pysat Documentation

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CHAPTER ONE

INTRODUCTION

The Python Science Analysis Toolkit (pysat) is a package providing a simple and flexible interface for downloading, loading, cleaning, managing, processing, and analyzing scientific measurements. Though pysat was initially designed for in-situ satellite based measurements it aims to support all instruments in space science.

Every scientific instrument has unique properties though the general process for science data analysis is independent of platform. Find and download the data, write code to load the data, clean the data, apply custom analysis functions, and plot the results. Pysat provides a framework for this general process that builds upon these commonalities to simplify adding new instruments, reduce data management overhead, and enable instrument independent analysis routines.

This instrument independence is achieved through a pysat.Instrument object which provides a layer of separation between the user and the particulars of any given science data set. Loading data for any instrument becomes the same process with the same result, instrument.load() produces data in instrument.data. Behind the scenes different load functions will actually be called for different instruments, as appropriate, but this is now a hidden implementation detail.

Frequently science data sets don't have all of the parameters needed for a given analysis. If an analysis routine is to be truly instrument independent then there needs to be a mechanism to get custom data into a routine without having to modify the routine itself. Thus, a nano-kernel is attached to the pysat.Instrument object. Upon each instrument.load call a queue of user selected custom functions are applied before the data is available in instrument.data. The instrument object is 'set and forget', regardless of location the data available in instrument.data will be properly processed.

The final component for instrument independence requires the Python Data Analysis Library (pandas), the underlying data object, capable of handling 1D through nD data in a single structure. Pandas data structures are also indexed, thus math operations between two arrays A and B are aligned before the operation. Measurements across platforms are rarely always at the same time, thus pandas also significantly reduces the overhead while increasing the rigour of inter-platform comparisons.

This document covers installation, a tutorial on pysat including demonstration codes, an overview of adding new instruments to pysat, and an API reference.

CHAPTER

TWO

INSTALLATION

Starting from scratch

Python and associated packages for science are freely available. Convenient science python package setups are available from Enthought and Contiuum Analytics. Enthought also includes an IDE, though there are a number of choices. Core science packages such as numpy, scipy, matplotlib, pandas and many others may also be installed directly via pip or your favorite package manager.

For educational users, an IDE from Jet Brains is available for free.

pysat

Pysat itself may be installed from a terminal command line via:

```
pip install pysat
```

Pysat requires some external non-python libraries for loading science data sets stored in netCDF and CDF formats.

Set Data Directory

Pysat will maintain organization of data from various platforms. Upon the first

```
import pysat
```

pysat will remind you to set the top level directory that will hold the data,

```
pysat.utils.set_data_dir(path=path)
```

Common Data Format

The CDF library must be installed, along with python support, before pysat is able to load CDF files.

- **CDF Library from NASA (http://cdf.gsfc.nasa.gov)**
  - Mac OS X Installer
- SpacePy

```
pip install spacepy
```

netCDF

netCDF libraries must be installed, along with python support, before pysat is able to load netCDF files.

- netCDF C Library from Unidata (http://www.unidata.ucar.edu/downloads/netcdf/index.jsp)
- netCDF4-python

```
pip install netCDF4
```

pandas

To get the forked pandas that accommodates pandas Series and DataFrames within each cell of a Series use:

```
pip install git+https://github.com/rstoneback/pandas.git
```

The forked pandas is required for full support of higher dimensional data sets. A pull-request is planned.

CHAPTER

THREE

TUTORIAL

3.1 Basics

The core functionality of pysat is exposed through the pysat.Instrument object. The intent of the Instrument object is to offer a single interface for interacting with science data that is independent of measurement platform. The layer of abstraction presented by the Instrument object allows for things to occur in the background that can make science data analysis simpler and more rigorous.

To begin,

```
import pysat
```

The data directory pysat looks in for data (pysat_data_dir) needs to be set upon the first import,

```
pysat.utils.set_data_dir(path=path_to_existing_directory)
```

Instantiation

To create a pysat.Instrument object, select a platform, instrument name, and measurement type to be analyzed from the list of Supported Instruments. To work with Magnetometer data from the Vector Electric Field Instrument onboard the Communications/Navigation Outage Forecasting System (C/NOFS), use:

```
vefi = pysat.Instrument(platform='cnofs', name='vefi', tag='dc_b')
```

Behind the scenes pysat uses a python module named cnofs_vefi that understands how to interact with 'dc_b' data. VEFI also measures electric fields in several modes that offer different data products. Though these measurements are not currently supported by the cnofs_vefi module, when they are, they can be selected via the tag string.

To load measurements from a different instrument on C/NOFS, the Ion Velocity Meter, which measures thermal plasma parameters, use:

```
ivm = pysat.Instrument(platform='cnofs', name='ivm')
```

In the background pysat uses the module cnofs_ivm to handle this data. There is only one measurement option from IVM, so no tag string is required.

Measurements from a constellation of COSMIC satellites are also available. These satellites measure GPS signals as they travel through the atmosphere. A number of different data sets are available from COSMIC, and are also supported by the relevant module.

```
# electron density profiles
cosmic = pysat.Instrument(platform='cosmic2013', name='gps', tag='ionprf')
# atmosphere profiles
cosmic = pysat.Instrument(platform='cosmic2013', name='gps', tag='atmprf')
```

Though the particulars of VEFI magnetometer data, IVM plasma parameters, and COSMIC atmospheric measurements are going to be quite different, the processes demonstrated below with VEFI also apply equally to IVM and COSMIC.

Download

Let's download some data. VEFI data is hosted by the NASA Coordinated Data Analysis Web (CDAWeb) at http://cdaweb.gsfc.nasa.gov. The proper process for downloading VEFI data is built into the cnofs_vefi module, which is handled by pysat. All we have to do is invoke the .download method attached to the VEFI object, or any other pysat Instrument.

```
# define date range to download data and download
start = pysat.datetime(2009,5,6)
stop = pysat.datetime(2009,5,9)
vefi.download(start, stop)

# download COSMIC data, which requires username and password
cosmic.download(start, stop, user=user, password=password)
```

The data is downloaded to pysat_data_dir/platform/name/tag/, in this case pysat_data_dir/cnofs/vefi/dc_b/. At the end of the download, pysat will update the list of files associated with VEFI.

Load Data

Data is loaded into vefi using the .load method using year, day of year; date; or filename.

```
vefi.load(2009,126)
vefi.load(date=start)
vefi.load(fname='cnofs_vefi_bfield_1sec_20090506_v05.cdf')
```

When the pysat load routine runs it stores the instrument data into vefi.data. The data structure is a pandas DataFrame, a highly capable structure with labeled rows and columns. Convenience access to the data is also available at the instrument level.

```
# all data
print vefi.data
# particular magnetic component
print vefi.data.dB_mer

# Convenience access
print vefi['dB_mer']
# slicing
print vefi[0:10, 'dB_mer']
# slicing by date time
print vefi[start:stop, 'dB_mer']
```

See *Instrument* for more.

To load data over a season, pysat provides a convenience function that returns an array of dates over a season. The season need not be continuous.

```
import pandas
import matplotlib.pyplot as plt
import numpy as np

# create empty series to hold result
mean_dB = pandas.Series()
```

```
# get list of dates between start and stop
date_array = pysat.utils.season_date_range(start, stop)
# iterate over season, calculate the mean absolute perturbation in
# meridional magnetic field
for date in date_array:
     vefi.load(date=date)
     if not vefi.data.empty:
         # isolate data to locations near geographic equator
         idx, = np.where((vefi['latitude'] < 5) & (vefi['latitude'] > -5))
         vefi.data = vefi.data.iloc[idx]
         # compute mean absolute db_Mer using pandas functions and store
         mean_dB[vefi.date] = vefi['dB_mer'].abs().mean(skipna=True)
# plot the result using pandas functionality
mean_dB.plot(title='Mean Absolute Perturbation in Meridional Magnetic Field')
plt.ylabel('Mean Absolute Perturbation ('+vefi.meta['dB_mer'].units+')')
```

Note, the numpy.where may be removed using the convenience access to the attached pandas data object.

```
idx, = np.where((vefi['latitude'] < 5) & (vefi['latitude'] > -5))
vefi.data = vefi.data.iloc[idx]
```

is equivalent to

```
vefi.data = vefi[(vefi['latitude'] < 5) & (vefi['latitude'] > -5)]
```

Clean Data

Before data is available in .data it passes through an instrument specific cleaning routine. The amount of cleaning is set by the clean_level keyword,

```
vefi = pysat.Instrument(platform='cnofs', name='vefi',
                        tag='dc_b', clean_level='none')
```

Four levels of cleaning may be specified,

clean_level	Result
clean	Generally good data
dusty	Light cleaning, use with care
dirty	Minimal cleaning, use with caution
none	No cleaning, use at your own risk

Metadata

Metadata is also stored along with the main science data.

```
# all metadata
print vefi.meta.data
# dB_mer metadata
print vefi.meta['dB_mer']
# units
vefi.meta['dB_mer'].units
# update units for dB_mer
vefi.meta['dB_mer'] = {'units':'new_units'}
# update display name, long_name
vefi.meta['dB_mer'] = {'long_name':'Fancy Name'}
# add new meta data
vefi.meta['new'] = {'units':'fake', 'long_name':'Display'}
```

Data may be assigned to the instrument, with or without metadata.

```
vefi['new_data'] = new_data
```

The same activities may be performed for other instruments in the same manner. In particular, for measurements from the Ion Velocity Meter and profiles of electron density from COSMIC, use

```
# assignment with metadata
ivm = pysat.Instrument(platform='cnofs', name='ivm', tag='')
ivm.load(date=date)
ivm['double_mlt'] = {'data':2.*inst['mlt'], 'long_name':'Double MLT',
                     'units':'hours'}
```

```
cosmic = pysat.Instrument('cosmic2013','gps', tag='ionprf',  clean_level='clean')
start = pysat.datetime(2009,1,2)
stop = pysat.datetime(2009,1,3)
# requires CDAAC account
cosmic.download(start, stop, user='', password='')
cosmic.load(date=start)
# the profiles column has a DataFrame in each element which stores
# all relevant profile information indexed by altitude
# print part of the first profile, selection by integer location
print cosmic[0,'profiles'].iloc[55:60, 0:3]
# print part of profile, selection by altitude value
print cosmic[0,'profiles'].ix[196:207, 0:3]
```

Output for both print statements:

```
              ELEC_dens    GEO_lat    GEO_lon
MSL_alt
196.465454  81807.843750 -15.595786 -73.431015
198.882019  83305.007812 -15.585764 -73.430191
201.294342  84696.546875 -15.575747 -73.429382
203.702469  86303.039062 -15.565735 -73.428589
206.106354  87460.015625 -15.555729 -73.427803
```

3.2 Custom Functions

Science analysis is built upon custom data processing. To simplify this task and enable instrument independent analysis, custom functions may be attached to the Instrument object. Each function is run automatically when new data is loaded before it is made available in .data.

Modify Functions

The instrument object is passed to function without copying, modify in place.

```
def custom_func_modify(inst, optional_param=False):
    inst['double_mlt'] = 2.*inst['mlt']
```

Add Functions

A copy of the instrument is passed to function, data to be added is returned.

```
def custom_func_add(inst, optional_param=False):
    return 2.*inst['mlt']
```

Add Function Including Metadata

```
def custom_func_add(inst, optional_param1=False, optional_param2=False):
    return {'data':2.*inst['mlt'], 'name':'double_mlt',
            'long_name':'doubledouble', 'units':'hours'}
```

Attaching Custom Function

```
ivm.custom.add(custom_func_modify, 'modify', optional_param2=True)
ivm.load(2009,1)
print ivm['double_mlt']
ivm.custom.add(custom_func_add, 'add', optional_param2=True)
ivm.bounds = (start,stop)
custom_complicated_analysis_over_season(ivm)
```

The output of custom_func_modify will always be available from instrument object, regardless of what level the science analysis is performed.

We can repeat the earlier VEFI example, this time using nano-kernel functionality.

```
import pandas
import matplotlib.pyplot as plt
import numpy as np

vefi = pysat.Instrument(platform='cnofs', name='vefi', tag='dc_b')

def filter_vefi(inst):
    # select data near geographic equator
    idx, = np.where((vefi['latitude'] < 5) & (vefi['latitude'] > -5))
    vefi.data = vefi.data.iloc[idx]
    return
# attach filter to vefi object, function is run upon every load
vefi.custom.add(filter_ivm, 'modify')

# create empty series to hold result
mean_dB = pandas.Series()
# get list of dates between start and stop
date_array = pysat.utils.season_date_range(start, stop)
# iterate over season, calculate the mean absolute perturbation in
# meridional magnetic field
for date in date_array:
     vefi.load(date=date)
     if not vefi.data.empty:
         # compute mean absolute db_Mer using pandas functions and store
         mean_dB[vefi.date] = vefi['dB_mer'].abs().mean(skipna=True)
# plot the result using pandas functionality
mean_dB.plot(title='Mean Absolute Perturbation in Meridional Magnetic Field')
plt.ylabel('Mean Absolute Perturbation ('+vefi.meta['dB_mer'].units+')')
```

Note the same result is obtained. The VEFI instrument object and analysis are performed at the same level, so there is no strict gain by using the pysat nano-kernel in this simple demonstration. However, we can use the nano-kernel to translate this daily mean into an versatile instrument independent function.

Adding Instrument Independence

```
import pandas
import matplotlib.pyplot as plt
import numpy as np

def daily_mean(inst, start, stop, data_label):

   # create empty series to hold result
```

```
    mean_val = pandas.Series()
    # get list of dates between start and stop
    date_array = pysat.utils.season_date_range(start, stop)
    # iterate over season, calculate the mean
    for date in date_array:
        inst.load(date=date)
        if not inst.data.empty:
            # compute mean absolute db_Mer using pandas functions and store
            mean_val[inst.date] = inst[data_label].abs().mean(skipna=True)
    return mean_val

vefi = pysat.Instrument(platform='cnofs', name='vefi', tag='dc_b')

def filter_vefi(inst):
    # select data near geographic equator
    idx, = np.where((vefi['latitude'] < 5) & (vefi['latitude'] > -5))
    vefi.data = vefi.data.iloc[idx]
    return
# attach filter to vefi object, function is run upon every load
vefi.custom.add(filter_ivm, 'modify')

# make a plot of daily dB_mer
mean_dB = daily_mean(vefi, start, stop, 'dB_mer')

# plot the result using pandas functionality
mean_dB.plot(title='Absolute Daily Mean of '
             + vefi.meta['dB_mer'].long_name)
plt.ylabel('Absolute Daily Mean ('+vefi.meta['dB_mer'].units+')')
```

The pysat nano-kernel lets you modify any data set as needed so that you can get the daily mean you desire, without having to modify the daily_mean function.

Check the instrument independence using a different instrument. Whatever instrument is supplied may be modified in arbitrary ways by the nano-kernel.

```
cosmic = pysat.Instrument('cosmic2013','gps', tag='ionprf', clean_level='clean', altitude_bin=3)

def filter_cosmic(inst):
    cosmic.data = cosmic[(cosmic['edmaxlat'] > -15) & (cosmic['edmaxlat'] < 15)]
    return

cosmic.custom.add(filter_cosmic, 'modify')
data_label = 'edmax'
mean_max_dens = daily_mean(cosmic, start, stop, data_label)

# plot the result using pandas functionality
mean_max_dens.plot(title='Absolute Daily Mean of ' + cosmic.meta[data_label].long_name)
plt.ylabel('Absolute Daily Mean ('+cosmic.meta[data_label].units+')')
```

daily_mean now works for any instrument, as long as the data to be averaged is 1D. This can be fixed.

Partial Independence from Dimensionality

```
import pandas
import pysat

def daily_mean(inst, start, stop, data_label):

    # create empty series to hold result
```

```
    mean_val = pandas.Series()
    # get list of dates between start and stop
    date_array = pysat.utils.season_date_range(start, stop)
    # iterate over season, calculate the mean
    for date in date_array:
        inst.load(date=date)
        if not inst.data.empty:
            # compute mean absolute using pandas functions and store
            # data could be an image, or lower dimension, account for 2D and lower
            data = inst[data_label]
            if isinstance(data.iloc[0], pandas.DataFrame):
                # 3D data, 2D data at every time
                data_panel = pandas.Panel.from_dict(dict([(i,data.iloc[i]) for i in xrange(len(data))
                mean_val[inst.date] = data_panel.abs().mean(axis=0,skipna=True)
            elif isinstance(data.iloc[0], pandas.Series):
                # 2D data, 1D data for each time
                data_frame = pandas.DataFrame(data.tolist())
                data_frame.index = data.index
                mean_val[inst.date] = data_frame.abs().mean(axis=0, skipna=True)
            else:
               # 1D data
                mean_val[inst.date] = inst[data_label].abs().mean(axis=0,skipna=True)

return mean_val
```

This code works for 1D, 2D, and 3D datasets, regardless of instrument platform, with only some minor changes from the initial VEFI specific code. In-situ measurements, remote profiles, and remote images. It is true the nested if statements aren't the most elegant. Particularly the 3D case. However this code puts the data into an appropriate structure for pandas to align each of the profiles/images by their respective indices before performing the average. Note that the line to obtain the arithmetic mean is the same in all cases, .mean(axis=0, skipna=True). There is an opportunity here for pysat to clean up the little mess caused by dimensionality (pending).

3.3 Time Series Analysis

Pending

3.4 Iteration

The seasonal analysis loop is repeated commonly:

```
date_array = pysat.utils.season_date_range(start,stop)
for date in date_array:
    vefi.load(date=date)
    print 'Maximum meridional magnetic perturbation ', vefi['dB_mer'].max()
```

Iteration support is built into the Instrument object to support this and similar cases. The whole VEFI data set may be iterated over on a daily basis using

```
for vefi in vefi:
    print 'Maximum meridional magnetic perturbation ', vefi['dB_mer'].max()
```

Each loop of the python for iteration initiates a vefi.load() for the next date, starting with the first available date. By default the instrument instance will iterate over all available data. To control the range, set the instrument bounds,

```
# multi-season season
vefi.bounds = ([start1, start2], [stop1, stop2])
# continuous season
vefi.bounds = (start, stop)
# iterate over custom season
for vefi in vefi:
    print 'Maximum meridional magnetic perturbation ', vefi['dB_mer'].max()
```

The output is,

```
Returning cnofs vefi dc_b data for 05/09/10
Maximum meridional magnetic perturbation  19.3937
Returning cnofs vefi dc_b data for 05/10/10
Maximum meridional magnetic perturbation  23.745
Returning cnofs vefi dc_b data for 05/11/10
Maximum meridional magnetic perturbation  25.673
Returning cnofs vefi dc_b data for 05/12/10
Maximum meridional magnetic perturbation  26.583
```

So far, the iteration support has only saved a single line of code, the .load line. However, this line in the examples above is tied to loading by date. What if we wanted to load by file instead? This would require changing the code. However, with the abstraction provided by the Instrument iteration, that is no longer the case.

```
vefi.bounds( 'filename1', 'filename2')
for vefi in vefi:
    print 'Maximum meridional magnetic perturbation ', vefi['dB_mer'].max()
```

For VEFI there is only one file per day so there is no practical difference between the previous example. However, for instruments that have more than one file a day, there is a difference.

Building support for this iteration into the mean_day example is easy.

```
import pandas
import pysat

def daily_mean(inst, data_label):

    # create empty series to hold result
    mean_val = pandas.Series()

    for inst in inst:
        if not inst.data.empty:
            # compute mean absolute using pandas functions and store
            # data could be an image, or lower dimension, account for 2D and lower
            data = inst[data_label]
            if isinstance(data.iloc[0], pandas.DataFrame):
                # 3D data, 2D data at every time
                data_panel = pandas.Panel.from_dict(dict([(i,data.iloc[i]) for i in xrange(len(data))
                mean_val[inst.date] = data_panel.abs().mean(axis=0,skipna=True)
            elif isinstance(data.iloc[0], pandas.Series):
                # 2D data, 1D data for each time
                data_frame = pandas.DataFrame(data.tolist())
                data_frame.index = data.index
                mean_val[inst.date] = data_frame.abs().mean(axis=0, skipna=True)
            else:
                # 1D data
                mean_val[inst.date] = inst[data_label].abs().mean(axis=0,skipna=True)

    return mean_val
```

Since bounds are attached to the Instrument object, the start and stop dates for the season are no longer required as inputs. If a user forgets to specify the bounds, the loop will start on the first day of data and end on the last day.

```
# make a plot of daily dB_mer
vefi.bounds = (start, stop)
mean_dB = daily_mean(vefi, 'dB_mer')

# plot the result using pandas functionality
mean_dB.plot(title='Absolute Daily Mean of '
             + vefi.meta['dB_mer'].long_name)
plt.ylabel('Absolute Daily Mean ('+vefi.meta['dB_mer'].units+')')
```

The abstraction provided by the iteration support is also used for the next section on orbit data.

3.5 Orbit Support

Pysat has functionality to determine orbits on the fly from loaded data. These orbits will span day breaks as needed (generally). Information about the orbit needs to be provided at initialization. The 'index' is the name of the data to be used for determining orbits, and 'kind' indicates type of orbit. See `pysat.Orbits` for latest inputs.

There are several orbits to choose from,

kind	method
local time	Uses negative gradients to delineate orbits
longitude	Uses negative gradients to delineate orbits
polar	Uses sign changes to delineate orbits

Changes in universal time are also used to delineate orbits. Pysat compares any gaps to the supplied orbital period, nominally assumed to be 97 minutes. As orbit periods aren't constant, a 100% success rate is not be guaranteed.

This section of pysat is still under development.

```
info = {'index':'mlt', 'kind':'local time'}
ivm = pysat.Instrument(platform='cnofs', name='ivm', orbit_info=info, clean_level='None')
```

Orbit determination acts upon data loaded in the ivm object, so to begin we must load some data.

```
ivm.load(date=start)
```

Orbits may be selected directly from the attached .orbit class. The data for the orbit is stored in .data.

```
In [50]: ivm.orbits[1]
Out[50]:
Returning cnofs ivm  data for 12/27/12
Returning cnofs ivm  data for 12/28/12
Loaded Orbit:1
```

Note that getting the first orbit caused pysat to load the day previous, and then back to the current day. Orbits are one indexed though this will change. Pysat is checking here if the first orbit for 12/28/2012 actually started on 12/27/2012. In this case it does.

```
In [51]: ivm[0:5,'mlt']
Out[51]:
2012-12-27 23:05:14.584000    0.002449
2012-12-27 23:05:15.584000    0.006380
2012-12-27 23:05:16.584000    0.010313
2012-12-27 23:05:17.584000    0.014245
2012-12-27 23:05:18.584000    0.018178
Name: mlt, dtype: float32
```

```
In [52]: ivm[-5:,'mlt']
Out[52]:
2012-12-28 00:41:50.563000    23.985415
2012-12-28 00:41:51.563000    23.989031
2012-12-28 00:41:52.563000    23.992649
2012-12-28 00:41:53.563000    23.996267
2012-12-28 00:41:54.563000    23.999886
Name: mlt, dtype: float32
```

Let's go back an orbit.

```
In [53]: ivm.orbits.prev()
Out[53]:
Returning cnofs ivm  data for 12/27/12
Loaded Orbit:15

In [54]: ivm[-5:,'mlt']
Out[54]:
2012-12-27 23:05:09.584000    23.982796
2012-12-27 23:05:10.584000    23.986725
2012-12-27 23:05:11.584000    23.990656
2012-12-27 23:05:12.584000    23.994587
2012-12-27 23:05:13.584000    23.998516
Name: mlt, dtype: float32
```

pysat loads the previous day, as needed, and returns the last orbit for 12/27/2012 that does not (or should not) extend into 12/28.

If we continue to iterate orbits using

```
ivm.orbits.next()
```

eventually the next day will be loaded to try and form a complete orbit. You can skip the iteration and just go for the last orbit of a day,

```
In[] : ivm.orbits[-1]
Out[]:
Returning cnofs ivm  data for 12/29/12
Loaded Orbit:1
```

```
In[72] : ivm[:5,'mlt']
Out[72]:
2012-12-28 23:03:34.160000    0.003109
2012-12-28 23:03:35.152000    0.007052
2012-12-28 23:03:36.160000    0.010996
2012-12-28 23:03:37.152000    0.014940
2012-12-28 23:03:38.160000    0.018884
Name: mlt, dtype: float32

In[73] : ivm[-5:,'mlt']
Out[73]:
2012-12-29 00:40:13.119000    23.982937
2012-12-29 00:40:14.119000    23.986605
2012-12-29 00:40:15.119000    23.990273
2012-12-29 00:40:16.119000    23.993940
2012-12-29 00:40:17.119000    23.997608
Name: mlt, dtype: float32
```

Pysat loads the next day of data to see if the last orbit on 12/28/12 extends into 12/29/12, which it does. Note that the last orbit of 12/28/12 is the same as the first orbit of 12/29/12. Thus, if we ask for the next orbit,

```
In[] : ivm.orbits.next()
Loaded Orbit:2
```

pysat will indicate it is the second orbit of the day. Going back an orbit gives us orbit 16, but referenced to a different day. Earlier, the same orbit was labeled orbit 1.

```
In[] : ivm.orbits.prev()
Returning cnofs ivm  data for 12/28/12
Loaded Orbit:16
```

Orbit iteration is built into ivm.orbits just like iteration by day is built into ivm.

```
start = [pandas.datetime(2009,1,1), pandas.datetime(2010,1,1)]
stop = [pandas.datetime(2009,4,1), pandas.datetime(2010,4,1)]
ivm.bounds = (start, stop)
for ivm in ivm.orbits:
    print 'next available orbit ', ivm.data
```

3.6 Iteration and Instrument Independent Analysis

Now we can generalize daily_mean into two functions, one that averages by day, the other by orbit. Strictly speaking, the daily_mean above already does this with the right input.

```
mean_daily_val = daily_mean(vefi, 'dB_mer')
mean_orbit_val = daily_mean(vefi.orbits, 'dB_mer')
```

However, the output of the by_orbit attempt gets rewritten for most orbits since the output from daily_mean is stored by date. Though this could be fixed, supplying an instrument object/iterator in one case and an orbit iterator in the other might be a bit inconsistent. Even if not, let's try another route.

We also don't want to maintain two code bases that do almost the same thing. So instead, let's create three functions, two of which simply call a hidden third.

Iteration Independence

```
def daily_mean(inst, data_label):
    """Mean of data_label by day/file over Instrument.bounds"""
    return _core_mean(inst, data_label, by_day=True)

def by_orbit_mean(inst, data_label):
    """Mean of data_label by orbit over Instrument.bounds"""
    return _core_mean(inst, data_label, by_orbit=True)

def _core_mean(inst, data_label, by_orbit=False, by_day=False):

    if by_orbit:
        iterator = inst.orbits
    elif by_day:
        iterator = inst
    else:
        raise ValueError('A choice must be made, by day/file, or by orbit')
    if by_orbit and by_day:
        raise ValueError('A choice must be made, by day/file, or by orbit')

    # create empty series to hold result
    mean_val = pandas.Series()
```

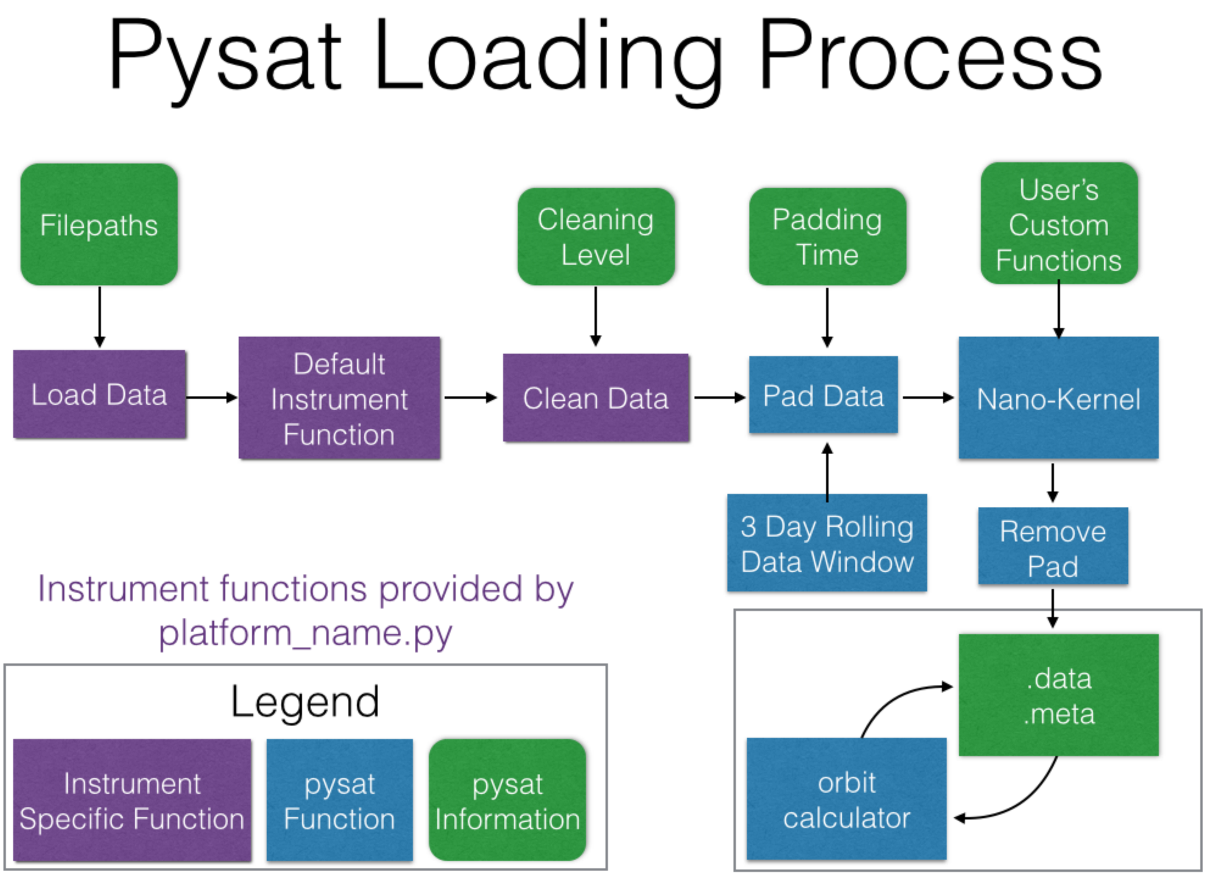
```
    # iterate over season, calculate the mean
    for inst in iterator:
        if not inst.data.empty:
            # compute mean absolute using pandas functions and store
            # data could be an image, or lower dimension, account for 2D and lower
            data = inst[data_label]
            data.dropna(inplace=True)

            if by_orbit:
                date = inst.data.index[0]
            else:
                date = inst.date

            if isinstance(data.iloc[0], pandas.DataFrame):
                data_panel = pandas.Panel.from_dict(dict([(i,data.iloc[i]) for i in xrange(len(dat
                mean_val[date] = data_panel.abs().mean(axis=0,skipna=True)
            elif isinstance(data.iloc[0], pandas.Series):
                data_frame = pandas.DataFrame(data.tolist())
                data_frame.index = data.index
                mean_val[date] = data_frame.abs().mean(axis=0, skipna=True)
            else:
                mean_val[date] = inst[data_label].abs().mean(axis=0,skipna=True)
    del iterator
    return mean_val
```

The addition of a few more lines to the daily_mean function adds support for averages by orbit, or by day, for any platform with data 3D or less. The date issue and the type of iteration are solved with simple if else checks. From a practical perspective, the code doesn't really deviate from the first solution of simply passing in vefi.orbits, except for the fact that the .orbits switch is 'hidden' in the code. NaN values are also dropped from the data. If the first element is a NaN, it isn't handled by the simple instance check.

A name change and a couple more dummy functions separates out the orbit vs daily iteration clearly, without having multiple codebases. Iteration by file and by date are handled by the same Instrument iterator, controlled by the settings in Instrument.bounds. A by_file_mean was not created because bounds could be set by date and then by_file_mean applied. Of course this could set up to produce an error. However, the settings on Instrument.bounds controls the iteration type between files and dates, so we maintain this view with the expressed calls. Similarly, the orbit iteration is a separate iterator, with a separate call. This technique above is used by other seasonal analysis routines in pysat.

You may notice that the mean call could also easily be replaced by a median, or even a mode. We might also want to return the standard deviation, or appropriate measure. Perhaps another level of generalization is needed?

3.7 Summary Flow Charts



CHAPTER

FOUR

EXAMPLES

Pysat tends to reduce certain science data investigations to the construction of a routine(s) that makes that investigation unique, a call to a seasonal analysis routine, and some plotting commands. Several demonstrations are offered in this section.

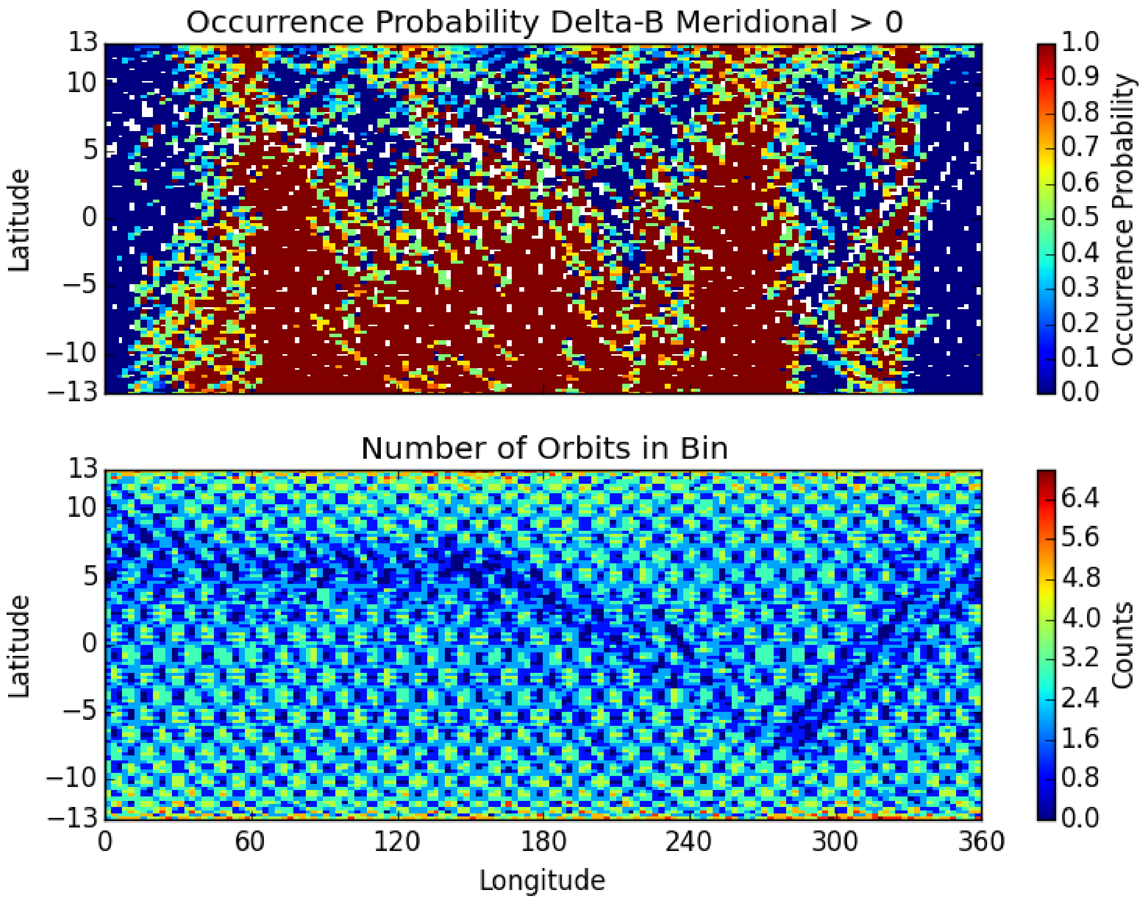
4.1 Seasonal Occurrence by Orbit

How often does a particular thing occur on a orbit-by-orbit basis? Let's find out. For VEFI, let us calculate the occurrence of a positive perturbation in the meridional component of the geomagnetic field.

```
import os
import pysat
import matplotlib.pyplot as plt
import pandas as pds
import numpy as np

# set the directory to save plots to
results_dir = ''

# select vefi dc magnetometer data, use longitude to determine where
# there are changes in the orbit (local time info not in file)
orbit_info = {'index':'longitude', 'kind':'longitude'}
vefi = pysat.Instrument(platform='cnofs', name='vefi', tag='dc_b',
                        clean_level=None, orbit_info=orbit_info)

# define function to remove flagged values
def filter_vefi(inst):
    idx, = np.where(vefi['B_flag']==0)
    vefi.data = vefi.data.iloc[idx]
    return
# attach function to vefi
vefi.custom.add(filter_vefi,'modify')
# set limits on dates analysis will cover, inclusive
start = pds.datetime(2010,5,9)
stop = pds.datetime(2010,5,15)

# if there is no vefi dc magnetometer data on your system
# run command below
# where start and stop are pandas datetimes (from above)
# pysat will automatically register the addition of this data at the end
# of download
vefi.download(start, stop)
```

```
# leave bounds unassigned to cover the whole dataset
vefi.bounds = (start,stop)

# perform occurrence probability calculation
# any data added by custom functions is available within routine below
ans = pysat.ssnl.occur_prob.by_orbit2D(vefi, [0,360,144], 'longitude',
             [-13,13,104], 'latitude', ['dB_mer'], [0.], returnBins=True)

# a dict indexed by data_label is returned
# in this case, only one, we'll pull it out
ans = ans['dB_mer']
# plot occurrence probability
f, axarr = plt.subplots(2,1, sharex=True, sharey=True)
masked = np.ma.array(ans['prob'], mask=np.isnan(ans['prob']))
im=axarr[0].pcolor(ans['binx'], ans['biny'], masked)
axarr[0].set_title('Occurrence Probability Delta-B Meridional > 0')
axarr[0].set_ylabel('Latitude')
axarr[0].set_yticks((-13,-10,-5,0,5,10,13))
axarr[0].set_ylim((ans['biny'][0],ans['biny'][-1]))
plt.colorbar(im,ax=axarr[0], label='Occurrence Probability')

im=axarr[1].pcolor(ans['binx'], ans['biny'],ans['count'])
axarr[1].set_xlabel('Longitude')
axarr[1].set_xticks((0,60,120,180,240,300,360))
axarr[1].set_xlim((ans['binx'][0],ans['binx'][-1]))
axarr[1].set_ylabel('Latitude')
axarr[1].set_title('Number of Orbits in Bin')

plt.colorbar(im,ax=axarr[1], label='Counts')
f.tight_layout()
plt.show()
plt.savefig(os.path.join(results_dir,'ssnl_occurrence_by_orbit_demo') )
```

Result



The top plot shows the occurrence probability of a positive magnetic field perturbation as a function of geographic longitude and latitude. The bottom plot shows the number of times the satellite was in each bin with data (on per orbit basis). Individual orbit tracks may be seen. The hatched pattern is formed from the satellite traveling North to South and vice-versa. At the latitudinal extremes of the orbit the latitudinal velocity goes through zero providing a greater coverage density. The satellite doesn't return to the same locations on each pass so there is a reduction in counts between orbit tracks. All local times are covered by this plot, overrepresenting the coverage of a single satellite.

The horizontal blue band that varies in latitude as a function of longitude is the location of the magnetic equator. Torque rod firings that help C/NOFS maintain proper attitude are performed at the magnetic equator. Data during these firings is excluded by the custom function attached to the vefi instrument object.

4.2 Orbit-by-Orbit Plots

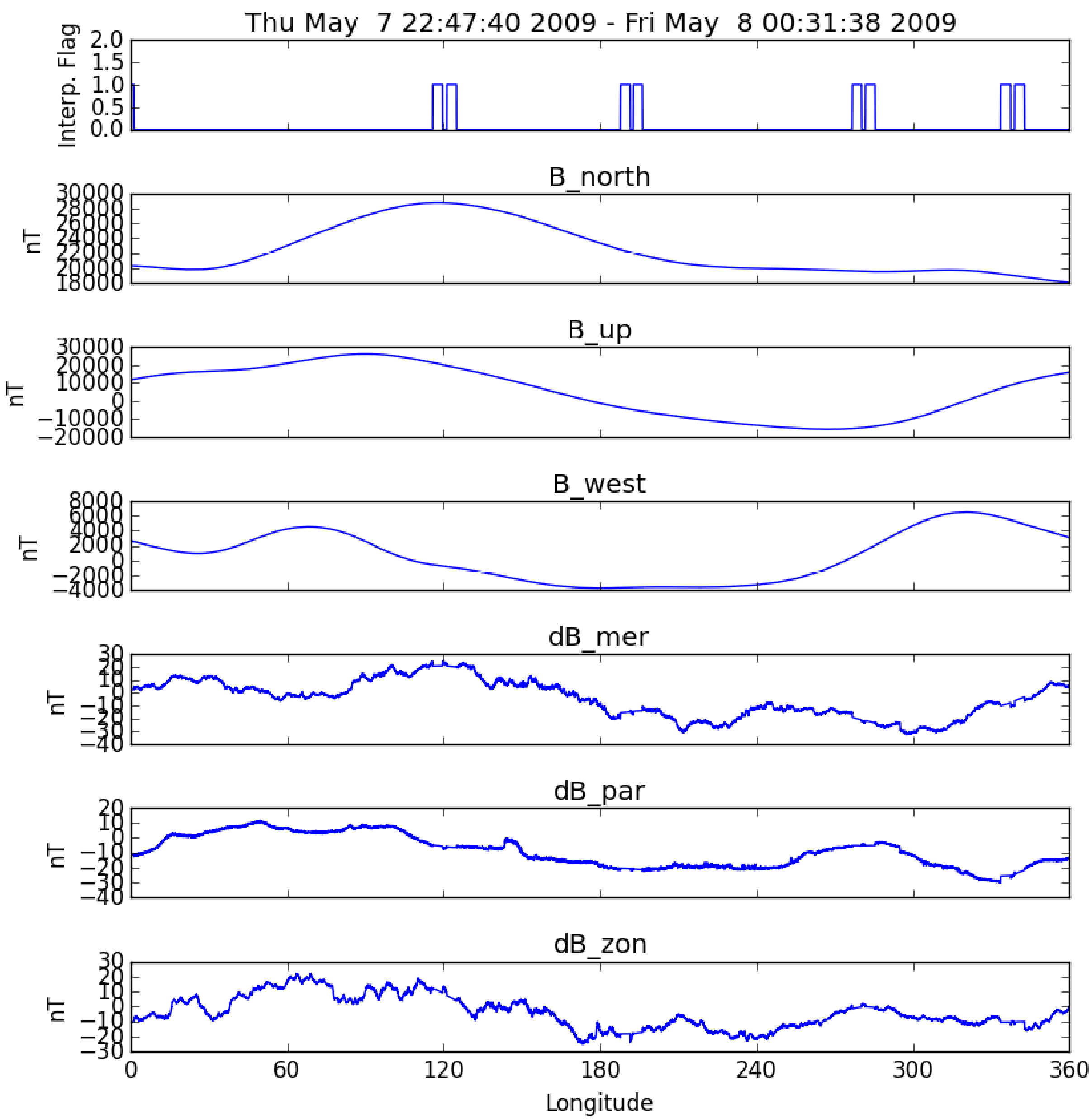
Plotting a series of orbit-by-orbit plots is a great way to become familiar with a data set. If the data set doesn't come with orbit information, this can be a challenge. Orbits also go past day breaks, so if data comes in daily files this requires loading multiple files at once, joining the data together, etc. pysat goes through that trouble for you.

```
import os
import pysat
import matplotlib.pyplot as plt
import pandas as pds

# set the directory to save plots to
```

```python
results_dir = ''

# select vefi dc magnetometer data, use longitude to determine where
# there are changes in the orbit (local time info not in file)
orbit_info = {'index':'longitude', 'kind':'longitude'}
vefi = pysat.Instrument(platform='cnofs', name='vefi', tag='dc_b',
                        clean_level=None, orbit_info=orbit_info)

# set limits on dates analysis will cover, inclusive
start = pysat.datetime(2010,5,9)
stop = pysat.datetime(2010,5,12)

# if there is no vefi dc magnetometer data on your system
# then run command below
# where start and stop are pandas datetimes (from above)
# pysat will automatically register the addition of this data at the end
# of download
vefi.download(start, stop)

# leave bounds unassigned to cover the whole dataset
vefi.bounds = (start,stop)

for orbit_count, vefi in enumerate(vefi.orbits):
    # for each loop pysat puts a copy of the next available
    # orbit into   vefi.data
    # changing .data at this level does not alter other orbits
    # reloading the same orbit will erase any changes made

    # satellite data can have time gaps, which leads to plots
    # with erroneous lines connecting measurements on
    # both sides of the gap
    # command below fills in any data gaps using a
    # 1-second cadence with NaNs
    # see pandas documentation for more info
    vefi.data = vefi.data.resample('1S',  fill_method='ffill',
                                   limit=1, label='left' )

    f, ax = plt.subplots(7, sharex=True, figsize=(8.5,11))

    ax[0].plot(vefi['longitude'], vefi['B_flag'])
    ax[0].set_title( vefi.data.index[0].ctime() +' - ' +
                     vefi.data.index[-1].ctime() )
    ax[0].set_ylabel('Interp. Flag')
    ax[0].set_ylim((0,2))

    p_params = ['B_north', 'B_up', 'B_west', 'dB_mer',
                'dB_par', 'dB_zon']
    for a,param in zip(ax[1:],p_params):
       a.plot(vefi['longitude'], vefi[param])
       a.set_title(vefi.meta[param].long_name)
       a.set_ylabel(vefi.meta[param].units)

    ax[6].set_xlabel(vefi.meta['longitude'].long_name)
    ax[6].set_xticks([0,60,120,180,240,300,360])
    ax[6].set_xlim((0,360))

    f.tight_layout()
    fname = 'orbit_%05i.png' % orbit_count
```

```
    plt.savefig(os.path.join(results_dir, fname) )
    plt.close()
```

Output

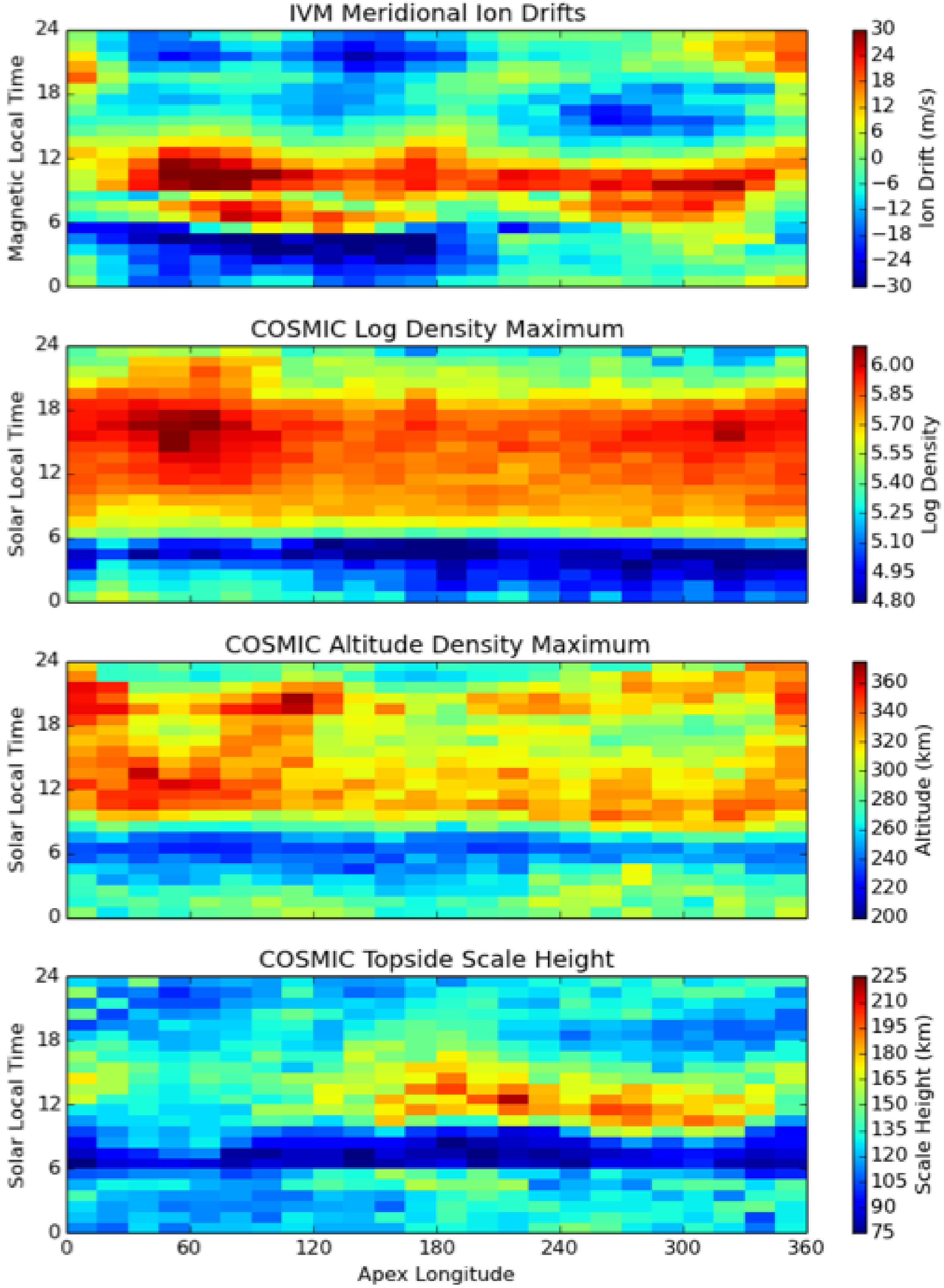


4.3 Seasonal Averaging of Ion Drifts and Density Profiles

In-situ measurements of the ionosphere by the Ion Velocity Meter onboard C/NOFS provides information on plasma density, composition, ion temperature, and ion drifts. This provides a great deal of information on the ionosphere though this information is limited to the immediate vicinity of the satellite. COSMIC GPS measurements, with some processing, provide information on the vertical electron density distribution in the ionosphere. The vertical motion of ions measured by IVM should be reflected in the vertical plasma densities measured by COSMIC. To look at this relationship over all longitudes and local times, for magnetic latitudes near the geomagnetic equator, use the code below:

Note the same averaging routine is used for both COSMIC and IVM, and that both 1D and 2D data are handled correctly. The routine below has not yet been uploaded to the repo. (Pending)

```
# instantiate IVM Object
ivm = pysat.Instrument(platform='cnofs',name='ivm',clean_level='clean')
# restrict meausurements to those near geomagnetic equator
ivm.custom.add(restrictMLAT, 'modify', maxMLAT=25.)
# perform seasonal average
ivm.bounds(startDate, stopDate)
ivmResults = pysat.ssnl.avg.median2D(ivm, [0,360,24], 'apex_long',
                  [0,24,24], 'mlt', ['iv_mer'])

# create CODMIC instrument object
cosmic = pysat.Instrument(platform='cosmic2013', name='gps',tag='ionprf',
             clean_level='clean', altitude_bin=3)
# apply custom functions to all data that is loaded through cosmic
cosmic.custom.add(addApexLong, 'add')
# select locations near the magnetic equator
cosmic.custom.add(filterMLAT, 'modify', mlatRange=(0.,10.) )
# take the log of NmF2 and add to the dataframe
cosmic.custom.add(addlogNm, 'add')
# calculates the height above hmF2 to reach Ne < NmF2/e
cosmic.custom.add(addTopsideScaleHeight, 'add')

# do an average of multiple COSMIC data products from startDate through stopDate
# a mixture of 1D and 2D data is averaged
cosmic.bounds(startDate, stopDate)
cosmicResults = pysat.ssnl.avg.median2D(cosmic, [0,360,24], 'apex_long',
       [0,24,24],'edmaxlct', ['profiles', 'edmaxalt', 'lognm', 'thf2'])

# the work is done, plot the results
```



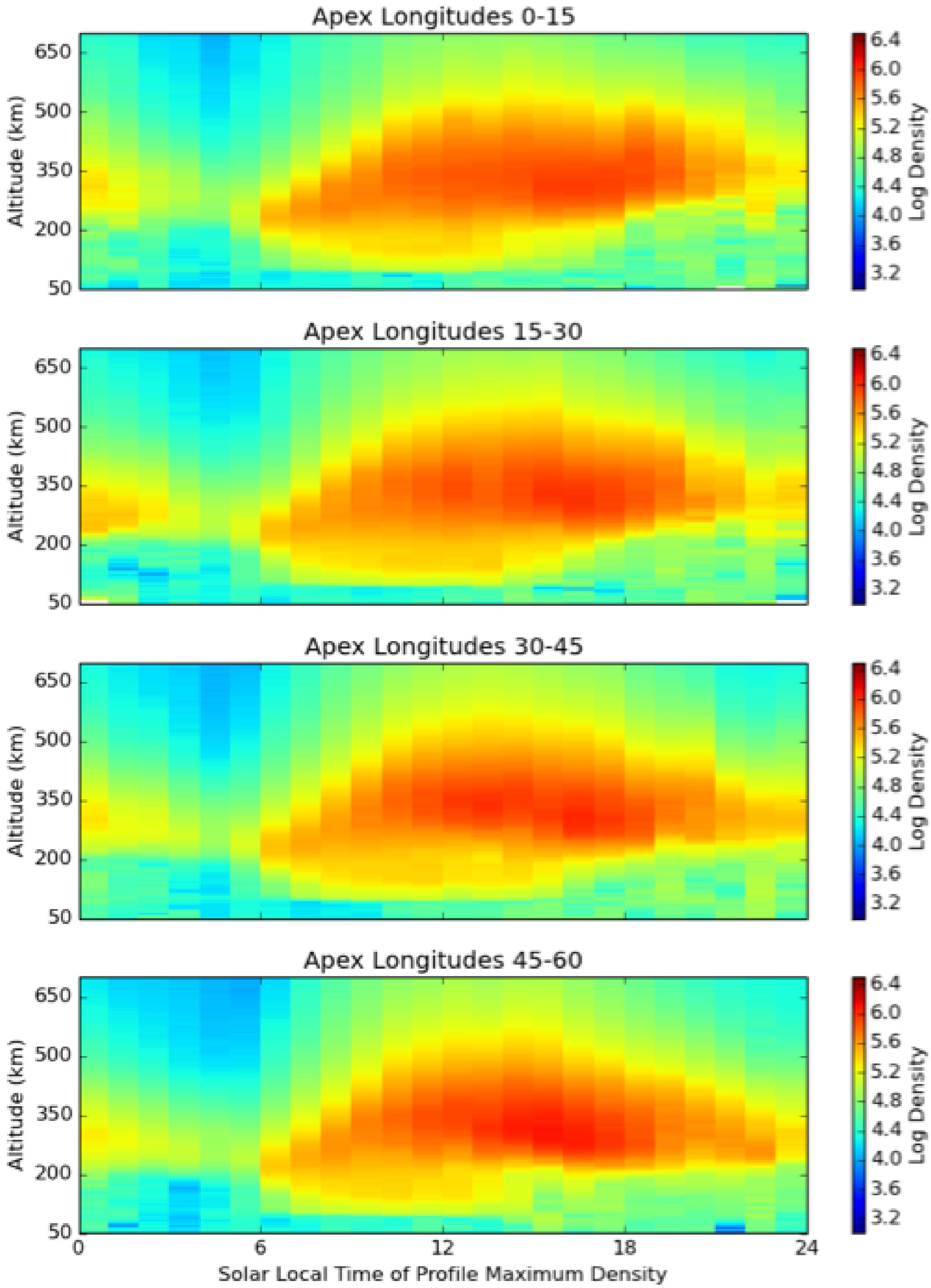
The top image is the median ion drift from the IVM, while the remaining plots are derived from the COSMIC density profiles. COSMIC data does not come with the location of the profiles in magnetic coordinates, so this information is added using the nano-kernel.

```
cosmic.custom.add(addApexLong, 'add')
```

call runs a routine that adds the needed information. This routine is currently only using a simple titled dipole model. Similarly, using custom functions, locations away from the magnetic equator are filtered out and a couple new quantities are added.

There is a strong correspondence between the distribution of downward drifts between noon and midnight and a reduction in the height of the peak ionospheric density around local sunset. There isn't the same strong correspondence with the other parameters but ion density profiles are also affected by production and loss processes, not measured by IVM.

The median averaging routine also produced a series a median altitude profiles as a function of longitude and local time. A selection are shown below.



There is a gradient in the altitude distribution over longitude near sunset. Between 0-15 longitude an upward slope is seen in bottom-side density levels with local time though higher altitudes have a flatter gradient. This is consistent with the upward ion drifts reported by IVM. Between 45-60 the bottom-side ionosphere is flat with local time, while densities at higher altitudes drop steadily. Ion drifts in this sector become downward at night. Downward drifts lower plasma into exponentially higher neutral densities, rapidly neutralizing plasma and producing an effective flat bottom. Thus, the COSMIC profile in this sector is also consistent with the IVM drifts.

Between 15-30 degrees longitude, ion drifts are upward, but less than the 0-15 sector. Similarly, the density profile in the same sector has a weaker upward gradient with local time than the 0-15 sector. Between 30-45 longitude, drifts are mixed, then transition into weaker downward drifts than between 45-60 longitude. The corresponding profiles have a flatter bottom-side gradient than sectors with upward drift (0-30), and a flatter top-side gradient than when drifts are more downward (45-60), consistent with the ion drifts.

CHAPTER

FIVE

SUPPORTED INSTRUMENTS

5.1 C/NOFS VEFI

Supports the Vector Electric Field Instrument (VEFI) onboard the Communication and Navigation Outage Forecasting System (C/NOFS) satellite. Downloads data from the NASA Coordinated Data Analysis Web (CDAWeb).

param tag

type tag {'dc_b'}

Notes

- tag = 'dc_b': 1 second DC magnetometer data

> **Warning:**
> - Currently no cleaning routine.
> - Module not written by VEFI team.

5.2 C/NOFS IVM

Supports the Ion Velocity Meter (IVM) onboard the Communication and Navigation Outage Forecasting System (C/NOFS) satellite, part of the Coupled Ion Netural Dynamics Investigation (CINDI). Downloads data from the NASA Coordinated Data Analysis Web (CDAWeb) in CDF format.

param tag No tags supported

type tag string

> **Warning:**
> - The sampling rate of the instrument changes on July 29th, 2010. The rate is attached to the instrument object as .sample_rate.
> - The cleaning parameters for the instrument are still under development.

5.3 COSMIC 2013 GPS

Loads data from the COSMIC satellite, 2013 reprocessing.

The Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC) is comprised of six satellites in LEO with GPS receivers. The occultation of GPS signals by the atmosphere provides a measurement of atmospheric parameters. Data downloaded from the COSMIC Data Analaysis and Archival Center.

param altitude_bin Number of kilometers to bin altitude profiles by when loading. Currently only supported for tag='ionprf'.

type altitude_bin integer

Notes

- 'ionprf: 'ionPrf' ionosphere profiles
- 'sonprf': 'sonPrf' files
- 'wetprf': 'wetPrf' files
- 'atmPrf': 'atmPrf' files

> **Warning:**
> - Routine was not produced by COSMIC team

5.4 COSMIC GPS

Loads and downloads data from the COSMIC satellite.

The Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC) is comprised of six satellites in LEO with GPS receivers. The occultation of GPS signals by the atmosphere provides a measurement of atmospheric parameters. Data downloaded from the COSMIC Data Analaysis and Archival Center.

Notes

- 'ionprf: 'ionPrf' ionosphere profiles
- 'sonprf': 'sonPrf' files
- 'wetprf': 'wetPrf' files
- 'atmPrf': 'atmPrf' files

> **Warning:**
> - Routine was not produced by COSMIC team

5.5 SuperDARN

SuperDARN data support (Alpha Level!)

CHAPTER

SIX

ADDING A NEW INSTRUMENT

pysat works by calling modules written for specific instruments that load and process the data consistent with the pysat standard. The name of the module corresponds to the combination 'platform_name' provided when initializing a pysat instrument object. The module should be placed in the pysat instruments directory or in the user specified location (via mechanism to be added) for automatic discovery. A compatible module may also be supplied directly to pysat.Instrument(inst_module=input module) if it also contains attributes platform and name.

Three functions are required:

6.1 List Files

Pysat maintains a list of files to enable data management functionality. It needs a pandas Series of filenames indexed by time. Pysat expects the module method platform_name.list_files to be:

```
def list_files(tag=None, data_path=None):
    return pandas.Series(files, index=datetime_index)
```

where tag indicates a specific subset of the available data from cnofs_vefi.

See pysat.utils.create_datetime_index for creating a datetime index for an array of irregularly sampled times.

Pysat will store data in pysat_data_dir/platform/name/tag, helpfully provided in data_path, where pysat_data_dir is specified by user in pysat settings.

pysat.Files.from_os is a convenience constructor provided for filenames that include time information in the filename and utilize a constant field width. The location and format of the time information is specified using standard python formatting and keywords year, month, day, hour, minute, second. A complete list_files routine could be as simple as

```
def list_files(tag=None, data_path=None):
    return pysat.Files.from_os(data_path=data_path,
                format_str='cindi-{year:4d}{day:03d}-ivm.hdf')
```

6.2 Load Data

Loading is a fundamental pysat activity, this routine enables the user to consider loading a hidden implementation 'detail'.

```
def load(fnames, tag=None):
    return data, meta
```

- The load routine should return a tuple with (data, pysat metadata object).
- data is a pandas DataFrame, column names are the data labels, rows are indexed by datetime objects.

- pysat.utils.create_datetime_index provides for quick generation of an appropriate datetime index for irregulary sampled data set with gaps
- pysat meta object obtained from pysat.Meta(). Use pandas DataFrame indexed by name with columns for 'units' and 'long_name'. Additional arbitrary columns allowed. See pysat.Meta for more information on creating the initial metadata.
- If metadata is already stored with the file, creating the Meta object is trivial. If this isn't the case, it can be tedious to fill out all information if there are many data parameters. In this case it is easier to fill out a text file. A convenience function is provided for this s situation. See pysat.Meta.from_csv for more information.

6.3 Download Data

Download support significantly lowers the hassle in dealing with any dataset. Fetch data from the internet.

```
def download(date_array, data_path=None, user=None, password=None):
    return
```

- date_array, a list of dates to download data for
- data_path, the full path to the directory to store data
- user, string for username
- password, string for password

Routine should download data and write it to disk.

6.4 Optional Routines

Initialize

Initialize any specific instrument info. Runs once.

```
def init(inst):
    return None
```

inst is a pysat.Instrument() instance. init should modify inst in-place as needed; equivalent to a 'modify' custom routine.

Default

First custom function applied, once per instrument load.

```
def default(inst):
    return None
```

inst is a pysat.Instrument() instance. default should modify inst in-place as needed; equivalent to a 'modify' custom routine.

Clean Data

Cleans instrument for levels supplied in inst.clean_level.

- 'clean' : expectation of good data
- 'dusty' : probably good data, use with caution
- 'dirty' : minimal cleaning, only blatant instrument errors removed

- 'none' : no cleaning, routine not called

```
def clean(inst):
    return None
```

inst is a pysat.Instrument() instance. clean should modify inst in-place as needed; equivalent to a 'modify' custom routine.

CHAPTER

SEVEN

API

7.1 Instrument

class `pysat.Instrument` (*platform=None*, *name=None*, *tag=None*, *clean_level='clean'*, *update_files=False*, *pad=None*, *orbit_info=None*, *inst_module=None*, *multi_file_day=False*, **arg*, ***kwargs*)

Download, load, manage, modify and analyze science data.

Parameters

- **platform** (*string*) – name of platform/satellite.
- **name** (*string*) – name of instrument.
- **tag** (*string, optional*) – identifies particular subset of instrument data.
- **inst_module** (*module, optional*) – Provide instrument module directly. Takes precedence over platform/name.
- **clean_level** (*{'clean','dusty','dirty','none'}, optional*) – level of data quality
- **pad** (*pandas.DateOffset, or dictionary, optional*) – Length of time to pad the begining and end of loaded data for time-series processing. Extra data is removed after applying all custom functions. Dictionary, if supplied, is simply passed to pandas DateOffset.
- **orbit_info** (*dict*) – Orbit information, {'index':index, 'kind':kind, 'period':period}. See pysat.Orbits for more information.
- **update_files** (*boolean, optional*) – If True, query filesystem for instrument files and store. files.get_new() will return no files after this call until additional files are added.
- **multi_file_day** (*boolean, optional (False by default)*) – Set to True if Instrument data files for a day are spread across multiple files and data for day n could be found in a file with a timestamp of day n-1 or n+1.

data

pandas.DataFrame

loaded science data

date

pandas.datetime

date for loaded data

yr

int

year for loaded data

bounds
: *(datetime/filename/None, datetime/filename/None)*

  bounds for loading data, supply array_like for a season with gaps

doy
: *int*

  day of year for loaded data

files
: *pysat.Files*

  interface to instrument files

meta
: *pysat.Meta*

  interface to instrument metadata, similar to netCDF 1.6

orbits
: *pysat.Orbits*

  interface to extracting data orbit-by-orbit

custom
: *pysat.Custom*

  interface to instrument nano-kernel

kwargs
: *dictionary*

  keyword arguments passed to instrument loading routine

Note: Pysat attempts to load the module platform_name.py located in the pysat/instruments directory. This module provides the underlying functionality to download, load, and clean instrument data. Alternatively, the module may be supplied directly using keyword inst_module.

Examples

```
# 1-second mag field data
vefi = pysat.Instrument(platform='cnofs',
                        name='vefi',
                        tag='dc_b',
                        clean_level='clean')
start = pysat.datetime(2009,1,1)
stop = pysat.datetime(2009,1,2)
vefi.download(start, stop)
vefi.load(date=start)
print vefi['dB_mer']
print vefi.meta['db_mer']

# 1-second thermal plasma parameters
ivm = pysat.Instrument(platform='cnofs',
                        name='ivm',
                        tag='',
                        clean_level='clean')
ivm.download(start,stop)
ivm.load(2009,1)
```

```
    print ivm['ionVelmeridional']

    # Ionosphere profiles from GPS occultation
    cosmic = pysat.Instrument('cosmic2013',
                              'gps',
                              'ionprf',
                              altitude_bin=3)
    # bins profile using 3 km step
    cosmic.download(start, stop, user=user, password=password)
    cosmic.load(date=start)
```

__getitem__(*key*)

Convenience notation for accessing data; inst['name'] is inst.data.name

Examples

```
        # By name
        inst['name']
        # By position
        inst[row_index, 'name']
        # Slicing by row
        inst[row1:row2, 'name']
        # By Date
        inst[datetime, 'name']
        # Slicing by date, inclusive
        inst[datetime1:datetime2, 'name']
        # Slicing by name and row/date
        inst[datetime1:datetime1, 'name1':'name2']
```

__iter__()

Iterates instrument object by loading subsequent days or files.

Note: Limits of iteration, and iteration type (date/file) set by *bounds* attribute.

Default bounds are the first and last dates from files on local system.

Examples

```
        inst = pysat.Instrument(platform=platform,
                                name=name,
                                tag=tag)
        start = pysat.datetime(2009,1,1)
        stop = pysat.datetime(2009,1,31)
        inst.bounds = (start,stop)
        for inst in inst:
        print('Another day loaded', inst.date)
```

__setitem__(*key, new*)

Convenience method for adding data to instrument.

Examples

```
# Simple Assignment, default metadata assigned
# 'long_name' = 'name'
# 'units' = ''
inst['name'] = newData
# Assignment with Metadata
inst['name'] = {'data':new_data,
                'long_name':long_name,
                'units':units}
```

Note: If no metadata provided and if metadata for 'name' not already stored then default meta information is also added, long_name = 'name', and units = ''.

bounds

Boundaries for iterating over instrument object by date or file.

Parameters

- **start** (*datetime object, filename, or None (default)*) – start of iteration, if None uses first data date. list-like collection also accepted
- **end** (*datetime object, filename, or None (default)*) – end of iteration, inclusive. If None uses last data date. list-like collection also accepted

Note: Both start and stop must be the same type (date, or filename) or None

Examples

```
inst = pysat.Instrument(platform=platform,
                        name=name,
                        tag=tag)
start = pysat.datetime(2009,1,1)
stop = pysat.datetime(2009,1,31)
inst.bounds = (start,stop)

start2 = pysat.datetetime(2010,1,1)
stop2 = pysat.datetime(2010,2,14)
inst.bounds = ([start, start2], [stop, stop2])
```

copy()

Deep copy of the entire Instrument object.

download(*start*, *stop*, *user=None*, *password=None*)

Download data for given Instrument object from start to stop.

Parameters

- **start** (*pandas.datetime*) – start date to download data
- **stop** (*pandas.datetime*) – stop date to download data
- **user** (*string*) – username, if required by instrument data archive
- **password** (*string*) – password, if required by instrument data archive

Note: Data will be downloaded to pysat_data_dir/patform/name/tag

If Instrument bounds are set to defaults they are updated after files are downloaded.

---

load (*yr=None*, *doy=None*, *date=None*, *fname=None*, *fid=None*, *verifyPad=False*)
Load instrument data into Instrument object .data.

Parameters

- **yr** (*integer*) – year for desired data
- **doy** (*integer*) – day of year
- **date** (*datetime object*) – date to load
- **fname** (*'string'*) – filename to be loaded
- **verifyPad** (*boolean*) – if True, padding data not removed (debug purposes)

Note: Loads data for a chosen instrument into .data. Any functions chosen by the user and added to the custom processing queue (.custom.add) are automatically applied to the data before it is available to user in .data.

---

next ()
Manually iterate through the data loaded in Instrument object.

Bounds of iteration and iteration type (day/file) are set by *bounds* attribute.

Note: If there were no previous calls to load then the first day(default)/file will be loaded.

---

prev ()
Manually iterate backwards through the data in Instrument object.

Bounds of iteration and iteration type (day/file) are set by *bounds* attribute.

Note: If there were no previous calls to load then the first day(default)/file will be loaded.

---

to_netcdf3 (*fname=None*)
Stores loaded data into a netCDF3 64-bit file.

Parameters **fname** (*string*) – full path to save instrument object to

---

Note: Stores 1-D data along dimension 'time' - the date time index.

Stores object data (e.g. dataframes within series) separately

- The name of the series is used to prepend extra variable dimensions within netCDF, key_2, key_3; first dimension time
- The index organizing the data stored as key_sample_index
- from_netcdf3 uses this naming scheme to reconstruct data structure

The datetime index is stored as 'UNIX time'. netCDF-3 doesn't support 64-bit integers so it is stored as a 64-bit float. This results in a loss of datetime precision when converted back to datetime index up to hundreds of nanoseconds. Use netCDF4 if this is a problem.

All attributes attached to instrument meta are written to netCDF attrs.

7.2 Custom

class `pysat.Custom`

Applies a queue of functions when instrument.load called.

Nano-kernel functionality enables instrument objects that are 'set and forget'. The functions are always run whenever the instrument load routine is called so instrument objects may be passed safely to other routines and the data will always be processed appropriately.

Examples

```
def custom_func(inst, opt_param1=False, opt_param2=False):
    return None
instrument.custom.add(custom_func, 'modify', opt_param1=True)

def custom_func2(inst, opt_param1=False, opt_param2=False):
    return data_to_be_added
instrument.custom.add(custom_func2, 'add', opt_param2=True)
instrument.load(date=date)
print instrument['data_to_be_added']
```

See also:

`Custom.add`

Note: User should interact with Custom through pysat.Instrument instance's attribute, instrument.custom

`add` (*function*, *kind='add'*, *at_pos='end'*, **args*, ***kwargs*)

Add a function to custom processing queue.

Custom functions are applied automatically to associated pysat instrument whenever instrument.load command called.

Parameters

- **`function`** (*string or function object*) – name of function or function object to be added to queue
- **`kind`** (*{'add', 'modify', 'pass}*) –

  add Adds data returned from function to instrument object. A copy of pysat instrument object supplied to routine.

  modify pysat instrument object supplied to routine. Any and all changes to object are retained.

  pass A copy of pysat object is passed to function. No data is accepted from return.
- **`at_pos`** (*string or int*) – insert at position. (default, insert at end).
- **`args`** (*extra arguments*) – extra arguments are passed to the custom function (once)
- **`kwargs`** (*extra keyword arguments*) – extra keyword args are passed to the custom function (once)

Note: Allowed *add* function returns:

- {'data' : pandas Series/DataFrame/array_like, 'units' : string/array_like of strings, 'long_name' : string/array_like of strings, 'name' : string/array_like of strings (iff data array_like)}

- pandas DataFrame, names of columns are used
- pandas Series, .name required
- (string/list of strings, numpy array/list of arrays)

---

clear()
Clear custom function list.

7.3 Files

class pysat.**Files**(*sat*)
Maintains collection of files for instrument object.

Uses the list_files functions for each specific instrument to create an ordered collection of files in time. Used by instrument object to load the correct files. Files also contains helper methods for determining the presence of new files and creating an ordered list of files.

base_path
string

path to .pysat directory in user home

start_date
datetime

date of first file, used as default start bound for instrument object

stop_date
datetime

date of last file, used as default stop bound for instrument object

data_path
string

path to the directory containing instrument files, top_dir/platform/name/tag/

Note: User should generally use the interface provided by a pysat.Instrument instance. Exceptions are the classmethod from_os, provided to assist in generating the appropriate output for an instrument routine.

Examples

```
# convenient file access
inst = pysat.Instrument(platform=platform, name=name, tag=tag)
# first file
inst.files[0]

# files from start up to stop (exclusive on stop)
start = pysat.datetime(2009,1,1)
stop = pysat.datetime(2009,1,3)
print vefi.files[start:stop]

# files for date
print vefi.files[start]

# files by slicing
```

```
print vefi.files[0:4]

# get a list of new files
# new files are those that weren't present the last time
# a given instrument's file list was stored
new_files = vefi.files.get_new()

# search pysat appropriate directory for instrument files and
# update Files instance, knowledge not written to disk.
vefi.files.refresh()

# search pysat appropriate directory for files and store new list
vefi.files.refresh(store=True)
# running get_new will now return an empty list until
# additional files are introduced
```

classmethod from_os (*data_path=None*, *format_str=None*, *two_digit_year_break=None*)

Produces a list of files and and formats it for Files class.

Parameters

- **data_path** (*string*) – Top level directory to search files for. This directory is provided by pysat to the instrument_module.list_files functions as data_path.
- **format_string** (*string with python format codes*) – Provides the naming pattern of the instrument files and the locations of date information so an ordered list may be produced.
- **two_digit_year_break** (*int*) – If filenames only store two digits for the year, then '1900' will be added for years >= two_digit_year_break, and '2000' will be added for years < two_digit_year_break.

Note: Does not produce a Files instance, but the proper output from instrument_module.list_files method.

get_file_array (*start*, *end*)

Return a list of filenames between and including start and end.

Parameters

- **start** (*array_like or single string*) – filenames for start of returned filelist
- **stop** (*array_like or single string*) – filenames inclusive end of list

Returns

- *list of filenames between and including start and end over all*
- *intervals.*

get_index (*fname*)

Return index for a given filename.

Parameters fname (*string*) – filename

Note: If fname not found in the file information already attached to the instrument.files instance, then a files.refresh() call is made.

get_new ()

List all new files since last time list was stored.

pysat stores filenames in the user_home/.pysat directory. Returns a list of all new fileanmes since the last store. Filenames are stored if update_files is True at instrument object level and if files.refresh(store=True) is called.

Returns

- *pandas Series of filenames*
- *False if no filenames*

refresh(*store=False*)

Refresh loaded instrument filelist by searching filesystem.

Searches pysat provided path, pysat_data_dir/platform/name/tag/, where pysat_data_dir is set by pysat.utils.set_data_dir(path=path).

Parameters store (*boolean*) – set True to store loaded file names into .pysat directory

7.4 Meta

class pysat.**Meta**(*metadata=None*)

Stores metadata for Instrument instance, similar to CF-1.6 netCDFdata standard.

Parameters metadata (*pandas.DataFrame*) – DataFrame should be indexed by variable name that contains at minimum the standard_name (name), units, and long_name for the data stored in the associated pysat Instrument object.

data

pandas.DataFrame

index is variable standard name, 'units' and 'long_name' are also stored along with additional user provided labels.

__getitem__(*key*)

Convenience method for obtaining metadata.

Maps to pandas DataFrame.ix method.

Examples

```
print meta['name']
```

__setitem__(*name, value*)

Convenience method for adding metadata.

Examples

```
meta = pysat.Meta()
meta['name'] = {'long_name':string, 'units':string}
# update 'units' to new value
meta['name'] = {'units':string}
# update 'long_name' to new value
meta['name'] = {'long_name':string}
# attach new info with partial information, 'long_name' set to 'name2'
meta['name2'] = {'units':string}
# units are set to '' by default
meta['name3'] = {'long_name':string}
```

classmethod **`from_csv`**(*name=None*, *col_names=None*, *sep=None*, ***kwargs*)
Create instrument metadata object from csv.

Parameters

- **`name`** (*string*) – absolute filename for csv file or name of file stored in pandas instruments location
- **`col_names`** (*list-like collection of strings*) – column names in csv and resultant meta object
- **`sep`** (*string*) – column seperator for supplied csv filename

Note: column names must include at least ['name', 'long_name', 'units'], assumed if col_names is None.

classmethod **`from_dict`**()
not implemented yet, load metadata from dict of items/list types

classmethod **`from_nc`**()
not implemented yet, load metadata from netCDF

`replace`(*metadata=None*)
Replace stored metadata with input data.

Parameters **`metadata`** (*pandas.DataFrame*) – DataFrame should be indexed by variable name that contains at minimum the standard_name (name), units, and long_name for the data stored in the associated pysat Instrument object.

7.5 Orbits

class `pysat.`**`Orbits`**(*sat=None*, *index=None*, *kind=None*, *period=None*)
Determines orbits on the fly and provides orbital data in .data.

Determines the locations of orbit breaks in the loaded data in inst.data and provides iteration tools and convenient orbit selection via inst.orbit[orbit num].

Parameters

- **`sat`** (*pysat.Instrument instance*) – instrument object to determine orbits for
- **`index`** (*string*) – name of the data series to use for determing orbit breaks
- **`kind`** (*{'local time', 'longitude', 'polar'}*) – kind of orbit, determines how orbital breaks are determined
  - local time: negative gradients in lt or breaks in inst.data.index
  - longitude: negative gradients or breaks in inst.data.index
  - polar: zero crossings in latitude or breaks in inst.data.index
- **`period`** (*np.timedelta64*) – length of time for orbital period, used to gauge when a break in the datetime index (inst.data.index) is large enough to consider it a new orbit

Note: class should not be called directly by the user, use the interface provided by inst.orbits where inst = pysat.Instrument()

Warning: This class is still under development.

Examples

```
info = {'index':'longitude', 'kind':'longitude'}
vefi = pysat.Instrument(platform='cnofs', name='vefi', tag='dc_b',
                        clean_level=None, orbit_info=info)
start = pysat.datetime(2009,1,1)
stop = pysat.datetime(2009,1,10)
vefi.load(date=start)
vefi.bounds(start, stop)

# iterate over orbits
for vefi in vefi.orbits:
    print 'Next available orbit ', vefi['dB_mer']

# load fifth orbit of first day
vefi.load(date=start)
vefi.orbits[5]

# less convenient load
vefi.orbits.load(5)

# manually iterate orbit
vefi.orbits.next()
# backwards
vefi.orbits.prev()
```

`__getitem__`(*key*)

Enable convenience notation for loading orbit into parent object.

Examples

```
inst.load(date=date)
inst.orbits[4]
print 'Orbit data ', inst.data
```

Note: A day of data must already be loaded.

`__iter__`()

Support iteration by orbit.

For each iteration the next available orbit is loaded into inst.data.

Examples

```
for inst in inst.orbits:
    print 'next available orbit ', inst.data
```

Note: Limits of iteration set by setting inst.bounds.

`load`(*orbit=None*)

Load a particular orbit into .data for loaded day.

Parameters **`orbit`** (*int*) – orbit number, 1 indexed

Note: A day of data must be loaded before this routine functions properly. If the last orbit of the day is requested, it will automatically be padded with data from the next day. The orbit counter will be reset to 1.

next (**arg*, ***kwarg*)
Load the next orbit into .data.

Note: Forms complete orbits across day boundaries. If no data loaded then the first orbit from the first date of data is returned.

prev (**arg*, ***kwarg*)
Load the next orbit into .data.

Note: Forms complete orbits across day boundaries. If no data loaded then the last orbit of data from the last day is loaded into .data.

7.6 Seasonal Analysis

7.6.1 Occurrence Probability

Occurrence probability routines, daily or by orbit.

Routines calculate the occurrence of an event greater than a supplied gate occuring at least once per day, or once per orbit. The probability is calculated as the (number of times with at least one hit in bin)/(number of times in the bin).The data used to determine the occurrence must be 1D. If a property of a 2D or higher dataset is needed attach a custom function that performs the check and returns a 1D Series.

Note: The included routines use the bounds attached to the supplied instrument object as the season of interest.

pysat.ssnl.occur_prob.**by_orbit2D** (*inst*, *bin1*, *label1*, *bin2*, *label2*, *data_label*, *gate*, *returnBins=False*)
2D Occurrence Probability of data_label orbit-by-orbit over a season.

If data_label is greater than gate atleast once per orbit, then a 100% occurrence probability results. Season delineated by the bounds attached to Instrument object. Prob = (# of times with at least one hit)/(# of times in bin)

Parameters

- **inst** (pysat.Instrument()) – Instrument to use for calculating occurrence probability
- **binx** (*list*) – [min value, max value, number of bins]
- **labelx** (*string*) – identifies data product for binx
- **data_label** (*list of strings*) – identifies data product(s) to calculate occurrence probability
- **gate** (*list of values*) – values that data_label must achieve to be counted as an occurrence
- **returnBins** (*Boolean*) – if True, return arrays with values of bin edges, useful for pcolor

Returns **occur_prob** – A dict of dicts indexed by data_label. Each entry is dict with entries 'prob' for the probability and 'count' for the number of orbits with any data; 'bin_x' and 'bin_y' are also returned if requested. Note that arrays are organized for direct plotting, y values along rows, x along columns.

Return type dictionary

Note: Season delineated by the bounds attached to Instrument object.

`pysat.ssnl.occur_prob.`**`by_orbit3D`**(*inst*, *bin1*, *label1*, *bin2*, *label2*, *bin3*, *label3*, *data_label*, *gate*, *returnBins=False*)

3D Occurrence Probability of data_label orbit-by-orbit over a season.

If data_label is greater than gate atleast once per orbit, then a 100% occurrence probability results. Season delineated by the bounds attached to Instrument object. Prob = (# of times with at least one hit)/(# of times in bin)

Parameters

- **inst** (pysat.Instrument()) – Instrument to use for calculating occurrence probability
- **binx** (*list*) – [min value, max value, number of bins]
- **labelx** (*string*) – identifies data product for binx
- **data_label** (*list of strings*) – identifies data product(s) to calculate occurrence probability
- **gate** (*list of values*) – values that data_label must achieve to be counted as an occurrence
- **returnBins** (*Boolean*) – if True, return arrays with values of bin edges, useful for pcolor

Returns **occur_prob** – A dict of dicts indexed by data_label. Each entry is dict with entries 'prob' for the probability and 'count' for the number of orbits with any data; 'bin_x', 'bin_y', and 'bin_z' are also returned if requested. Note that arrays are organized for direct plotting, z,y,x.

Return type dictionary

Note: Season delineated by the bounds attached to Instrument object.

`pysat.ssnl.occur_prob.`**`daily2D`**(*inst*, *bin1*, *label1*, *bin2*, *label2*, *data_label*, *gate*, *returnBins=False*)

2D Daily Occurrence Probability of data_label > gate over a season.

If data_label is greater than gate at least once per day, then a 100% occurrence probability results.Season delineated by the bounds attached to Instrument object. Prob = (# of times with at least one hit)/(# of times in bin)

Parameters

- **inst** (pysat.Instrument()) – Instrument to use for calculating occurrence probability
- **binx** (*list*) – [min, max, number of bins]
- **labelx** (*string*) – name for data product for binx
- **data_label** (*list of strings*) – identifies data product(s) to calculate occurrence probability e.g. inst[data_label]
- **gate** (*list of values*) – values that data_label must achieve to be counted as an occurrence
- **returnBins** (*Boolean*) – if True, return arrays with values of bin edges, useful for pcolor

Returns **occur_prob** – A dict of dicts indexed by data_label. Each entry is dict with entries 'prob' for the probability and 'count' for the number of days with any data; 'bin_x' and 'bin_y' are also returned if requested. Note that arrays are organized for direct plotting, y values along rows, x along columns.

Return type dictionary

Note: Season delineated by the bounds attached to Instrument object.

`pysat.ssnl.occur_prob.`**`daily3D`**(*inst*, *bin1*, *label1*, *bin2*, *label2*, *bin3*, *label3*, *data_label*, *gate*, *returnBins=False*)

3D Daily Occurrence Probability of data_label > gate over a season.

If data_label is greater than gate atleast once per day, then a 100% occurrence probability results. Season delineated by the bounds attached to Instrument object. Prob = (# of times with at least one hit)/(# of times in bin)

Parameters

- **`inst`** (pysat.Instrument()) – Instrument to use for calculating occurrence probability
- **`binx`** (*list*) – [min, max, number of bins]
- **`labelx`** (*string*) – name for data product for binx
- **`data_label`** (*list of strings*) – identifies data product(s) to calculate occurrence probability
- **`gate`** (*list of values*) – values that data_label must achieve to be counted as an occurrence
- **`returnBins`** (*Boolean*) – if True, return arrays with values of bin edges, useful for pcolor

Returns **occur_prob** – A dict of dicts indexed by data_label. Each entry is dict with entries 'prob' for the probability and 'count' for the number of days with any data; 'bin_x', 'bin_y', and 'bin_z' are also returned if requested. Note that arrays are organized for direct plotting, z,y,x.

Return type dictionary

Note: Season delineated by the bounds attached to Instrument object.

7.6.2 Average

Instrument independent seasonal averaging routine. Supports averaging 1D and 2D data.

`pysat.ssnl.avg.`**`mean_by_day`**(*inst*, *data_label*)

Mean of data_label by day over Instrument.bounds

Parameters **`data_label`** (*string*) – string identifying data product to be averaged

Returns **mean** – simple mean of data_label indexed by day

Return type pandas Series

`pysat.ssnl.avg.`**`mean_by_file`**(*inst*, *data_label*)

Mean of data_label by orbit over Instrument.bounds

Parameters **`data_label`** (*string*) – string identifying data product to be averaged

Returns **mean** – simple mean of data_label indexed by start of each file

Return type pandas Series

`pysat.ssnl.avg.`**`mean_by_orbit`**(*inst*, *data_label*)

Mean of data_label by orbit over Instrument.bounds

Parameters **`data_label`** (*string*) – string identifying data product to be averaged

Returns **mean** – simple mean of data_label indexed by start of each orbit

Return type pandas Series

`pysat.ssnl.avg.`**`median2D`**(*inst*, *bin1*, *label1*, *bin2*, *label2*, *data_label*, *returnData=False*)

Return a 2D average of data_label over a season and label1, label2.

Parameters

- **`bin#`** (*[min, max, number of bins]*) –
- **`label#`** (*string*) – identifies data product for bin#
- **`data_label`** (*list-like*) – contains strings identifying data product(s) to be averaged

Returns **median** – 2D median accessed by data_label as a function of label1 and label2 over the season delineated by bounds of passed instrument objects. Also includes 'count' and 'avg_abs_dev' as well as the values of the bin edges in 'bin_x' and 'bin_y'.

Return type dictionary

7.6.3 Plot

`pysat.ssnl.plot.`**`scatterplot`**(*inst*, *labelx*, *labely*, *data_label*, *datalim*, *xlim=None*, *ylim=None*)

Return scatterplot of data_label(s) as functions of labelx,y over a season.

Parameters

- **`labelx`** (*string*) – data product for x-axis
- **`labely`** (*string*) – data product for y-axis
- **`data_label`** (*string, array-like of strings*) – data product(s) to be scatter plotted
- **`datalim`** (*numyp array*) – plot limits for data_label

Returns

- *Returns a list of scatter plots of data_label as a function*
- *of labelx and labely over the season delineated by start and*
- *stop datetime objects.*

7.7 Utilities

`pysat.utils.`**`create_datetime_index`**(*year=None*, *month=None*, *day=None*, *uts=None*)

Create a timeseries index using supplied year, month, day, and ut in seconds.

Parameters

- **`year`** (*array_like of ints*) –
- **`month`** (*array_like of ints or None*) –
- **`day`** (*array_like of ints*) – for day (default) or day of year (use month=None)
- **`uts`** (*array_like of floats*) –

Returns

Return type Pandas timeseries index.

Note: Leap seconds have no meaning here.

pysat.utils.**getyrdoy**(*date*)

Return a tuple of year, day of year for a supplied datetime object.

pysat.utils.**load_netcdf3**(*fnames=None*, *strict_meta=False*, *index_label=None*, *unix_time=False*, ***kwargs*)

Load netCDF-3 file produced by pysat.

Parameters

- **fnames** (*string or array_like of strings*) – filenames to load
- **strict_meta** (*boolean*) – check if metadata across filenames is the same
- **index_label** (*string*) – name of data to be used as DataFrame index
- **unix_time** (*boolean*) – True if index_label refers to UNIX time

pysat.utils.**season_date_range**(*start*, *stop*, *freq='D'*)

Return array of datetime objects using input frequency from start to stop

Supports single datetime object or list, tuple, ndarray of start and stop dates.

freq codes correspond to pandas date_range codes, D daily, M monthly, S secondly

pysat.utils.**set_data_dir**(*path=None*)

set the top level directory pysat uses to look for data.

p

Symbols

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