_merit** (*float or NoneType*) – Minimum value for the default figure of merit or None to not apply a custom minimum (default=None)
- **ocb_max_merit** (*float or NoneTye*) – Maximum value for the default figure of merit or None to not apply a custom maximum (default=None)
- **ocb_kwargs** (*dict or NoneType*) – Dict with optional selection criteria. The key should correspond to a data attribute and the value must be a tuple with the first value specifying 'max', 'min', 'maxeq', 'mineq', or 'equal' and the second value specifying the value to use in the comparison. None provides no optional selection criteria. (default=None)
- **eab_min_merit** (*float or NoneType*) – Minimum value for the default figure of merit or None to not apply a custom minimum (default=None)
- **eab_max_merit** (*float or NoneTye*) – Maximum value for the default figure of merit or None to not apply a custom maximum (default=None)
- **eab_kwargs** (*dict or NoneType*) – Dict with optional selection criteria. The key should correspond to a data attribute and the value must be a tuple with the first value specifying 'max', 'min', 'maxeq', 'mineq', or 'equal' and the second value specifying the value to use in the comparison. None provides no optional selection criteria. (default=None)

class ocbpy._boundary.**EABoundary**(*filename='default'*, *instrument=''*, *hemisphere=1*, *boundary_lat=64.0*, *stime=None*, *etime=None*, *rfunc=None*, *rfunc_kwargs=None*)

Object containing equatorward auroral boundary (EAB) data.

Parameters

- **filename** (*str or NoneType*) – File containing the required equatorward auroral boundary data sorted by time. If NoneType, no file is loaded. If 'default', *ocbpy.boundaries.files.get_default_file* is called. (default='default')
- **instrument** (*str*) – Instrument providing the EABoundaries. Requires 'image' or 'dmsp-ssj' if a file is provided. If using filename='default', also accepts 'si12', 'si13', 'wic', and ''. (default='')
- **hemisphere** (*int*) – Integer (+/- 1) denoting northern/southern hemisphere (default=1)
- **boundary_lat** (*float*) – Typical EABoundary latitude in AACGM coordinates. Hemisphere will give this boundary the desired sign. (default=64.0)
- **stime** (*dt.datetime or NoneType*) – First time to load data or beginning of file. If specifying time, be sure to start before the time of the data to allow the best match within the allowable time tolerance to be found. (default=None)
- **etime** (*dt.datetime or NoneType*) – Last time to load data or ending of file. If specifying time, be sure to end after the last data point you wish to match to, to ensure the best match within the allowable time tolerance is made. (default=None)

- **rfunc** (*numpy.ndarray, function, or NoneType*) – EAB radius correction function. If None, will use the instrument default. Function must have AACGM MLT (in hours) as argument input. To allow the boundary shape to change with univeral time, each temporal instance may have a different function (array input). If a single function is provided, will recast as an array that specifies this function for all times. (default=None)
- **rfunc_kwargs** (*numpy.ndarray, dict, or NoneType*) – Optional keyword arguements for *rfunc*. If None is specified, uses function defaults. If dict is specified, recasts as an array of this dict for all times. Array must be an array of dicts. (default=None)

See also:

`ocbpy.OCBoundary`

Raises `ValueError` – Incorrect or incompatible input

class ocbpy._boundary.**OCBoundary**(*filename='default'*, *instrument=''*, *hemisphere=1*, *boundary_lat=74.0*, *stime=None*, *etime=None*, *rfunc=None*, *rfunc_kwargs=None*)

Object containing open-closed field-line boundary (OCB) data.

Parameters

- **filename** (*str or NoneType*) – File containing the required open-closed boundary data sorted by time. If NoneType, no file is loaded. If 'default', *ocbpy.boundaries.files.get_default_file* is called. (default='default')
- **instrument** (*str*) – Instrument providing the OCBoundaries. Requires 'image', 'ampere', or 'dmsp-ssj' if a file is provided. If using filename='default', also accepts 'amp', 'si12', 'si13', 'wic', and ''. (default='')
- **hemisphere** (*int*) – Integer (+/- 1) denoting northern/southern hemisphere (default=1)
- **boundary_lat** (*float*) – Typical OCBoundary latitude in AACGM coordinates. Hemisphere will give this boundary the desired sign. (default=74.0)
- **stime** (*dt.datetime or NoneType*) – First time to load data or beginning of file. If specifying time, be sure to start before the time of the data to allow the best match within the allowable time tolerance to be found. (default=None)
- **etime** (*dt.datetime or NoneType*) – Last time to load data or ending of file. If specifying time, be sure to end after the last data point you wish to match to, to ensure the best match within the allowable time tolerance is made. (default=None)
- **rfunc** (*numpy.ndarray, function, or NoneType*) – OCB radius correction function. If None, will use the instrument default. Function must have AACGM MLT (in hours) as argument input. To allow the boundary shape to change with univeral time, each temporal instance may have a different function (array input). If a single function is provided, will recast as an array that specifies this function for all times. (default=None)
- **rfunc_kwargs** (*numpy.ndarray, dict, or NoneType*) – Optional keyword arguements for *rfunc*. If None is specified, uses function defaults. If dict is specified, recasts as an array of this dict for all times. Array must be an array of dicts. (default=None)

records
Number of boundary records (default=0)

Type int

rec_ind
Current boundary record index (default=0; initialised=-1)

Type int

dtime
Numpy array of boundary datetimes (default=None)

Type numpy.ndarray or NoneType

phi_cent
Numpy array of floats that give the angle from AACGM midnight of the boundary pole in degrees (default=None)

Type numpy.ndarray or NoneType

r_cent
Numpy array of floats that give the AACGM co-latitude of the boundary pole in degrees (default=None)

Type numpy.ndarray or NoneType

r
Numpy array of floats that give the radius of the boundary in degrees (default=None)

Type numpy.ndarray or NoneType

fom
Numpy array of floats that provides a figure of merit that can be used to evaluate the quality of the boundary (default=None)

Type numpy.ndarray or NoneType

min_fom
Minimum acceptable figure of merit for data (default=-np.inf)

Type float

max_fom
Maximum acceptable figure of merit for data (default=np.inf)

Type float

x, y, etc.
Numpy array of floats that hold the remaining values held in *filename*

Type numpy.ndarray or NoneType

inst_defaults()
Get the instrument-specific boundary file loading information.

load()
Load the data from the specified boundary file.

get_next_good_ocb_ind()
Cycle to the the next quality boundary record.

normal_coord()
Convert data position(s) to normalised co-ordinates relative to the OCB.

revert_coord()
Convert the position of a measurement in OCB into AACGM co-ordinates.

get_aacgm_boundary_lat()
Calculate the OCB latitude in AACGM coordinates at specified MLTs.

Raises ValueError – Incorrect or incompatible input

get_aacgm_boundary_lat(*aacgm_mlt*, *rec_ind=None*, *overwrite=False*, *set_lon=True*)
Calculate the OCB latitude in AACGM coordinates at specified MLTs.

Parameters

- **aacgm_mlt** (*int, float, or array-like*) – AACGM longitude location(s) (in degrees) for which the OCB latitude will be calculated.
- **rec_ind** (*int, array-like, or NoneType*) – Record index for which the OCB AACGM latitude will be calculated, or None to calculate all boundary locations (default=None).
- **overwrite** (*bool*) – Overwrite previous boundary locations if this time already has calculated boundary latitudes for a different set of input longitudes (default=False).
- **set_lon** (*bool*) – Calculate the AACGM longitude of the OCB alongside the MLT (default=True).

Notes

Updates OCBoundary object with list attributes. If no boundary value is calculated at a certain time, the list is padded with None. If a boundary latitude cannot be calculated at that time and longitude, that time and longitude is filled with NaN.

aacgm_boundary_lat contains the AACGM latitude location(s) of the OCB (in degrees) for each requested time[3].

aacgm_boundary_mlt holds the aacgm_mlt input for each requested time. The requested MLT may differ from time to time, to allow easy comparison with satellite passes[3].

aacgm_boundary_lon holds the aacgm_lon input for each requested time. This is calculated from *aacgm_boundary_mlt* by default[3].

If the boundary radius is not defined at all MLT (possible for poorly constrained boundaries), then MLT with multiple boundary values will only return one possible solution.

get_next_good_ocb_ind(*min_merit=None*, *max_merit=None*, ***kwargs*)
Cycle to the the next quality OCB record.

Parameters

- **min_merit** (*float or NoneType*) – Minimum value for the default figure of merit or None to not apply a custom minimum (default=None)
- **max_merit** (*float or NoneTye*) – Maximum value for the default figure of merit or None to not apply a custom maximum (default=None)
- **min_sectors** (*int*) – Minimum number of MLT sectors required for good OCB. Deprecated, will be removed in version 0.3.1+ (default=7)
- **rcent_dev** (*float*) –

  Maximum number of degrees between the new centre and the AACGM pole
  Deprecated, will be removed in version 0.3.1+ (default=8.0)
- **max_r** (*float*) – Maximum radius for open-closed field line boundary in degrees. Deprecated, will be removed in version 0.3.1+ (default=23.0)
- **min_r** (*float*) – Minimum radius for open-closed field line boundary in degrees Deprecated, will be removed in version 0.3.1+ (default=10.0)

[3] Shepherd, S. G. (2014), Altitude-adjusted corrected geomagnetic coordinates: Definition and functional approximations, Journal of Geophysical Research: Space Physics, 119, 7501–7521, doi:10.1002/2014JA020264.

- **kwargs** (*dict*) – Dict with optional selection criteria. The key should correspond to a data attribute and the value must be a tuple with the first value specifying 'max', 'min', 'maxeq', 'mineq', or 'equal' and the second value specifying the value to use in the comparison.

Notes

Updates self.rec_ind to the index of next good OCB record or a value greater than self.records if there aren't any more good records available after the starting point

Deprecated IMAGE FUV checks that: - more than 6 MLT boundary values have contributed to OCB circle - the OCB 'pole' is with 8 degrees of the AACGM pole - the OCB 'radius' is greater than 10 and less than 23 degrees AMPERE/DMSP-SSJ and new IMAGE FUV checks that: - the Figure of Merit is greater than or equal to the specified minimum

(*min_fom*) or less than or equal to the specified maximum (*max_fom*)

inst_defaults()
Get the instrument-specific OCB file loading information.

Returns

- **hlines** (*int*) – Number of header lines
- **ocb_cols** (*str*) – String containing the names for each data column
- **datetime_fmt** (*str*) – String containing the datetime format

Notes

Updates the min_fom attribute for AMPERE and DMSP-SSJ

load(*hlines=0*, *ocb_cols='year soy num_sectors phi_cent r_cent r a r_err fom'*, *datetime_fmt=''*, *stime=None*, *etime=None*)
Load the data from the specified boundary file.

Parameters

- **ocb_cols** (*str*) – String specifying format of OCB file. All but the first two columns must be included in the string, additional data values will be ignored. If 'year soy' aren't used, expects 'date time' in 'YYYY-MM-DD HH:MM:SS' format. (default='year soy num_sectors phi_cent r_cent r a r_err r_merit')
- **hlines** (*int*) – Number of header lines preceeding data in the OCB file (default=0)
- **datetime_fmt** (*str*) – A string used to read in 'date time' data. Not used if 'year soy' is specified. (default='')
- **stime** (*dt.datetime or NoneType*) – Time to start loading data or None to start at beginning of file. (default=None)
- **etime** (*datetime or NoneType*) – Time to stop loading data or None to end at the end of the file. (default=None)

normal_coord(*lat*, *lt*, *coords='magnetic'*, *height=350.0*, *method='ALLOWTRACE'*)
Convert position(s) to normalised co-ordinates relative to the OCB.

Parameters

- **lat** (*float or array-like*) – Input latitude (degrees), must be geographic, geodetic, or AACGMV2

- **lt** (*float or array-like*) – Input local time (hours), must be solar or AACGMV2 magnetic
- **coords** (*str*) – Input coordiate system. Accepts 'magnetic', 'geocentric', or 'geodetic' (default='magnetic')
- **height** (*float or array-like*) – Height (km) at which AACGMV2 coordinates will be calculated, if geographic coordinates are provided (default=350.0)
- **method** (*str*) – String denoting which type(s) of conversion to perform, if geographic coordinates are provided. Expects either 'TRACE' or 'ALLOWTRACE'. See AACGMV2 for details[2]. (default='ALLOWTRACE')

Returns

- **ocb_lat** (*float or array-like*) – Magnetic latitude relative to OCB (degrees)
- **ocb_mlt** (*float or array-like*) – Magnetic local time relative to OCB (hours)
- **r_corr** (*float or array-like*) – Radius correction to OCB (degrees)

Notes

Approximation - Conversion assumes a planar surface

See also:

`aacgmv2()`

revert_coord(*ocb_lat*, *ocb_mlt*, *r_corr=0.0*, *coords='magnetic'*, *height=350.0*, *method='ALLOWTRACE'*)

Convert the position of a measurement in OCB into AACGM co-ordinates.

Parameters

- **ocb_lat** (*float or array-like*) – Input OCB latitude in degrees
- **ocb_mlt** (*float or array-like*) – Input OCB local time in hours
- **r_corr** (*float or array-like*) – Input OCB radial correction in degrees, may be a function of AACGM MLT (default=0.0)
- **coords** (*str*) – Output coordiate system. Accepts 'magnetic', 'geocentric', or 'geodetic' (default='magnetic')
- **height** (*float or array-like*) – Geocentric height above sea level (km) at which AACGMV2 coordinates will be calculated, if geographic coordinates are desired (default=350.0)
- **method** (*str*) – String denoting which type(s) of conversion to perform, if geographic coordinates are provided. Expects either 'TRACE' or 'ALLOWTRACE'. See AACGMV2 for details[2]. (default='ALLOWTRACE')

Returns

- **lat** (*float or array-like*) – latitude (degrees)
- **lt** (*float or array-like*) – local time (hours)

Notes

Approximation - Conversion assumes a planar surface

See also:

`aacgmv2()`

4.2 Cycle Boundary Module

Routines to match and cycle through the OCboundary class records.

`ocbpy.cycle_boundary.`**`match_data_ocb`**(*ocb*, *dat_dtime*, *idat=0*, *max_tol=60*, *min_merit=None*, *max_merit=None*, ***kwargs*)

Match data records with OCB records.

Parameters

- **ocb** (*ocbpy.OCBoundary, ocbpy.EABoundary, or ocbpy.DualBoundary*) – Class containing the open-close field line, equatorial auroral boundary, or dual-boundary data
- **dat_dtime** (*list-like*) – List or array of datetime objects where data exists
- **idat** (*int*) – Current data index (default=0)
- **max_tol** (*int*) – maximum seconds between OCB and data record in sec (default=60)
- **min_merit** (*float or NoneType*) – Minimum value for the default figure of merit or None to not apply a custom minimum (default=None)
- **max_merit** (*float or NoneTye*) – Maximum value for the default figure of merit or None to not apply a custom maximum (default=None)
- **kwargs** (*dict*) – Dict with optional selection criteria. The key should correspond to a data attribute and the value must be a tuple with the first value specifying 'max', 'min', 'maxeq', 'mineq', or 'equal' and the second value specifying the value to use in the comparison.
- **min_sectors** (*int*) – Minimum number of MLT sectors required for good OCB. Deprecated, will be removed in version 0.3.1+ (default=7)
- **rcent_dev** (*float*) – Maximum number of degrees between the new centre and the AACGM pole. Deprecated, will be removed in version 0.3.1+ (default=8.0)
- **max_r** (*float*) – Maximum radius for open-closed field line boundary in degrees Deprecated, will be removed in version 0.3.1+ (default=23.0)
- **min_r** (*float*) – Minimum radius for open-closed field line boundary in degrees Deprecated, will be removed in version 0.3.1+ (default=10.0)

Returns **idat** – Data index for match value, None if all of the data have been searched

Return type int or NoneType

Raises `ValueError` – If the input boundary class has an unknown cycling method name

Notes

Updates *ocb.rec_ind* for matched value. This attribute is set to None if all of the boundaries have been searched.

ocbpy.cycle_boundary.**retrieve_all_good_indices**(*ocb*, *min_merit=None*, *max_merit=None*, ***kwargs*)

Retrieve all good indices from the OCBoundary class.

Parameters

- **ocb** (*ocbpy.OCBoundary or ocbpy.EABoundary*) – Class containing the open-close field line or equatorward auroral boundary data
- **min_merit** (*float or NoneType*) – Minimum value for the default figure of merit or None to not apply a custom minimum (default=None)
- **max_merit** (*float or NoneTye*) – Maximum value for the default figure of merit or None to not apply a custom maximum (default=None)
- **kwargs** (*dict*) – Dict with optional selection criteria. The key should correspond to a data attribute and the value must be a tuple with the first value specifying 'max', 'min', 'maxeq', 'mineq', or 'equal' and the second value specifying the value to use in the comparison.

Returns **good_ind** – List of indices containing good OCBs

Return type list

ocbpy.cycle_boundary.**satellite_track**(*lat*, *mlt*, *x1*, *y1*, *x2*, *y2*, *hemisphere*, *del_x=1.0*, *del_y=1.0*, *past_bound=5.0*)

Determine whether or not a point lies along the satellite track.

Parameters

- **lat** (*array-like*) – AACGM latitude in degrees
- **mlt** (*array-like*) – AACGM local time in hours
- **x1** (*float*) – Cartesian x-coordinate of the first boundary location in AACGM degrees along the Dawn-Dusk axis
- **y1** (*float*) – Cartesian y-coordinate of the first boundary location in AACGM degrees along the Noon-Midnight axis
- **x2** (*float*) – Cartesian x-coordinate of the second boundary location in AACGM degrees along the Dawn-Dusk axis
- **y2** (*float*) – Cartesian y-coordinate of the second boundary location in AACGM degrees along the Noon-Midnight axis
- **hemisphere** (*int*) – Integer (+/- 1) denoting northern/southern hemisphere
- **del_x** (*float*) – Allowable distance from the track in AACGM degrees along the x-axis (default=1.0)
- **del_y** (*float*) – Allowable distance from the track in AACGM degrees along the y-axis (default=1.0)
- **past_bound** (*float*) – Allowable distance equatorward from the boundary in AACGM degrees (default=5.0)

Returns **good** – Array of booleans that are True if location is along the track and False if the location falls outside of the track

Return type array-like

Raises ValueError – If the boundary values are negative or if an unknown hemisphere is specified

4.3 OCB Scaling Module

Scale data affected by magnetic field direction or electric field.

References

class ocbpy.ocb_scaling.**VectorData**(*dat_ind*, *ocb_ind*, *aacgm_lat*, *aacgm_mlt*, *ocb_lat=nan*, *ocb_mlt=nan*, *r_corr=nan*, *aacgm_n=0.0*, *aacgm_e=0.0*, *aacgm_z=0.0*, *aacgm_mag=nan*, *dat_name=None*, *dat_units=None*, *scale_func=None*)

Object containing a vector data.

Parameters

- **dat_ind** (*int or array-like*) – Data index (zero offset) for the input
- **ocb_ind** (*int or array-like*) – OCBoundary or DualBoundary record index matched to this data index (zero offset)
- **aacgm_lat** (*float or array-like*) – Vector AACGM latitude (degrees)
- **aacgm_mlt** (*float or array-like*) – Vector AACGM MLT (hours)
- **ocb_lat** (*float or array-like*) – Vector OCB latitude (degrees) (default=np.nan)
- **ocb_mlt** (*float or array-like*) – Vector OCB MLT (hours) (default=np.nan)
- **aacgm_n** (*float or array-like*) – AACGM North pointing vector (positive towards North) (default=0.0)
- **aacgm_e** (*float or array-like*) – AACGM East pointing vector (completes right-handed coordinate system (default = 0.0)
- **aacgm_z** (*float or array-like*) – AACGM Vertical pointing vector (positive down) (default=0.0)
- **aacgm_mag** (*float or array-like*) – Vector magnitude (default=np.nan)
- **dat_name** (*str*) – Data name (default=None)
- **dat_units** (*str*) – Data units (default=None)
- **scale_func** (*function*) – Function for scaling AACGM magnitude with arguements: [measurement value, mesurement AACGM latitude (degrees), mesurement OCB latitude (degrees)] (default=None)

vshape
Shape of output data

Type array-like

unscaled_r
Radius of polar cap in degrees

Type float or array-like

scaled_r
Radius of normalised OCB polar cap in degrees

Type float or array-like

ocb_n
OCB north component of data vector (default=np.nan)

Type float or array-like

ocb_e
OCB east component of data vector (default=np.nan)

Type float or array-like

ocb_z
OCB vertical component of data vector (default=np.nan)

Type float or array-like

ocb_mag
OCB magnitude of data vector (default=np.nan)

Type float or array-like

ocb_quad
AACGM quadrant of OCB pole (default=0)

Type int or array-like

vec_quad
AACGM quadrant of Vector (default=0)

Type int or array-like

pole_angle
Angle at vector location appended by AACGM and OCB poles in degrees (default=np.nan)

Type float or array-like

aacgm_naz
AACGM north azimuth of data vector in degrees (default=np.nan)

Type float or array-like

ocb_aacgm_lat
AACGM latitude of OCB pole in degrees (default=np.nan)

Type float or array-like

ocb_aacgm_mlt
AACGM MLT of OCB pole in hours (default=np.nan)

Type float or array-like

Notes

May only handle one data type, so scale_func cannot be an array

aacgm_mag
Magntiude of the AACGM vector(s).

calc_ocb_polar_angle()
Calculate the OCB north azimuth angle.

Returns **ocb_naz** – Angle between measurement vector and OCB pole in degrees

Return type float or array-like

Raises `ValueError` – If the required input is undefined

Notes

Requires *ocb_quad*, *vec_quad*, *aacgm_naz*, and *pole_angle*

calc_ocb_vec_sign(*north=False*, *east=False*, *quads={}*)
Calculate the sign of the North and East components.

Parameters

- **north** (*bool*) – Get the sign of the north component(s) (default=False)
- **east** (*bool*) – Get the sign of the east component(s) (default=False)
- **quads** (*dict*) – Dictionary of boolean values or arrays of boolean values for OCB and Vector quadrants. (default=dict())

Returns **vsigns** – Dictionary with keys 'north' and 'east' containing the desired signs

Return type dict

Raises ValueError – If the required input is undefined

Notes

Requires *ocb_quad*, *vec_quad*, *aacgm_naz*, and *pole_angle*

calc_vec_pole_angle()
Calc the angle between the AACGM pole, data, and the OCB pole.

Raises ValueError – If the input is undefined or inappropriately sized arrays

Notes

Requires *aacgm_mlt*, *aacgm_lat*, *ocb_aacgm_mlt*, and *ocb_aacgm_lat*. Updates *pole_angle* using spherical trigonometry.

clear_data()
Clear or initialize the output data attributes.

dat_ind
Data index(es).

define_quadrants()
Define AACGM MLT quadrants for the OCB pole and data vector.

Notes

North (N) and East (E) are defined by the AACGM directions centred on the data vector location, assuming vertical is positive downwards Quadrants: 1 [N, E]; 2 [N, W]; 3 [S, W]; 4 [S, E]

Requires *ocb_aacgm_mlt*, *aacgm_mlt*, and *pole_angle*. Updates *ocb_quad* and *vec_quad*

Raises ValueError – If the required input is undefined

ocb_ind
Boundary index(es).

ocb_lat
Boundary latitude in degrees.

ocb_mlt
Boundary magnetic local time in hours.

r_corr
Boundary radius correction in degrees.

scale_vector()
Normalise a variable proportional to the curl of the electric field.

Raises ValueError – If the required input is not defined

Notes

Requires *ocb_lat*, *ocb_mlt*, *ocb_aacgm_mlt*, and *pole_angle*. Updates *ocb_n*, *ocb_e*, *ocb_z*, and *ocb_mag*

set_ocb(*ocb*, *scale_func=None*)
Set the OCBoundary values for provided data (updates all attributes).

Parameters

- **ocb** (*ocbpy.OCBoundary or ocbpy.DualBoundary*) – OCB, EAB, or Dual boundary object
- **scale_func** (*function*) – Function for scaling AACGM magnitude with arguments: [measurement value, mesurement AACGM latitude (degrees), mesurement OCB latitude (degrees)] Not necessary if defined earlier or no scaling is needed. (default=None)

ocbpy.ocb_scaling.**archav**(*hav*)
Calculate the inverse haversine.

Parameters **hav** (*float or array-like*) – Haversine of an angle

Returns **alpha** – Angle in radians

Return type float or array-like

Notes

The input must be positive. However, any number with a magnitude below 10-16 will be rounded to zero. More negative numbers will return NaN.

ocbpy.ocb_scaling.**hav**(*alpha*)
Calculate the haversine.

Parameters **alpha** (*float or array-like*) – Angle in radians

Returns **hav_alpha** – Haversine of alpha, equal to the square of the sine of half-alpha

Return type float or array-like

ocbpy.ocb_scaling.**normal_curl_evar**(*curl_evar*, *unscaled_r*, *scaled_r*)
Normalise a variable proportional to the curl of the electric field.

Parameters

- **curl_evar** (*float or array*) – Variable related to electric field (e.g. vorticity)
- **unscaled_r** (*float or array*) – Radius of polar cap in degrees
- **scaled_r** (*float or array*) – Radius of normalised OCB polar cap in degrees

Returns **nvar** – Normalised variable

Return type float or array

Notes

Assumes that the cross polar cap potential is fixed across the polar cap regardless of the radius of the Open Closed field line Boundary. This is commonly assumed when looking at statistical patterns that control the IMF (which accounts for dayside reconnection) and assume that the nightside reconnection influence is averaged out over the averaged period[1].

ocbpy.ocb_scaling.**normal_evar**(*evar*, *unscaled_r*, *scaled_r*)

Normalise a variable proportional to the electric field.

Parameters

- **evar** (*float or array*) – Variable related to electric field (e.g. velocity)
- **unscaled_r** (*float or array*) – Radius of polar cap in degrees
- **scaled_r** (*float or array*) – Radius of normalised OCB polar cap in degrees

Returns **nvar** – Normalised variable

Return type float or array

Notes

Assumes that the cross polar cap potential is fixed across the polar cap regardless of the radius of the Open Closed field line Boundary. This is commonly assumed when looking at statistical patterns that control the IMF (which accounts for dayside reconnection) and assume that the nightside reconnection influence is averaged out over the averaged period[1].

[1] Chisham, G. (2017), A new methodology for the development of high-latitude ionospheric climatologies and empirical models, Journal of Geophysical Research: Space Physics, 122, doi:10.1002/2016JA023235.

CHAPTER 5

OCB Boundary Correction

Many high-latitude boundaries are related to each other. Both the poleward edge of the auroral oval and the R1/R2 current boundary have been successfully related to the OCB. If you have a data set of boundaries that can be related to the OCB, OCBpy is capable of applying this correction as a function of MLT. These corrections are applied using the `rfunc` and `rfunc_kwargs` keyword arguments in *`OCBoundary`* object. Several correction functions are provided as a part of *`ocbpy.ocb_correction`* module.

5.1 OCB Correction Module

Functions that specify the boundary location as a function of MLT

References

`ocbpy.ocb_correction.`**`circular`**(*mlt*, *r_add=0.0*)
Return a circular boundary correction.

Parameters

- **`mlt`** (*`float or array-like`*) – Magnetic local time in hours (not actually used)
- **`r_add`** (*`float`*) – Offset added to default radius in degrees. Positive values shift the boundary equatorward, whilst negative values shift the boundary poleward. (default=0.0)

Returns **r_corr** – Radius correction in degrees at this MLT

Return type float or array-like

`ocbpy.ocb_correction.`**`elliptical`**(*mlt*, *instrument='ampere'*, *method='median'*)
Return the results of an elliptical correction to the data boundary.

Parameters

- **`mlt`** (*`float or array-like`*) – Magnetic local time in hours
- **`instrument`** (*`str`*) – Data set's instrument name (default='ampere')

- **method** (*str*) – Method used to calculate the elliptical correction, accepts 'median' or 'gaussian'. (default='median')

Returns **r_corr** – Radius correction in degrees at this MLT

Return type float or array-like

References

Prefered AMPERE boundary correction validated in[4].

ocbpy.ocb_correction.**harmonic**(*mlt*, *instrument='ampere'*, *method='median'*)
Return the results of a harmonic fit correction to the data boundary.

Parameters

- **mlt** (*float or array-like*) – Magnetic local time in hours
- **instrument** (*str*) – Data set's instrument name (default='ampere')
- **method** (*str*) – Method used to determine coefficients; accepts 'median' or 'gaussian' when *instrument* is 'ampere'. Otherwise, accepts 'eab' or 'ocb'. (default='median')

Returns **r_corr** – Radius correction in degrees at this MLT

Return type float or array-like

References

AMPERE boundaries obtained from[4]. IMAGE boundaries obtained from[6].

[4] Burrell, A. G. et al.: AMPERE Polar Cap Boundaries, Ann. Geophys., 38, 481-490, doi:10.5194/angeo-38-481-2020, 2020.
[6] Chisham, G. et al.: Ionospheric Boundaries Derived from Auroral Images, in prep, 2022.

CHAPTER 6

Supported Instrument Data Sets

Currently, support is included for files from the following sources:

1. SuperMAG (*ocbpy.instruments.supermag*)
2. SuperDARN Vorticity (*ocbpy.instruments.vort*)
3. pysat (*ocbpy.instruments.pysat_instruments*)

These routines may be used as a guide to write routines for other data sets. A *ocbpy.instruments.general* loading sub-module is also provided for ASCII files. All the non-boundary data routines are part of the ocbpy.instruments module. Support for time-handling that may be useful for specific data sets are provided in *ocbpy.ocb_time*.

6.1 General Instrument Module

General loading routines for data files.

ocbpy.instruments.general.**load_ascii_data**(*filename*, *hlines*, *gft_kwargs={}*, *hsplit=None*, *datetime_cols=None*, *datetime_fmt=None*, *int_cols=None*, *str_cols=None*, *max_str_length=50*, *header=None*)

Load an ASCII data file into a dict of numpy arrays.

Parameters

- **filename** (*str*) – data file name
- **hlines** (*int*) – number of lines in header. If zero, must include header.
- **gft_kwargs** (*dict*) – Dictionary holding optional keyword arguments for the numpy genfromtxt routine (default=dict())
- **hsplit** (*str, NoneType*) – character seperating data labels in header. None splits on all whitespace characters. (default=None)

- **datetime_cols** (*list, NoneType*) – If there are date strings or values that should be converted to a datetime object, list them in order here. Not processed as floats. NoneType produces an empty list. (default=None)
- **datetime_fmt** (*str, NoneType*) – Format needed to convert the datetime_cols entries into a datetime object. Special formats permitted are: 'YEAR SOY', 'SOD'. 'YEAR SOY' must be used together; 'SOD' indicates seconds of day, and may be used with any date format (default=None)
- **int_cols** (*list, NoneType*) – Data that should be processed as integers, not floats. NoneType produces an empty list. (default=None)
- **str_cols** (*list, NoneType*) – Data that should be processed as strings, not floats. NoneType produces an empty list. (default=None)
- **max_str_length** (*int*) – Maximum allowed string length. (default=50)
- **header** (*list, NoneType*) – Header string(s) where the last line contains whitespace separated data names. NoneType produces an empty list. (default=None)

Returns

- **header** (*list of strings*) – Contains all specified header lines
- **out** (*dict of numpy.arrays*) – The dict keys are specified by the header data line, the data for each key are stored in the numpy array

Notes

Data is assumed to be float unless otherwise stated.

ocbpy.instruments.general.**test_file**(*filename*)

Test to ensure the file is small enough to load.

Parameters **filename** (*str*) – Filename to test

Returns **good_flag** – True if good, bad if false

Return type bool

Notes

Python can only allocate 2GB of data without crashing

6.2 SuperMAG Instrument Module

Perform OCB gridding for SuperMAG data.

Notes

SuperMAG data available at: http://supermag.jhuapl.edu/

ocbpy.instruments.supermag.**load_supermag_ascii_data**(*filename*)

Load a SuperMAG ASCII data file.

Parameters **filename** (*str*) – SuperMAG ASCI data file name

Returns **out** – The dict keys are specified by the header data line, the data for each key are stored in the numpy array

Return type dict

ocbpy.instruments.supermag.**supermag2ascii_ocb**(*smagfile*, *outfile*, *hemisphere=0*, *ocb=None*, *ocbfile='default'*, *instrument=''*, *max_sdiff=600*, *min_merit=None*, *max_merit=None*, *scale_func=<function normal_curl_evar>*, ***kwargs*)

Covert and scales the SuperMAG data into OCB coordinates.

Parameters

- **smagfile** (*str*) – File containing the required SuperMAG file sorted by time
- **outfile** (*str*) – Filename for the output data
- **hemisphere** (*int*) – Hemisphere to process (can only do one at a time). 1=Northern, -1=Southern, 0=Determine from data (default=0)
- **ocb** (*ocbpy.OCBoundary, ocbpy.DualBoundary, or NoneType*) – OCBoundary or DualBoundary object with data loaded already. If None, looks to *ocbfile* and creates an OCBoundary object. (default=None)
- **ocbfile** (*str*) – File containing the required OC Boundary data sorted by time, or 'default' to load default file for time and hemisphere. Only used if no OCBoundary object is supplied (default='default')
- **instrument** (*str*) – Instrument providing the OCBoundaries. Requires 'image' or 'ampere' if a file is provided. If using filename='default', also accepts 'amp', 'si12', 'si13', 'wic', and ''. (default='')
- **max_sdiff** (*int*) – Maximum seconds between OCB and data record in sec (default=60)
- **min_merit** (*float or NoneType*) – Minimum value for the default figure of merit or None to not apply a custom minimum (default=None)
- **max_merit** (*float or NoneTye*) – Maximum value for the default figure of merit or None to not apply a custom maximum (default=None)
- **kwargs** (*dict*) – Dict with optional selection criteria. The key should correspond to a data attribute and the value must be a tuple with the first value specifying 'max', 'min', 'maxeq', 'mineq', or 'equal' and the second value specifying the value to use in the comparison.
- **min_sectors** (*int*) – Minimum number of MLT sectors required for good OCB. Deprecated, will be removed in version 0.3.1+ (default=7).
- **rcent_dev** (*float*) – Maximum number of degrees between the new centre and the AACGM pole. Deprecated, will be removed in version 0.3.1+ (default=8.0)
- **max_r** (*float*) – Maximum radius for open-closed field line boundary in degrees/ Deprecated, will be removed in version 0.3.1+ (default=23.0)
- **min_r** (*float*) – Minimum radius for open-closed field line boundary in degrees. Deprecated, will be removed in version 0.3.1+ (default=10.0)
- **scale_func** (*function or NoneType*) – Scale the magnetic field observations unless None (default=ocbpy.ocb_scale.normal_curl_evar)

Raises IOError – If unable to open the input or output file

Notes

May only process one hemisphere at a time.

See also:

`ocbpy.ocb_scale.normal_curl_evar()`

6.3 SuperDARN Vorticity Instrument Module

Perform OCB gridding for SuperDARN vorticity data.

Notes

Specialised SuperDARN data product, available from: gchi@bas.ac.uk

`ocbpy.instruments.vort.`**`load_vorticity_ascii_data`**(*vortfile*, *save_all=False*)

Load SuperDARN vorticity data files.

Parameters

- **`vortfile`** (*`str`*) – SuperDARN vorticity file in block format
- **`save_all`** (*`bool`*) – Save all data from the file (True), or only data needed to calculate the OCB coordinates and normalised vorticity (False). (default=False)

Returns **vdata** – Dictionary of numpy arrays

Return type dict

`ocbpy.instruments.vort.`**`vort2ascii_ocb`**(*vortfile*, *outfile*, *hemisphere=0*, *ocb=None*, *ocbfile='default'*, *instrument=''*, *max_sdiff=600*, *save_all=False*, *min_merit=None*, *max_merit=None*, *scale_func=<function normal_curl_evar>*, ***kwargs*)

Covert the location of vorticity data from AACGM to OCB coordinates.

Parameters

- **`vortfile`** (*`str`*) – file containing the required vorticity file sorted by time
- **`outfile`** (*`str`*) – filename for the output data
- **`hemisphere`** (*`int`*) – Hemisphere to process (can only do one at a time). 1=Northern, -1=Southern, 0=Determine from data (default=0)
- **`ocb`** (*`ocbpy.ocboundary.OCBoundary`*, *`ocbpy.DualBoundary`*, *or `NoneType`*) – OCBoundary or DualBoundary object with data loaded already. If None, looks to *ocbfile* and creates an OCBoundary object. (default=None)
- **`ocbfile`** (*`str`*) – File containing the required OC boundary data sorted by time, or 'default' to load default file for time and hemisphere. Only used if no OCBoundary object is supplied (default='default')
- **`instrument`** (*`str`*) – Instrument providing the OCBoundaries. Requires 'image' or 'ampere' if a file is provided. If using filename='default', also accepts 'amp', 'si12', 'si13', 'wic', and ''. (default='')
- **`max_sdiff`** (*`int`*) – maximum seconds between OCB and data record in sec (default=600)

- **save_all** (*bool*) – Save all data (True), or only that needed to calcuate OCB and vorticity (False). (default=False)
- **min_merit** (*float or NoneType*) – Minimum value for the default figure of merit or None to not apply a custom minimum (default=None)
- **max_merit** (*float or NoneTye*) – Maximum value for the default figure of merit or None to not apply a custom maximum (default=None)
- **kwargs** (*dict*) – Dict with optional selection criteria. The key should correspond to a data attribute and the value must be a tuple with the first value specifying 'max', 'min', 'maxeq', 'mineq', or 'equal' and the second value specifying the value to use in the comparison.
- **min_sectors** (*int*) – Minimum number of MLT sectors required for good OCB. Deprecated, will be removed in version 0.3.1+ (default=7)
- **rcent_dev** (*float*) – Maximum number of degrees between the new centre and the AACGM pole. Deprecated, will be removed in version 0.3.1+ (default=8.0)
- **max_r** (*float*) – Maximum radius for open-closed field line boundary in degrees. Deprecated, will be removed in version 0.3.1+ (default=23.0)
- **min_r** (*float*) – Minimum radius for open-closed field line boundary in degrees. Deprecated, will be removed in version 0.3.1+ (default=10.0)
- **scale_func** (*function or NoneType*) – Scaling function for Vorticity data or None to not scale (default=ocbpy.ocb_scale.normal_curl_evar)

Raises

- IOError – If unable to open input or output file
- ValueError – If unable to retrieve all necessary data from the input file

Notes

Input header or col_names must include the names in the default string.

6.4 pysat Instrument Module

Perform OCB gridding for appropriate instrument data loaded in pysat.

Notes

pysat is available at: http://github.com/pysat/pysat or pypi

ocbpy.instruments.pysat_instruments.**add_ocb_to_data**(*pysat_inst*, *mlat_name=''*, *mlt_name=''*, *evar_names=None*, *curl_evar_names=None*, *vector_names=None*, *hemisphere=0*, *ocb=None*, *ocbfile='default'*, *instrument=''*, *max_sdiff=60*, *min_merit=None*, *max_merit=None*, ***kwargs*)

Covert the location of pysat data into OCB, EAB, or Dual coordinates.

Parameters

- **pysat_inst** (*pysat.Instrument*) – pysat.Instrument class object containing magnetic coordinates
- **mlat_name** (*str*) – Instrument data key or column for magnetic latitudes (default='')
- **mlt_name** (*str*) – Instrument data key or column for magnetic local times (default='')
- **evar_names** (*list or NoneType*) – List of Instrument data keys or columns pointing to measurements that are proportional to the electric field (E); e.g. ion drift (default=None)
- **curl_evar_names** (*list or NoneType*) – List of Instrument data keys or columns pointing to measurements that are proportional to the curl of E; e.g. ion vorticity (default=None)
- **vector_names** (*dict or NoneType*) – Dict of Instrument data keys or columns pointing to measurements that are vectors that are proportional to either E or the curl of E. The key should correspond to one of the values in the evar_names or curl_evar_names list. If this is not done, a scaling function must be provided. The value corresponding to each key must be a dict that indicates the names holding data needed to initialise the ocbpy.ocb_scaling.VectorData object (default=None)
- **hemisphere** (*int*) – Hemisphere to process (can only do one at a time). 1=Northern, -1=Southern, 0=Determine from data (default=0)
- **ocb** (*ocbpy.OCBoundary, ocbpy.DualBoundary, or NoneType*) – OCBoundary or DualBoundary object with data loaded already. If None, looks to *ocbfile* and creates an OCBoundary object. (default=None)
- **ocbfile** (*str*) – file containing the required OC boundary data sorted by time, ignorned if OCBoundary object supplied (default='default')
- **instrument** (*str*) – Instrument providing the OCBoundaries. Requires 'image' or 'ampere' if a file is provided. If using filename='default', also accepts 'amp', 'si12', 'si13', 'wic', and '' (default='')
- **max_sdiff** (*int*) – maximum seconds between OCB and data record in sec (default=60)
- **min_merit** (*float or NoneType*) – Minimum value for the default figure of merit or None to not apply a custom minimum (default=None)
- **max_merit** (*float or NoneTye*) – Maximum value for the default figure of merit or None to not apply a custom maximum (default=None)
- **kwargs** (*dict*) – Dict with optional selection criteria. The key should correspond to a data attribute and the value must be a tuple with the first value specifying 'max', 'min', 'maxeq', 'mineq', or 'equal' and the second value specifying the value to use in the comparison.
- **min_sectors** (*int*) – Minimum number of MLT sectors required for good OCB. Deprecated, will be removed in version 0.3.1+ (default=7)
- **rcent_dev** (*float*) – Maximum number of degrees between the new centre and the AACGM pole. Deprecated, will be removed in version 0.3.1+ (default=8.0)
- **max_r** (*float*) – Maximum radius for open-closed field line boundary in degrees. Deprecated, will be removed in version 0.3.1+ (default=23.0)
- **min_r** (*float*) – Minimum radius for open-closed field line boundary in degrees. Deprecated, will be removed in version 0.3.1+ (default=10.0)

Raises ValueError – If the pysat Instrument doesn't have the necessary data values or if the input provided is not a pysat Instrument.

Notes

This may be run on a pysat instrument or as a custom function when loading pysat data.

Examples

```
# Example vector name input looks like:
vector_names={'vel': {'aacgm_n': 'vel_n', 'aacgm_e': 'vel_e',
                      'dat_name': 'velocity', 'dat_units': 'm/s'},
              'dat': {'aacgm_n': 'dat_n', 'aacgm_e': 'dat_e',
                      'scale_func': local_scale_func}}
```

ocbpy.instruments.pysat_instruments.**add_ocb_to_metadata**(*pysat_inst*, *ocb_name*, *pysat_name*, *overwrite=False*, *notes=''*, *isvector=False*)

Update pysat metadata for OCB data.

Parameters

- **pysat_inst** (*pysat.Instrument*) – pysat.Instrument class object containing magnetic coordinates
- **ocb_name** (*str*) – Data column name for OCB data
- **pysat_name** (*str*) – Data column name for non-OCB version of this data
- **overwrite** (*bool*) – Overwrite existing metadata, if present (default=False)
- **notes** (*str)*) – Notes about this OCB data (default='')
- **isvector** (*bool*) – Is this vector data or not (default=False)

Raises ValueError – If input pysat Instrument object is the wrong class

6.5 Time Handling Module

Routines to convert from different file timekeeping methods to datetime.

ocbpy.ocb_time.**convert_time**(*year=None*, *soy=None*, *yyddd=None*, *sod=None*, *date=None*, *tod=None*, *datetime_fmt='%Y-%m-%d %H:%M:%S'*)

Convert to datetime from multiple time formats.

Parameters

- **year** (*int or NoneType*) – Year or None if not in year-soy format (default=None)
- **soy** (*int or NoneType*) – Seconds of year or None if not in year-soy format (default=None)
- **yyddd** (*str or NoneType*) – String containing years since 1900 and 3-digit day of year (default=None)
- **sod** (*int, float, or NoneType*) – Seconds of day or None if the time of day is not in this format (default=None)
- **date** (*str or NoneType*) – String containing date information or None if not in datetime format (default=None)

- **tod** (*str or NoneType*) – String containing time of day information or None if not in date-time format (default=None)
- **datetime_fmt** (*str*) – String with the date-time or date format (default='%Y-%m-%d %H:%M:%S')

Returns **dtime** – Datetime object

Return type dt.datetime

ocbpy.ocb_time.**datetime2hr**(*dtime*)
Calculate hours of day from datetime.

Parameters **dtime** (*dt.datetime*) – Universal time as a timestamp

Returns **uth** – Hours of day, includes fractional hours

Return type float

ocbpy.ocb_time.**deg2hr**(*lon*)
Convert from degrees to hours.

Parameters **lon** (*float or array-like*) – Longitude-like value in degrees

Returns **lt** – Local time-like value in hours

Return type float or array-like

ocbpy.ocb_time.**fix_range**(*values*, *min_val*, *max_val*, *val_range=None*)
Ensure cyclic values lie below the maximum and at or above the mininum.

Parameters

- **values** (*int, float, or array-like*) – Values to adjust
- **min_val** (*int or float*) – Maximum that values may not meet or exceed
- **max_val** (*int or float*) – Minimum that values may not lie below
- **val_range** (*int, float, or NoneType*) – Value range or None to calculate from min and max (default=None)

Returns **fixed_vals** – Values adjusted to lie min_val <= fixed_vals < max_val

Return type int, float, or array-like

ocbpy.ocb_time.**get_datetime_fmt_len**(*datetime_fmt*)
Get the lenght of a string line needed for a specific datetime format.

Parameters **datetime_fmt** (*str*) – Formatting string used to convert between datetime and string object

Returns **str_len** – Minimum length of a string needed to hold the specified data

Return type int

Notes

See the datetime documentation for meanings of the datetime directives

ocbpy.ocb_time.**glon2slt**(*glon*, *dtime*)
Convert from geographic longitude to solar local time.

Parameters

- **glon** (*float or array-like*) – Geographic longitude in degrees

- **dtime** (*dt.datetime*) – Universal time as a timestamp

Returns **slt** – Solar local time in hours

Return type float or array-like

ocbpy.ocb_time.**hr2deg**(*lt*)
Convert from degrees to hours.

Parameters **lt** (*float or array-like*) – Local time-like value in hours

Returns **lon** – Longitude-like value in degrees

Return type float or array-like

ocbpy.ocb_time.**hr2rad**(*lt*)
Convert from hours to radians.

Parameters **lt** (*float or array-like*) – Local time-like value in hours

Returns **lon** – Longitude-like value in radians

Return type float or array-like

ocbpy.ocb_time.**rad2hr**(*lon*)
Convert from radians to hours.

Parameters **lon** (*float or array-like*) – Longitude-like value in radians

Returns **lt** – Local time-like value in hours

Return type float or array-like

ocbpy.ocb_time.**slt2glon**(*slt*, *dtime*)
Convert from solar local time to geographic longitude.

Parameters

- **slt** (*float or array-like*) – Solar local time in hours
- **dtime** (*dt.datetime*) – Universal time as a timestamp

Returns **glon** – Geographic longitude in degrees

Return type float or array-like

ocbpy.ocb_time.**year_soy_to_datetime**(*yyyy*, *soy*)
Converts year and soy to datetime.

Parameters

- **yyyy** (*int*) – 4 digit year
- **soy** (*float*) – seconds of year

Returns **dtime** – datetime object

Return type dt.datetime

ocbpy.ocb_time.**yyddd_to_date**(*yyddd*)
Convert from years since 1900 and day of year to datetime.

Parameters **yyddd** (*str*) – String containing years since 1900 and day of year (e.g. 100126 = 2000-05-5).

Returns **dtime** – Datetime object containing date information

Return type dt.datetime

CHAPTER 7

Examples

Here are some simple examples that will show how to initialise an `OCBoundary` object, find a trustworthy open-closed boundary, convert between AACGM and OCB coordinates, and more.

7.1 Getting Started

`ocbpy` is centred around Boundary class objects. The default class for most functions and examples, is the Open-Closed field line Boundary class, *`OCBoundary`*.

7.1.1 Initialise an OCBoundary object

Start a python or iPython session, and begin by importing ocbpy, numpy, matplotlib, and datetime.

```
import numpy as np
import datetime as dt
import matplotlib as mpl
import matplotlib.pyplot as plt
import ocbpy
```

Next, initialise an *`OCBoundary`* object. This uses the default IMAGE FUV file and will take a few minutes to load.

```
ocb = ocbpy.OCBoundary()
print(ocb)

OCBoundary file: ~/ocbpy/ocbpy/boundaries/image_north_circle.ocb
Source instrument: IMAGE
Boundary reference latitude: 74.0 degrees

305805 records from 2000-05-04 03:03:20 to 2002-10-31 20:05:16

YYYY-MM-DD HH:MM:SS Phi_Centre R_Centre R
--------------------------------------------------------------------------------
```

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```
2000-05-04 03:03:20 4.64 2.70 21.00
2000-05-04 03:07:15 147.24 2.63 7.09
2002-10-31 20:03:16 207.11 5.94 22.86
2002-10-31 20:05:16 335.47 6.76 11.97

Uses scaling function(s):
ocbpy.ocb_correction.circular(**{})
```

7.1.2 Other Boundary classes

The other Boundary classes, *EABoundary* and *DualBoundary*, build upon the *OCBoundary* class. Initialising these classes is done bascially the same way. To make this example run more quickly, we will limit the period of time over which boundaries are loaded. The same temporal selection procedure works with the other Boundary classes.

```
stime = dt.datetime(2000, 5, 5)
etime = dt.datetime(2000, 5, 8)

dual = ocbpy.DualBoundary(stime=stime, etime=etime)
print(dual)

Dual Boundary data
13 good boundary pairs from 2000-05-05 11:58:48 to 2000-05-05 15:30:23
Maximum  boundary difference of 60.0 s

EABoundary file: ~/ocbpy/ocbpy/boundaries/image_north_circle.eab
Source instrument: IMAGE
Boundary reference latitude: 64.0 degrees

81 records from 2000-05-05 11:35:27 to 2000-05-07 23:32:14

YYYY-MM-DD HH:MM:SS Phi_Centre R_Centre R
-------------------------------------------------------------------------
2000-05-05 11:35:27 111.80 2.34 25.12
2000-05-05 11:37:23 296.23 1.42 26.57
2000-05-07 21:50:20 220.84 7.50 16.89
2000-05-07 23:32:14 141.27 10.33 18.32

Uses scaling function(s):
ocbpy.ocb_correction.circular(**{})

OCBoundary file: ~/ocbpy/ocbpy/boundaries/image_north_circle.ocb
Source instrument: IMAGE
Boundary reference latitude: 74.0 degrees

76 records from 2000-05-05 11:19:52 to 2000-05-07 23:32:14

YYYY-MM-DD HH:MM:SS Phi_Centre R_Centre R
-------------------------------------------------------------------------
2000-05-05 11:19:52 218.54 9.44 11.48
2000-05-05 11:35:27 304.51 8.69 15.69
2000-05-07 23:24:14 199.84 10.91 12.69
2000-05-07 23:32:14 141.53 9.24 13.03


Uses scaling function(s):
```

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```
ocbpy.ocb_correction.circular(**{})
```

7.2 Selecting Boundaries

Each of the *Boundary Data Sets* has a figure of merit that can be used to select quality records. The various Boundary classes also contain methods to cycle to the next good record. Unlike standard Python indices, the Boundary `rec_ind` must be positive. This allows the user to know whether or not quality Boundaries have been identified.

7.2.1 Retrieve a good OCB record

Continuing from the previous example, our next step is to get the first good OCB record. The *OCBoundary* and *EABoundary* objects start without any good indices chosen to allow you to specify your desired selection criteria. This section uses the `ocb` from the previous section (with default keyword arguements).

```
ocb.get_next_good_ocb_ind()
print(ocb.rec_ind)
0
```

To get the OCB record closest to a specified time, use *match_data_ocb()*. In this example the maximum time tolerance is changed from the default of 60 seconds to 30 seconds to ensure only one of the test times (that have a 60 second resolution) is returned.

```
test_times = [ocb.dtime[ocb.rec_ind] + dt.timedelta(minutes=(i - 2))
              for i in range(5)]
itest = ocbpy.match_data_ocb(ocb, test_times, idat=0, max_tol=30)
print(itest, ocb.rec_ind, test_times[itest], ocb.dtime[ocb.rec_ind])

2 0 2000-05-04 03:03:20 2000-05-04 03:03:20
```

7.2.2 Retrive a good DualBoundary record

The *DualBoundary* class starts with good Boundaries selected using the default criteria for the given instrument. You can change that at any time, as shown below. This example uses the `dual` variable set in the first example.

```
# Before resetting, check that this is: 0 13 12 12
print(dual.rec_ind, dual.records, dual.ocb.rec_ind, dual.eab.rec_ind)

# Reset the good boundary pairs using more restrictive FOM values
dual.set_good_ind(ocb_max_merit=dual.ocb.max_fom - 1.0,
                  eab_max_merit=dual.eab.max_fom - 1.0)
print(dual.rec_ind, dual.records, dual.ocb.rec_ind, dual.eab.rec_ind)

0 9 14 14
```

Cycling to the next record will increment *rec_ind* by one and updates the sub-class record indices to their next good paired values.

```
dual.get_next_good_ind()
print(dual.rec_ind, dual.records, dual.ocb.rec_ind, dual.eab.rec_ind)

1 9 17 18
```

7.3 Coordinate Convertion

All Boundary classes have methods to convert between magnetic, geodetic, or geographic and normalised boundary coordinates. When geodetic or geographic coordinates are provided, `aacgmv2` is used to perform the conversion at a specified height.

7.3.1 Convert between AACGM and OCB coordinates

We'll start by visualising the location of the OCB using the first good OCB in the default IMAGE FUV file.

```
def set_up_polar_plot(ax, hemi=1):
    """Set the formatting for a polar plot.

    Parameters
    ----------
    ax : Axes object
        Subplot Axes object to be formatted
    hemi : int
        Hemisphere, 1 is North and -1 is South (default=1)

    """
    ss = "" if hemi == 1 else "-"
    ax.set_theta_zero_location("S")
    ax.xaxis.set_ticks([0, 0.5 * np.pi, np.pi, 1.5 * np.pi])
    ax.xaxis.set_ticklabels(["00:00", "06:00", "12:00 MLT", "18:00"])
    ax.set_rlim(0, 25)
    ax.set_rticks([5, 10, 15, 20])
    ax.yaxis.set_ticklabels([ss + "85$^\circ$", ss + "80$^\circ$",
                             ss + "75$^\circ$", ss + "70$^\circ$"])
    return

fig = plt.figure()
ax = fig.add_subplot(111, projection="polar")
set_up_polar_plot(ax)
```

Mark the location of the circle centre in AACGM coordinates

```
# Use the OCB of the first good, paired OCB loaded in the `dual` example
ocb.rec_ind = dual.ocb_ind[0]
ax.plot(np.radians(ocb.phi_cent[ocb.rec_ind]), ocb.r_cent[ocb.rec_ind],
        "mx", ms=10, label="OCB Pole")
```

Calculate and plot the location of the OCB in AACGM coordinates

```
mlt = np.linspace(0.0, 24.0, num=64)
ocb.get_aacgm_boundary_lat(mlt, rec_ind=ocb.rec_ind)
theta = ocbpy.ocb_time.hr2rad(mlt)
rad = 90.0 - ocb.aacgm_boundary_lat[ocb.rec_ind]
ax.plot(theta, rad, "m-", linewidth=2, label="OCB")
ax.text(theta[40], rad[40] + 2, "{:.0f}$^\circ$".format(ocb.boundary_lat),
        fontsize="medium", color="m")
```

Add more reference labels for OCB coordinates. Since we know the location that we want to place these labels in OCB coordinates, the *`revert_coord()`* method can be used to get the location in AACGM coordinates.

```
# Define a latitude grid for the OCB coordinates
grid_ocb = 0.5 * (90 - abs(ocb.boundary_lat)) + ocb.boundary_lat
grid_lat, grid_mlt = ocb.revert_coord(grid_ocb, mlt)
grid_lat = 90.0 - grid_lat
grid_theta = grid_mlt * np.pi / 12.0

# Define the MLT grid in OCB coordinates
lon_clock = list()
lat_clock = list()
for ocb_mlt in np.arange(0.0, 24.0, 6.0):
    aa, oo = ocb.revert_coord(ocb.boundary_lat, ocb_mlt)
    lon_clock.append(oo * np.pi / 12.0)
    lat_clock.append(90.0 - aa)

# Plot the OCB latitude and MLT grid
ax.plot(lon_clock, lat_clock, "m+")
ax.plot([lon_clock[0], lon_clock[2]], [lat_clock[0], lat_clock[2]], "-",
        color="lightpink", zorder=1)
ax.plot([lon_clock[1], lon_clock[3]], [lat_clock[1], lat_clock[3]], "-",
        color="lightpink", zorder=1)
ax.plot(grid_theta, grid_lat, "-", color="lightpink", zorder=1)
ax.text(lon_clock[2] + .2, lat_clock[2] + 1.0, "12:00",fontsize="medium",
        color="m")
ax.text(grid_theta[40], grid_lat[40] + 2, "{:.0f}$^\circ$".format(grid_ocb),
        fontsize="medium", color="m")
```

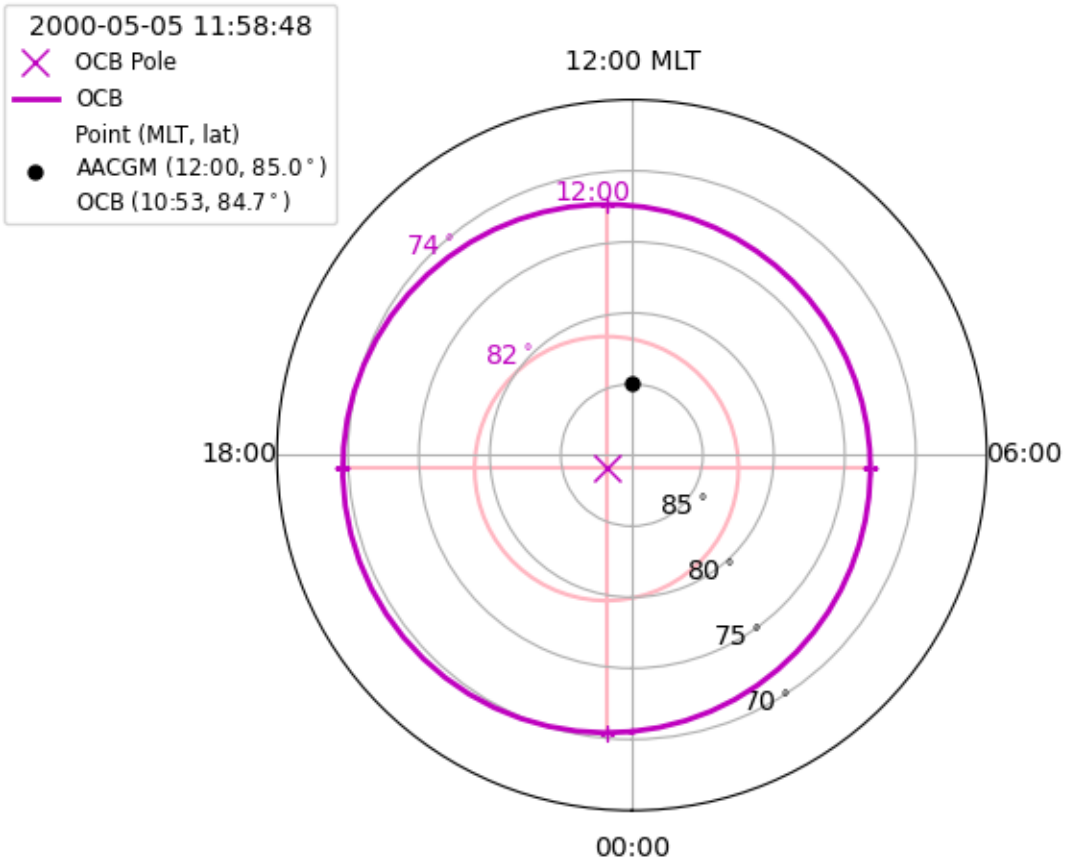
Now add the location of a point in AACGM coordinates, calculate the location relative to the OCB, and output both coordinates in the legend

```
aacgm_lat = 85.0
aacgm_theta = np.pi
ocb_lat, ocb_mlt, _ = ocb.normal_coord(aacgm_lat, aacgm_theta * 12.0 / np.pi)

plabel = "\n".join(["Point (MLT, lat)", "AACGM (12:00, 85.0$^\circ$)",
                    "OCB ({:02.0f}:{:02.0f}, {:.1f}$^\circ$)".format(
                        np.floor(ocb_mlt),
                        (ocb_mlt - np.floor(ocb_mlt)) * 60.0, ocb_lat)])
ax.plot([aacgm_theta], [90.0 - aacgm_lat], "ko", ms=5, label=plabel)
```

Add a legend to finish the figure.

```
ax.legend(loc=2, fontsize="small", title="{:}".format(
    ocb.dtime[ocb.rec_ind]), bbox_to_anchor=(-0.4, 1.15))
```



Scaling of values dependent on the electric potential can be found in the *ocbpy.ocb_scaling* module.

7.3.2 Convert between AACGM and dual-boundary coordinates

Now let us perform the same visualisation using a paired EAB and OCB. The prior example ensured that this was a time with a good dual-boundary for `dual` from the prior examples. Continue by adding the EAB to the existing figure.

```
dual.rec_ind = 0
ax.plot(np.radians(dual.eab.phi_cent[dual.eab.rec_ind]),
                   dual.eab.r_cent[dual.eab.rec_ind],
                   "+", color='purple', ms=10, label="EAB Pole")
```

Calculate and plot the location of the EAB in AACGM coordinates, expanding the radial boundaries of the figure as needed.

```
dual.get_aacgm_boundary_lats(mlt, rec_ind=dual.rec_ind, overwrite=True)
rad = 90.0 - dual.eab.aacgm_boundary_lat[dual.eab.rec_ind]
ax.plot(theta, rad, "-", color='purple', linewidth=2, label="EAB")
ax.text(theta[40], rad[40] + 2,
        "{:.0f}$^\circ$".format(dual.eab.boundary_lat), fontsize="medium",
        color="m")
ax.set_rmax(np.ceil(max(rad) / 10.0) * 10.0)
```

Add more reference labels for the dual-boundary coordinates. This is harder to do, because there is no direct conversion

beween the dual-boundary coordinates and AACGM coordinates without already knowing the AACGM MLT. To allow forward and backward transformations, *normal_coord()* also returns the OCB coordinates, which can be reverted using *revert_coord()*. Without this knowledge, you must provide the AACGM MLT. This is only a barrier for locations equatorward of the OCB.

```
# Define a latitude grid midway between the EAB and OCB. Since no locations
# at or poleward of the OCB are provided, the reversion will only use the
# shape of the `mlt` arg input.
grid_eab = 0.5 * (dual.ocb.boundary_lat
                  - dual.eab.boundary_lat) + dual.eab.boundary_lat
grid_lat, grid_mlt = dual.revert_coord(grid_eab, mlt, aacgm_mlt=mlt,
                                       is_ocb=False)
grid_lat = 90.0 - grid_lat
grid_theta = grid_mlt * np.pi / 12.0

ax.plot(grid_theta, grid_lat, "-", color="lightpink", zorder=1)
ax.text(grid_theta[40], grid_lat[40] + 2, "{:.0f}$^\circ$".format(grid_eab),
        fontsize="medium", color="m")

# Extend the MLT grid in dual-boundary coordinates
fine_mlt = np.linspace(0, 24.0, num=500)
dual.get_aacgm_boundary_lats(fine_mlt, rec_ind=dual.rec_ind, overwrite=True)
for i, ocb_mlt in enumerate(np.arange(0.0, 24.0, 6.0)):
    ocb_lat, omlt, _ = dual.ocb.normal_coord(
        dual.eab.aacgm_boundary_lat[dual.eab.rec_ind] - 10.0, fine_mlt)
    j = abs(omlt - ocb_mlt).argmin()
    if ocb_mlt == 0:
        j2 = abs(omlt - 24).argmin()
        if abs(omlt[j2] - ocb_mlt) < abs(omlt[j] - ocb_mlt):
            j = j2

    aa, oo = dual.revert_coord(ocb_lat[j], ocb_mlt)
    lon_outer = oo * np.pi / 12.0
    lat_outer = 90.0 - aa

    ax.plot([lon_clock[i], lon_outer], [lat_clock[i], lat_outer], "-",
            color="lightpink", zorder=1)
```

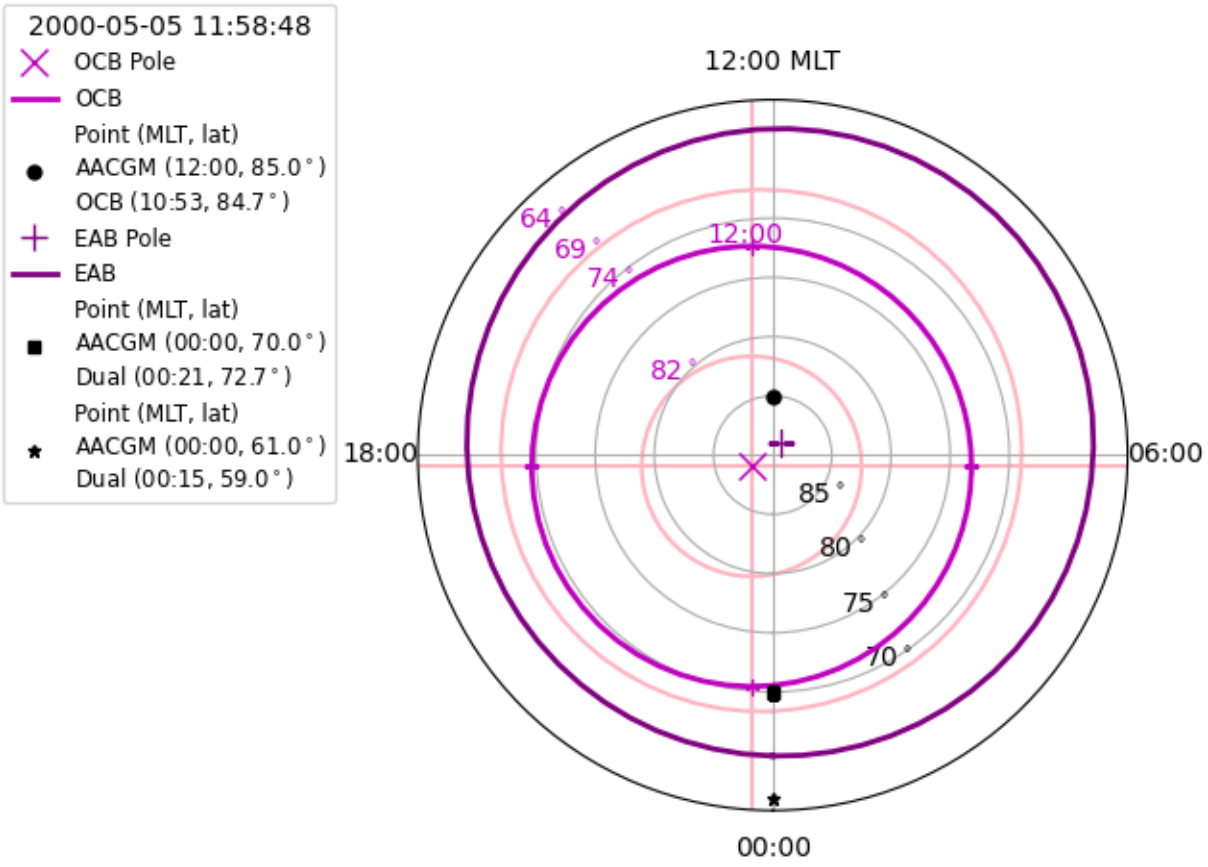
Now add the location of two more points in AACGM coordinates, calculating the dual-boundary location, and output both coordinates in the legend

```
aacgm_lat = [70.0, 61.0]
aacgm_mlt = 0.0
bound_lat, bound_mlt, _, _ = dual.normal_coord(aacgm_lat, aacgm_mlt)

markers = ['s', '*']
for i, lat in enumerate(aacgm_lat):
    plabel = "\n".join(["Point (MLT, lat)",
                        "AACGM (00:00, {:.1f}$^\circ$)".format(lat),
                        "Dual ({:02.0f}:{:02.0f}, {:.1f}$^\circ$)".format(
                            np.floor(bound_mlt[i]),
                            (bound_mlt[i] - np.floor(bound_mlt[i])) * 60.0,
                            bound_lat[i])])
    fmt = 'k{:s}'.format(markers[i])
    ax.plot([aacgm_mlt * np.pi / 12.0], [90.0 - lat], fmt, ms=5,
            label=plabel)
```

Update the legend to finish the figure.

```
fig.subplots_adjust(left=.3, right=.99)
ax.legend(loc=2, fontsize="small", title="{:}".format(
    dual.dtime[dual.rec_ind]), bbox_to_anchor=(-0.6, 1.15))
```



7.4 DMSP SSJ Boundaries

For more information about these boundaries, see Section *DMSP SSJ*.

7.4.1 Loading DMSP SSJ Boundaries

Unlike the IMAGE and AMPERE boundaries, the DMSP SSJ boundaries are not included with the package. However, routines to obtain them are. To use them, you need to install the ssj_auroral_boundary package. Once installed, you can download DMSP SSJ data and obtain a boundary file for a specified time period using `ocbpy.boundaries.dmsp_ssj_files`. For this example, we'll use a single day. You can download the files into any directory, but this example will put them in the same directory as the other OCB files.

```
import datetime as dt
import matplotlib.pyplot as plt
import ocbpy
import os

```

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```
stime = dt.datetime(2010, 12, 31)
etime = stime + dt.timedelta(days=1)
out_dir = os.path.join(os.path.split(ocbpy.__file__)[0], "boundaries")

bfiles = ocbpy.boundaries.dmsp_ssj_files.fetch_format_ssj_boundary_files(
    stime, etime, out_dir=out_dir, rm_temp=False)
```

By setting `rm_temp=False`, all of the different DMSP files will be kept in the specified output directory. You should have three CDF files (the data downloaded from each DMSP spacecraft), the CSV files (the boundaries calculated for each DMSP spacecraft) and four boundary files. The boundary files have an extention of `.eab` for the Equatorial Auroral Boundary and `.ocb` for the Open-Closed field line Boundary. The files are separated by hemisphere, and also specify the date range. Because only one day was obtained, the start and end dates in the filename are identical. When `rm_temp=True`, the CDF and CSV files are removed.

You can now load the DMSP SSJ boundaries by specifying the desired filename, instrument, and hemisphere or merely the instrument and hemisphere.

```
# Load with filename, instrument, and hemisphere
south_file = os.path.join(out_dir,
                          "dmsp-ssj_south_20101231_20101231_v1.1.2.ocb")
ocb_south = ocbpy.OCBoundary(filename=south_file, instrument='dmsp-ssj',
                             hemisphere=-1)
print(ocb_south)

OCBoundary file: ~/ocbpy/ocbpy/boundaries/dmsp-ssj_south_20101231_20101231_v1.1.2.ocb
Source instrument: DMSP-SSJ
Boundary reference latitude: -74.0 degrees

21 records from 2010-12-31 00:27:23 to 2010-12-31 22:11:38

YYYY-MM-DD HH:MM:SS Phi_Centre R_Centre R
------------------------------------------------------------------------------
2010-12-31 00:27:23 356.72 14.02 12.13
2010-12-31 12:27:56 324.82 0.86 14.73
2010-12-31 18:49:58 233.68 6.12 14.10
2010-12-31 22:11:38 318.60 4.64 12.34

Uses scaling function(s):
ocbpy.ocb_correction.circular(**{})

# Load with date, instrument, and hemisphere
ocb_north = ocbpy.OCBoundary(stime=stime, instrument='dmsp-ssj',
                             hemisphere=1)
print(ocb_north)

OCBoundary file: ~/ocbpy/ocbpy/boundaries/dmsp-ssj_north_20101231_20101231_v1.1.2.ocb
Source instrument: DMSP-SSJ
Boundary reference latitude: 74.0 degrees

27 records from 2010-12-31 01:19:13 to 2010-12-31 23:02:48

YYYY-MM-DD HH:MM:SS Phi_Centre R_Centre R
------------------------------------------------------------------------------
2010-12-31 01:19:13 191.07 10.69 8.59
2010-12-31 06:27:18 195.29 13.52 6.77
2010-12-31 21:21:32 259.27 2.73 10.45
```

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```
2010-12-31 23:02:48 234.73 3.94 10.79

Uses scaling function(s):
ocbpy.ocb_correction.circular(**{})
```

The circular scaling function with no input adds zero the the boundaries, and so performs no scaling.

7.4.2 Using DMSP SSJ Boundaries

Because DMSP SSJ Boundaries are only measured along a satellite track, you cannot use these boundaries to convert between magnetic and OCB or Dual-boundary coordinates at just any location or local time. To address this issue, the *ocbpy.cycle_boundary.satellite_track()* function can be used to determine whether or not a location is close enough to the satellite track. This example shows the width along the linear approximation of the satellite track allowed along the Boundary latitude. The axis formatting is performed using the *set_up_polar_plot* function defined in the *Coordinate Convertion* example.

```
# Set up the figure
fig = plt.figure()
ax = fig.add_subplot(111, projection="polar"
set_up_polar_plot(ax, hemi=ocb_south.hemisphere)

# Get the OCB location in AACGM coordinates
mlt = np.linspace(0, 24, 64)
ocb_south.get_aacgm_boundary_lat(mlt)

# Plot the OCB location
ax.plot(mlt * np.pi / 12.0,
        90 + ocb_south.aacgm_boundary_lat[ocb_south.rec_ind], "m-", lw=2,
        label="OCB")

# Deterimine which OCB locations are along the satellite track
igood = ocbpy.cycle_boundary.satellite_track(
    ocb_south.aacgm_boundary_lat[ocb_south.rec_ind],
    ocb_south.aacgm_boundary_mlt[ocb_south.rec_ind],
    ocb_south.x_1[ocb_south.rec_ind], ocb_south.y_1[ocb_south.rec_ind],
    ocb_south.x_2[ocb_south.rec_ind], ocb_south.y_2[ocb_south.rec_ind],
    hemisphere=ocb_south.hemisphere)
ax.plot(mlt[igood] * np.pi / 12.0,
        90 + ocb_south.aacgm_boundary_lat[ocb_south.rec_ind][igood], "ks",
        label="Measured OCB")
```

The default constraints for *ocbpy.cycle_boundary.satellite_track()* allow a 1 degree deviation in either Cartesian direction and a maximum distance of 5 degrees equatorward of the Boundary.

```
lat = np.arange(-90, -60, 1)
grid_mlt, grid_lat = np.meshgrid(mlt, lat)
grid_mlt = grid_mlt.flatten()
grid_lat = grid_lat.flatten()

igood = ocbpy.cycle_boundary.satellite_track(
    grid_lat, grid_mlt, ocb_south.x_1[ocb_south.rec_ind],
    ocb_south.y_1[ocb_south.rec_ind], ocb_south.x_2[ocb_south.rec_ind],
    ocb_south.y_2[ocb_south.rec_ind], hemisphere=ocb_south.hemisphere)
ax.plot(grid_mlt[~igood] * np.pi / 12.0, 90 + grid_lat[~igood], ".",
        color="palegreen", label="Data", zorder=1)
```

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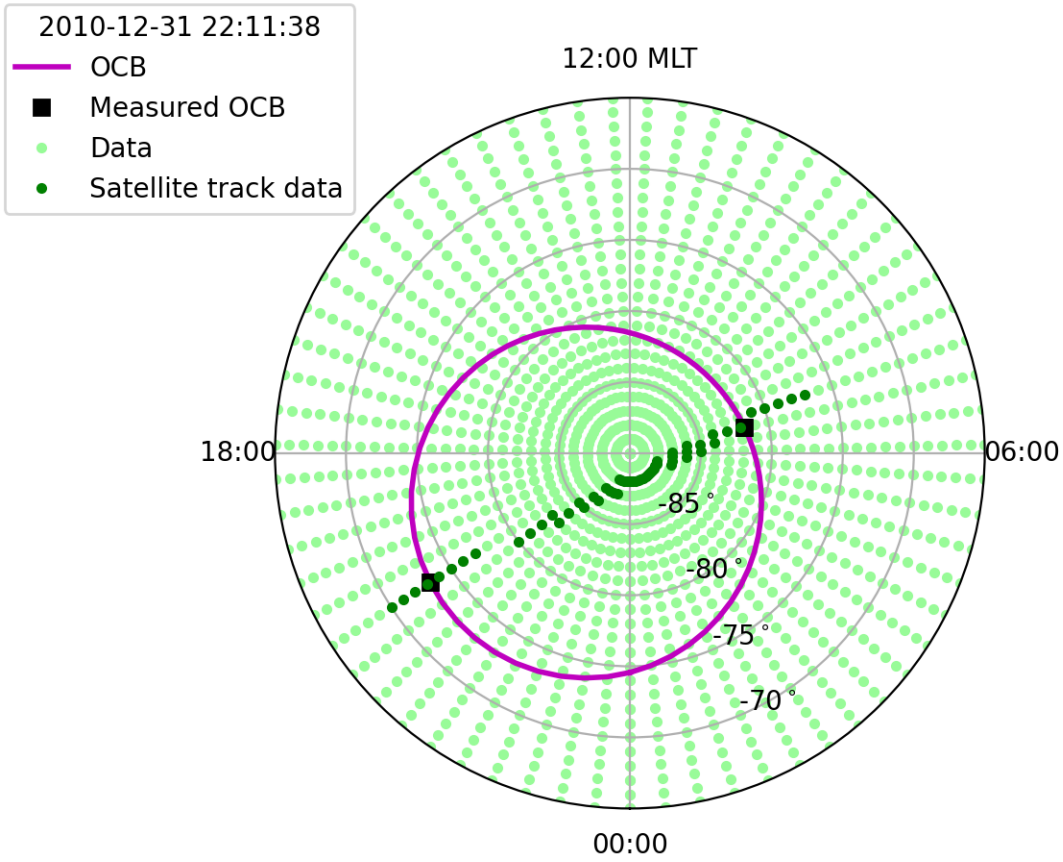
```
ax.plot(grid_mlt[igood] * np.pi / 12.0, 90 + grid_lat[igood], "g.",
        label="Satellite track data")
ax.legend(loc=2, title="{:}".format(ocb_south.dtime[ocb_south.rec_ind]),
          bbox_to_anchor=(-0.4, 1.15))
```



Note that because the OCB is determined based off of only two points, the OCB MLT is not very accurate. **With poorly defined OCBs, we recommend using only the gridded latitude along the satellite track.**

7.5 Load a general data file (DMSP SSIES)

DMSP SSIES provides commonly used polar data, which can be accessed from Madrigal, which also has a Python API called madrigalWeb. To run this example, follow the previous link(s) and download the ASCII file for F15 on 23 May 2000. Choosing the UT DMSP with quality flags for the best calcuations of ion drift and selecting ASCII instead of HDF5 will provide you with a file named **dms_ut_20000523_15.002.txt**. To load this file, use the following commands.

```
import datetime as dt
import numpy as np
import matplotlib as mlt
import matplotlib.pyplot as plt
import ocbpy
```

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```
hh = ["YEAR     MONTH      DAY       HOUR      MIN       SEC       RECNO     KINDAT␣
↪   KINST       UT1_UNIX        UT2_UNIX       GDALT      GDLAT      GLON       MLAT␣
↪        MLT      ION_V_SAT_FOR ION_V_SAT_LEFT VERT_ION_V       NI           PO+     ␣
↪      PHE+         PH+        TI         TE     RPA_FLAG_UT IDM_FLAG_UT     RMS_X   ␣
↪     SIGMA_VY      SIGMA_VZ"]
dmsp_filename = "dms_ut_20000423_15.002.txt"
dmsp_head, dmsp_data = ocbpy.instruments.general.load_ascii_data(dmsp_filename, 1,␣
↪datetime_cols=[0, 1, 2, 3, 4, 5], header=hh, datetime_fmt="%Y %m %d %H %M %S", int_
↪cols=[6, 7, 8, 25, 26])

print(dmsp_data['TI'].shape, dmsp_data.keys())

(200060,), ['PH+', 'KINST', 'MIN', 'RPA_FLAG_UT', 'KINDAT', 'datetime', 'MLAT', 'UT2_
↪UNIX', 'ION_V_SAT_FOR', 'ION_V_SAT_LEFT', 'GDALT', 'UT1_UNIX', 'GDLAT', 'HOUR',
↪'PHE+', 'IDM_FLAG_UT', 'SIGMA_VZ', 'SIGMA_VY', 'SEC', 'RMS_X', 'TI', 'TE', 'DAY',
↪'GLON', 'NI', 'RECNO', 'PO+', 'MLT', 'YEAR', 'MONTH', 'VERT_ION_V']
```

In the call to *ocbpy.instruments.general.load_ascii_data()*, quality flags and number of points are saved as integers by specifying int_cols. The header may not need to be specified using `header`; have a go loading it without this keyword arguement. The results will be the same as long as there are no errors in the file header specification.

Before calculating the OCB coordinates, add space in the data dictionary for the OCB coordinates and find out which data have a good quality flag.

```
ram_key = 'ION_V_SAT_FOR'
rpa_key = 'RPA_FLAG_UT'
idm_key = 'IDM_FLAG_UT'
dmsp_data['OCB_MLT'] = np.full(shape=dmsp_data[ram_key].shape,
                               fill_value=np.nan)
dmsp_data['OCB_LAT'] = np.full(shape=dmsp_data[ram_key].shape,
                               fill_value=np.nan)
igood = np.where((dmsp_data[rpa_key] < 3) & (dmsp_data[idm_key] < 3))
print(len(igood[0]), dmsp_data[ram_key][igood].max(),
      dmsp_data[ram_key][igood].min())

7623 978.0 -2159.0
```

Now get the OCB coordinates for each location. This will not be possible everywhere, since IMAGE doesn't provide Southern Hemisphere data and only times with a good OCB established within the last 5 minutes will be used.

```
idmsp = 0
ndmsp = len(igood[0])
ocb = ocbpy.OCBoundary()
ocb.get_next_good_ocb_ind()

print(idmsp, ndmsp, ocb.rec_ind, ocb.records)

0 7623 0 305805
```

This is the starting point for cycling through the records.

```
while idmsp < ndmsp and ocb.rec_ind < ocb.records:
    idmsp = ocbpy.match_data_ocb(ocb, dmsp_data['datetime'][igood],
                                 idat=idmsp, max_tol=600)
    if idmsp < ndmsp and ocb.rec_ind < ocb.records:
```

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```
        nlat, nmlt, r_corr = ocb.normal_coord(
            dmsp_data['MLAT'][igood[0][idmsp]],
            dmsp_data['MLT'][igood[0][idmsp]])
        dmsp_data['OCB_LAT'][igood[0][idmsp]] = nlat
        dmsp_data['OCB_MLT'][igood[0][idmsp]] = nmlt
        idmsp += 1

igood = np.where(~np.isnan(dmsp_data['OCB_LAT']))
print(len(igood[0]), dmsp_data['OCB_LAT'][igood].max())

2218 89.5098551674689
```

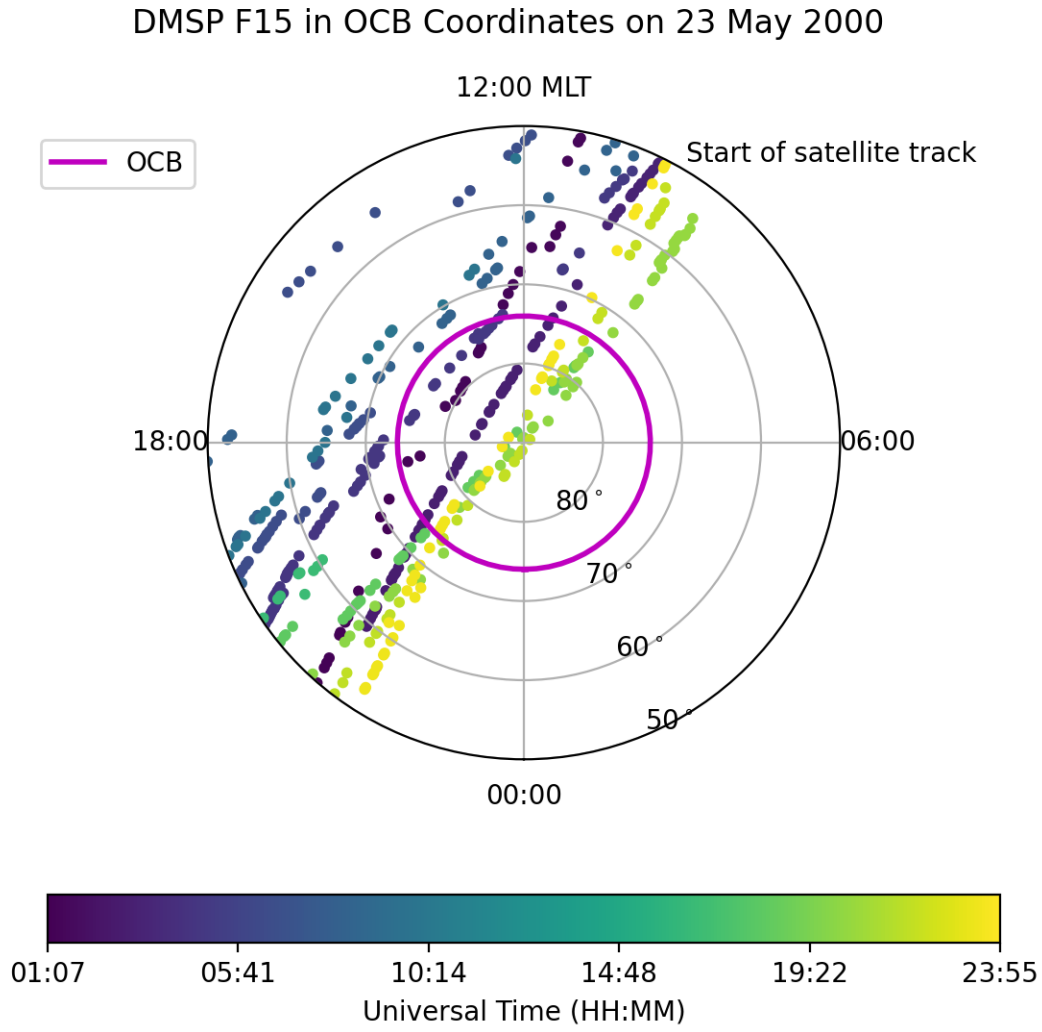
Now, let's plot the satellite track over the pole, relative to the OCB, with the location accouting for changes in the OCB at a 5 minute resolution. Note how the resolution results in apparent jumps in the satellite location. We aren't going to plot the ion velocity here, because it is provided in spacecraft coordinates rather than magnetic coordinates, adding an additional (and not intensive) level of processing.

```
fig = plt.figure()
fig.suptitle("DMSP F15 in OCB Coordinates on {:}".format(
    dmsp_data['datetime'][igood][0].strftime('%d %B %Y')))
ax = fig.add_subplot(111, projection="polar")
ax.set_theta_zero_location("S")
ax.xaxis.set_ticks([0, 0.5 * np.pi, np.pi, 1.5 * np.pi])
ax.xaxis.set_ticklabels(["00:00", "06:00", "12:00 MLT", "18:00"])
ax.set_rlim(0, 40)
ax.set_rticks([10, 20, 30, 40])
ax.yaxis.set_ticklabels(["80$^\circ$", "70$^\circ$", "60$^\circ$",
                         "50$^\circ$"])

lon = np.arange(0.0, 2.0 * np.pi + 0.1, 0.1)
lat = np.ones(shape=lon.shape) * (90.0 - ocb.boundary_lat)
ax.plot(lon, lat, "m-", linewidth=2, label="OCB")

dmsp_lon = dmsp_data['OCB_MLT'][igood] * np.pi / 12.0
dmsp_lat = 90.0 - dmsp_data['OCB_LAT'][igood]
dmsp_time = mpl.dates.date2num(dmsp_data['datetime'][igood])
ax.scatter(dmsp_lon, dmsp_lat, c=dmsp_time, cmap=mpl.cm.get_cmap("viridis"),
           marker="o", s=10)
ax.text(10 * np.pi / 12.0, 41, "Start of satellite track")

tticks = np.linspace(dmsp_time.min(), dmsp_time.max(), 6, endpoint=True)
dticks = ["{:s}".format(mpl.dates.num2date(tval).strftime("%H:%M"))
          for tval in tticks]
cb = fig.colorbar(ax.collections[0], ax=ax, ticks=tticks,
                  orientation='horizontal')
cb.ax.set_xticklabels(dticks)
cb.set_label('Universal Time (HH:MM)')
ax.legend(fontsize='medium', bbox_to_anchor=(0.0,1.0))
```



7.6 Grid and scale vector data

Many space science observations, such as ion drifts, are vectors. The *ocbpy.ocb_scaling.VectorData* class ensures that the vector location, direction, and magnitude are gridded and scaled appropriately.

The example presented here uses SuperDARN data. The example file, **20010214.0100.00.pgr.grd** may be obtained by fitting and then gridding the rawacf file, available from any of the SuperDARN mirrors. FitACF v3.0 was used to create this file. See the Radar Software Toolkit for more information.

The SuperDARN data may be read in python using pydarn. To load this file (or any other grid file), use the following commands.

```
import datetime as dt
import numpy as np
import matplotlib as mpl
```

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```
import matplotlib.pyplot as plt

import aacgmv2
import ocbpy
import pydarn

filename = '20010214.0100.00.pgr.grd'
sd_read = pydarn.SuperDARNRead(filename)
grd_data = sd_read.read_grid()
print(len(grd_data))

13
```

If you used the same file, there will be 13 grid records. Next, load the appropriate northern hemisphere boundaries (PGR is a Canadian radar).

7.6.1 Single Boundary Transformation

If using only a single boundary with vector data, it is highly recommended that you use an OCB or OCB proxy rather than an EAB or EAB proxy. This example shows how the data period and hemisphere automatically select the most trusted OCB data set available.

```
stime = dt.datetime(grd_data[0]['start.year'], grd_data[0]['start.month'],
                    grd_data[0]['start.day'], grd_data[0]['start.hour'],
                    grd_data[0]['start.minute'],
                    int(np.floor(grd_data[0]['start.second'])))
etime = dt.datetime(grd_data[-1]['start.year'], grd_data[-1]['start.month'],
                    grd_data[-1]['start.day'], grd_data[-1]['start.hour'],
                    grd_data[-1]['start.minute'],
                    int(np.floor(grd_data[-1]['start.second'])))
ocb = ocbpy.OCBoundary(stime=stime, etime=etime)
print(ocb)

OCBoundary file: ~/ocbpy/ocbpy/boundaries/image_north_circle.ocb
Source instrument: IMAGE
Boundary reference latitude: 74.0 degrees

12 records from 2001-02-14 01:33:24 to 2001-02-14 01:55:54

YYYY-MM-DD HH:MM:SS Phi_Centre R_Centre R
------------------------------------------------------------------------
2001-02-14 01:33:24 169.01 1.94 15.85
2001-02-14 01:35:26 170.18 1.56 16.47
2001-02-14 01:53:51 239.81 1.57 15.70
2001-02-14 01:55:54 210.02 2.09 15.89

Uses scaling function(s):
ocbpy.ocb_correction.circular(**{})
```

To convert this vector into OCB coordinates, we first need to pair the grid record to an approriate boundary. In this instance, the first record in each case is appropriate.

```
ocb.get_next_good_ocb_ind()
print(ocb.dtime[ocb.rec_ind] - stime)
```

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```
0:01:24
```

If you are using a different file, you can use *match_data_ocb()* to find an appropriate pairing, as illustrated in previous examples.

Now that the data are paired, we can initialise a *ocbpy.ocb_scaling.VectorData* object. To do this, however, we need the SuperDARN LoS velocity data in North-East-Vertical coordinates. SuperDARN grid files determine the median magnitude and direction of Line-of-Sight (LoS) Doppler velocities. For each period of time, the velocity is expressed in terms of a median vector magnitude and an angle off of magnetic north. To convert between the two, use the following routine.

```
def kvect_to_ne(kvect, vmag):
    drifts_n = vmag * np.cos(np.radians(kvect))
    drifts_e = vmag * np.sin(np.radians(kvect))
    return drifts_e, drifts_n

# Calculate the drift components
drifts_e, drifts_n = kvect_to_ne(grd_data[0]['vector.kvect'],
                                 grd_data[0]['vector.vel.median'])

# Create an array of the data indices
dat_ind = np.arange(0, len(grd_data[0]['vector.kvect']))

# Calculate the magnetic local time from the magnetic longitude
mlt = aacgmv2.convert_mlt(grd_data[0]['vector.mlon'], stime)

# Initialise the vector data object
pgr_vect = ocbpy.ocb_scaling.VectorData(
    dat_ind, ocb.rec_ind, grd_data[0]['vector.mlat'], mlt,
    aacgm_n=drifts_n, aacgm_e=drifts_e,
    aacgm_mag=grd_data[0]['vector.vel.median'], dat_name='LoS Velocity',
    dat_units='m s$^{-1}$', scale_func=ocbpy.ocb_scaling.normal_curl_evar)

# Calculate the OCB coordinates of the vector data
pgr_vect.set_ocb(ocb)
```

Because there are 110 vectors at this time and location, printing `pgr_vect` will create a long string! Vector data does not require array input, but does allow it to reduce the time needed for calculating data observed at the same time. A better way to visualise the array of vector velocity data is to plot it. The following code will create a figure that shows the AACGMV2 velocities on the left and the OCB velocities on the right. Because data from only one radar is plotted, only a fraction of the polar region is plotted.

```
# Initialise the figure and axes
fig = plt.figure(figsize=([8.36, 4.8]))
fig.subplots_adjust(wspace=.2, top=.95, bottom=.05)
axa = fig.add_subplot(1, 2, 1, projection='polar')
axo = fig.add_subplot(1, 2, 2, projection='polar')

# Format the axes
xticks = np.linspace(0, 2.0 * np.pi, 9)
for aa in [axa, axo]:
    aa.set_theta_zero_location('S')
    aa.xaxis.set_ticks(xticks)
    aa.xaxis.set_ticklabels(["{:02d}:00{:s}".format(int(tt), ' MLT'
                                                    if tt == 12.0 else '')
```

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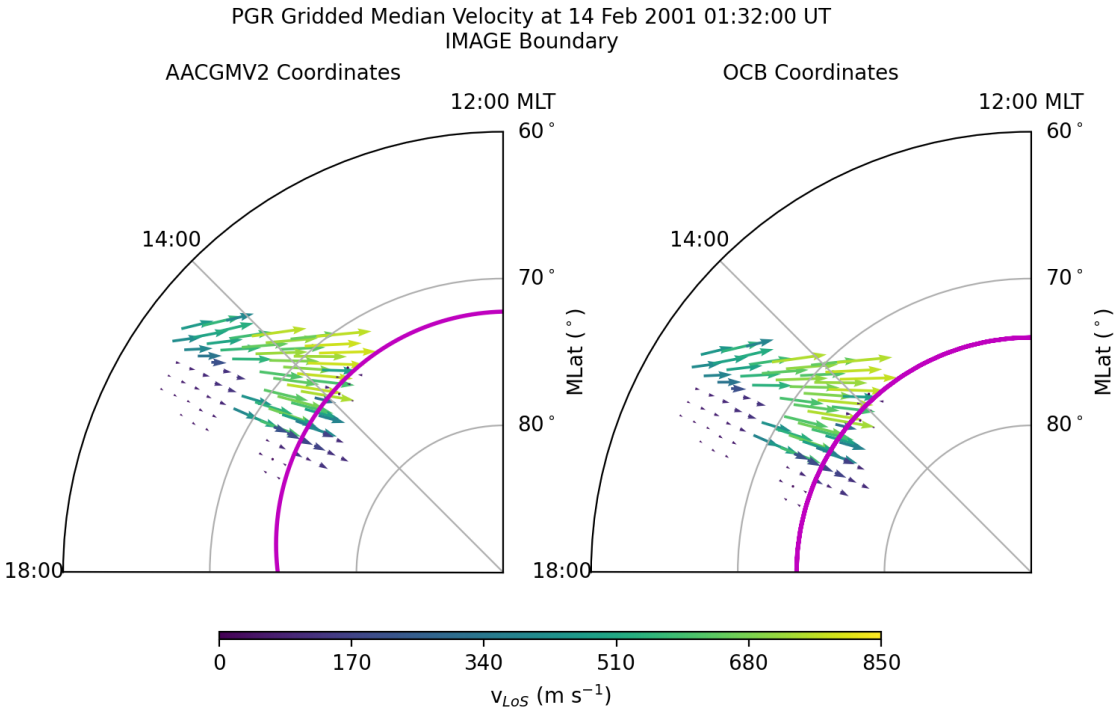
```
                                for tt in ocbpy.ocb_time.rad2hr(xticks)])
    aa.set_rlim(0, 30)
    aa.set_rticks([10, 20, 30])
    aa.yaxis.set_ticklabels(["80$^\circ$", "70$^\circ$", "60$^\circ$"])
    aa.set_thetamin(180)
    aa.set_thetamax(270)
    aa.set_ylabel('MLat ($^\circ$)', labelpad=30)
    aa.yaxis.set_label_position('right')

fig.suptitle(
    'PGR Gridded Median Velocity at {:} UT\n{:s} Boundary'.format(
        stime.strftime('%d %b %Y %H:%M:%S'), ocb.instrument.upper()),
    fontsize='medium')
axa.set_title('AACGMV2 Coordinates', fontsize='medium')
axo.set_title('OCB Coordinates', fontsize='medium')

# Get and plot the OCB
xmlt = np.arange(0.0, 24.1, .1)
blat, bmlt = ocb.revert_coord(ocb.boundary_lat, xmlt)
axa.plot(ocbpy.ocb_time.hr2rad(bmlt), 90.0 - blat , 'm-', lw=2, label='OCB')
axo.plot(ocbpy.ocb_time.hr2rad(xmlt),
         90.0 - np.full(shape=xmlt.shape, fill_value=ocb.boundary_lat),
         'm-', lw=2, label='OCB')

# Get and plot the gridded LoS velocities.  The quiver plot requires these
# in Cartesian coordinates
def ne_to_xy(mlt, vect_n, vect_e):
    theta = ocbpy.ocb_time.hr2rad(mlt) - 0.5 * np.pi
    drifts_x = -vect_n * np.cos(theta) - vect_e * np.sin(theta)
    drifts_y = -vect_n * np.sin(theta) + vect_e * np.cos(theta)
    return drifts_x, drifts_y

adrift_x, adrift_y = ne_to_xy(mlt, drifts_n, drifts_e)
odrift_x, odrift_y = ne_to_xy(pgr_vect.ocb_mlt, pgr_vect.ocb_n,
                              pgr_vect.ocb_e)

vmin = 0.0
vmax = 850.0
vnorm = mpl.colors.Normalize(vmin, vmax)

axa.quiver(ocbpy.ocb_time.hr2rad(mlt), 90.0 - grd_data[0]['vector.mlat'],
           adrift_x, adrift_y, grd_data[0]['vector.vel.median'], norm=vnorm)
axo.quiver(ocbpy.ocb_time.hr2rad(pgr_vect.ocb_mlt), 90.0 - pgr_vect.ocb_lat,
           odrift_x, odrift_y, pgr_vect.ocb_mag, norm=vnorm)

# Add a colour bar
cax = fig.add_axes([.25, .1, .53, .01])
cb = fig.colorbar(axa.collections[0], cax=cax,
                  ticks=np.linspace(vmin, vmax, 6, endpoint=True),
                  orientation='horizontal')
cb.set_label('v$_{LoS}$ (m s$^{-1}$)')
```

After displaying or saving this file, the results shoud look like the figure shown below. Note how the velocities increase as the beam directions align more closely with the direction of convection. However, across all beams the speeds inside the OCB are slow while those outside (in the auroral oval) are fast. The location and direction of the vectors have only shifted to maintain their position relative to the OCB. The magnitude has also been scaled, but the influence is small.



7.6.2 Dual Boundary Transformation

Now let us transform the same data using both the EAB and OCB.

```
dual = ocbpy.DualBoundary(stime=stime, etime=etime)
print(dual)

Dual Boundary data
11 good boundary pairs from 2001-02-14 01:33:24 to 2001-02-14 01:55:54
Maximum  boundary difference of 60.0 s

EABoundary file: ~/ocbpy/ocbpy/boundaries/image_north_circle.eab
Source instrument: IMAGE
Boundary reference latitude: 64.0 degrees

12 records from 2001-02-14 01:33:24 to 2001-02-14 01:55:54

YYYY-MM-DD HH:MM:SS Phi_Centre R_Centre R
------------------------------------------------------------------------------
2001-02-14 01:33:24 26.27 3.24 26.76
2001-02-14 01:35:26 26.54 3.59 26.53
2001-02-14 01:53:51 9.72 4.20 26.37
2001-02-14 01:55:54 13.46 3.06 26.78

Uses scaling function(s):
ocbpy.ocb_correction.circular(**{})

OCBoundary file: ~/ocbpy/ocbpy/boundaries/image_north_circle.ocb
Source instrument: IMAGE
Boundary reference latitude: 74.0 degrees
```

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```
12 records from 2001-02-14 01:33:24 to 2001-02-14 01:55:54

YYYY-MM-DD HH:MM:SS Phi_Centre R_Centre R
------------------------------------------------------------------------------
2001-02-14 01:33:24 169.01 1.94 15.85
2001-02-14 01:35:26 170.18 1.56 16.47
2001-02-14 01:53:51 239.81 1.57 15.70
2001-02-14 01:55:54 210.02 2.09 15.89

Uses scaling function(s):
ocbpy.ocb_correction.circular(**{})
```

For the *DualBoundary* class, we don't need to initialise the first good record index. However, if you are using a different file, you should use *match_data_ocb()* to find an appropriate pairing before continuing.

Because we are paired, we can re-initialise a *ocbpy.ocb_scaling.VectorData* object. To do this, however, we need the SuperDARN LoS velocity data in North-East-Vertical coordinates. SuperDARN grid files determine the median magnitude and direction of Line-of-Sight (LoS) Doppler velocities. For each period of time, the velocity is expressed in terms of a median vector magnitude and an angle off of magnetic north. To convert between the two, use the following routine.

```
# Re-initialise the vector data object
pgr_vect = ocbpy.ocb_scaling.VectorData(
    dat_ind, dual.rec_ind, grd_data[0]['vector.mlat'], mlt,
    aacgm_n=drifts_n, aacgm_e=drifts_e,
    aacgm_mag=grd_data[0]['vector.vel.median'], dat_name='LoS Velocity',
    dat_units='m s$^{-1}$', scale_func=ocbpy.ocb_scaling.normal_curl_evar)

# Calculate the dual-boundary coordinates of the vector data
pgr_vect.set_ocb(dual)
```

Now let us update the current figure with the new data.

```
# Remove the data from the OCB coordinate axis
axa.lines.pop()  # Remove the OCB
axo.lines.pop()  # Remove the OCB
axo.collections.pop()  # Remove the vectors
axo.set_title('Dual Boundary Coordinates', fontsize='medium')

# Get and plot the OCB and EAB
xmlt = np.arange(0.0, 24.1, .1)
dual.get_aacgm_boundary_lats(xmlt, rec_ind=dual.rec_ind, overwrite=True)
axa.plot(ocbpy.ocb_time.hr2rad(
    dual.ocb.aacgm_boundary_mlt[dual.ocb.rec_ind]),
         90.0 - dual.ocb.aacgm_boundary_lat[dual.ocb.rec_ind], 'm-',
         lw=2, label='OCB')
axa.plot(ocbpy.ocb_time.hr2rad(
    dual.eab.aacgm_boundary_mlt[dual.eab.rec_ind]),
         90.0 - dual.eab.aacgm_boundary_lat[dual.eab.rec_ind], '-',
         lw=2, color='purple', label='EAB')
axo.plot(ocbpy.ocb_time.hr2rad(xmlt),
         90.0 - np.full(shape=xmlt.shape, fill_value=dual.ocb.boundary_lat),
         'm-', lw=2, label='OCB')
axo.plot(ocbpy.ocb_time.hr2rad(xmlt),
         90.0 - np.full(shape=xmlt.shape, fill_value=dual.eab.boundary_lat),
         '-', lw=2, color='purple', label='EAB')
```

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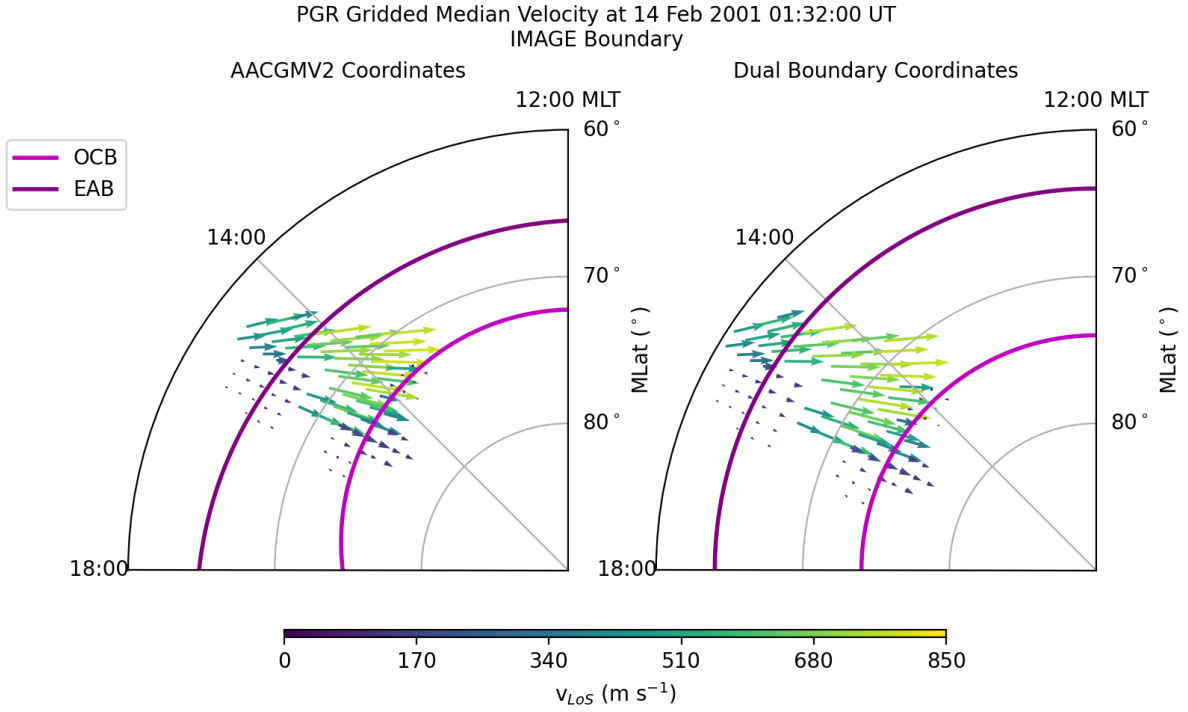
```
# Add the dual-boundary quivers
axo.quiver(ocbpy.ocb_time.hr2rad(pgr_vect.ocb_mlt), 90.0 - pgr_vect.ocb_lat,
           odrift_x, odrift_y, pgr_vect.ocb_mag, norm=vnorm)

# Add a legend
axa.legend(fontsize='medium', loc=2, bbox_to_anchor=(-.3, 1.0))
```

After displaying or saving this file, the results shoud look like the figure shown below. The biggest difference between the dual and single boundary results are the locations in the auroral oval.



7.7 Using data from pysat (with EAB)

This example showcases Equatorward Auroral Boundaries (EABs), while demonstrating how to use `pysat` with `ocbpy`.

7.7.1 Using Equatorward Auroral Boundaries

EABs may be loaded using the *`EABoundary`* class. This is a wrapper for the *`OCBoundary`* class with different defaults more appropriate for EABs. Currently, *IMAGE* and *DMSP SSJ* both have EAB data. This example uses the default file for IMAGE from the Northern hemisphere. It is very similar to *Getting Started*, the first example in this section.

```
import ocbpy

eab = ocbpy.EABoundary(instrument='image', hemisphere=1)
print(eab)
```

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```
EABoundary file: ~/ocbpy/ocbpy/boundaries/image_north_circle.eab
Source instrument: IMAGE
Boundary reference latitude: 64.0 degrees

305861 records from 2000-05-03 02:41:43 to 2002-10-31 20:05:16

YYYY-MM-DD HH:MM:SS Phi_Centre R_Centre R
-----------------------------------------
2000-05-03 02:41:43 251.57 5.45 14.16
2000-05-05 11:35:27 111.80 2.34 25.12
2002-10-31 20:03:16 354.41 6.22 20.87
2002-10-31 20:05:16 2.87 14.67 13.10

Uses scaling function(s):
ocbpy.ocb_correction.circular(**{})
```

To prepare to use the EAB data, find the time with the first quality boundary. The expected record index, `eab.rec_ind`, is `1`.

```
eab.get_next_good_ocb_ind()
```

7.7.2 Load a pysat Instrument (Madrigal TEC)

Total Electron Content (TEC) is one of the most valuable ionospheric data sets. Madrigal provides Vertical TEC (VTEC) maps from the 1990's onward that specify the median VTEC in 1 degree x 1 degree geographic latitude x longitude bins. The pysat package, pysatMadrigal has an instrument for obtaining, managing, and processing this VTEC data. To run this example, you must have `pysatMadrigal` installed. After setting up `pysat`, download the file needed for this example using the following commands.

```
import pysat
import pysatMadrigal as py_mad

# Replace `user` with a string holding your name and `password` with your
# email.  Madrigal uses these to demonstrate their utility to funders.
tec = pysat.Instrumet(inst_module=py_mad.instruments.gnss_tec, tag='vtec',
                      user=user, password=password)
tec.download(start=eab.dtime[eab.rec_ind])
print(tec.files.files)

2000-05-04    gps000504g.001.netCDF4
2000-05-05    gps000505g.001.netCDF4
2000-05-06    gps000506g.001.netCDF4
dtype: object
```

`pysat` makes it possible to perform well-defined data analysis prodedures while loading the desired data. The `ocbpy.instrument.pysat_instrument` module contains functions that may be applied using the `pysat` custom interface. However, before this can be done the magnetic locations need to be calculated. This can be done by writing an appropriate function that takes the `pysat.Instrument` object as input and updates it within the function.

```
import aacgmv2
import numpy as np
```

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```
def add_mag_coords(inst, lat='gdlat', lon='glon', alt='gdalt'):
    """Add AACGMV2 magnetic coordinates.

    Parameters
    ----------
    inst : pysat.Instrument
        Data object
    lat : str
        Geodetic latitude key (default='gdlat')
    lon : str
        Geographic longitude key (default='glon')
    alt : str
        Geodetic altitude key (default='gdalt')
    """
    # Initalize the data arrays
    mlat = np.full(shape=tuple(tec.data.dims[kk]
                               for kk in ['time', lat, lon]),
                   fill_value=np.nan)
    mlt = np.full(shape=mlat.shape, fill_value=np.nan)

    # Cycle through all times, calculating magnetic locations
    for i, dtime in enumerate(inst.index):
        for j, gdlat in enumerate(inst[lat].values):
            height = inst[alt][i, j].values
            if not np.isnan(height).all():
                mlat[i, j], mlon, r = aacgmv2.convert_latlon_arr(
                    gdlat, inst[lon].values, height, dtime)
                mlt[i, j] = aacgmv2.convert_mlt(mlon, dtime)

    # Assign the magnetic data to the input Instrument
    inst.data = inst.data.assign({"mlat": (("time", lat, lon), mlat),
                                  "mlt": (("time", lat, lon), mlt)})
    return
```

Assign this function and the ocbpy function in the desired order of operations.

```
tec.custom_attach(add_mag_coords)
tec.custom_attach(ocbpy.instruments.pysat_instruments.add_ocb_to_data,
                  kwargs={'ocb': eab, 'mlat_name': 'mlat',
                  'mlt_name': 'mlt', 'max_sdiff': 150})
tec.load(date=eab.dtime[eab.rec_ind])
print(tec.variables)

['time', 'gdlat', 'glon', 'dtec', 'gdalt', 'tec', 'mlat', 'mlt', 'mlat_ocb',
 'mlt_ocb', 'r_corr_ocb']
```

Now we have the EAB coordinates for each location in the Northern Hemisphere where a good EAB was found within 2.5 minutes of the data record. This time difference was chosen because the VTEC data has a 5 minute resolution.

Now, let's plot the average of the VTEC poleward of the EAB. To do this we will first need to calculate these averages.

```
del_lat = 2.0
del_mlt = 2.0
ave_lat = np.arange(eab.boundary_lat, 90, del_lat)
ave_mlt = np.arange(0, 24, del_mlt)
ave_tec = np.full(shape=tec['tec'].shape, fill_value=np.nan)
```

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```
for lat in ave_lat:
    for mlt in ave_mlt:
        # We are not overlapping bins, so don't need to worry about MLT
        # rollover from 0-24
        sel_tec = tec['tec'].where(
            (tec['mlat_ocb'] > lat) & (tec['mlat_ocb'] <= lat + del_lat)
            & (tec['mlt_ocb'] >= mlt) & (tec['mlt_ocb'] < mlt + del_mlt))
        inds = np.where(~np.isnan(sel_tec.values))
        if len(inds[0]) > 0:
            ave_tec[inds] = np.nanmean(sel_tec.values)
```

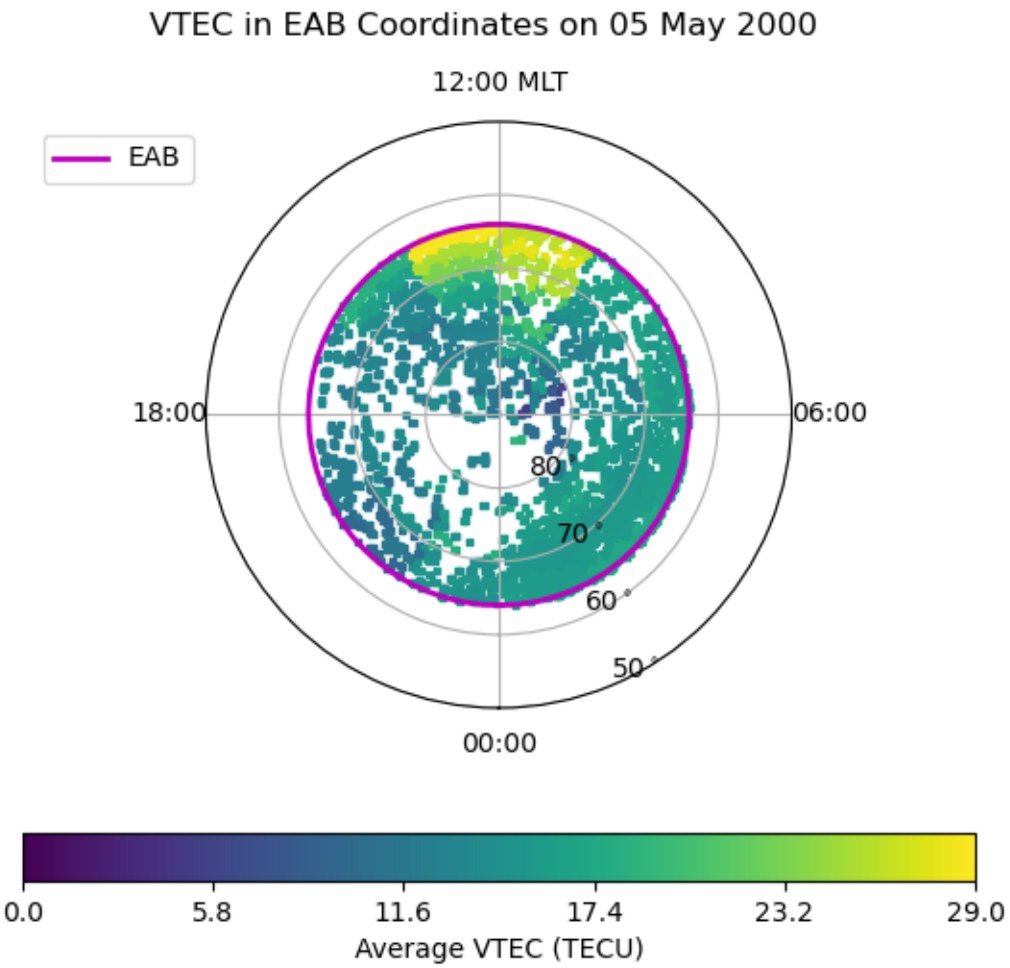
Now let us plot these averages at the EAB location of each measurement. This will provide us with knowledge of the coverage as well as knowledge of the average behaviour.

```
# Initialise the figure
fig = plt.figure()
fig.suptitle("VTEC in EAB Coordinates on {:}".format(
    tec.date.strftime('%d %B %Y')))
ax = fig.add_subplot(111, projection="polar")
ax.set_theta_zero_location("S")
ax.xaxis.set_ticks([0, 0.5 * np.pi, np.pi, 1.5 * np.pi])
ax.xaxis.set_ticklabels(["00:00", "06:00", "12:00 MLT", "18:00"])
ax.set_rlim(0, 40)
ax.set_rticks([10, 20, 30, 40])
ax.yaxis.set_ticklabels(["80$^\circ$", "70$^\circ$", "60$^\circ$",
                         "50$^\circ$"])

# Add the boundary location
lon = np.arange(0.0, 2.0 * np.pi + 0.1, 0.1)
lat = np.ones(shape=lon.shape) * (90.0 - eab.boundary_lat)
ax.plot(lon, lat, "m-", linewidth=2, label="EAB")

# Plot the VTEC data
tec_lon = tec['mlt_ocb'].values * np.pi / 12.0
tec_lat = 90.0 - tec['mlat_ocb'].values
tec_max = np.ceil(np.nanmax(ave_tec))
con = ax.scatter(tec_lon, tec_lat, c=ave_tec, marker="s",
                 cmap=mpl.cm.get_cmap("viridis"), s=5, vmin=0, vmax=tec_max)

# Add a colourbar and labels
tticks = np.linspace(0, tec_max, 6, endpoint=True)
cb = fig.colorbar(ax.collections[0], ax=ax, ticks=tticks,
                  orientation='horizontal')
cb.set_label('Average VTEC (TECU)')
ax.legend(fontsize='medium', bbox_to_anchor=(0.0, 1.0))
```


VTEC in EAB Coordinates on 05 May 2000
12:00 MLT
EAB
18:00
06:00
00:00
80
70
60
50
0.0
5.8
11.6
17.4
23.2
29.0
Average VTEC (TECU)

CHAPTER 8

Contributing

Bug reports, feature suggestions and other contributions are greatly appreciated! While I can't promise to implement everything, I will always try to respond in a timely manner.

8.1 Short version

- Submit bug reports and feature requests at GitHub
- Make pull requests to the `develop` branch

8.2 Bug reports

When reporting a bug please include:

- Your operating system name and version
- Any details about your local setup that might be helpful in troubleshooting
- Detailed steps to reproduce the bug

8.3 Feature requests and feedback

The best way to send feedback is to file an issue at GitHub.

If you are proposing a feature:

- Explain in detail how it would work.
- Keep the scope as narrow as possible, to make it easier to implement.
- Remember that this is a volunteer-driven project, and that code contributions are welcome :)

8.4 Development

To set up *ocbpy* for local development:

1. Fork ocbpy on GitHub.
2. Clone your fork locally:

```
git clone git@github.com:your_name_here/ocbpy.git
```

3. Create a branch for local development:

```
git checkout -b name-of-your-bugfix-or-feature
```

   Now you can make your changes locally. Add tests for bugs and new features into the `ocbpy/tests/` directory, either in the appropriately named file (for changes to an existing file) or in a new file (that should share the name of the new file, prepended by `test_`. The tests use unittest. Changes or additions to the documentation (located in `docs`) should also be made at this time.

4. When you're done making changes, run the tests locally before submitting a pull request
5. Commit your changes and push your branch to GitHub:

```
git add .
git commit -m "Brief description of your changes"
git push origin name-of-your-bugfix-or-feature
```

6. Submit a pull request through the GitHub website. Pull requests should be made to the `develop` branch.

8.4.1 Pull Request Guidelines

If you need some code review or feedback while you're developing the code, just make a pull request.

Do not merge any pull requests, the local maintainer is in charge of merging until this project grows.

8.4.2 Tips

To run a subset of tests from the test directory for a specific environment:

```
python test_name.py
```

To run all the tests for a specific environment:

```
python setup.py test
```

8.5 Contributor Covenant Code of Conduct

8.5.1 Our Pledge

In the interest of fostering an open and welcoming environment, we as contributors and maintainers pledge to making participation in our project and our community a harassment-free experience for everyone, regardless of age, body size, disability, ethnicity, gender identity and expression, level of experience, nationality, personal appearance, race, religion, or sexual identity and orientation.

8.5.2 Our Standards

Examples of behavior that contributes to creating a positive environment include:

- Using welcoming and inclusive language
- Being respectful of differing viewpoints and experiences
- Gracefully accepting constructive criticism
- Focusing on what is best for the community
- Showing empathy towards other community members

Examples of unacceptable behavior by participants include:

- The use of sexualized language or imagery and unwelcome sexual attention or advances
- Trolling, insulting/derogatory comments, and personal or political attacks
- Public or private harassment
- Publishing others' private information, such as a physical or electronic address, without explicit permission
- Other conduct which could reasonably be considered inappropriate in a professional setting

8.5.3 Our Responsibilities

Project maintainers are responsible for clarifying the standards of acceptable behavior and are expected to take appropriate and fair corrective action in response to any instances of unacceptable behavior.

Project maintainers have the right and responsibility to remove, edit, or reject comments, commits, code, wiki edits, issues, and other contributions that are not aligned to this Code of Conduct, or to ban temporarily or permanently any contributor for other behaviors that they deem inappropriate, threatening, offensive, or harmful.

8.5.4 Scope

This Code of Conduct applies both within project spaces and in public spaces when an individual is representing the project or its community. Examples of representing a project or community include using an official project e-mail address, posting via an official social media account, or acting as an appointed representative at an online or offline event. Representation of a project may be further defined and clarified by project maintainers.

8.5.5 Enforcement

Instances of abusive, harassing, or otherwise unacceptable behavior may be reported by contacting the project team at angeline.burrell@nrl.navy.mil. The project team will review and investigate all complaints, and will respond in a way that it deems appropriate to the circumstances. The project team is obligated to maintain confidentiality with regard to the reporter of an incident. Further details of specific enforcement policies may be posted separately.

Project maintainers who do not follow or enforce the Code of Conduct in good faith may face temporary or permanent repercussions as determined by other members of the project's leadership.

8.5.6 Attribution

This Code of Conduct is adapted from the Contributor Covenant [homepage], version [1.4].

8.6 Changelog

Summary of all changes made since the first stable release

8.6.1 0.3.0 (10-21-2022)

- BUG: Fixed header initialization error general instrument loading routine
- BUG: Fixed time cycling in the *supermag2ascii_ocb* function
- DEP: Moved OCBoundary class to hidden sub-module, *_boundary*
- DEP: Moved *ocboundary* functions to new sub-module, *cycle_boundary*
- DEP: Deprecated kwargs no longer needed to select good IMAGE data
- DEP: Changed the format for vector data stored in pysat Instruments
- DOC: Improved the PEP8 and numpydoc compliance in the documentation examples
- DOC: Updated citations
- DOC: Updated cross-referencing and added missing API sections
- **DOC: Added examples for DMSP SSJ boundaries, pysat Instruments, and the** DualBoundary class, updated the README example
- DOC: Improved documentation configuration
- ENH: Added a setup configuration file
- ENH: Changed class *__repr__* to produce a string *eval* can use as input
- ENH: Updated the IMAGE OCB files and added EAB files
- ENH: Added EAB and dual-boundary classes
- ENH: Added function to select data along a satellite track
- **ENH: Changed attributes in VectorData into properties to ensure expected** behaviour if altering the class data after initialisation
- ENH: Added IMAGE SI12, SI13, and WIC DMSP corrections to *harmonic*
- ENH: Made scaling optional for SuperMAG and SuperDARN vorticity data
- MAINT: Removed support for Python 2.7, 3.5, and 3.6; added support for 3.10
- MAINT: Improved PEP8 compliance
- MAINT: Updated pysat routines to v3.0.0 standards
- MAINT: Updated CDF installation
- MAINT: Removed now-unnecessary logic in unit tests for Windows OS
- REL: Added a .zenodo.json file
- TST: Integrated and removed Requires.io; it requires a payed plan for GitHub
- TST: Added flake8 and documentation tests to CI
- TST: Moved all configurations to setup.cfg, removing .coveragecfg
- **TST: Improved test coverage, specifically adding pysat xarray tests and** expanding unit tests for *__repr__* methods

- TST: Migrated to GitHub Actions from Travis CI and Appveyor

8.6.2 0.2.1 (11-24-2020)

- DOC: Updated examples in README
- BUG: Fixed an error in determining the sign and direction of OCB vectors
- STY: Changed a ValueError in VectorData to logger warning

8.6.3 0.2.0 (10-08-2020)

- First stable release

CHAPTER 9

Indices and tables

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Bibliography

[homepage] https://contributor-covenant.org

[1.4] https://contributor-covenant.org/version/1/4/

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