
SpacePy Documentation

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The SpacePy Team

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SpacePy is a package for Python, targeted at the space sciences, that aims to make basic data analysis, modeling and visualization easier. It builds on the capabilities of the well-known NumPy and Matplotlib packages. Publication quality output direct from analyses is emphasized among other goals:

- Quickly obtain data
- Create publications quality plots
- Perform complicated analysis easily
- Run common empirical models
- Change coordinates effortlessly
- Harness the power of Python

The SpacePy project seeks to promote accurate and open research standards by providing an open environment for code development. In the space physics community there has long been a significant reliance on proprietary languages that restrict free transfer of data and reproducibility of results. By providing a comprehensive, open-source library of widely-used analysis and visualization tools in a free, modern and intuitive language, we hope that this reliance will be diminished.

When publishing research which used SpacePy, please provide appropriate credit to the SpacePy team via citation or acknowledgment.

To cite SpacePy in publications, use (BibTeX code): @INPROCEEDINGS{spacepy11, author = {{Morley}, S.~K. and {Koller}, J. and {Welling}, D.~T. and {Larsen}, B.~A. and {Henderson}, M.~G. and {Niehof}, J.~T.}, title = “{Spacepy - A Python-based library of tools for the space sciences}”, booktitle = “{Proceedings of the 9th Python in science conference (SciPy 2010)}”, year = 2011, address = {Austin, TX} }

Certain modules may provide additional citations in the `__citation__` attribute. Contact a module’s author (details in the `__citation__` attribute) before publication or public presentation of analysis performed by that module, or in case of questions about the module. This allows the author to validate the analysis and receive appropriate credit for his or her work.

SPACEPY DOCUMENTS

1.1 Installing SpacePy

SpacePy uses the standard Python distutils to compile and install. For detailed, platform-specific installation instructions, see:

1.1.1 Linux Installation

Dependencies

To ensure that you have all dependencies for SpacePy satisfied, there are two approaches. The first is to download a single software suite that installs a comprehensive set of Python libraries; the second is to install the core dependencies yourself.

The Easy Way

Either the [Enthought Python Distribution \(EPD\)](#) or the [Python\(x,y\) distribution](#) will provide Python, numpy, scipy, matplotlib and a host of other useful 3rd-party libraries. In both cases you will still need to install [ffnet](#) and [CDF](#) by hand.

If you are installing by hand, follow the instructions for your linux distribution below.

Debian and Ubuntu

The following command will install most of the dependencies. It has been checked for Ubuntu 11.10 and Debian 7.0 “wheezy”:

```
sudo apt-get install python-dev python-numpy build-essential \  
python-scipy python-matplotlib python-networkx python-h5py \  
python-f2py gfortran ncurses-dev
```

You can also, of course, install the same packages via synaptic or other package manager of your choice.

Since no packages are available for them, install [CDF](#) and [ffnet](#) by hand.

Other distributions

For other distributions, check dependencies and install by hand or via your package manager. Once you figure it out, please contact the SpacePy team so we can update this documentation.

CDF

Download the latest [CDF library](#). Choose the file ending in `-dist-all.tar.gz` from the `linux` directory. Untar and `cd` into the resulting directory. Then build:

```
make OS=linux ENV=gnu CURSES=yes FORTRAN=no UCOPTIONS=-O2 SHARED=yes all
```

Use `CURSES=no` if the `curses` library is not installed. (The distribution-specific directions above will install `curses`.)

Install:

```
sudo make install
```

This will install the library into the default location `/usr/local/cdf`, where SpacePy can find it. If you choose to install elsewhere, see the CDF documentation, particularly the notes on the `CDF_BASE` and `CDF_LIB` environment variables. SpacePy uses these variables to find the library.

ffnet

Download the latest [ffnet module](#). Compilation requires `f2py` (from `numpy`), installed in the distribution-specific directions above. Untar and `cd` into the resulting directory. Then build:

```
python setup.py build
```

Either install just for one user:

```
python setup.py install --user
```

Or install for all users on the system:

```
sudo python setup.py install
```

Normally the correct Fortran compiler will be found; if compilation fails, try specifying the older GNU compiler at the build step:

```
python setup.py build --fcompiler=gnu
```

SpacePy

With the dependencies installed, SpacePy is ready to build and install. This uses the same basic setup as `ffnet` (standard Python distutils).

Build:

```
python setup.py build
```

If this fails, specify a Fortran compiler:

```
python setup.py build --fcompiler=gnu
```

(`python setup.py build --help-fcompiler` will list options for Fortran compilers.)

Install for one user:

```
python setup.py install --user
```

Or install for all users on the system:


```
sudo python setup.py install
```

1.1.2 MacOS Installation

Binary Installers

OSX install has become a challenge. With the Enthought transition to Canopy we cannot figure out clean install directions for 3rd party packages and therefore can no longer recommend using EPD for SpacePy.

Python

The Python that ships with OSX is not going to work. We recommend Python 2.7 from <http://www.python.org/download/>

Numpy

There is an OSX package at <http://sourceforge.net/projects/numpy/files/NumPy/1.7.1/>

Scipy

There is an OSX package at <http://sourceforge.net/projects/scipy/files/scipy/0.12.0/>

Matplotlib

There is an OSX package at <http://matplotlib.org/downloads.html>

CDF

If you wish to use CDF files, download and install the [NASA CDF library](#). The default installation directory is recommended to help SpacePy find the library. There is an OSX install package.

1. Get the package from ftp://cdaweb.gsfc.nasa.gov/pub/software/cdf/dist/cdf34_1/macosX/
2. Unzip and install

ffnet

```
easy_install --user ffnet
```

SpacePy

With the dependencies installed, SpacePy is ready to build and install. This uses the same basic setup as ffnet (standard Python distutils).

Build:

```
python setup.py build
```

If this fails, specify a FORTRAN compiler:

```
python setup.py build --fcompiler=gnu
```

(python setup.py build --help-fcompiler will list options for FORTRAN compilers.)

Install for one user:

```
python setup.py install --user
```

Or install for all users on the system:

```
sudo python setup.py install
```

Full MacPorts Install Instructions

These were current as of 13-May-2013, path especially go out of date quickly. We recommend installing this way for the best results.

Dependencies

1. Install xcode from the app store
2. Open xcode
3. Xcode -> preferences -> Downloads -> install command line tools
4. Install MacPorts (<http://www.macports.org/install.php>)
5. `sudo port -v selfupdate`
6. `sudo xcode-select -switch /Applications/Xcode.app`
7. `sudo port install python27`
8. `sudo port select -set python python27`
9. `sudo port install py27-ipython py27-scipy py27-numpy py27-matplotlib readline py27-h5py ipython-select`
10. `sudo port select -set ipython ipython27`
11. Download and install gfortran (<http://gcc.gnu.org/wiki/GFortranBinaries>)
12. Download spacepy source (or clone from git) (<http://spacepy.lanl.gov/download.shtml>)

INSTALL SPACEPY

1. `python setup.py install --user` (in the spacepy directory after unzip)

POST INSTALL TWEAKING

1. Create `.matplotlib/matplotlibrc`
2. Add: backend : MacOSX
3. Add: interactive : True

1.1.3 Windows Installation

Although the SpacePy team makes every effort to keep code portable, and has expended considerable effort on Windows specifically, Windows is not a primary development platform for any of the developers. There may be some limitations and/or bugs under Windows which are not present in OSX or Linux. Bug reports and patches are always welcome.

The Easy Way

Download the [Python\(x,y\) distribution](#). The standard plugins include most of the dependencies required for SpacePy. Like SpacePy, this currently only supports 32-bit code, but will run on 64-bit machines.

If you wish to use the `lanlstar` module, you will need `ffnet-0.7.1.win32-py2.7.exe`.

If you wish to use CDF files, download and install the [NASA CDF library](#). Again, the 32-bit installer is required, e.g. `CDF34_1_0-SETUP-32.EXE`. The default installation directory is recommended to help SpacePy find the library.

Finally, install SpacePy using the installer EXE. Be sure to choose the installer that matches your version of Python, either 2.6 or 2.7.

The Hard Way

Installing dependencies

This is a step-by-step guide to installing all of the spacepy dependencies individually. This is the easiest way to install all dependencies by hand; if you are comfortable downloading, compiling, and installing Python modules yourself, that will also work.

Download and install the 32-bit [Python Windows installer](#). The 2.7 version is recommended since most dependencies are now built against 2.7.

The following filenames are given for Python 2.7 and were the latest as of this writing; download the appropriate file for your version of Python and the latest version available of the required package.

Download and install `numpy-1.7.1-win32-superpack-python2.7.exe`.

Download and install `scipy-0.12.0-win32-superpack-python2.7.exe`.

Download and install `matplotlib-1.2.1.win32-py2.7.exe`.

Download and install `h5py-2.1.3.win32-py2.7.msi`.

Download and install `networkx-1.7_py27.exe`.

Download and install `ffnet-0.7.1.win32-py2.7.exe`.

If you wish to use CDF files, download and install the [NASA CDF library](#). Again, the 32-bit installer is required, e.g. `CDF34_1_0-SETUP-32.EXE`. The default installation directory is recommended to help SpacePy find the library.

At this point, you can install SpacePy from the installer EXE, or continue to build SpacePy from source.

Building and installing SpacePy

Edit your Windows path: Right-click my computer, choose properties, advanced, environment variables. Edit the path variable: append `;c:\python27;c:\python27\Scripts;c:\MinGW\bin` ([more information](#)).

Download the latest [mingwget](#). `mingw32` is the only C and Fortran compiler supported by SpacePy on Windows. Unzip into C:\MinGW. At a command prompt (Start, Run, cmd) type:

```
mingw-get install gcc g++ mingw32-make fortran
```

See also the [mingw docs](#)

Create a file `distutils.cfg` in `C:\Python27\Lib\distutils` (change appropriately for Python 2.6). It should contain:

```
[build]
compiler=mingw32
```

Unzip the SpacePy source documentation. Open a command prompt in the resulting directory and run:

```
python setup.py install
```

Developers

If you want to build the documentation yourself (rather than using the documentation shipped with SpacePy), install `sphinx` and `numpydoc`. The easiest way is via `pip`.

Download and run [distribute_setup.py](#).

Download and run [get-pip.py](#).

Then:

```
pip install sphinx numpydoc
```

For a list of dependencies, see [dependencies](#).

Following are generic instructions.

Option 1) to install it in a standard location (depending on your system):

```
python setup.py install
```

or:

```
sudo python setup.py install
```

or:

```
python setup.py install --user
```

If you do not have administrative privileges, or you will be developing for SpacePy, the latter is recommended.

Option 2) to install in custom location, e.g.:

```
python setup.py install --home=/n/packages/lib/python
```

It is also possible to select a specific compiler for installing the IRBEM-LIB library as part of SpacePy. Currently the following flags are supported: `gnu95`, `gnu`, `pg`. You can invoke these by using one of the following commands below but not all of them are supported on all platforms:

- `python setup.py install --fcompiler=pg` #(will use pgi compiler suite)
- `python setup.py install --fcompiler=gnu` #(will use g77)
- `python setup.py install --fcompiler=gnu95` #(default option for using gfortran)

SpacePy: Space Science Tools for Python

SpacePy is a package of tools primarily aimed at the space science community. This `__init__.py` file sets the parameters for import statements.

If running the ipython shell, simply type '?' after any command for help. ipython also offers tab completion, so hitting tab after '<module name>.' will list all available functions, classes and variables.

Detailed HTML documentation is available locally in the spacepy/doc directory and can be launched by typing: >>> spacepy.help()

Most functionality is in spacepy's submodules. Each module has specific help available:

```
coordinates data_assimilation datamodel empiricals irbempy LANLstar omni poppy pybats pycdf radbelt
seapy time toolbox
```

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1.2 SpacePy - A Quick Start Documentation

The SpacePy Team (Steve Morley, Josef Koller, Dan Welling, Brian Larsen, Jon Niehof, Mike Henderson)

1.2.1 Installation

See *Installing SpacePy*.

1.2.2 Toolbox - A Box Full of Tools

Contains tools that don't fit anywhere else but are, in general, quite useful. The following functions are a selection of those implemented:

- `toolbox.windowMean()`: windowing mean with variable window size and overlap
- `toolbox.dicttree()`: pretty prints the contents of dictionaries (recursively)
- `toolbox.loadpickle()`: single line convenience routine for loading Python pickles
- `toolbox.savepickle()`: same as loadpickle, but for saving
- `toolbox.update()`: updates the OMNI database and the leap seconds database (internet connection required)
- `toolbox.tOverlap()`: find interval of overlap between two time series
- `toolbox.tCommon()`: find times common to two time series
- `toolbox.binHisto()`: calculate number of bins for a histogram
- `toolbox.medAbsDev()`: find the median absolute deviation of a data series
- `toolbox.normalize()`: normalize a data series
- `toolbox.listUniq()`: returns the uniq items in a list (in order)
- `toolbox.leapyear()`: ultra fast leap year query function
- `toolbox.applySmartTimeTicks()`: smartens up the time ticks on a plot
- `toolbox.feq()`: floating point equals

Import this module as:

```
>>> import spacepy.toolbox as tb
```

Examples:

```
>>> import spacepy.toolbox as tb
>>> a = {'entry1':'vall', 'entry2':2, 'recurse1':{'one':1, 'two':2}}
>>> tb.dicttree(a)
+
|____entry1
|____entry2
|____recurse1
|         |____one
|         |____two
>>> import numpy as np
>>> dat = np.random.random_sample(100)
>>> tb.binHisto(dat)
(0.19151723370512266, 5.0)
```

1.2.3 Time and Coordinate Transformations

Import the modules as:

```
>>> import spacepy.time as spt
>>> import spacepy.coords as spc
```

Ticktock Class

The Ticktock class provides a number of time conversion routines and is implemented as a container class built on the functionality of the Python datetime module. The following time coordinates are provided

- UTC: Coordinated Universal Time implemented as a `datetime.datetime` class
- ISO: standard ISO 8601 format like `2002-10-25T14:33:59`
- TAI: International Atomic Time in units of seconds since Jan 1, 1958 (midnight) and includes leap seconds, i.e. every second has the same length
- JD: Julian Day
- MJD: Modified Julian Day
- UNIX: UNIX time in seconds since Jan 1, 1970
- RDT: Rata Die Time (Gregorian Ordinal Time) in days since Jan 1, 1 AD midnight
- CDF: CDF Epoch time in milliseconds since Jan 1, year 0
- DOY: Day of Year including fractions
- leaps: Leap seconds according to <ftp://maia.usno.navy.mil/ser7/tai-utc.dat>

To access these time coordinates, you'll create an instance of a Ticktock class, e.g.:

```
>>> t = spt.Ticktock('2002-10-25T12:30:00', 'ISO')
```

Instead of ISO you may use any of the formats listed above. You can also use numpy arrays or lists of time points. `t` has now the class attributes:

```
>>> t.dtype = 'ISO'
>>> t.data = '2002-10-25T12:30:00'
```

FYI `t.UTC` is added automatically.

If you want to convert/add a class attribute from the list above, simply type e.g.:

```
>>> t.RTD
```

You can replace RTD with any from the list above.

You can find out how many leap seconds were used by issuing the command:

```
>>> t.getleapsecs()
```

Tickdelta Class

You can add/subtract time from a Ticktock class instance by creating a Tickdelta instance first.:

```
>>> dt = spt.Tickdelta(days=2.3)
```

Then you can add by e.g.:

```
>>> t+dt
```

Coords Class

The spatial coordinate class includes the following coordinate systems in Cartesian and spherical forms.

- GZD: (altitude, latitude, longitude) in km, deg, deg
- GEO: cartesian, Re
- GSM: cartesian, Re
- GSE: cartesian, Re
- SM: cartesian, Re
- GEI: cartesian, Re
- MAG: cartesian, Re
- SPH: same as GEO but in spherical
- RLL: radial distance, latitude, longitude, Re, deg, deg.

Create a Coords instance with spherical='sph' or cartesian='car' coordinates:

```
>>> spaco = spc.Coords([[1,2,4],[1,2,2]], 'GEO', 'car')
```

This will let you request, for example, all y-coordinates by `spaco.y` or if given in spherical coordinates by `spaco.lati`. One can transform the coordinates by `newcoord = spaco.convert('GSM', 'sph')`. This will return GSM coordinates in a spherical system. Since GSM coordinates depend on time, you'll have to add first a Ticktock vector with the name `ticks` like `spaco.ticks = spt.Ticktock(['2002-02-02T12:00:00', '2002-02-02T12:00:00'], 'ISO')`

Unit conversion will be implemented in the future.

1.2.4 The radbelt Module

The radiation belt module currently includes a simple radial diffusion code as a class. Import the module and instantiate a radbelt object:

```
>>> import spacepy.radbelt as sprb
>>> rb = sprb.RBmodel()
```

Add a time grid for a particular period that you are interested in:

```
>>> rb.setup_ticks('2002-02-01T00:00:00', '2002-02-10T00:00:00', 0.25)
```

This will automatically lookup required geomagnetic/solar wind conditions for that period. Run the diffusion solver for that setup and plot the results:

```
>>> rb.evolve()
>>> rb.plot()
```

1.2.5 The Data Assimilation Module

This module includes data assimilation capabilities, through the assimilation class. The class assimilates data for the radiation belt model using the Ensemble Kalman Filter. The algorithm used is the SVD method presented by Evensen in 2003 (Evensen, G., Ocean dynamics, 53, pp.343–367, 2003). To compensate for model errors, three inflation algorithms are implemented. The inflation methodology is specified by the inflation argument, where the options are the following:

- inflation = 0: Add model error (perturbation for the ensemble) around model state values only where observations are available (DEFAULT).
- inflation = 1: Add model error (perturbation for the ensemble) around observation values only where observations are available.
- inflation = 2: Inflate around ensemble average for EnKF.

Prior to assimilation, a set of data values has to be specified by setting the start and end dates, and time step, using the `setup_ticks` function of the radiation belt model:

```
>>> import spacepy
>>> import datetime
>>> from spacepy import radbelt

>>> start = datetime.datetime(2002,10,23)
>>> end = datetime.datetime(2002,11,4)
>>> delta = datetime.timedelta(hours=0.5)
>>> rmod.setup_ticks(start, end, delta, dtype='UTC')
```

Once the dates and time step are specified, the data is added using the `add_PSD` function (NOTE: This requires a database available from the SpacePy team):

```
>>> rmod.add_PSD()
```

The observations are averaged over the time windows, whose interval is give by the time step. Once the dates and data are set, the assimilation is performed using the `assimilate` function:

```
>>> rmod.assimilate(inflation=1)
```

This function will add the PSDa values, which are the analysis state of the radiation belt using the observations within the dates. To plot the analysis simply use the `plot` function:

```
>>> rmod.plot(values=rmod.PSDa, clim=[-10,-6], Lmax=False, Kp=False, Dst=False)
```

Additionally, to create a summary plot of the observations use the `plot_obs` function within the `radbelt` module. For reference, the last closed drift shell, Dst, and Kp are all included. These can be disabled individually using the corresponding Boolean kwargs.

The `clims` kwarg can be used to manually set the color bar range. To use, set it equal to a two-element list containing minimum and maximum \log_{10} value to plot. Default action is to use [0,10] as the \log_{10} of the color range. This is

good enough for most applications. The title of the top most plot defaults to ‘Summary Plot’ but can be customized using the title kwarg.

The figure object and all three axis objects (PSD axis, Dst axis, and Kp axis) are all returned to allow the user to further customize the plots as necessary. If any of the plots are excluded, None is returned in their stead.

Example:

```
>>> rmod.plot_obs(clims=[-10,-6],Lmax=False,Kp=False,Dst=False,title='Observations Plot')
```

This command would create the summary plot with a color bar range of 10^{-10} to 10^{-6} . The Lmax line, Kp and Dst values would be excluded. The title of the topmost plot (phase space density) would be set to ‘Observations Plot’.

1.2.6 OMNI Module

The OMNI database is an hourly resolution, multi-source data set with coverage from November 1963; higher temporal resolution versions of the OMNI database exist, but with coverage from 1995. The primary data are near-Earth solar wind, magnetic field and plasma parameters. However, a number of modern magnetic field models require derived input parameters, and Qin and Denton (2007) have used the publicly-available OMNI database to provide a modified version of this database containing all parameters necessary for these magnetic field models. These data are available through ViRBO - the Virtual Radiation Belt Observatory.

In SpacePy this data is made available, at 1-hourly resolution, on request on first import; if not downloaded when SpacePy is first used then any attempt to import the omni module will ask the user whether they wish to download the data. Should the user require the latest data, the toolbox.update function can be used to fetch the latest files from ViRBO.

The following example fetches the OMNI data for the storms of October and November, 2003.:

```
>>> import spacepy.time as spt
>>> import spacepy.omni as om
>>> import datetime as dt
>>> st = dt.datetime(2003,10,20)
>>> en = dt.datetime(2003,12,5)
>>> delta = dt.timedelta(days=1)
>>> ticks = spt.tickrange(st, en, delta, 'UTC')
>>> data = om.get_omni(ticks)
```

data is a dictionary containing all the OMNI data, by variable, for the timestamps contained within the Ticktock object *ticks*. Now it is simple to plot Dst values for instance:

```
>>> import pyplot as p
>>> p.plot(ticks.eDOY, data['Dst'])
```

1.2.7 The irbempy Module

ONERA (Office National d’Etudes et Recherches Aerospatiales) initiated a well-known FORTRAN library that provides routines to compute magnetic coordinates for any location in the Earth’s magnetic field, to perform coordinate conversions, to compute magnetic field vectors in geospace for a number of external field models, and to propagate satellite orbits in time. Older versions of this library were called ONERA-DESP-LIB. Recently the library has changed its name to IRBEM-LIB and is maintained by a number of different institutions.

A number of key routines in IRBEM-LIB have been made available through the module *irbempy*. Current functionality includes calls to calculate the local magnetic field vectors at any point in geospace, calculation of the magnetic mirror point for a particle of a given pitch angle (the angle between a particle’s velocity vector and the magnetic field line that it immediately orbits such that a pitch angle of 90 degrees signifies gyration perpendicular to the local field) anywhere in geospace, and calculation of electron drift shells in the inner magnetosphere.:

```
>>> import spacepy.time as spt
>>> import spacepy.coordinates as spc
>>> import spacepy.irbempy as ib
>>> t = spt.Ticktock(['2002-02-02T12:00:00', '2002-02-02T12:10:00'], 'ISO')
>>> y = spc.Coords([[3,0,0],[2,0,0]], 'GEO', 'car')
>>> ib.get_Bfield(t,y)
>>> # {'Blocal': array([ 976.42565251, 3396.25991675]),
>>> #      'Bvec': array([[ -5.01738885e-01, -1.65104338e+02,  9.62365503e+02], [  3.33497974e+02,
```

One can also calculate the drift shell L^* for a 90 degree pitch angle value by using:

```
>>> ib.get_Lstar(t,y, [90])
>>> # {'Bmin': array([ 975.59122652, 3388.2476667 ]),
>>> #      'Bmirr': array([[ 976.42565251], [ 3396.25991675]]),
>>> #      'Lm': array([[ 3.13508015], [ 2.07013638]]),
>>> #      'Lstar': array([[ 2.86958324], [ 1.95259007]]),
>>> #      'MLT': array([ 11.97222034, 12.13378624]),
>>> #      'Xj': array([[ 0.00081949], [ 0.00270321]])}
```

Other function wrapped with the IRBEM library include:

- `find_Bmirror()`
- `find_magequator()`
- `coord_trans()`

1.2.8 pyCDF - Python Access to NASA CDF Library

pycdf provides a “pythonic” interface to the NASA CDF library. It requires that the NASA CDF C-library is properly installed. The module can then be imported, e.g.:

```
>>> import spacepy.pycdf as cdf
```

To open and close a CDF file, we use the `CDF` class:

```
>>> cdf_file = cdf.CDF('filename.cdf')
>>> cdf_file.close()
```

CDF files, like standard Python files, act as context managers:

```
>>> with cdf.CDF('filename.cdf') as cdf_file:
>>>     #do brilliant things with cdf_file
>>> #cdf_file is automatically closed here
```

CDF files act as Python dictionaries, holding CDF variables keyed by the variable name:

```
>>> var_names = keys(cdf_file) #list of all variables
>>> for var_name in cdf_file:
>>>     print(len(cdf_file[var_name])) #number of records in each variable
>>> #list comprehensions work, too
>>> lengths = [len(cdf_file[var_name]) for var_name in cdf_file]
```

Each CDF variable acts like a numpy array, where the first dimension is the record number. Multidimensional CDF variables can be subscripted using numpy’s multidimensional slice notation. Many common list operations are also implemented, where each record acts as one element of the list and can be independently deleted, inserted, etc. Creating a Python `Var` object does not read the data from disc; data are only read as they are accessed:

```
>>> epoch = cdf_file['Epoch'] #Python object created, nothing read from disc
>>> epoch[0] #time of first record in CDF (datetime object)
>>> a = epoch[...] #copy all times to list a
>>> a = epoch[-5:] #copy last five times to list a
>>> b_gse = cdf_file['B_GSE'] #B_GSE is a 1D, three-element array
>>> bz = b_gse[0,2] #Z component of first record
>>> bx = b_gse[:,0] #copy X component of all records to bx
>>> bx = cdf_file['B_GSE'][:,0] #same as above
```

1.2.9 The datamodel Module

The SpacePy datamodel module implements classes that are designed to make implementing a standard data model easy. The concepts are very similar to those used in standards like HDF5, netCDF and NASA CDF.

The basic container type is analogous to a folder (on a filesystem; HDF5 calls this a group): Here we implement this as a dictionary-like object, a `datamodel.SpaceData` object, which also carries attributes. These attributes can be considered to be global, i.e. relevant for the entire folder. The next container type is for storing data and is based on a numpy array, this class is `datamodel.darray` and also carries attributes. The `darray` class is analogous to an HDF5 dataset.

Guide for NASA CDF users

By definition, a NASA CDF only has a single ‘layer’. That is, a CDF contains a series of records (stored variables of various types) and a set of attributes that are either global or local in scope. Thus to use SpacePy’s datamodel to capture the functionality of CDF the two basic data types are all that is required, and the main constraint is that `datamodel.SpaceData` objects cannot be nested (more on this later, if conversion from a nested datamodel to a flat datamodel is required).

This is best illustrated with an example. Imagine representing some satellite data within a CDF – the global attributes might be the mission name and the instrument PI, the variables might be the instrument counts [n-dimensional array], timestamps [1-dimensional array] and an orbit number [scalar]. Each variable will have one attribute (for this example).

```
>>> import spacepy.datamodel as dm
>>> mydata = dm.SpaceData(attrs={'MissionName': 'BigSat1'})
>>> mydata['Counts'] = dm.darray([[42, 69, 77], [100, 200, 250]], attrs={'Units': 'cnts/s'})
>>> mydata['Epoch'] = dm.darray([1, 2, 3], attrs={'units': 'minutes'})
>>> mydata['OrbitNumber'] = dm.darray(16, attrs={'StartsFrom': 1})
>>> mydata.attrs['PI'] = 'Prof. Big Shot'
```

This has now populated a structure that can map directly to a NASA CDF. To visualize our datamodel, we can use the `datamodel.SpaceData.tree()` method, which is equivalent to `toolbox.dicttree()` (which works for any dictionary-like object, including PyCDF file objects).

```
>>> mydata.tree(attrs=True)
+
:|__MissionName
:|__PI
|__Counts
:|__Units
|__Epoch
:|__units
|__OrbitNumber
:|__StartsFrom
>>> import spacepy.toolbox as tb
>>> tb.dicttree(mydata, attrs=True)
+
```

```
:|____MissionName
:|____PI
|____Counts
    :|____Units
|____Epoch
    :|____units
|____OrbitNumber
    :|____StartsFrom
```

Attributes are denoted by a leading colon. The global attributes are those in the base level, and the local attributes are attached to each variable.

If we have data that has nested ‘folders’, allowed by HDF5 but not by NASA CDF, then how can this be represented such that the data structure can be mapped directly to a NASA CDF? The data will need to be flattened so that it is single layered. Let us now store some ephemerides in our data structure:

```
>>> mydata['Ephemeris'] = dm.SpaceData()
>>> mydata['Ephemeris']['GSM'] = dm.dndarray([[1,3,3], [1.2,4,2.5], [1.4,5,1.9]])
>>> tb.dicttree(mydata, attrs=True)
+
:|____MissionName
:|____PI
|____Counts
    :|____Units
|____Ephemeris
    |____GSM
|____Epoch
    :|____units
|____OrbitNumber
    :|____StartsFrom
```

Nested dictionary-like objects is not uncommon in Python (and can be exceptionally useful for representing data, so to make this compatible with NASA CDF we call the `datamodel.SpaceData.flatten()` method .

```
>>> mydata.flatten()
>>> tb.dicttree(mydata, attrs=True)
+
:|____MissionName
:|____PI
|____Counts
    :|____Units
|____Ephemeris<--GSM
|____Epoch
    :|____units
|____OrbitNumber
    :|____StartsFrom
```

Note that the nested `SpaceData` has been moved to a variable with a new name reflecting its origin. The data structure is now flat again and can be mapped directly to NASA CDF.

Converters to/from datamodel

Currently converters exist to read HDF5 and NASA CDF files directly to a SpacePy datamodel. This capability also exists for JSON-headed ASCII files (RBSP/AutoPlot-compatible). A converter from the datamodel to HDF5 is now available and a converter to NASA CDF is under development. Also under development is the reverse of the `SpaceData.flatten` method, so that flattened objects can be restored to their former glory.

1.2.10 Empiricals Module

The empiricals module provides access to some useful empirical models. As of SpacePy 0.1.2, the models available are:

- `empiricals.getLmax()` An empirical parametrization of the L^* of the last closed drift shell (Lmax)
- `empiricals.getPlasmaPause()` The plasmopause location, following either Carpenter and Anderson (1992) or Moldwin et al. (2002)
- `empiricals.getMPstandoff()` The magnetopause standoff location (i.e. the sub-solar point), using the Shue et al. (1997) model
- `empiricals.vampolaPA()` A conversion of omnidirectional electron flux to pitch-angle dependent flux, using the \sin^n model of Vampola (1996)

Each of the first three models is called by passing it a Ticktock object (see above) which then calculates the model output using the 1-hour Qin-Denton OMNI data (from the OMNI module; see above). For example:

```
>>> import spacepy.time as spt
>>> import spacepy.empiricals as emp
>>> ticks = spt.tickrange('2002-01-01T12:00:00', '2002-01-04T00:00:00', .25)
```

calls `time.tickrange()` and makes a Ticktock object with times from midday on January 1st 2002 to midnight January 4th 2002, incremented 6-hourly:

```
>>> Lpp = emp.getPlasmaPause(ticks)
```

then returns the model plasmopause location using the default setting of the Moldwin et al. (2002) model. The Carpenter and Anderson model can be used by setting the `Lpp_model` keyword to 'CA1992'.

The magnetopause standoff location can be called using this syntax, or can be called for specific solar wind parameters (ram pressure, P , and IMF B_z) passed through in a Python dictionary:

```
>>> data = {'P': [2,4], 'Bz': [-2.4, -2.4]}
>>> emp.getMPstandoff(data)
>>> # array([ 10.29156018,  8.96790412])
```

1.2.11 SeaPy - Superposed Epoch Analysis in Python

Superposed epoch analysis is a technique used to reveal consistent responses, relative to some repeatable phenomenon, in noisy data. Time series of the variables under investigation are extracted from a window around the epoch and all data at a given time relative to epoch forms the sample of events at that lag. The data at each time lag are then averaged so that fluctuations not consistent about the epoch cancel. In many superposed epoch analyses the mean of the data at each time u relative to epoch, is used to represent the central tendency. In SeaPy we calculate both the mean and the median, since the median is a more robust measure of central tendency and is less affected by departures from normality. SeaPy also calculates a measure of spread at each time relative to epoch when performing the superposed epoch analysis; the interquartile range is the default, but the median absolute deviation and bootstrapped confidence intervals of the median (or mean) are also available.

As an example we fetch OMNI data for 4 years and perform a superposed epoch analysis of the solar wind radial velocity, with a set of epoch times read from a text file:

```
>>> import datetime as dt
>>> import spacepy.seapy as sea
>>> import spacepy.omni as om
>>> import spacepy.toolbox as tb
>>> import spacepy.time as spt
>>> # now read the epochs for the analysis (the path specified is the default
```

```
>>> # install location on linux, different OS will have this elsewhere)
>>> epochs = sea.readepochs('~/.local/lib/python2.7/site-packages/spacepy/data/SEA_epochs_OMNI.txt')
```

The readepochs function can handle multiple formats by a user-specified format code. ISO 8601 format is directly supported though it is not used here. The the readepochs docstring for more information. As above, we use the get_omni function to retrieve the hourly data from the OMNI module:

```
>>> ticks = spt.tickrange(dt.datetime(2005,1,1), dt.datetime(2009,1,1), dt.timedelta(hours=1))
>>> omnilhr = om.get_omni(ticks)
>>> omnilhr.tree(levels=1, verbose=True)
```

```
•
|__ByIMF (spacepy.datamodel.darray (35065,)) |__Bz1 (spacepy.datamodel.darray (35065,))
|__Bz2 (spacepy.datamodel.darray (35065,)) |__Bz3 (spacepy.datamodel.darray (35065,))
|__Bz4 (spacepy.datamodel.darray (35065,)) |__Bz5 (spacepy.datamodel.darray (35065,))
|__Bz6 (spacepy.datamodel.darray (35065,)) |__BzIMF (spacepy.datamodel.darray (35065,))
|__DOY (spacepy.datamodel.darray (35065,)) |__Dst (spacepy.datamodel.darray (35065,))
|__G (spacepy.datamodel.darray (35065, 3)) |__Hr (spacepy.datamodel.darray (35065,)) |__Kp
(spacepy.datamodel.darray (35065,)) |__Pdyn (spacepy.datamodel.darray (35065,)) |__Qbits
(spacepy.datamodel.SpaceData [7]) |__RDT (spacepy.datamodel.darray (35065,)) |__UTC
(spacepy.datamodel.darray (35065,)) |__W (spacepy.datamodel.darray (35065, 6)) |__Year
(spacepy.datamodel.darray (35065,)) |__akp3 (spacepy.datamodel.darray (35065,)) |__dens
(spacepy.datamodel.darray (35065,))
```

and these data are used for the superposed epoch analysis. the temporal resolution is 1 hr and the window is +/- 3 days

```
>>> delta = dt.timedelta(hours=1)
>>> window= dt.timedelta(days=3)
>>> sevx = sea.Sea(omnilhr['velo'], omnilhr['UTC'], epochs, window, delta)
#rather than quartiles, we calculate the 95% confidence interval on the median
>>> sevx.sea(ci=True)
>>> sevx.plot()
```

1.3 Documentation Standard

SpacePy aims to be a high quality product, and as such we (the SpacePy Team) encourage a a high degree of uniformity in the documentation across included modules. If you are contributing to SpacePy, or hope to, please take the time to make your code compliant with the documentation standard.

SpacePy uses [Sphinx](#) to generate its documentation. This allows most of the documentation to be built from docstrings in the code, with additional information being provided in reStructured Text files. This allows easy generation of high-quality, searchable HTML documentation.

In addition to Sphinx, SpacePy uses the following extensions:

- 'sphinx.ext.autodoc'
- 'sphinx.ext.doctest'
- 'sphinx.ext.intersphinx'
- 'sphinx.ext.todo'
- 'sphinx.ext.pngmath'
- 'sphinx.ext.ifconfig'
- 'sphinx.ext.viewcode'

- ‘numpydoc’
- ‘sphinx.ext.inheritance_diagram’
- ‘sphinx.ext.autosummary’
- ‘sphinx.ext.extlinks’

1.3.1 So what do I need to do in my code?

Since we are using the ‘numpydoc’ extension there are fixed headings that may appear in your documentation block. There are a few things to note: * No other headings can appear in your docstrings * Most reStructuredText commands cannot appear in your docstrings either (e.g. .. Note:) * Since ‘numpydoc’ is not well documented, the best way of finding out what you can do in your docstrings is to look at the source for the SpacePy documentation or the numpy documentation.

Allowed headings

Always use

- Parameters
- Returns

Use as needed

- Attributes
- Raises
- Warns
- Other Parameters
- See Also
- Notes
- Warnings
- References
- Examples
- Methods

No need to use

- Summary
- Extended Summary
- index

Do not use

- Signature

Examples

- Use them, but they must be fully stand alone; the user should be able to type the exact code in the example and it should work as shown (doctest can help with this)

1.3.2 Function Example

This code from toolbox shows what a function should look like in your code

```
def logspace(min, max, num, **kwargs):
    """
    Returns log spaced bins. Same as numpy logspace except the min and max are the ,min and max
    not log10(min) and log10(max)

    Parameters
    =====
    min : float
        minimum value
    max : float
        maximum value
    num : integer
        number of log spaced bins

    Other Parameters
    =====
    kwargs : dict
        additional keywords passed into matplotlib.dates.num2date

    Returns
    =====
    out : array
        log spaced bins from min to max in a numpy array

    Notes
    =====
    This function works on both numbers and datetime objects

    Examples
    =====
    >>> import spacepy.toolbox as tb
    >>> tb.logspace(1, 100, 5)
    array([ 1.          ,  3.16227766, 10.          , 31.6227766 , 100.          ])
    """
    from numpy import logspace, log10
    if isinstance(min, datetime.datetime):
        from matplotlib.dates import date2num, num2date
        return num2date(logspace(log10(date2num(min)), log10(date2num(max)), num, **kwargs))
    else:
        return logspace(log10(min), log10(max), num, **kwargs)
```

Which then renders as:

```
spacepy.toolbox.logspace (min, max, num, **kwargs)
    Returns log-spaced bins. Same as numpy.logspace except the min and max are the min and max not
    log10(min) and log10(max)

    Parameters min : float
        minimum value
    max : float
        maximum value
    num : integer
```


number of log spaced bins

Returns out : array

log-spaced bins from min to max in a numpy array

Other Parameters kwargs : dict

additional keywords passed into matplotlib.dates.num2date

See also:

`geospace`, `linspace`

Notes

This function works on both numbers and datetime objects

Examples

```
>>> import spacepy.toolbox as tb
>>> tb.logspace(1, 100, 5)
array([ 1.          ,  3.16227766, 10.         , 31.6227766 , 100.         ])
```

1.4 SpacePy Python Programming Tips

One often hears that interpreted languages are too slow for whatever task someone needs to do. In many cases this belief is unfounded. As the time spent programming and debugging in an interpreted language is of far less than for a compiled language, the programmer has more time to identify bottlenecks in the code and optimize it where necessary. This page is dedicated to that idea, providing examples of code speedup and best practices.

One often neglected way to speed up development time is to use established libraries, and the time spent finding existing code that does what you want can be more productive than trying to write and optimize your own algorithms. We recommend exploring the SpacePy documentation, as well as taking the time to learn some of the vast functionality already in `numpy` and the Python standard library.

- [Basic examples](#)
- [Lists, for loops, and arrays](#)
- [Zip](#)
- [External links](#)

1.4.1 Basic examples

Though there are some similarities, Python does not look like (or work like) Matlab or IDL. As (most of us) are, or have been, Matlab or IDL programmers, we have to rethink how we do things – what is efficient in one language may not be the most efficient in another. One truth that Python shares with these other languages, however, is that if you are using a for loop there is likely to be a faster way...

Take the simple case of a large data array where you want to add one to each element. Here we show four of the possible ways to do this, and by using a profiling tool, we can show that the speeds of the different methods can vary substantially.

Create the data

```
>>> data = range(10000000)
```

The most C-like way is just a straight up for loop

```
>>> for i in range(len(data)):
>>>     data[i] += 1
```

This is 6 function calls in 2.590 CPU seconds (from `cProfile`)

The next, more Pythonic, way is with a list comprehension

```
>>> data = [val+1 for val in data]
```

This is 4 function calls in 1.643 CPU seconds (~1.6x)

Next we introduce `numpy` and change our list to an array then add one

```
>>> data = np.asarray(data)
>>> data += 1
```

This is 6 function calls in 1.959 CPU seconds (~1.3x), better than the for loop but worse than the list comprehension

Next we do this the *right* way and just create it in `numpy` and never leave

```
>>> data = np.arange(10000000)
>>> data += 1
```

this is 4 function calls in 0.049 CPU seconds (~53x).

While this is a really simple example it shows the basic premise, if you need to work with `numpy`, start in `numpy` and stay in `numpy`. This will usually be true for array-based manipulations.

If in doubt, and speed is not a major consideration, use the most human-readable form. This will make your code more maintainable and encourage its use by others.

1.4.2 Lists, for loops, and arrays

This example teaches the lesson that most advanced `IDL` or `Matlab` programmers already know; do everything in arrays and never use a for loop if there is another choice. The language has optimized array manipulation and it is unlikely that you will find a faster way with your own code.

The following bit of code takes in a series of coordinates, computes their displacement, and drops the largest 100 of them.

This is how the code started out, `Shell_x0_y0_z0` is an Nx3 numpy array, `ShellCenter` is a 3 element list or array, and `Num_Pts_Removed` is the number of points to drop:

```
import numpy as np
def SortRemove_HighFluxPts_(Shell_x0_y0_z0, ShellCenter, Num_Pts_Removed):
    #Sort the Shell Points based on radial distance (Flux prop to 1/R^2) and remove Num_Pts_Removed
    Num_Pts_Removed = np.abs(Num_Pts_Removed) #make sure the number is positive
    #Generate an array of radial distances of points from origin
    R = []
    for xyz in Shell_x0_y0_z0:
        R.append(1/np.linalg.norm(xyz + ShellCenter)) #Flux prop to 1/r^2, but don't need the ^2
    R = np.asarray(R)
    ARG = np.argsort(R) # array of sorted indices based on flux in 1st column
    Shell_x0_y0_z0 = np.take(Shell_x0_y0_z0, ARG, axis = 0) # sort based on index order
    return Shell_x0_y0_z0[:-Num_Pts_Removed,:] #remove last points that have the "anomalously" high
```

A cProfile of this yields a lot of time spent just in the function itself; this is the for loop (list comprehension is a little faster but not much in this case):

Tue Jun 14 10:10:56 2011 SortRemove_HighFluxPts_.prof

700009 function calls in 4.209 seconds

Ordered by: cumulative time

List reduced from 14 to 10 due to restriction <10>

ncalls	tottime	percall	cumtime	percall	filename:lineno(function)
1	0.002	0.002	4.209	4.209	<string>:1(<module>)
1	2.638	2.638	4.207	4.207	test1.py:235(SortRemove_HighFluxPts_)
100000	0.952	0.000	1.529	0.000	/opt/local/Library/Frameworks/Python.framework/Versions
100001	0.099	0.000	0.240	0.000	/opt/local/Library/Frameworks/Python.framework/Versions
100000	0.229	0.000	0.229	0.000	{method 'reduce' of 'numpy.ufunc' objects}
100001	0.141	0.000	0.141	0.000	{numpy.core.multiarray.array}
100000	0.082	0.000	0.082	0.000	{method 'ravel' of 'numpy.ndarray' objects}
100000	0.042	0.000	0.042	0.000	{method 'conj' of 'numpy.ndarray' objects}
100000	0.016	0.000	0.016	0.000	{method 'append' of 'list' objects}
1	0.000	0.000	0.005	0.005	/opt/local/Library/Frameworks/Python.framework/Versions

Simply moving the addition outside the for-loop gives a factor of 2.3 speedup. We believe that the difference arising from moving the addition lets numpy (which works primarily in C) operate once only. This massively reduces the calling overhead as array operations are done as for loops in C, and not in element-wise in python:

```
def SortRemove_HighFluxPts_(Shell_x0_y0_z0, ShellCenter, Num_Pts_Removed):
    #Sort the Shell Points based on radial distance (Flux prop to 1/R^2) and remove Num_Pts_Removed p
    Num_Pts_Removed = np.abs(Num_Pts_Removed) #make sure the number is positive
    #Generate an array of radial distances of points from origin
    R = []
    Shell_xyz = Shell_x0_y0_z0 + ShellCenter
    for xyz in Shell_xyz:
        R.append(1/np.linalg.norm(xyz)) #Flux prop to 1/r^2, but don't need the ^2
    R = np.asarray(R)
    ARG = np.argsort(R) # array of sorted indices based on flux in 1st column
    Shell_x0_y0_z0 = np.take(Shell_x0_y0_z0, ARG, axis = 0) # sort based on index order
    return Shell_x0_y0_z0[:-Num_Pts_Removed,:] #remove last points that have the "anomalously" high
```

A quick profile:

Tue Jun 14 10:18:39 2011 SortRemove_HighFluxPts_.prof

700009 function calls in 1.802 seconds

Ordered by: cumulative time

List reduced from 14 to 10 due to restriction <10>

ncalls	tottime	percall	cumtime	percall	filename:lineno(function)
1	0.001	0.001	1.802	1.802	<string>:1(<module>)
1	0.402	0.402	1.801	1.801	test1.py:235(SortRemove_HighFluxPts_)
100000	0.862	0.000	1.361	0.000	/opt/local/Library/Frameworks/Python.framework/Versions
100000	0.207	0.000	0.207	0.000	{method 'reduce' of 'numpy.ufunc' objects}
100001	0.080	0.000	0.199	0.000	/opt/local/Library/Frameworks/Python.framework/Versions
100001	0.120	0.000	0.120	0.000	{numpy.core.multiarray.array}
100000	0.067	0.000	0.067	0.000	{method 'ravel' of 'numpy.ndarray' objects}
100000	0.041	0.000	0.041	0.000	{method 'conj' of 'numpy.ndarray' objects}
100000	0.014	0.000	0.014	0.000	{method 'append' of 'list' objects}
1	0.000	0.000	0.005	0.005	/opt/local/Library/Frameworks/Python.framework/Versions

A closer look here reveals that all of this can be done on the arrays without the for loop (or list comprehension):

```
def SortRemove_HighFluxPts_(Shell_x0_y0_z0, ShellCenter, Num_Pts_Removed):
    #Sort the Shell Points based on radial distance (Flux prop to 1/R^2) and remove # points with the
    Num_Pts_Removed = np.abs(Num_Pts_Removed) #make sure the number is positive
    #Generate an array of radial distances of points from origin
    R = 1 / np.sum((Shell_x0_y0_z0 + ShellCenter) ** 2, 1)
    ARG = np.argsort(R) # array of sorted indices based on flux in 1st column
    Shell_x0_y0_z0 = np.take(Shell_x0_y0_z0, ARG, axis = 0) # sort based on index order
    return Shell_x0_y0_z0[:-Num_Pts_Removed,:] #remove last points that have the "anomalously" high
```

The answer is exactly the same and comparing to the initial version of this code we have managed a speedup of 382x:

```
Tue Jun 14 10:21:54 2011      SortRemove_HighFluxPts_.prof
```

```
10 function calls in 0.011 seconds
```

```
Ordered by: cumulative time
```

ncalls	totttime	percall	cumtime	percall	filename:lineno(function)
1	0.000	0.000	0.011	0.011	<string>:1(<module>)
1	0.002	0.002	0.011	0.011	test1.py:236(SortRemove_HighFluxPts_)
1	0.000	0.000	0.004	0.004	/opt/local/Library/Frameworks/Python.framework/Versions
1	0.004	0.004	0.004	0.004	{method 'argsort' of 'numpy.ndarray' objects}
1	0.000	0.000	0.003	0.003	/opt/local/Library/Frameworks/Python.framework/Versions
1	0.003	0.003	0.003	0.003	{method 'take' of 'numpy.ndarray' objects}
1	0.000	0.000	0.002	0.002	/opt/local/Library/Frameworks/Python.framework/Versions
1	0.002	0.002	0.002	0.002	{method 'sum' of 'numpy.ndarray' objects}
1	0.000	0.000	0.000	0.000	{isinstance}
1	0.000	0.000	0.000	0.000	{method 'disable' of '_lsprof.Profiler' objects}

In summary, when working on arrays it's worth taking the time to think about whether you can get the results you need without for-loops or list comprehensions. The small amount of development time will likely be recouped very quickly.

1.4.3 Zip

The `zip()` function is extremely useful, but it is really slow. If you find yourself using it on large amounts of data then significant time-savings might be achieved by re-writing your code to make the `zip()` operation unnecessary. A good alternative, if you do need the functionality of `zip()`, is in `itertools.izip()`. This is far more efficient as it builds an iterator.

This example generates N points, evenly distributed on the unit sphere centered at (0,0,0) using the “Golden Spiral” method.

The original code:

```
import numpy as np
def PointsOnSphere(N):
    # Generate evenly distributed N points on the unit sphere centered at (0,0,0)
    # Uses "Golden Spiral" method
    x0 = np.array((N,), dtype= float)
    y0 = np.array((N,), dtype= float)
    z0 = np.array((N,), dtype= float)
    phi = (1 + np.sqrt(5)) / 2. # the golden ratio
    long_incr = 2.0*np.pi / phi # how much to increment the longitude
    dz = 2.0 / float(N) # a unit sphere has diameter 2
    bands = np.arange(0, N, 1) # each band will have one point placed on it
```

```

z0 = bands * dz - 1 + (dz/2) # the z location of each band/point
r = np.sqrt(1 - z0*z0)      # the radius can be directly determined from height
az = bands * long_incr # the azimuth where to place the point
x0 = r * np.cos(az)
y0 = r * np.sin(az)
x0_y0_z0 = np.array(zip(x0,y0,z0))      #combine into 3 column (x,y,z) file
return (x0_y0_z0)

```

Profiling this with `cProfile` shows that a lot of time is spent in `zip()`:

Tue Jun 14 09:54:41 2011 PointsOnSphere.prof

9 function calls in 8.132 seconds

Ordered by: cumulative time

ncalls	totttime	percall	cumtime	percall	filename:lineno(function)
1	0.010	0.010	8.132	8.132	<string>:1(<module>)
1	0.470	0.470	8.122	8.122	test1.py:192(PointsOnSphere)
4	6.993	1.748	6.993	1.748	{numpy.core.multiarray.array}
1	0.654	0.654	0.654	0.654	{zip}
1	0.005	0.005	0.005	0.005	{numpy.core.multiarray.arange}
1	0.000	0.000	0.000	0.000	{method 'disable' of '_lsprof.Profiler' objects}

So lets try and do a few simple rewrites to make this faster. Using `numpy.vstack` is the first one that came to mind. The change here is to replace building up the array from the elements made by `zip()` to just concatenating the arrays we already have:

```

def PointsOnSphere(N):
    # Generate evenly distributed N points on the unit sphere centered at (0,0,0)
    # Uses "Golden Spiral" method
    x0 = np.array((N,), dtype= float)
    y0 = np.array((N,), dtype= float)
    z0 = np.array((N,), dtype= float)
    phi = (1 + np.sqrt(5)) / 2. # the golden ratio
    long_incr = 2.0*np.pi / phi # how much to increment the longitude
    dz = 2.0 / float(N)      # a unit sphere has diameter 2
    bands = np.arange(0, N, 1) # each band will have one point placed on it
    z0 = bands * dz - 1 + (dz/2) # the z location of each band/point
    r = np.sqrt(1 - z0*z0)      # the radius can be directly determined from height
    az = bands * long_incr # the azimuth where to place the point
    x0 = r * np.cos(az)
    y0 = r * np.sin(az)
    x0_y0_z0 = np.vstack((x0, y0, z0)).transpose()
    return (x0_y0_z0)

```

Profiling this with `cProfile` one can see that this is now fast enough for me, no more work to do. We picked up a 48x speed increase, I'm sure this can still be made better and let the SpacePy team know if you rewrite it and it will be included:

Tue Jun 14 09:57:41 2011 PointsOnSphere.prof

32 function calls in 0.168 seconds

Ordered by: cumulative time

List reduced from 13 to 10 due to restriction <10>

ncalls	totttime	percall	cumtime	percall	filename:lineno(function)
1	0.010	0.010	0.168	0.168	<string>:1(<module>)

```
1      0.123      0.123      0.159      0.159 test1.py:217 (PointsOnSphere)
1      0.000      0.000      0.034      0.034 /opt/local/Library/Frameworks/Python.framework/Versions
1      0.034      0.034      0.034      0.034 {numpy.core.multiarray.concatenate}
1      0.002      0.002      0.002      0.002 {numpy.core.multiarray.arange}
1      0.000      0.000      0.000      0.000 {map}
3      0.000      0.000      0.000      0.000 /opt/local/Library/Frameworks/Python.framework/Versions
6      0.000      0.000      0.000      0.000 {numpy.core.multiarray.array}
3      0.000      0.000      0.000      0.000 /opt/local/Library/Frameworks/Python.framework/Versions
1      0.000      0.000      0.000      0.000 {method 'transpose' of 'numpy.ndarray' objects}
```

1.4.4 External links

To learn about NumPy from a MatLab user's perspective

- [NumPy for MatLab users](#)
- [Mathesaurus](#)

And if you're coming from an IDL, or R, background

- [Mathesaurus](#)

Here is a collection of links that serve as a decent reference for Python and speed

- [PythonSpeed PerformanceTips](#)
- [scipy array tip sheet](#)
- [Python Tips, Tricks, and Hacks](#)

Release 0.1.5

Doc generation date December 23, 2014

For additions or fixes to this page contact the SpacePy team at Los Alamos.

1.5 SpacePy Configuration

SpacePy has a few tunable options that can be altered through the `spacepy.rc` configuration file. All options have defaults which will be used if not specified in the configuration file. These defaults are usually fine for most people and may change between SpacePy releases, so we do not recommend changing the configuration file without substantial reason.

`spacepy.rc` lives in the per-user SpacePy directory, called `.spacepy`. On Unix-like operating systems, it is in a user's home directory; on Windows, in the user's Documents and Settings folder. If it doesn't exist, this directory (and `spacepy.rc`) is automatically created when SpacePy is imported.

`spacepy.rc` has an INI-style format, parsed by `ConfigParser`. It contains a single section, `[spacepy]`.

- [The spacepy directory](#)
- [Available configuration options](#)
- [Developer documentation](#)

1.5.1 The spacepy directory

When first imported, spacepy will create a `.spacepy` directory in your `$HOME` folder. If you prefer a different location for this directory, set the environment variable `$SPACEPY` to a location of your choice. For example, with a `csh`, or `tcsh` you would:

```
setenv SPACEPY /a/different/dir
```

for the `bash` shell you would:

```
export SPACEPY=/a/different/dir
```

If you change the default location, make sure you add the environment variable `$SPACEPY` to your `.cshrc`, `.tcshrc`, or `.bashrc` script.

1.5.2 Available configuration options

enable_deprecation_warning SpacePy raises `DeprecationWarning` when deprecated functions are called. Starting in Python 2.7, these are ignored. SpacePy adds a warnings filter to force display of deprecation warnings from SpacePy the first time a deprecated function is called. Set this option to `False` to retain the default Python behavior. (See `warnings` module for details on custom warning filters.)

leapsec_url URL of the leapsecond database used by time conversions. `update()` will download from the URL. The default should almost always be acceptable.

ncpus Number of CPUs to use for computations that can be multithreaded/multiprocessed. By default, they will use the number of CPUs reported by `multiprocessing.cpu_count()`. You may wish to set this to a lower number if you need to reserve other processors on your machine.

notice True to display the SpacePy license and other information on import (default); False to omit.

omni2_url URL containing the OMNI2 data. `update()` will download from the URL. The default should almost always be acceptable.

qindenton_url URL containing Qin-Denton packaging of OMNI data. `update()` will download from the URL. The default should almost always be acceptable.

psddata_url URL containing PSD data. `update()` will download from the URL if requested. The default should almost always be acceptable.

user_agent User Agent for network access. If this is set, `update()` will use this User Agent string on all HTTP requests. Normally leaving this unset should be fine.

1.5.3 Developer documentation

`spacepy.rc` is loaded into a dictionary (`spacepy.config`) by SpacePy's main `__init__.py`. All options from the `[spacepy]` section are loaded, with no developer intervention needed. Each key is the option's name; the associated value is the option's value. To specify a default, add to the `defaults` dictionary at the top of `_read_config`; each default, if not overridden by the config file, will be included in the config dict. Values are assumed to be strings. The `caster` dictionary is keyed by option name; the value for each key is a function to be applied to the value with the same key to produce a different type from a string.

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For additions or fixes to this page, contact the SpacePy Team at Los Alamos.

1.6 SpacePy Case Studies

The SpacePy team has prepared case studies showing how to reproduce the results from published papers using Python-based tools, including SpacePy. It is hoped that these extensively-documented examples will ease the transition to Python for space scientists.

Basic familiarity with programming and general computing tasks in your chosen environment is assumed, including editing text files, copying and deleting files, etc. No Python-specific knowledge is assumed, although it is recommended to at least skim the excellent [Python tutorial](#).

1.6.1 Paulikas and Blake revisited (Reeves et al. 2011)

This case study reproduces the figures of Reeves et al. (2011), “On the relationship between relativistic electron flux and solar wind velocity: Paulikas and Blake revisited” ([doi:10.1029/2010JA015735](https://doi.org/10.1029/2010JA015735)).

Setup

Create a directory to hold files for this case study. Within this directory, create subdirectories `code`, `data`, and `plots`. (Using version control on the code directory is recommended; the SpacePy team uses [git](#).)

Obtaining energetic particle data

We require the 1.8-3.5 MeV electron flux from the LANL-GEO ESP detector, available in the paper’s [auxiliary material](#). The ESP data are in Data Set S1. Save this file to the `data` directory; the filename is assumed to be `2010ja015735-ds01.txt`.

The data file was corrupted on upload to AGU, and the code to fix it is non-trivial, so this is a good chance to learn how to run someone else’s code. ([Appendix: Fixing the ESP data file](#) has step-by-step information on each portion of this process.) Copy all of the following and paste it into a file called `fix_esp_data.py` in the `code` directory.

```
import os.path

datadir = os.path.join('.', 'data')
in_name = os.path.join(datadir, '2010ja015735-ds01.txt')
out_name = os.path.join(datadir, '2010ja015735-ds01_FIXED.txt')
infile = open(in_name, 'r')
outfile = open(out_name, 'w')
data = infile.read()
infile.close()

data = data.replace('\r', '\n')
data = data.replace('\n\n', '\n')
data = data.split('\n')

for i in range(15):
    outfile.write(data.pop(0) + '\n')
oldline = None
for line in data:
    if line[0:2] in ['19', '20', '2']:
        if not oldline is None:
            outfile.write(oldline + '\n')
            oldline = line
    else:
```



```

        oldline += line
outfile.write(oldline + '\n')
outfile.close()

```

Now this script can be run with `python fix_esp_data.py`. It should create a file called `2010ja015735-ds01_FIXED.txt` in the data directory.

File fixed, we can load and begin examining the data. Change to the `code` directory and start your Python interpreter. (IPython is recommended, but not required.)

In the following examples, do not type the leading `>>>`; this is the Python interpreter prompt. IPython has a different prompt that looks like `In [1]`.

```

>>> import os.path
>>> datadir = os.path.join '..', 'data'
>>> print(datadir)
../data

```

The first line imports the `os.path` module from the Python standard library. Python has a huge [standard library](#). To keep this code organized, it is divided into many modules, and a module must be imported before it can be used. (The [Python module of the week](#) is a great way to explore the standard library.)

The second line makes a variable, `datadir`, which will contain the path of the data directory. The `os.path.join()` function provides a portable way of “gluing” together directories in a path, and will use backslashes on Windows and forward slashes on Unix. The third line then prints out the value of this variable for confirmation; note this is a Unix system.

Note that string constants in Python can use single or double quotes; we could just as well have written:

```

>>> datadir = os.path.join("../", "data")

```

or even:

```

>>> datadir = os.path.join('..', "data")

```

The full path can also be used (and this is a better case for using a variable.) For example, I am preparing this example in a directory `reeves_morley_friedel_2011` in my home directory, so I could use:

```

>>> datadir = os.path.join('home', 'jniehof', 'reeves_morley_friedel_2011',
...                        'data')

```

This very long line can be typed across two lines in Python, and because the line break happens within parentheses, a line continuation character is not required.

Returning to reading the ESP data file:

```

>>> fname = os.path.join(datadir, '2010ja015735-ds01_FIXED.txt')

```

creates a variable holding the full path to the fixed file.

```

>>> import numpy

```

The import statement imports any installed [module](#), just as if it were in the standard library. Here we import the very useful `numpy` module, which is a prerequisite for SpacePy and useful in its own right.

```

>>> esp_fluxes = numpy.loadtxt(fname, skiprows=14, usecols=[1])

```

`loadtxt()` makes it easy to load data from a file into a numpy `ndarray`, a very useful data container. `skiprows` skips the header information, and specifying only column 1 (first column is column 0) with `usecols` will only load the fluxes for 1.8-3.5MeV. We only load the fluxes at this point because they can be represented as floats, which numpy arrays store very efficiently.

```
>>> import datetime
```

The `datetime` module provides Python objects which can manipulate dates and times and have some understanding of the meanings of dates, making for easy comparisons between dates, date arithmetic, and other useful features.

```
>>> convert = lambda x: datetime.datetime.strptime(x, '%Y-%m-%d')
```

This line sets up a converter to be used later. `strptime()` creates a `datetime` from a string, given a format definition (here specified as year-month-day). So:

```
>>> print(datetime.datetime.strptime('2010-01-02', '%Y-%m-%d'))
2010-01-02 00:00:00
```

`lambda` is a simple shortcut for a one-liner function; wherever `convert(x)` is used after the definition, it functions like `datetime.datetime.strptime(x, '%Y-%m-%d')`. This makes it easier to parse a date string without specifying the format all the time:

```
>>> print(convert('2010-01-02'))
```

This converter can be used with `loadtxt()`:

```
>>> esp_times = numpy.loadtxt(fname, skiprows=14, usecols=[0],
...                           converters={0: convert}, dtype=numpy.object)
```

The `converters` option takes a Python `dictionary`. The default `dtype` is `float`, which cannot store datetimes; using `numpy.object` allows storage of any Python object.

Since it would be useful to be able to load the data without typing so many lines, create a file called `common.py` in the `code` directory with the following contents:

```
import datetime
import os.path

import numpy

datadir = os.path.join '..', 'data'

def load_esp():
    fname = os.path.join(datadir, '2010ja015735-ds01_FIXED.txt')
    esp_fluxes = numpy.loadtxt(fname, skiprows=14, usecols=[1])
    convert = lambda x: datetime.datetime.strptime(x, '%Y-%m-%d')
    esp_times = numpy.loadtxt(fname, skiprows=14, usecols=[0],
                              converters={0: convert}, dtype=numpy.object)
    return (esp_times, esp_fluxes)
```

All needed imports are at the top of the file, with one blank line between standard library imports and other imports and two blank lines after them. `datadir` is defined as a global variable, outside of the function (but notice that it is available to the `load_esp` function.)

The rest of the file defines a `function` which returns the dates and fluxes in a `tuple`. The next section shows how to use this function.

Solar Wind data and averaging

The top panel of figure 1 shows the ESP fluxes overplotted with the solar wind velocity. Fortunately, the `omni` module of SpacePy provides an interface to the hourly solar wind dataset, OMNI. `get_omni()` returns data for a particular set of times. In this case, we want hourly data, covering 1989 through 2010 (we'll cut it down to size later. `tickrange()` allows us to specify a start time, stop time, and time step.

```
>>> import spacepy.omni
>>> import spacepy.time
>>> times = spacepy.time.tickrange('1989-01-01', '2011-01-01',
...                               datetime.timedelta(hours=1))
>>> d = spacepy.omni.get_omni(times)
>>> vsw = d['velo']
>>> vsw_times = d['UTC']
```

We'll also load the esp data:

```
>>> import common
>>> esp_times, esp_flux = common.load_esp()
```

Even though we have not installed `common.py`, the `import` statement finds it because it is in the current directory.

`load_esp` returns a `tuple`, which can be *unpacked* into separate variables.

Now we need to produce 27-day running averages of both the flux and the solar wind speed. Fortunately there are no gaps in the time series:

```
>>> import numpy
>>> d = numpy.diff(vsw_times)
>>> print(d.min())
1:00:00
>>> print(d.max())
1:00:00
>>> d = numpy.diff(esp_times)
>>> print(d.min())
1 day, 0:00:00
>>> print(d.max())
1 day, 0:00:00
```

`numpy.diff()` returns the difference between every element of an array and the previous element. `min()` and `max()` do exactly what they sound like. So this code confirms that every time in the vsw data is on a continuous one hour cadence, and the ESP data is on a continuous one day cadence.

```
>>> import scipy.stats
>>> esp_flux_av = numpy.empty(shape=esp_flux.shape, dtype=esp_flux.dtype)
>>> for i in range(len(esp_flux_av)):
...     esp_flux_av[i] = scipy.stats.nanmean(esp_flux[max(i - 13, 0):i + 14])
```

`numpy.empty()` creates an empty array, taking the shape and dtype from the `esp_flux` array. `empty` does not initialize the data in the array, so it is essentially random junk; use `zeros()` to create an array filled with zeros.

`len()` returns the length of an array, and `range()` then iterates over each number from 0 to length minus 1, i.e. the entire array. Each element is then set to a 27-day average: from 13 days before a day's measurement through 13 days after. (Python slices do not include the last element listed; they are half-open). Note that these slices can happily run off the end of the `esp_flux` array, but we use `max()` to ensure the first index does not go negative. (Negative indices have special meaning in Python.)

`nanmean()` takes the mean of a numpy array, but skips any elements with a value of “not a number” (nan), which is often used for fill. (This is our first exposure to the `scipy` module.)

The solar wind data covers from 1963, whereas the ESP data starts in 1989. Although for proper averaging we want to keep some solar wind data “off the end” of the ESP data, 35 years is a bit much. So let's cut out the solar wind data from before 1989:

```
>>> import bisect
>>> import datetime
>>> idx = bisect.bisect_left(vsw_times, datetime.datetime(1989, 1, 1))
```

```
>>> vsw_times = vsw_times[idx:]
>>> vsw = vsw[idx:]
```

`bisect` provides fast functions for searching in sorted data; `bisect_left()` is roughly a find-the-position-of function. Having found the position of the start of 1989, we then keep times from then on (specifying a start index without a stop index in Python means “from start to end of the list.”) Note that, although `bisect` is meant to work on lists, it works fine on numpy arrays; this is a common feature of Python known as [duck typing](#).

For the solar wind averaging, the times need to cover the $24 * 13.5 = 324$ hours previous, and 324 hours following (non-inclusive). There is also a more efficient way than using an explicit loop:

```
>>> vsw_av = numpy.fromiter((scipy.stats.nanmean(vsw[max(0, i - 324):i + 324])
...                          for i in range(len(vsw))),
...                          count=len(vsw), dtype=vsw.dtype)
```

`fromiter()` makes a numpy array from an [iterator](#), which is like a list except that it holds information on generating each element in a sequence rather than creating the entire sequence. `count` provides numpy with the number of elements in the output (so it can make the entire array at once); `dtype` here is just copied from the input.

The type of iterator used here is a [generator expression](#), closely related to a [list comprehension](#). These are among the most powerful and most difficult to understand concepts in Python. An illustrative, although not useful, example:

```
>>> for i in (x + 1 for x in range(10)):
...     print(i)
```

Here `(x + 1 for x in range(10))` is a generator expression that creates an iterator, which will return the numbers 1 through 10. At no point is the complete list of all numbers constructed, saving memory.

In our calculation of `esp_flux_av`, we created an explicit loop in Python. The generator expression used to compute `vsw_av` has no explicit loop, and the actual looping is handled in (much faster) compiled C code.

Making Figure 1

To actually plot, we need access to the `pyplot` module:

```
>>> import matplotlib.pyplot as plt
>>> plt.ion()
```

This alternate form of the import statement shouldn’t be overused (it can make code harder to read by masking the origin of functions), but is conventional for matplotlib.

`ion()` turns on interactive mode so plots appear and are updated as they’re created.

```
>>> plt.semilogy(esp_times, 10 ** esp_flux_av, 'b')
>>> plt.draw()
>>> plt.draw()
```

`semilogy()` creates a semilog plot, log on the Y axis. The first two arguments are a list of X and Y values; after that there are many options to specify formatting (such as the color, used here.)

The ESP fluxes are stored as the log of the flux; `**` is the exponentiation operator so the (geometric!) average is plotted properly.

`draw()` draws the updated plot; sometimes it needs to be called repeatedly. Use it whenever you want the plot updated; it will not be included from here on.

```
>>> plt.xlabel('Year', weight='bold')
>>> plt.ylabel('Electron Flux\n1.8-3.5 MeV', color='blue', weight='bold')
>>> plt.ylim(1e-2, 10)
(0.01, 10)
```

`xlabel()` and `ylabel()` set the labels for the axes. Note the newline (`\n`) in the string for the Y label. `ylim()` sets the lower and upper limits for the Y axis; there is, of course, `xlim()` as well.

These are the simplest, although not most flexible, ways to work with plots. To produce the full Figure 1, we'll move out of interactive mode:

```
>>> plt.ioff()
>>> plt.show()
```

`ioff()` turns off interactive mode. Once interactive mode is off, `show()` displays the full plot, including controls for panning, zooming, etc. Until the plot is closed, nothing further can happen in the Python window.

```
>>> fig = plt.figure(figsize=[11, 8.5])
```

`figure()` creates a new `Figure`; the size specified here is US-letter paper, landscape orientation.

```
>>> ax = fig.add_subplot(111)
```

`add_subplot()` creates an `Axes` object, which can contain an actual plot. 111 here means that the figure will have 1 subplot and the new subplot should be in position (1, 1); more on this later.

```
>>> fluxline = ax.plot(esp_times, 10 ** esp_flux_av, 'b')
```

`plot()` puts the relevant data into the plot; again specifying a blue line. It returns a list of `Line2D` objects, which we save for later use.

```
>>> ax.set_yscale('log')
```

`set_yscale()` switches the Y axis between log and linear (`set_xscale()` for the X axis).

```
>>> ax.set_ylim(1e-2, 10)
>>> ax.set_xlabel('Year', weight='bold')
>>> ax.set_ylabel('Electron Flux\n1.8-3.5 MeV', color='b', weight='bold')
```

`set_ylim()` (and `set_xlim()`), `set_xlabel()`, and `set_ylabel()` function much as above, but operate on a particular `Axes` object.

```
>>> ax2 = ax.twinx()
```

`twinx()` establishes a second Y axis (two values twinned on one X axis) on the same plot.

```
>>> vswline = ax2.plot(vsw_times, vsw_av, 'r')
>>> ax2.set_ylim(300, 650)
>>> ax2.set_ylabel('Solar Wind Speed', color='r', rotation=270, weight='bold')
```

The resulting `Axes` object has all the methods that we've used before. Note rotation on `set_ylabel()` to make the text run top-to-bottom rather than bottom-to-top.

```
>>> ax.set_xlim(esp_times[0], esp_times[-1])
```

Since the solar wind data extends beyond the ESP data, this sets the X axis to match the ESP data. Note `-1` to refer to the last element of the array.

```
>>> leg = ax.legend([fluxline[0], vswline[0]], ['Flux', 'Vsw'],
...                 loc='upper left', frameon=False)
```

`legend()`, as may be expected, creates a `Legend` on the axes. The first parameter is a list of the matplotlib objects to make a legend for; since the plotting commands return these, we can pass them back in. Each plotting command returns a *list*. In this case we just take the 0th element of each list since we know there's only one line from each plotting command. The second parameter is the text used to annotate each line.

```
>>> fluxtext, vswtext = leg.get_texts()
>>> fluxtext.set_color(fluxline[0].get_color())
>>> vswtext.set_color(vswline[0].get_color())
```

The default text color is black, so we use `get_texts()` to get the `Text` objects for the annotations. Again, we know there are two (we just created the legend). Then `set_color()` sets the color based on the the existing color for each line (`get_color()`).

To see the results:

```
>>> plt.show()
```

Close the window when done. Now we want to save the output:

```
>>> fig_fname = os.path.join('..', 'plots', 'fig1a.eps')
>>> fig.savefig(fig_fname)
```

`savefig()` saves the figure, in this case as an encapsulated PostScript file (to the `plots` directory).

Let's tweak a few things. For one, there's a lot of padding around the figure, which can make it difficult to properly scale for publication. The way around this is to specify a `Bbox` (bounding box), basically the lower left and upper right corners (in inches) to include in the saved figure. Getting this right tends to be a matter of trial and error. (`get_tightbbox()` is supposed to help with this, but it doesn't quite work yet.)

```
>>> import matplotlib.transforms
>>> bob = matplotlib.transforms.Bbox([[0.52, 0.35], [10.5, 7.95]])
>>> fig.savefig(fig_fname, bbox_inches=bob, pad_inches=0.0)
```

Better, but all the text is awfully small. Once the figure is fit in the paper it'll be really small. And the font isn't that great.

```
>>> import matplotlib
>>> matplotlib.rcParams['axes.unicode_minus'] = False
>>> matplotlib.rcParams['text.usetex'] = True
>>> matplotlib.rcParams['font.family'] = 'serif'
>>> matplotlib.rcParams['font.size'] = 14
>>> bob = matplotlib.transforms.Bbox([[0.4, 0.35], [10.7, 7.95]])
>>> fig.savefig(fig_fname, bbox_inches=bob, pad_inches=0.0)
```

Now the font is bigger and it's rendered using TeX, which should match the body of the paper better (assuming the paper is in LaTeX). The larger font means tweaking the bounding box. `unicode_minus` fixes a problem where negative numbers on the axis don't render properly in TeX. Matplotlib has many more options for [customization](#).

The end result is a nice figure that can be printed full-size, put in a PDF, or included directly in a paper.

Now we need the bottom half of Figure 1. From [SIDC](#), download the “monthly and monthly smoothed sunspot number” (`monthssn.dat`). Put it in the data directory.

```
>>> monthfile = os.path.join(common.datadir, 'monthssn.dat')
>>> convert = lambda x: datetime.datetime.strptime(x, '%Y%m')
>>> ssn_data = numpy.genfromtxt(monthfile, skip_header=2400, usecols=[0, 2, 3],
...                             converters={0: convert}, dtype=numpy.object,
...                             skip_footer=24)
>>> idx = bisect.bisect_left(ssn_data[:, 0], datetime.datetime(1989, 1, 1))
>>> ssn_data = ssn_data[idx:]
>>> ssn_times = ssn_data[:, 0]
>>> ssn = numpy.asarray(ssn_data[:, 1], dtype=numpy.float64)
>>> smooth_ssn = numpy.asarray(ssn_data[:, 2], dtype=numpy.float64)
>>> ssn_times += datetime.timedelta(days=15)
```

Much of this should be familiar. `genfromtxt()` is a little more flexible than `loadtxt()`; here it allows the skipping of lines at the end as well as the beginning (skipping 200 years at the start, 2 at the end, where data are provisional.) Here we load both times and the sunspot numbers in the same command so that if any lines don't load, they will not wind up in any of the arrays. We then use `asarray()` to convert the `ssn` and `smooth_ssn` columns to float arrays. Note the slice notation: `[:, 0]` means take all indices of the first dimension (line number) and only the 0th index of the second dimension (column in the line). Finally, we use `timedelta` to shift the date associated with a month from the beginning to roughly the middle of the month. Adding a scalar to an array does an elementwise addition.

```
>>> import matplotlib.figure
>>> fig = plt.figure(figsize=[11, 8.5],
...                  subplotpars=matplotlib.figure.SubplotParams(hspace=0.1))
>>> ax = fig.add_subplot(211)
```

When creating the figure this time, we use `SubplotParams` to choose a slightly smaller vertical spacing between adjacent subplots. Tweaking `SubplotParams` also provides an alternative to tweaking bounding boxes.

Then we create a subplot with the information that there will be 2 rows, 1 column, and this is the first subplot. Now everything acting on `ax`, above, can be repeated, although we skip setting the `xlabel` since only the bottom axis will be labeled.

```
>>> fluxline = ax.plot(esp_times, 10 ** esp_flux_av, 'b')
>>> ax.set_yscale('log')
>>> ax.set_ylim(1e-2, 10)
>>> ax.set_ylabel('Electron Flux\n1.8-3.5 MeV', color='b', weight='bold')
>>> ax2 = ax.twinx()
>>> vswline = ax2.plot(vsw_times, vsw_av, 'r')
>>> ax2.set_ylim(300, 650)
>>> ax2.set_ylabel('Solar Wind Speed', color='r', rotation=270, weight='bold')
>>> ax.set_xlim(esp_times[0], esp_times[-1])
>>> leg = ax.legend([fluxline[0], vswline[0]], ['Flux', 'Vsw'],
...               loc='upper left', frameon=False)
>>> fluxtext, vswtext = leg.get_texts()
>>> fluxtext.set_color(fluxline[0].get_color())
>>> vswtext.set_color(vswline[0].get_color())
```

Then we move on to adding the solar wind:

```
>>> ax3 = fig.add_subplot(212, sharex=ax)
```

This adds another subplot, the second in the 2x1 array. Its x axis is shared with the existing `ax`. (This is poorly documented; see this [example](#))

```
>>> plt.setp(ax.get_xticklabels(), visible=False)
>>> plt.setp(ax2.get_xticklabels(), visible=False)
```

`setp()` sets a property. `get_xticklabels()` returns all the tick labels (`Text`) for the x axis; `setp` then sets visible to `False` for all of them. This hides the labeling on the axis for the upper subfigure.

```
>>> ax3.set_xlabel('Year', weight='bold')
>>> ax3.set_ylabel('Sunspot Number', weight='bold')
>>> smoothline = ax3.plot(ssn_times, smooth_ssn, lw=2.0, color='k')
>>> ssinline = ax3.plot(ssn_times, ssn, color='k', linestyle='dotted')
```

There is nothing new here except for the specifications of `linewidth` and `linestyle`; see `plot()` for details. Note `k` as the abbreviation for black (to avoid confusion with blue.)

```
>>> leg2 = ax3.legend([ssinline[0], smoothline[0]],
...                  ['Sunspot Number', 'Smoothed SSN'],
...                  loc='upper right', frameon=False)
```

```
>>> ax3.set_ylim(0, 200)
>>> ax3.set_xlim(esp_times[0], esp_times[-1])

>>> fig_fname = os.path.join('.', 'plots', 'fig1.eps')
>>> fig.savefig(fig_fname, bbox_inches=bob, pad_inches=0.0)
```

All of this has been seen for the top half of figure 1.

Following is the complete code to reproduce Figure 1.

```
import bisect
import datetime

import common
import matplotlib
import matplotlib.figure
import matplotlib.pyplot as plt
import matplotlib.transforms
import numpy
import scipy
import scipy.stats
import spacepy.omni
import spacepy.time

matplotlib.rcParams['axes.unicode_minus'] = False
matplotlib.rcParams['text.usetex'] = True
matplotlib.rcParams['font.family'] = 'serif'
matplotlib.rcParams['font.size'] = 14
bob = matplotlib.transforms.Bbox([[0.4, 0.35], [10.7, 7.95]])

times = spacepy.time.tickrange('1989-01-01', '2011-01-01',
                                datetime.timedelta(hours=1))
d = spacepy.omni.get_omni(times)
vsw = d['vsw']
vsw_times = d['UTC']
esp_times, esp_flux = common.load_esp()
esp_flux_av = numpy.empty(shape=esp_flux.shape, dtype=esp_flux.dtype)
for i in range(len(esp_flux_av)):
    esp_flux_av[i] = scipy.stats.nanmean(esp_flux[max(i - 13, 0):i + 14])
idx = bisect.bisect_left(vsw_times, datetime.datetime(1989, 1, 1))
vsw_times = vsw_times[idx:]
vsw = vsw[idx:]
vsw_av = numpy.fromiter((scipy.stats.nanmean(vsw[max(0, i - 324):i + 324])
                        for i in range(len(vsw))),
                        count=len(vsw), dtype=vsw.dtype)
monthfile = os.path.join(common.datadir, 'monthssn.dat')
convert = lambda x: datetime.datetime.strptime(x, '%Y%m')
ssn_data = numpy.genfromtxt(monthfile, skip_header=2400, usecols=[0, 2, 3],
                             converters={0: convert}, dtype=numpy.object,
                             skip_footer=24)
idx = bisect.bisect_left(ssn_data[:, 0], datetime.datetime(1989, 1, 1))
ssn_data = ssn_data[idx:]
ssn_times = ssn_data[:, 0]
ssn = numpy.asarray(ssn_data[:, 1], dtype=numpy.float64)
smooth_ssn = numpy.asarray(ssn_data[:, 2], dtype=numpy.float64)
ssn_times += datetime.timedelta(days=15)

fig = plt.figure(figsize=[11, 8.5],
```



```

        subplotpars=matplotlib.figure.SubplotParams(hspace=0.1))
ax = fig.add_subplot(211)
fluxline = ax.plot(esp_times, 10 ** esp_flux_av, 'b')
ax.set_yscale('log')
ax.set_ylim(1e-2, 10)
ax.set_ylabel('Electron Flux\n1.8-3.5 MeV', color='b', weight='bold')
ax2 = ax.twinx()
vswline = ax2.plot(vsw_times, vsw_av, 'r')
ax2.set_ylim(300, 650)
ax2.set_ylabel('Solar Wind Speed', color='r', rotation=270, weight='bold')
ax.set_xlim(esp_times[0], esp_times[-1])
leg = ax.legend([fluxline[0], vswline[0]], ['Flux', 'Vsw'],
                loc='upper left', frameon=False)
fluxtext, vswtext = leg.get_texts()
fluxtext.set_color(fluxline[0].get_color())
vswtext.set_color(vswline[0].get_color())

ax3 = fig.add_subplot(212, sharex=ax)
plt.setp(ax.get_xticklabels(), visible=False)
plt.setp(ax2.get_xticklabels(), visible=False)
ax3.set_xlabel('Year', weight='bold')
ax3.set_ylabel('Sunspot Number', weight='bold')
smoothline = ax3.plot(ssn_times, smooth_ssn, lw=2.0, color='k')
ssnline = ax3.plot(ssn_times, ssn, color='k', linestyle='dotted')
leg2 = ax3.legend([ssnline[0], smoothline[0]],
                  ['Sunspot Number', 'Smoothed SSN'],
                  loc='upper right', frameon=False)
ax3.set_ylim(0, 200)
ax3.set_xlim(esp_times[0], esp_times[-1])

fig_fname = os.path.join('..', 'plots', 'fig1.eps')
fig.savefig(fig_fname, bbox_inches=bbox, pad_inches=0.0)

```

Appendix: Fixing the ESP data file

This appendix provides a detailed explanation of the script that fixes the ESP data file.

First set up a variable to hold the location of the data, as above:

```

>>> import os.path
>>> datadir = os.path.join('..', 'data')

```

Examining the data file, it is clear that something is odd: lines appear to have been broken inappropriately; for example, the data for 1989-10-12 are split across two lines. So the first task is to fix this file, first opening the original (broken) file and an output (fixed) file:

```

>>> in_name = os.path.join(datadir, '2010ja015735-ds01.txt')
>>> out_name = os.path.join(datadir, '2010ja015735-ds01_FIXED.txt')
>>> infile = open(in_name, 'r')
>>> outfile = open(out_name, 'w')

```

These lines `open()` the original file for reading (r), and a new file for writing (w). Note that opening a file for writing will destroy any existing contents.

The file happens to contain a mixture of carriage returns and proper newlines, so to begin all the carriage returns need to be rewritten as newlines:

```
>>> data = infile.read()
>>> infile.close()
>>> data = data.replace('\r', '\n')
>>> data = data.replace('\n\n', '\n')
```

`read()` reads *all* data from the file at once, so this is not recommended for large files. In this case it makes things easier. Once the data are read, `close()` the file. Calling the `replace()` method on `data` replaces all instances of the first parameter (`'\r'`) with the second (`'\n'`). `\r` is the special code indicating a carriage return; `\n`, a newline. For a literal backslash, use `\\`. Once the carriage returns have been replaced with newlines, a second round of replacement eliminates duplicates.

Now that the line endings have been cleaned up, it's time to rejoin the erroneously split lines. First copy over the 15 lines of header verbatim:

```
>>> data = data.split('\n')
>>> for i in range(15):
...     outfile.write(data.pop(0) + '\n')
```

`split()` splits a string into a *list*, with the split between elements happening wherever the provided parameter occurs. A simple example:

```
>>> foo = 'a.b.c'.split('.')
>>> print(foo)
['a', 'b', 'c']
```

The splitting character is not present in the output.

The advantage of a list is that it makes it easy to access individual elements: `>>> print(foo[1])` b

The first element of a Python list is numbered zero.

`range()` returns a list of numbers, starting from 0, with the parameter specifying how many elements are in the list:

```
>>> print(range(5))
[0, 1, 2, 3, 4]
```

The last number is 4 (not 5 as might be expected), but there are 5 elements in the list.

The `for` executes the following indented statement once for every element in the `in` list:

```
>>> for i in ['a', 'b', 'c']:
...     print i
a
b
c
```

Indentation is significant in Python! Normally indents are four spaces and the tab key will do the job. (In the above example, you may need to hit enter twice after the print statement, the second to terminate the indentation.)

`pop` returns one element from a list, and deletes it from the list. Using 0 pops off the first element, and `write()` writes a string to a file. `+` can be used to concatenate two strings together. Since `split()` removed the newlines, they need to be readed.

So this little block of code splits the data into a list on newlines and, repeating fifteen times, takes the first element of that list and writes it, with a newline, to the output. Now `data` contains only the actual lines of data.

```
>>> oldline = None
>>> for line in data:
...     if line[0:2] in ['19', '20', '2']:
...         if not oldline is None:
...             outfile.write(oldline + '\n')
```

```

...         oldline = line
...     else:
...         oldline += line
>>> outfile.write(oldline + '\n')
>>> outfile.close()

```

None is a special Python value specifically indicating nothing; it's used here to mark the first time around the loop.

`line[0:2]` gets the first two characters in the string *line*, and the `in` operator compares the resulting string to see if it is present in the following list. This will return `True` if the line begins with 19 or 20. The `if` statement executes the following indented block if the condition is `True`. So, if this is `True`, the previous line probably ended properly and it can be written out. First there is an additional check that this isn't the first time around the loop, and then the *previous* line (which we know ended cleanly) is written out. The currently-read line then becomes the new "previous" line.

The 2 is a special case: if the line is less than two characters long, `line[0:2]` will return the entire line, and it so happens that these cases always correspond to the previous line being whole.

If this test fails, everything under `else` is executed. Here the assumption is that the previous line didn't end cleanly and the current line is actually a continuation of it, so the current line is appended to the previous. `a += b` is a shortcut for `a = a + b`.

Once the loop terminates, the last line is written out, and the file closed.

1.7 Publication List

The following publications have been prepared using SpacePy. If you have published a paper using SpacePy, contact the SpacePy team to be added to this list. Please also provide a citation or acknowledgment, as appropriate, in your paper.

1.7.1 Papers using SpacePy

Peer-reviewed papers

- Niehof, J. T., S. K. Morley, and R. H. W. Friedel (2012), Association of cusp energetic ions with geomagnetic storms and substorms, *Ann. Geophys.*, 30 (12), 1633-1643, doi:10.5194/angeo-30-1633-2012.
- Turner, D. L., V. Angelopoulos, Y. Shprits, A. Kellerman, P. Cruce and D. Larson (2012), Radial distributions of equatorial phase space density for outer radiation belt electrons, *Geophys. Res. Lett.*, 39, L09101, doi:10.1029/2012GL051722.
- Welling, D. T. and A. J. Ridley (2010), Exploring sources of magnetospheric plasma using multispecies MHD, *Journal of Geophysical Research*, 115, 4201, doi:10.1029/2009JA014596.
- Morley, S. K., R. H. W. Friedel, E. L. Spanswick, G. D. Reeves, J. T. Steinberg, J. Koller, T. Cayton and E. Noveroske (2010), Dropouts of the outer electron radiation belt in response to solar wind stream interfaces: Global Positioning System observations, *Proceedings of the Royal Society A*, doi:10.1098/rspa.2010.0078.

Other publications and presentations

- Niehof, J. T. and S. K. Morley (2012), Determining the significance of associations between two series of discrete events: bootstrap methods, Tech Report LA-14453, Los Alamos National Laboratory, Los Alamos, NM, doi:10.2172/1035497.

1.7.2 Papers about SpacePy

Peer-reviewed papers

- Morley, S. K., D. T. Welling, J. Koller, B. A. Larsen, M. G. Henderson and J. Niehof (2010), SpacePy - A Python-based library of tools for the space sciences, Proceedings of the 9th Python in Science Conference (SciPy 2010), presented in Austin, TX, June 30 - July 1, 2010 [pdf](#). [full proceedings](#)

Other publications and presentations

- Niehof, J. T., M. G. Henderson, J. Koller, B. A. Larsen, S. Morley, D. T. Welling, Y. Yu (2012), Space Science with the SpacePy Toolkit, Abstract IN53C-1746 presented at 2012 Fall Meeting, AGU, San Francisco, Calif., 3-7 Dec. ([pdf](#))
- The SpacePy Developer Team (2010), SpacePy - Python-Based of Tools for the Space Science Community, A Tri-Fold [pdf](#).
- Morley, S. K., D. T. Welling, J. Koller, B. A. Larsen, M. G. Henderson (2010), SpacePy - Data Analysis and Visualization Tools for the Space Sciences, presented at GEM 2010 Summer Workshop, Snowmass, CO, June 20-25. ([pdf](#))

SPACEPY CODE

2.1 coordinates - module for coordinate transforms

Implementation of Coords class functions for coordinate transformations

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`Coords(data, dtype, carsph, [units, ticks])` A class holding spatial coordinates in Cartesian/spherical

2.1.1 `spacepy.coordinates.Coords`

class `spacepy.coordinates.Coords` (*data, dtype, carsph* [, *units, ticks*])

A class holding spatial coordinates in Cartesian/spherical in units of Re and degrees

Coordinate transforms are based on the IRBEM library; [its manual](#) may prove useful. There is good background information on space physics coordinate systems at [SPENVIS](#) and [RAL](#)

Parameters **data** : list or ndarray, dim = (n,3)

coordinate points [X,Y,Z] or [rad, lat, lon]

dtype : string

coordinate system, possible are GDZ, GEO, GSM, GSE, SM, GEI, MAG, SPH, RLL

carsph : string

Cartesian or spherical, 'car' or 'sph'

units : list of strings, optional

standard are ['Re', 'Re', 'Re'] or ['Re', 'deg', 'deg'] depending on the carsph content

ticks : Ticktock instance, optional

used for coordinate transformations (see `a.convert`)

Returns **out** : Coords instance

instance with `a.data`, `a.carsph`, etc.

See also:

`spacepy.time.Ticktock`

Examples

```
>>> from spacepy import coordinates as coord
>>> cvals = coord.Coords([[1,2,4],[1,2,2]], 'GEO', 'car')
>>> cvals.x # returns all x coordinates
array([1, 1])
>>> from spacepy.time import Ticktock
>>> cvals.ticks = Ticktock(['2002-02-02T12:00:00', '2002-02-02T12:00:00'], 'ISO') # add ticks
>>> newcoord = cvals.convert('GSM', 'sph')
>>> newcoord
```

<code>append(other)</code>	Append another Coords instance to the current one
<code>convert(returntype, returncarsph)</code>	Create a new Coords instance with new coordinate types

`append(other)`

Append another Coords instance to the current one

Parameters `other` : Coords instance

Coords instance to append

`convert(returntype, returncarsph)`

Create a new Coords instance with new coordinate types

Parameters `returntype` : string

coordinate system, possible are GDZ, GEO, GSM, GSE, SM, GEI, MAG, SPH, RLL

returncarsph : string

coordinate type, possible 'car' for Cartesian and 'sph' for spherical

Returns out : Coords object

Coords object in the new coordinate system

Examples

```
>>> from spacepy.coordinates import Coords
>>> y = Coords([[1,2,4],[1,2,2]], 'GEO', 'car')
>>> from spacepy.time import Ticktock
>>> y.ticks = Ticktock(['2002-02-02T12:00:00', '2002-02-02T12:00:00'], 'ISO')
>>> x = y.convert('SM', 'car')
>>> x
Coords( [[ 0.81134097  2.6493305  3.6500375 ]
 [ 0.92060408  2.30678864  1.68262126]] ), dtype=SM,car, units=['Re', 'Re', 'Re']
```

2.2 datamodel - easy to use general data model

The datamodel classes constitute a data model implementation meant to mirror the functionality of the data model output from pycdf, though implemented slightly differently.

This contains the following classes:

- `dmarray` - numpy arrays that support `.attrs` for information about the data
- `SpaceData` - base class that extends dict, to be extended by others

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2.2.1 About datamodel

The SpacePy datamodel module implements classes that are designed to make implementing a standard data model easy. The concepts are very similar to those used in standards like HDF5, netCDF and NASA CDF.

The basic container type is analogous to a folder (on a filesystem; HDF5 calls this a group): Here we implement this as a dictionary-like object, a `datamodel.SpaceData` object, which also carries attributes. These attributes can be considered to be global, i.e. relevant for the entire folder. The next container type is for storing data and is based on a numpy array, this class is `datamodel.darray` and also carries attributes. The `darray` class is analogous to an HDF5 dataset.

In fact, HDF5 can be loaded directly into a SpacePy datamodel, carrying across all attributes, using the function `fromHDF5`:

```
>>> import spacepy.datamodel as dm
>>> data = dm.fromHDF5('test.h5')
```

Functions are also available to directly load data and metadata into a SpacePy datamodel from NASA CDF as well as JSON-headed ASCII. Writers also exist to output a SpacePy datamodel directly to HDF5 or JSON-headed ASCII. See `datamodel.fromCDF()`, `datamodel.readJSONheadedASCII()`, `datamodel.toHDF5()`, and `datamodel.toJSONheadedASCII()` for more details.

2.2.2 Examples

Imagine representing some satellite data within the global attributes might be the mission name and the instrument PI, the variables might be the instrument counts [n-dimensional array], timestamps [1-dimensional array and an orbit number [scalar]. Each variable will have one attribute (for this example).

```
>>> import spacepy.datamodel as dm
>>> mydata = dm.SpaceData(attrs={'MissionName': 'BigSat1'})
>>> mydata['Counts'] = dm.darray([[42, 69, 77], [100, 200, 250]], attrs={'Units': 'cnts/s'})
>>> mydata['Epoch'] = dm.darray([1, 2, 3], attrs={'units': 'minutes'})
>>> mydata['OrbitNumber'] = dm.darray(16, attrs={'StartsFrom': 1})
>>> mydata.attrs['PI'] = 'Prof. Big Shot'
```

This has now populated a structure that can map directly to a NASA CDF, HDF5 or JSON-headed ASCII file. To visualize our datamodel, we can use tree method (which can be applied to any dictionary-like object using the `toolbox.dictree()` function).

```
>>> mydata.tree(attrs=True)
+
:|____MissionName
:|____PI
|____Counts
:|____Units
|____Epoch
:|____units
```

```
|____OrbitNumber
      :|____StartsFrom
```

2.2.3 Guide for NASA CDF users

By definition, a NASA CDF only has a single ‘layer’. That is, a CDF contains a series of records (stored variables of various types) and a set of attributes that are either global or local in scope. Thus to use SpacePy’s datamodel to capture the functionality of CDF the two basic data types are all that is required, and the main constraint is that datamodel.SpaceData objects cannot be nested (more on this later, if conversion from a nested datamodel to a flat datamodel is required).

Opening a CDF and working directly with the contents can be easily done using the PyCDF module, however, if you wish to load the entire contents of a CDF directly into a datamodel (complete with attributes) the following will make life easier:

```
>>> import spacepy.datamodel as dm
>>> data = dm.fromCDF('inFile.cdf')
```

2.2.4 A quick guide to JSON-headed ASCII

In many cases it is preferred to have a human-readable ASCII file, rather than a binary file like CDF or HDF5. To make it easier to carry all the same metadata that is available in HDF5 or CDF we have developed an ASCII data storage format that encodes the metadata using JSON (JavaScript Object Notation). This notation supports two basic datatypes: key/value collections (like a SpaceData) and ordered lists (which can represent arrays). JSON is human-readable, but if large arrays are stored in metadata is quickly becomes difficult to read. For this reason we use JSON to encode the metadata (usually smaller datasets) and store the data in a standard flat-ASCII format. The metadata is provided as a header that describes the contents of the file.

To use JSON for storing only metadata associated with the data to be written to an ASCII file a minimal metadata standard must be implemented. We use the following attribute names: DIMENSION and START_COLUMN. We also recommend using the NASA ISTP metadata standard to assign attribute names. The biggest limitation of flat ASCII is that sensibly formatting datasets of more than 2-dimensions (i.e. ranks greater than 2) is not possible. For this reason if you have datasets of rank 3 or greater then we recommend using HDF5. If text is absolutely required then it is possible to encode multi-dimensional arrays in the JSON metadata, but this is not recommended.

This format is best understood by illustration. The following example builds a toy SpacePy datamodel and writes it to a JSON-headed ASCII file. The contents of the file are then shown.

```
>>> import spacepy.datamodel as dm
>>> data = dm.SpaceData()
>>> data.attrs['Global'] = 'A global attribute'
>>> data['Var1'] = dm.darray([1,2,3,4,5], attrs={'Local1': 'A local attribute'})
>>> data['Var2'] = dm.darray([[8,9],[9,1],[3,4],[8,9],[7,8]])
>>> data['MVar'] = dm.darray([7.8], attrs={'Note': 'Metadata'})
>>> dm.toJSONheadedASCII('outFile.txt', data, depend0='Var1', order=['Var1'])
#Note that not all field names are required, those not given will be listed
#alphabetically after those that are specified
```

The file looks like:

```
# {
#   "MVar": {
#     "Note": "Metadata",
#     "VALUES": [7.8]
#   },
```



```
# "Global": "A global attribute",
# "Var1": {
#     "Local1": "A local attribute",
#     "DIMENSION": [1],
#     "START_COLUMN": 0
# },
# "Var2": {
#     "DIMENSION": [2],
#     "START_COLUMN": 2
# }
#}
1 8 9
2 9 1
3 3 4
4 8 9
5 7 8
```

Classes

<code>SpaceData(*args, **kwargs)</code>	Datamodel class extending dict by adding attributes.
<code>dmarray</code>	Container for data within a SpaceData object
<code>DMWarning</code>	Warnings class for datamodel, subclassed so it can be set to always

2.2.5 spacepy.datamodel.SpaceData

class `spacepy.datamodel.SpaceData(*args, **kwargs)`
 Datamodel class extending dict by adding attributes.

<code>flatten()</code>	Method to collapse datamodel to one level deep
<code>tree(**kwargs)</code>	Print the contents of the SpaceData object in a visual tree

flatten()
 Method to collapse datamodel to one level deep

Examples

```
>>> import spacepy.datamodel as dm
>>> import spacepy.toolbox as tb
>>> a = dm.SpaceData()
>>> a['1'] = dm.SpaceData(dog = 5, pig = dm.SpaceData(fish=dm.SpaceData(a='carp', b='perch'))
>>> a['4'] = dm.SpaceData(cat = 'kitty')
>>> a['5'] = 4
>>> a.tree()
+
|____1
|    |____dog
|    |____pig
|    |    |____fish
|    |    |    |____a
|    |    |    |____b
|____4
```

```
    |____cat
|____5

>>> b = dm.flatten(a)
>>> b.tree()
+
|____1<--dog
|____1<--pig<--fish<--a
|____1<--pig<--fish<--b
|____4<--cat
|____5

>>> a.flatten()
>>> a.tree()
+
|____1<--dog
|____1<--pig<--fish<--a
|____1<--pig<--fish<--b
|____4<--cat
|____5
```

tree (***kwargs*)

Print the contents of the SpaceData object in a visual tree

Other Parameters **verbose** : boolean (optional)

print more info

spaces : string (optional)

string will added for every line

levels : integer (optional)

number of levels to recurse through (True means all)

attrs : boolean (optional)

display information for attributes

See also:

`toolbox.dictree`

Examples

```
>>> import spacepy.datamodel as dm
>>> import spacepy.toolbox as tb
>>> a = dm.SpaceData()
>>> a['1'] = dm.SpaceData(dog = 5)
>>> a['4'] = dm.SpaceData(cat = 'kitty')
>>> a['5'] = 4
>>> a.tree()
+
|____1
    |____dog
|____4
    |____cat
|____5
```

2.2.6 spacepy.datamodel.darray

class spacepy.datamodel.darray
Container for data within a SpaceData object

Raises NameError :

raised is the request name was not added to the allowed attributes list

Examples

```
>>> import spacepy.datamodel as datamodel
>>> position = datamodel.darray([1,2,3], attrs={'coord_system': 'GSM'})
>>> position
darray([1, 2, 3])
>>> position.attrs
{'coord_system': 'GSM'}
```

The darray, like a numpy ndarray, is versatile and can store any datatype; darrays are not just for arrays.

```
>>> name = datamodel.darray('TestName')
darray('TestName')
```

To extract the string (or scalar quantity), use the tolist method

```
>>> name.tolist()
'TestName'
```

`addAttribute(name[, value])` Method to add an attribute to a darray

addAttribute (name, value=None)

Method to add an attribute to a darray equivalent to `a = datamodel.darray([1,2,3])` `a.Allowed_Attributes = a.Allowed_Attributes + ['blabla']`

2.2.7 spacepy.datamodel.DMWarning

class spacepy.datamodel.DMWarning
Warnings class for datamodel, subclassed so it can be set to always

Functions

<code>dmcopy(dobj)</code>	Generic copy utility to return a copy of a (datamodel) object
<code>dmfilled(shape[, fillval, dtype, order, attrs])</code>	Return a new darray of given shape and type, filled with a specified value
<code>flatten(dobj)</code>	Collapse datamodel to one level deep
<code>fromCDF(fname, **kwargs)</code>	Create a SpacePy datamodel representation of a NASA CDF file
<code>fromHDF5(fname, **kwargs)</code>	Create a SpacePy datamodel representation of an HDF5 file or netCDF4
<code>toCDF(fname, SDOobject, **kwargs)</code>	Create a CDF file from a SpacePy datamodel representation
<code>toHDF5(fname, SDOobject, **kwargs)</code>	Create an HDF5 file from a SpacePy datamodel representation
<code>toHTML(fname, SDOobject[, attrs, varLinks, ...])</code>	Create an HTML dump of the structure of a spacedata
<code>toJSONheadedASCII(fname, insd[, metadata, ...])</code>	Write JSON-headed ASCII file of data with metadata from SpaceData object
<code>unflatten(dobj[, marker])</code>	Collapse datamodel to one level deep

Table 2.6 – continued from previous page

<code>readJSONMetadata(fname, **kwargs)</code>	Read JSON metadata from an ASCII data file
<code>readJSONheadedASCII(fname[, mdata, comment, ...])</code>	read JSON-headed ASCII data files into a SpacePy datamodel
<code>writeJSONMetadata(fname, insd[, depend0, ...])</code>	Scrape metadata from SpaceData object and make a JSON header

2.2.8 spacepy.datamodel.dmcopu

`spacepy.datamodel.dmcopu(dobj)`

Generic copy utility to return a copy of a (datamodel) object

Parameters `dobj`: object

object to return a copy of

Returns `copy_obj`: object (same type as input) :

copy of input oibject

Examples

```
>>> import spacepy.datamodel as dm
>>> dat = dm.darray([2,3], attrs={'units': 'T'})
>>> dat1 = dm.dmcopu(dat)
>>> dat1.attrs['copy': True]
>>> dat is dat1
False
>>> dat1.attrs
{'copy': True, 'units': 'T'}
>>> dat.attrs
{'units': 'T'}
```

2.2.9 spacepy.datamodel.dmfilled

`spacepy.datamodel.dmfilled(shape, fillval=0, dtype=None, order='C', attrs=None)`

Return a new darray of given shape and type, filled with a specified value (default=0).

See also:

`numpy.ones`

Examples

```
>>> import spacepy.datamodel as dm
>>> dm.dmfilled(5, attrs={'units': 'nT'})
darray([ 0.,  0.,  0.,  0.,  0.])

>>> dm.dmfilled((5,), fillval=1, dtype=np.int)
darray([1, 1, 1, 1, 1])

>>> dm.dmfilled((2, 1), fillval=np.nan)
darray([[ nan],
        [ nan]])
```

```
>>> a = dm.dmfilled((2, 1), np.nan, attrs={'units': 'nT'})
>>> a
dmarray([[ nan],
         [ nan]])
>>> a.attrs
{'units': 'nT'}
```

2.2.10 spacepy.datamodel.flatten

`spacepy.datamodel.flatten` (*obj*)
Collapse datamodel to one level deep

See also:

`unflatten`, `SpaceData.flatten`

Examples

```
>>> import spacepy.datamodel as dm
>>> import spacepy.toolbox as tb
>>> a = dm.SpaceData()
>>> a['1'] = dm.SpaceData(dog = 5, pig = dm.SpaceData(fish=dm.SpaceData(a='carp', b='perch')))
>>> a['4'] = dm.SpaceData(cat = 'kitty')
>>> a['5'] = 4
>>> a.tree()
+
|___1
|   |___dog
|   |___pig
|       |___fish
|           |___a
|           |___b
|___4
|   |___cat
|___5

>>> b = dm.flatten(a)
>>> b.tree()
+
|___1<--dog
|___1<--pig<--fish<--a
|___1<--pig<--fish<--b
|___4<--cat
|___5

>>> a.flatten()
>>> a.tree()
+
|___1<--dog
|___1<--pig<--fish<--a
|___1<--pig<--fish<--b
|___4<--cat
|___5
```

2.2.11 spacepy.datamodel.fromCDF

`spacepy.datamodel.fromCDF` (*fname*, ***kwargs*)

Create a SpacePy datamodel representation of a NASA CDF file

Parameters *file* : string

the name of the cdf file to be loaded into a datamodel

Returns *out* : `spacepy.datamodel.SpaceData`

SpaceData with associated attributes and variables in dmarrays

See also:

`spacepy.pycdf.CDF.copy`

Examples

```
>>> import spacepy.datamodel as dm
>>> data = dm.fromCDF('test.cdf')
```

2.2.12 spacepy.datamodel.fromHDF5

`spacepy.datamodel.fromHDF5` (*fname*, ***kwargs*)

Create a SpacePy datamodel representation of an HDF5 file or netCDF4 file which is HDF5 compliant

Parameters *file* : string

the name of the HDF5/netCDF4 file to be loaded into a datamodel

Returns *out* : `spacepy.datamodel.SpaceData`

SpaceData with associated attributes and variables in dmarrays

Notes

Known issues – zero-sized datasets will break in h5py This is kluged by returning a dmarray containing a None

This function is expected to work with any HDF5-compliant files, including netCDF4 (not netCDF3) and Mat-Lab save files from v7.3 or later, but some datatypes are not supported, e.g., non-string vlen datatypes, and will raise a warning.

Examples

```
>>> import spacepy.datamodel as dm
>>> data = dm.fromHDF5('test.hdf')
```

2.2.13 spacepy.datamodel.toCDF

`spacepy.datamodel.toCDF` (*fname*, *SObject*, ***kwargs*)

Create a CDF file from a SpacePy datamodel representation

Parameters **fname** : str

Filename to write to

SObject : spacepy.datamodel.SpaceData

SpaceData with associated attributes and variables in dmarrays

Returns **None** :

Other Parameters **skeleton** : str (optional)

create new CDF from a skeleton file (default '')

flatten : bool (optional)

flatten incoming datamodel - if SpaceData objects are nested (default False)

overwrite : bool (optional)

allow overwrite of an existing target file (default False)

autoNRV : bool (optional)

attempt automatic identification of non-record varying entries in CDF

backward : bool (optional)

create CDF in backward-compatible format (default is v3+ compatibility only)

verbose : bool (optional)

verbosity flag

2.2.14 spacepy.datamodel.toHDF5

`spacepy.datamodel.toHDF5(fname, SObject, **kwargs)`

Create an HDF5 file from a SpacePy datamodel representation

Parameters **fname** : str

Filename to write to

SObject : spacepy.datamodel.SpaceData

SpaceData with associated attributes and variables in dmarrays

Returns **None** :

Other Parameters **overwrite** : bool (optional)

allow overwrite of an existing target file (default True)

mode : str (optional)

HDF5 file open mode (a, w, r) (default 'a')

compression : str (optional)

compress all the variables using this method (default None) (gzip, shuffle, fletcher32, szip, lzf)

compression_opts : str (optional)

options to the compression, see h5py documentation for more details

Examples

```
>>> import spacepy.datamodel as dm
>>> a = dm.SpaceData()
>>> a['data'] = dm.darray(range(100000), dtype=float)
>>> dm.toHDF5('test_gzip.h5', a, overwrite=True, compression='gzip')
>>> dm.toHDF5('test.h5', a, overwrite=True)
>>> # test_gzip.h5 was 118k, test.h5 was 785k
```

2.2.15 spacepy.datamodel.toHTML

`spacepy.datamodel.toHTML(fname, SDObject, attrs=(), varLinks=False, linkFormat=None, echo=False, tableTag='<table border="1">')`

Create an HTML dump of the structure of a spacedata

Parameters `fname` : str

Filename to write to

SDObject : `spacepy.datamodel.SpaceData`

SpaceData with associated attributes and variables in dmarrays

Other Parameters `overwrite` : bool (optional)

allow overwrite of an existing target file (default True)

mode : str (optional)

HDF5 file open mode (a, w, r) (default 'a')

echo : bool

echo the html to the screen

varLinks : bool

make the variable name a link to a stub page

2.2.16 spacepy.datamodel.toJSONheadedASCII

`spacepy.datamodel.toJSONheadedASCII(fname, insd, metadata=None, depend0=None, order=None, **kwargs)`

Write JSON-headed ASCII file of data with metadata from SpaceData object

Parameters `fname` : str

Filename to write to (can also use a file-like object) None can be given in conjunction with the `returnString` keyword to skip writing output

insd : `spacepy.datamodel.SpaceData`

SpaceData with associated attributes and variables in dmarrays

Returns None :

Other Parameters `depend0` : str (optional)

variable name to use to indicate parameter on which other data depend (e.g. Time)

order : list (optional)

list of key names in order of start column in output JSON file

metadata: str or file-like (optional) :

filename with JSON header to use (or file-like with JSON metadata)

delimiter: str :

delimiter to use in ASCII output (default is whitespace), for tab, use ‘ ‘

Examples

```
>>> import spacepy.datamodel as dm
>>> data = dm.SpaceData()
>>> data.attrs['Global'] = 'A global attribute'
>>> data['Var1'] = dm.darray([1,2,3,4,5], attrs={'Local1': 'A local attribute'})
>>> data['Var2'] = dm.darray([[8,9],[9,1],[3,4],[8,9],[7,8]])
>>> data['MVar'] = dm.darray([7.8], attrs={'Note': 'Metadata'})
>>> dm.toJSONheadedASCII('outFile.txt', data, depend0='Var1', order=['Var1'])
#Note that not all field names are required, those not given will be listed
#alphabetically after those that are specified
```

2.2.17 spacepy.datamodel.unflatten

`spacepy.datamodel.unflatten(dobj, marker='<-')`
Collapse datamodel to one level deep

Examples

```
>>> import spacepy.datamodel as dm
>>> import spacepy.toolbox as tb
>>> a = dm.SpaceData()
>>> a['1'] = dm.SpaceData(dog = 5, pig = dm.SpaceData(fish=dm.SpaceData(a='carp', b='perch')))
>>> a['4'] = dm.SpaceData(cat = 'kitty')
>>> a['5'] = 4
>>> a.tree()
+
|___1
|   |___dog
|   |___pig
|       |___fish
|           |___a
|           |___b
|___4
|   |___cat
|___5

>>> b = dm.flatten(a)
>>> b.tree()
+
|___1<--dog
|___1<--pig<--fish<--a
|___1<--pig<--fish<--b
|___4<--cat
|___5
```

```
>>> c = dm.unflatten(b)
>>> c.tree()
+
|___1
|   |___dog
|   |___pig
|       |___fish
|           |___a
|           |___b
|___4
|   |___cat
|___5
```

2.2.18 spacepy.datamodel.readJSONMetadata

`spacepy.datamodel.readJSONMetadata` (*fname*, ***kwargs*)

Read JSON metadata from an ASCII data file

Parameters *fname* : str

Filename to read metadata from

Returns *mdata*: `spacepy.datamodel.SpaceData` :

SpaceData with the metadata from the file

Other Parameters *verbose* : bool (optional)

set verbose output so metadata tree prints on read (default False)

2.2.19 spacepy.datamodel.readJSONheadedASCII

`spacepy.datamodel.readJSONheadedASCII` (*fname*, *mdata=None*, *comment='#*', *convert=False*)

read JSON-headed ASCII data files into a SpacePy datamodel

Parameters *fname* : str or list

Filename(s) to read data from

Returns *mdata*: `spacepy.datamodel.SpaceData` :

SpaceData with the data and metadata from the file

Other Parameters *mdata* : `spacepy.datamodel.SpaceData` (optional)

supply metadata object, otherwise is read from *fname* (default None)

comment: str (optional) :

comment string in file to be read; lines starting with comment are ignored (default '#')

convert: bool or dict-like (optional) :

If True, uses common names to try conversion from string. If a dict-like then uses the functions specified as the dict values to convert each element of 'key' to a non-string

2.2.20 spacepy.datamodel.writeJSONMetadata

`spacepy.datamodel.writeJSONMetadata` (*fname*, *insd*, *depend0=None*, *order=None*, *verbose=False*, *returnString=False*)

Scrape metadata from SpaceData object and make a JSON header

Parameters **fname** : str

Filename to write to (can also use a file-like object) None can be given in conjunction with the `returnString` keyword to skip writing output

insd : `spacepy.datamodel.SpaceData`

SpaceData with associated attributes and variables in dmarrays

Returns **None** (unless `returnString` keyword is **True**) :

Other Parameters **depend0** : str (optional)

variable name to use to indicate parameter on which other data depend (e.g. Time)

order : list (optional)

list of key names in order of start column in output JSON file

verbose: bool (optional) :

verbose output

returnString: bool (optional) :

return JSON header as string instead of returning None

2.3 data assimilation - data assimilation module

Classes

`ensemble`([ensembles]) Ensemble-based data assimilation subroutines for the Radiation Belt Model

2.3.1 spacepy.data_assimilation.ensemble

class `spacepy.data_assimilation.ensemble` (*ensembles=50*)

Ensemble-based data assimilation subroutines for the Radiation Belt Model

<code>EnKF(A, Psi, Inn, HAp)</code>	analysis subroutine after code example in
<code>EnKF_oneobs(A, Psi, Inn, HAp)</code>	analysis subroutine for a single observations
<code>add_model_error(model, A, PSDdata)</code>	this routine will add a standard error to the ensemble states
<code>add_model_error_obs(model, A, Lobs, y)</code>	this routine will add a standard error to the ensemble states
<code>getHA(model, Lobs, A)</code>	compute HA provided L vector of observations
<code>getHAprime(HA)</code>	calculate ensemble perturbation of HA
<code>getHPH(Lobs, Pfx)</code>	compute HPH
<code>getInnovation(y, Psi, HA)</code>	compute innovation ensemble D'
<code>getperturb(model, y)</code>	compute perturbations of observational vector

EnKF (*A, Psi, Inn, HAp*)

analysis subroutine after code example in Evensen 2003 this will take the prepared matrices and calculate

the analysis most efficiently, A will be returned

Parameters A :

Psi :

Inn :

HAp :

Returns out :

EnKF_oneobs (*A, Psi, Inn, HAp*)

analysis subroutine for a single observations with the EnKF. This is a special case.

Parameters A :

Psi :

Inn :

HAp :

Returns out :

add_model_error (*model, A, PSDdata*)

this routine will add a standard error to the ensemble states

Parameters model :

A :

PSDdata :

Returns out :

add_model_error_obs (*model, A, Lobs, y*)

this routine will add a standard error to the ensemble states

Parameters model :

A :

Lobs :

y :

Returns out :

getHA (*model, Lobs, A*)

compute HA provided L vector of observations and ensemble matrix A

Parameters model :

Lobs :

A :

Returns out :

getHAprime (*HA*)

calculate ensemble perturbation of HA $HA' = HA - HA_mean$

Parameters HA :

Returns out :

getHPH (*Lobs, Pfx*)

compute HPH

Parameters Lobs :

Pfxx :

Returns out :

getInnovation (*y, Psi, HA*)
compute innovation ensemble D'

Parameters y ::

Psi ::

HA ::

Returns out ::

getperturb (*model, y*)
compute perturbations of observational vector

Parameters model ::

y ::

Returns out ::

Functions

<code>average_window(PSDdata, Lgrid)</code>	combine observations on same L shell in
<code>getobs4window(dd, Tnow)</code>	get observations in time window [Tnow - Twindow, Tnow]
<code>output(init, result)</code>	write results to file and be done
<code>forecast(Tnow+Twindow)</code>	
<code>assimilate_JK(dd)</code>	this version is currently not working
<code>addmodelerror_old2(dd, A, y, L)</code>	this routine will add a standard error to the ensemble states
<code>addmodelerror_old(dd, A, y, L)</code>	this routine will add a standard error to the ensemble states

2.3.2 spacepy.data_assimilation.average_window

`spacepy.data_assimilation.average_window` (*PSDdata, Lgrid*)
combine observations on same L shell in

Parameters model ::

PSDdata ::

HAp ::

Returns out ::

2.3.3 spacepy.data_assimilation.getobs4window

`spacepy.data_assimilation.getobs4window` (*dd, Tnow*)
get observations in time window [Tnow - Twindow, Tnow] from all satellites lumped together into one y vector

Parameters model ::

PSDdata ::

HAp ::

Returns out :

2.3.4 spacepy.data_assimilation.output

`spacepy.data_assimilation.output` (*init, result*)
write results to file and be done

Parameters model :

PSDdata :

HAp :

Returns out :

2.3.5 spacepy.data_assimilation.forecast

`spacepy.data_assimilation.forecast` (*Tnow+Twindow*)

2.3.6 spacepy.data_assimilation.assimilate_JK

`spacepy.data_assimilation.assimilate_JK` (*dd*)
this version is currently not working main function to assimilate all data provided in init

Parameters model :

PSDdata :

HAp :

Returns out :

2.3.7 spacepy.data_assimilation.addmodelerror_old2

`spacepy.data_assimilation.addmodelerror_old2` (*dd, A, y, L*)
this routine will add a standard error to the ensemble states

2.3.8 spacepy.data_assimilation.addmodelerror_old

`spacepy.data_assimilation.addmodelerror_old` (*dd, A, y, L*)
this routine will add a standard error to the ensemble states

2.4 empiricals - module with heliospheric empirical modules

Module with some useful empirical models (plasmapause, magnetopause, Lmax)

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<code>getLmax(ticks[, model])</code>	calculate a simple empirical model for Lmax - last closed drift-shell
<code>getPlasmaPause(ticks[, model, LT, omnivals])</code>	PlasmaPause location model(s)

Continued on next page

Table 2.10 – continued from previous page

<code>getMPstandoff(ticks)</code>	Calculates the Shue et al.
<code>getDststar(ticks[, model])</code>	Calculate the pressure-corrected Dst index, Dst*
<code>getVampolaOrder(L)</code>	Empirical lookup of power for \sin^n pitch angle model from Vampola (1996)
<code>vampolaPA(omniflux, **kwargs)</code>	Pitch angle model of \sin^n form

2.4.1 spacepy.empiricals.getLmax

`spacepy.empiricals.getLmax(ticks, model='JKemp')`

calculate a simple empirical model for Lmax - last closed drift-shell

Uses the parametrized Lmax from: Koller and Morley (2010) ‘Magnetopause shadowing effects for radiation belt models during high-speed solar wind streams’ American Geophysical Union, Fall Meeting 2010, abstract #SM13A-1787

Parameters `ticks` : `spacepy.time.Ticktock`

Ticktock object of desired times

model : string, optional

‘JKemp’ (default - empirical model of J. Koller)

Returns `out` : `np.ndarray`

Lmax - L* of last closed drift shell

See also:

`spacepy.LANLstar.LANLmax`

Examples

```
>>> from spacepy.empiricals import getLmax
>>> import spacepy.time as st
>>> import datetime
>>> ticks = st.tickrange(datetime.datetime(2000, 1, 1), datetime.datetime(2000, 1, 3), deltadays
array([ 7.4928412,  8.3585632,  8.6463423])
```

2.4.2 spacepy.empiricals.getPlasmaPause

`spacepy.empiricals.getPlasmaPause(ticks, model='M2002', LT='all', omnivals=None)`

Plasmapause location model(s)

CA1992 – Carpenter, D. L., and R. R. Anderson, An ISEE/whistler model of equatorial electron density in the magnetosphere, J. Geophys. Res., 97, 1097, 1992. M2002 – Moldwin, M. B., L. Downward, H. K. Rassoul, R. Amin, and R. R. Anderson, A new model of the location of the plasmapause: CRRES results, J. Geophys. Res., 107(A11), 1339, doi:10.1029/2001JA009211, 2002.

Parameters `ticks` : `spacepy.time.Ticktock`

TickTock object of desired times

Lpp_model : string, optional

‘CA1992’ or ‘M2002’ (default) CA1992 returns the Carpenter and Anderson model,
M2002 returns the Moldwin et al. model

LT : int, float

requested local time sector, 'all' is valid option

omnivals : spacepy.datamodel.SpaceData, dict

dict-like containing UTC (datetimes) and Kp keys

Returns out : float

Plasmapause radius in Earth radii

Examples

```
>>> import spacepy.time as spt
>>> import spacepy.empiricals as emp
>>> ticks = spt.tickrange('2002-01-01T12:00:00', '2002-01-04T00:00:00', .25)
>>> emp.getPlasmaPause(ticks)
array([ 6.42140002,  6.42140002,  6.42140002,  6.42140002,  6.42140002,
        6.42140002,  6.42140002,  6.26859998,  5.772      ,  5.6574      ,
        5.6574      ])
```

2.4.3 spacepy.empiricals.getMPstandoff

spacepy.empiricals.getMPstandoff(*ticks*)

Calculates the Shue et al. (1997) subsolar magnetopause radius

Lets put the full reference here

Parameters ticks : spacepy.time.Ticktock

TickTock object of desired times (will be interpolated from hourly OMNI data) OR
dictionary of form {'P': [], 'Bz': []} Where P is SW ram pressure [nPa] and Bz is IMF
Bz (GSM) [nT]

Returns out : float

Magnetopause (sub-solar point) standoff distance [Re]

Examples

```
>>> import spacepy.time as spt
>>> import spacepy.empiricals as emp
>>> ticks = spt.tickrange('2002-01-01T12:00:00', '2002-01-04T00:00:00', .25)
>>> emp.ShueMP(ticks)
array([ 10.57319537,  10.91327764,  10.75086873,  10.77577207,
        9.78180261,  11.0374474 ,  11.4065      ,  11.27555451,
        11.47988573,  11.8202582 ,  11.23834814])
>>> data = {'P': [2,4], 'Bz': [-2.4, -2.4]}
>>> emp.ShueMP(data)
array([ 9.96096838,  8.96790412])
```

2.4.4 spacepy.empiricals.getDststar

spacepy.empiricals.getDststar(*ticks*, *model*='OBrien')

Calculate the pressure-corrected Dst index, Dst*

We need to add in the references to the models here!

Parameters `ticks` : spacepy.time.Ticktock

TickTock object of desired times (will be interpolated from hourly OMNI data) OR dictionary including 'Pdyn' and 'Dst' keys where data are lists or arrays and Dst is in [nT], and Pdyn is in [nPa]

Returns `out` : float

Dst* - the pressure corrected Dst index from OMNI [nT]

Examples

Coefficients are applied to the standard formulation e.g. Burton et al., 1975 of $Dst^* = Dst - b \cdot \sqrt{P_{dyn}} + c$. The default is the O'Brien and McPherron model (2002). Other options are Burton et al. (1975) and Borovsky and Denton (2010)

```
>>> import spacepy.time as spt
>>> import spacepy.omni as om
>>> import spacepy.empiricals as emp
>>> ticks = spt.tickrange('2000-10-16T00:00:00', '2000-10-31T12:00:00', 1/24.)
>>> dststar = emp.getDdststar(ticks)
>>> dststar[0]
-21.317220132108943
```

User-determined coefficients can also be supplied as a two-element list or tuple of the form (b,c), e.g.

```
>>> dststar = emp.getDdststar(ticks, model=(2,11)) #b is extreme driving from O'Brien
```

We have chosen the OBrien model as the default here as this was rigorously determined from a very long data set and is pertinent to most conditions. It is, however, the most conservative correction. Additionally, Siscoe, McPherron and Jordanova (2005) argue that the pressure contribution to Dst diminishes during magnetic storms.

To show the relative differences, run the following example:

```
>>> import matplotlib.pyplot as plt
>>> params = [('Burton', 'k-'), ('OBrien', 'r-'), ('Borovsky', 'b-')]
>>> for model, col in params:
    dststar = getDdststar(ticks, model=model)
    plt.plot(ticks.UTC, dststar, col)
```

2.4.5 spacepy.empiricals.getVampolaOrder

spacepy.empiricals.getVampolaOrder(*L*)

Empirical lookup of power for \sin^n pitch angle model from Vampola (1996)

Vampola, A.L. Outer zone energetic electron environment update, Final Report of ESA/ESTEC/WMA/P.O. 151351, ESA-ESTEC, Noordwijk, The Netherlands, 1996.

Parameters `L` : arraylike or float

Returns `order` : array

coefficient for \sin^n model corresponding to McIlwain L (computed for OP77?)

2.4.6 spacepy.empiricals.vampolaPA

`spacepy.empiricals.vampolaPA(omniflux, **kwargs)`

Pitch angle model of \sin^n form

Parameters `omniflux` : arraylike or float

omnidirectional number flux data

order : integer or float (optional)

order of \sin^n functional form for distribution (default=2)

alphas : arraylike (optional)

pitch angles at which to evaluate the differential number flux (default is 5 to 90 degrees in 36 steps)

Returns `dnflux` : array

differential number flux corresponding to pitch angles `alphas`

alphas : array

pitch angles at which the differential number flux was evaluated

Notes

Directional number flux integrated over pitch angle from 0 to 90 degrees is a factor of 4π lower than omnidirectional number flux.

Examples

Omnidirectional number flux of [3000, 6000]

```
>>> from spacepy.empiricals import vampolaPA
>>> vampolaPA(3000, alpha=[45, 90])
(array([ 75.99088773, 151.98177546]), [45, 90])
>>> data, pas = vampolaPA([3000, 6000], alpha=[45, 90])
>>> pas
[45, 90]
>>> data
array([[ 75.99088773, 151.98177546],
       [151.98177546, 303.96355093]])
```

2.5 irbempy - Python interface to irbem/ONERA library

module wrapper for `irbem_lib` Reference for this library <https://sourceforge.net/projects/irbem/> D. Boscher, S. Bourdarie, P. O'Brien, T. Guild, IRBEM library V4.3, 2004-2008

Most functions in this module use an options list to define the models used and the settings that define the quality level of the result. The options list is a 5-element list and is defined as follows.

2.5.1 Options

- 1st element: 0 - don't compute L^* or ϕ ; 1 - compute L^* ; 2- compute ϕ
- **2nd element: 0 - initialize IGRF field once per year (year.5);** $n - n$ is the frequency (in days) starting on January 1st of each year (i.e. if options(2nd element)=15 then IGRF will be updated on the following days of the year: 1, 15, 30, 45 ...)
- **3rd element: resolution to compute L^* (0 to 9) where 0 is the recommended value to ensure a good ratio** precision/computation time (i.e. an error of $\sim 2\%$ at $L=6$). The higher the value the better will be the precision, the longer will be the computing time. Generally there is not much improvement for values larger than 4. Note that this parameter defines the integration step (theta) along the field line such as $d\theta = (2\pi)/(720 * [\text{options}(3\text{rd element}) + 1])$
- **4th element: resolution to compute L^* (0 to 9). The higher the value the better will be** the precision, the longer will be the computing time. It is recommended to use 0 (usually sufficient) unless L^* is not computed on a LEO orbit. For LEO orbit higher values are recommended. Note that this parameter defines the integration step (ϕ) along the drift shell such as $d\phi = (2\pi)/(25 * [\text{options}(4\text{th element}) + 1])$
- **5th element: allows to select an internal magnetic field model (default is set to IGRF)**
 - 0 = IGRF
 - 1 = Eccentric tilted dipole
 - 2 = Jensen&Cain 1960
 - 3 = GSFC 12/66 updated to 1970
 - 4 = User-defined model (Default: Centred dipole + uniform [Dungey open model])
 - 5 = Centred dipole

The routines also require specification of the external magnetic field model. The default is the Tsyganenko 2001 storm-time model. The external model is always specified using the extMag keyword and the following options exist.

2.5.2 extMag

- '0' = No external field model
- 'MEAD' = Mead and Fairfield
- 'T87SHORT' = Tsyganenko 1987 short (inner magnetosphere)
- 'T87LONG' = Tsyganenko 1987 long (valid in extended tail region)
- 'T89' = Tsyganenko 1989
- 'OPQUIET' = Olsen-Pfitzer static model for quiet conditions
- 'OPDYN' = Olsen-Pfitzer static model for active conditions
- 'T96' = Tsyganenko 1996
- 'OSTA' = Ostapenko and Maltsev
- 'T01QUIET' = Tsyganenko 2001 model for quiet conditions
- 'T01STORM' = Tsyganenko 2001 model for active conditions
- 'T05' = Tsyganenko and Sitnov 2005 model
- 'ALEX' = Alexeev model

2.5.3 Authors

Josef Koller, Steve Morley

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This module provides a Python interface to the IRBEM library

Reference for this library <https://sourceforge.net/projects/irbem/>

D. Boscher, S. Bourdarie, P. O'Brien, T. Guild, IRBEM library V4.3, 2004-2008

Authors: Josef Koller, Steve Morley

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<code>get_AEP8(energy, loci[, model, fluxtype, ...])</code>	will return the flux from the AE8-AP8 model
<code>get_Bfield(ticks, loci[, extMag, options, ...])</code>	call <code>get_bfield</code> in <code>irbem</code> lib and return a dictionary with the B-field vector and
<code>get_Lm(ticks, loci, alpha[, extMag, intMag, ...])</code>	Return the MacIlwain L value for a given location, time and model
<code>get_Lstar(ticks, loci[, alpha, extMag, ...])</code>	This will call <code>make_lstar1</code> or <code>make_lstar_shell_splitting_1</code> from the <code>irbem</code> library
<code>find_Bmirror(ticks, loci, alpha[, extMag, ...])</code>	call <code>find_mirror_point</code> from <code>irbem</code> library and return a dictionary with values for
<code>find_magequator(ticks, loci[, extMag, ...])</code>	call <code>find_magequator</code> from <code>irbem</code> library and return a dictionary with values for
<code>car2sph(CARin)</code>	coordinate transformation from cartesian to spherical
<code>sph2car(SPHin)</code>	coordinate transformation from spherical to cartesian
<code>coord_trans(loca, returntype, returncarsph)</code>	thin layer to call <code>coord_trans1</code> from <code>irbem</code> lib
<code>get_sysaxes(dtype, carsph)</code>	will return the sysaxes according to the <code>irbem</code> library
<code>get_dtype(sysaxes)</code>	will return the coordinate system type as string
<code>prep_irbem([ticks, loci, alpha, extMag, ...])</code>	

2.5.4 spacepy.irbempy.get_AEP8

`spacepy.irbempy.get_AEP8(energy, loci, model='min', fluxtype='diff', particles='e')`
will return the flux from the AE8-AP8 model

Parameters - **energy (float)** : center energy in MeV; if `fluxtype=RANGE`, then needs to be a list [Emin, Emax]

- **loci (Coords)** [a `Coords` instance with the location inside the magnetosphere] optional instead of a `Coords` instance, one can also provide a list with [BBo, L] combination
- **model (str)** : MIN or MAX for solar cycle dependence
- **fluxtype (str)** : DIFF, RANGE, INT are possible types
- **particles (str)**: e or p or electrons or protons

Returns - **float** : flux from AE8/AP8 model

2.5.5 spacepy.irbempy.get_Bfield

`spacepy.irbempy.get_Bfield(ticks, loci, extMag='T01STORM', options=[1, 0, 0, 0, 0], omni-vals=None)`
call `get_bfield` in `irbem` lib and return a dictionary with the B-field vector and strenght.

Parameters - **ticks (Ticktock class)** : containing time information

- **loci (Coords class)** : containing spatial information

- **extMag (string)** [optional; will choose the external magnetic field model] possible values ['0', 'MEAD', 'T87SHORT', 'T87LONG', 'T89', 'OPQUIET', 'OPDYN', 'T96', 'OSTA', 'T01QUIET', 'T01STORM', 'T05', 'ALEX']
- options (optional list or array of integers length=5) : explained in Lstar
- omni values as dictionary (optional) : if not provided, will use lookup table
- (see Lstar documentation for further explanation)

Returns - results (dictionary) : containing keys: Bvec, and Blocal

See also:

`get_Lstar, find_Bmirror, find_magequator`

Examples

```
>>> import spacepy.time as spt
>>> import spacepy.coordinates as spc
>>> import spacepy.irbempy as ib
>>> t = spt.Ticktock(['2002-02-02T12:00:00', '2002-02-02T12:10:00'], 'ISO')
>>> y = spc.Coords([[3,0,0],[2,0,0]], 'GEO', 'car')
>>> ib.get_Bfield(t,y)
{'Blocal': array([ 976.42565251, 3396.25991675]),
 'Bvec': array([[ -5.01738885e-01, -1.65104338e+02, 9.62365503e+02],
 [ 3.33497974e+02, -5.42111173e+02, 3.33608693e+03]])}
```

2.5.6 spacepy.irbempy.get_Lm

`spacepy.irbempy.get_Lm(ticks, loci, alpha, extMag='T01STORM', intMag='IGRF', IGRFset=0, omnivals=None)`

Return the MacIlwain L value for a given location, time and model

Parameters - ticks (Ticktock class) : containing time information

- loci (Coords class) : containing spatial information
- alpha (list or ndarray) : pitch angles in degrees
- **extMag (string)** [optional; will choose the external magnetic field model] possible values ['0', 'MEAD', 'T87SHORT', 'T87LONG', 'T89', 'OPQUIET', 'OPDYN', 'T96', 'OSTA', 'T01QUIET', 'T01STORM', 'T05', 'ALEX']
- **intMag (string)** [optional: select the internal field model] possible values ['IGRF','EDIP','JC','GSFC','DUN','CDIP'] For full details see get_Lstar
- omni values as dictionary (optional) : if not provided, will use lookup table

Returns - results (dictionary) : containing keys: Lm, Bmin, Blocal (or Bmirr), Xj, MLT

if pitch angles provided in “alpha” then drift shells are calculated and “Bmirr” is returned if not provided, then “Blocal” at spacecraft is returned.

2.5.7 spacepy.irbempy.get_Lstar

`spacepy.irbempy.get_Lstar(ticks, loci, alpha=90, extMag='T01STORM', options=[1, 0, 0, 0, 0], omnivals=None)`

This will call `make_Lstar1` or `make_Lstar_shell_splitting_1` from the `irbem` library and will lookup omni values

for given time if not provided (optional). If pitch angles are provided, drift shell splitting will be calculated and “Bmirr” will be returned. If they are not provided, then no drift shell splitting is calculated and “Blocal” is returned.

Parameters - ticks (Ticktock class) : containing time information

- loci (Coords class) : containing spatial information
- **alpha (list or ndarray)** [optional pitch angles in degrees (default is 90);] if provided will calculate shell splitting; max 25 values
- **extMag (string)** [optional; will choose the external magnetic field model] possible values ['0', 'MEAD', 'T87SHORT', 'T87LONG', 'T89', 'OPQUIET', 'OPDYN', 'T96', 'OSTA', 'T01QUIET', 'T01STORM', 'T05', 'ALEX']
- options (optional list or array of integers length=5) : explained below
- omni values as dictionary (optional) : if not provided, will use lookup table

Returns - results (dictionary) : containing keys: Lm, Lstar, Bmin, Blocal (or Bmirr), Xj, MLT

if pitch angles provided in “alpha” then drift shells are calculated and “Bmirr” is returned if not provided, then “Blocal” at spacecraft is returned.

Notes

External Field

- 0 : no external field
- MEAD : Mead & Fairfield [1975] (uses $0 \leq Kp \leq 9$ - Valid for $rGEO \leq 17$. Re)
- T87SHORT: Tsyganenko short [1987] (uses $0 \leq Kp \leq 9$ - Valid for $rGEO \leq 30$. Re)
- T87LONG : Tsyganenko long [1987] (uses $0 \leq Kp \leq 9$ - Valid for $rGEO \leq 70$. Re)
- T89 : Tsyganenko [1989] (uses $0 \leq Kp \leq 9$ - Valid for $rGEO \leq 70$. Re)
- OPQUIET : Olson & Pfizter quiet [1977] (default - Valid for $rGEO \leq 15$. Re)
- OPDYN [Olson & Pfizter dynamic [1988] (uses $5. \leq \text{dens} \leq 50.$, $300. \leq \text{velo} \leq 500.$,] - $100. \leq \text{Dst} \leq 20$. - Valid for $rGEO \leq 60$. Re)
- T96 [Tsyganenko [1996] (uses $-100. \leq \text{Dst (nT)} \leq 20.$, $0.5 \leq \text{Pdyn (nPa)} < 10.$,] **IByIMF** (nT) $< 1 = 0.$, **BzIMF** (nT) < 10 . - Valid for $rGEO \leq 40$. Re)
- OSTA [Ostapenko & Maltsev [1997] (uses $\text{dst}, \text{Pdyn}, \text{BzIMF}, Kp$] T01QUIET: Tsyganenko [2002a,b] (uses $-50. < \text{Dst (nT)} < 20.$, $0.5 < \text{Pdyn (nPa)} \leq 5.$, **IByIMF** (nT) $< 5.$, **BzIMF** (nT) $< 5.$, $0. \leq G1 \leq 10.$, $0. \leq G2 \leq 10$. - Valid for $xGSM \geq -15$. Re)
- T01STORM: Tsyganenko, Singer & Kasper [2003] storm (uses Dst, Pdyn, ByIMF, BzIMF, G2, G3 - there is no upper or lower limit for those inputs - Valid for $xGSM \geq -15$. Re)
- T05 [Tsyganenko & Sitnov [2005] storm (uses Dst, Pdyn, ByIMF, BzIMF,] W1, W2, W3, W4, W5, W6 - no upper or lower limit for inputs - Valid for $xGSM \geq -15$. Re)

OMNI contents

- Kp: value of Kp as in OMNI2 files but has to be double instead of integer type
- Dst: Dst index (nT)
- dens: Solar Wind density (cm-3)
- velo: Solar Wind velocity (km/s)

- Pdyn: Solar Wind dynamic pressure (nPa)
- ByIMF: GSM y component of IMF mag. field (nT)
- BzIMF: GSM z component of IMF mag. field (nT)
- **G1: $G1 = \langle V_{sw} * (B_{perp}/40)^2 / (1 + B_{perp}/40) * \sin^3(\theta/2) \rangle$ where the $\langle \rangle$ mean an average over the previous 1 hour, V_{sw} is the solar wind speed, B_{perp} is the transverse IMF component (GSM) and θ is its clock angle.**
- **G2: $G2 = \langle a * V_{sw} * B_s \rangle$ where the $\langle \rangle$ mean an average over the previous 1 hour, V_{sw} is solar wind speed, $B_s = |IMF B_z|$ when $IMF B_z < 0$ and $B_s = 0$ when $IMF B_z > 0$, $a = 0.005$.**
- **G3: $G3 = \langle V_{sw} * D_{sw} * B_s / 2000 \rangle$ where the $\langle \rangle$ mean an average over the previous 1 hour, V_{sw} is the solar wind speed, D_{sw} is the solar wind density, $B_s = |IMF B_z|$ when $IMF B_z < 0$ and $B_s = 0$ when $IMF B_z > 0$.**
- W1 - W6: see definition in (JGR-A, v.110(A3), 2005.) (PDF 1.2MB)
- AL: the auroral index

Options

- 1st element: 0 - don't compute L^* or ϕ ; 1 - compute L^* ; 2- compute ϕ
- **2nd element: 0 - initialize IGRF field once per year (year.5);** n - n is the frequency (in days) starting on January 1st of each year (i.e. if options(2nd element)=15 then IGRF will be updated on the following days of the year: 1, 15, 30, 45 ...)
- **3rd element: resolution to compute L^* (0 to 9) where 0 is the recommended value to ensure a** good ratio precision/computation time (i.e. an error of ~2% at $L=6$). The higher the value the better will be the precision, the longer will be the computing time. Generally there is not much improvement for values larger than 4. Note that this parameter defines the integration step (θ) along the field line such as $d\theta = (2\pi) / (720 * [\text{options}(3\text{rd element}) + 1])$
- **4th element: resolution to compute L^* (0 to 9). The higher the value the better will be** the precision, the longer will be the computing time. It is recommended to use 0 (usually sufficient) unless L^* is not computed on a LEO orbit. For LEO orbit higher values are recommended. Note that this parameter defines the integration step (ϕ) along the drift shell such as $d\phi = (2\pi) / (25 * [\text{options}(4\text{th element}) + 1])$
- **5th element: allows to select an internal magnetic field model (default is set to IGRF)**
 - 0 = IGRF
 - 1 = Eccentric tilted dipole
 - 2 = Jensen&Cain 1960
 - 3 = GSFC 12/66 updated to 1970
 - 4 = User-defined model (Default: Centred dipole + uniform [Dungey open model])
 - 5 = Centred dipole

2.5.8 spacepy.irbempy.find_Bmirror

`spacepy.irbempy.find_Bmirror(ticks, loci, alpha, extMag='T01STORM', options=[1, 0, 0, 0, 0], omnivals=None)`

call `find_mirror_point` from `irbem` library and return a dictionary with values for Blocal, Bmirr and the GEO (cartesian) coordinates of the mirror point

Parameters `ticks` : Ticktock class

containing time information

loci [Coords class] containing spatial information

alpha [array-like] containing the pitch angles

extMag [str] optional; will choose the external magnetic field model possible values ['0', 'MEAD', 'T87SHORT', 'T87LONG', 'T89', 'OPQUIET', 'OPDYN', 'T96', 'OSTA', 'T01QUIET', 'T01STORM', 'T05', 'ALEX']

options [array-like (optional)] length=5 : explained in Lstar

omnivals [dict (optional)] if not provided, will use lookup table (see get_Lstar documentation for further explanation)

Returns results : dictionary

containing keys: Blocal, Bmirr, GEOcar

See also:

`get_Lstar`, `get_Bfield`, `find_magequator`

Examples

```
>>> t = Ticktock(['2002-02-02T12:00:00', '2002-02-02T12:10:00'], 'ISO')
>>> y = Coords([[3,0,0],[2,0,0]], 'GEO', 'car')
>>> ib.find_Bmirror(t,y,[90,80,60,10])
{'Blocal': array([ 0.,  0.]),
 'Bmirr': array([ 0.,  0.]),
 'loci': Coords( [[ NaN NaN NaN]
 [ NaN NaN NaN]] ), dtype=GEO,car, units=['Re', 'Re', 'Re']}
```

2.5.9 spacepy.irbempy.find_magequator

`spacepy.irbempy.find_magequator` (*ticks*, *loci*, *extMag*='T01STORM', *options*=[1, 0, 0, 0, 0], *omnivals*=None)

call `find_magequator` from `irbem` library and return a dictionary with values for Bmin and the GEO (cartesian) coordinates of the magnetic equator

Parameters - ticks (Ticktock class) : containing time information

- **loci** (Coords class) : containing spatial information
- **extMag (string)** [optional; will choose the external magnetic field model] possible values ['0', 'MEAD', 'T87SHORT', 'T87LONG', 'T89', 'OPQUIET', 'OPDYN', 'T96', 'OSTA', 'T01QUIET', 'T01STORM', 'T05', 'ALEX']
- **options** (optional list or array of integers length=5) : explained in Lstar
- **omni values as dictionary (optional)** : if not provided, will use lookup table
- (see Lstar documentation for further explanation)

Returns - results (dictionary) : containing keys: Bmin, Coords instance with GEO coordinates of the magnetic equator

See also:

`get_Lstar`, `get_Bfield`, `find_Bmirr`

Examples

```
>>> t = Ticktock(['2002-02-02T12:00:00', '2002-02-02T12:10:00'], 'ISO')
>>> y = Coords([[3,0,0],[2,0,0]], 'GEO', 'car')
>>> op.find_magequator(t,y)
{'Bmin': array([ 945.63652413, 3373.64496167]),
 'loci': Coords( [[ 2.99938371  0.00534151 -0.03213603]
 [ 2.00298822 -0.0073077  0.04584859]] ), dtype=GEO,car, units=['Re', 'Re', 'Re'])}
```

2.5.10 spacepy.irbempy.car2sph

spacepy.irbempy.**car2sph**(*CARin*)
coordinate transformation from cartesian to spherical

Parameters - **CARin** (list or ndarray) : coordinate points in (n,3) shape with n coordinate points in

units of [Re, Re, Re] = [x,y,z]

Returns - **results** (ndarray) : values after conversion to spherical coordinates in
radius, latitude, longitude in units of [Re, deg, deg]

See also:

[sph2car](#)

Examples

```
>>> sph2car([1,45,0])
array([ 0.70710678, 0. , 0.70710678])
```

2.5.11 spacepy.irbempy.sph2car

spacepy.irbempy.**sph2car**(*SPHin*)
coordinate transformation from spherical to cartesian

Parameters - **SPHin** (list or ndarray) : coordinate points in (n,3) shape with n coordinate points in
units of [Re, deg, deg] = [r, latitude, longitude]

Returns - **results** (ndarray) : values after conversion to cartesian coordinates x,y,z

See also:

[car2sph](#)

2.5.12 spacepy.irbempy.coord_trans

spacepy.irbempy.**coord_trans**(*loci, returntype, returncarsph*)
thin layer to call `coord_trans1` from `irbem` lib this will convert between systems GDZ, GEO, GSM, GSE, SM, GEI, MAG, SPH, RLL

Parameters - **loci** (Coords instance) : containing coordinate information, can contain n points

- **returntype** (str) : describing system as GDZ, GEO, GSM, GSE, SM, GEI, MAG, SPH, RLL

- `returncarsph (str)` : cartesian or spherical units 'car', 'sph'

Returns - `xout (ndarray)` : values after transformation in (n,3) dimensions

See also:

`sph2car, car2sph`

Examples

```
>>> c = Coords([[3,0,0],[2,0,0]], 'GEO', 'car')
>>> c.ticks = Ticktock(['2002-02-02T12:00:00', '2002-02-02T12:10:00'], 'ISO')
>>> coord_trans(c, 'GSM', 'car')
array([[ 2.8639301, -0.01848784,  0.89306361],
       [ 1.9124434,  0.07209424,  0.58082929]])
```

2.5.13 spacepy.irbempy.get_sysaxes

`spacepy.irbempy.get_sysaxes(dtype, carsph)`
will return the sysaxes according to the irbem library

Parameters - `dtype (str)` : coordinate system, possible values: GDZ, GEO, GSM, GSE, SM, GEI, MAG, SPH, RLL

- `carsph (str)` : cartesian or spherical, possible values: 'sph', 'car'

Returns - `sysaxes (int)` : value after oner_desp library from 0-8 (or None if not available)

See also:

`get_dtype`

2.5.14 spacepy.irbempy.get_dtype

`spacepy.irbempy.get_dtype(sysaxes)`
will return the coordinate system type as string

Parameters - `sysaxes (int)` : number according to the irbem, possible values: 0-8

Returns - `dtype (str)` : coordinate system GDZ, GEO, GSM, GSE, SM, GEI, MAG, SPH, RLL

- `carsph (str)` : cartesian or spherical 'car', 'sph'

See also:

`get_sysaxes`

2.5.15 spacepy.irbempy.prep_irbem

`spacepy.irbempy.prep_irbem(ticks=None, loci=None, alpha=[], extMag='T01STORM', options=[1, 0, 0, 0, 0], omnivals=None)`

2.6 lanlstar - module to calculate Lstar or Lmax using artificial neural network

Lstar and Lmax calculation using artificial neural network (ANN) technique.

This module requires the `ffnet` package.

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<code>LANLstar(inputdict, extMag)</code>	Calculate Lstar
<code>LANLmax(inputdict, extMag)</code>	Calculate last closed drift shell (Lmax)

2.6.1 spacepy.LANLstar.LANLstar

`spacepy.LANLstar.LANLstar(inputdict, extMag)`

Calculate Lstar

Based on the L* artificial neural network (ANN) trained from different magnetospheric field models.

Parameters `extMag` : list of string(s)

containing one or more of the following external magnetic field models: 'OPDYN', 'OPQUIET', 'T89', 'T96', 'T01QUIET', 'T01STORM', 'T05'

inputdict : dictionary

containing the following keys, each entry is a list or array. Note the keys for the above models are different.

—For OPDYN: ['Year', 'DOY', 'Hr', 'Dst', 'dens', 'velo', 'BzIMF', 'Lm', 'Bmirr', 'PA', 'rGSM', 'latGSM', 'lonGSM']

—For OPQUIET: ['Year', 'DOY', 'Hr', 'Dst', 'dens', 'velo', 'BzIMF', 'Lm', 'Bmirr', 'PA', 'rGSM', 'latGSM', 'lonGSM']

—For T89: ['Year', 'DOY', 'Hr', 'Kp', 'Pdyn', 'ByIMF', 'BzIMF', 'Lm', 'Bmirr', 'PA', 'rGSM', 'latGSM', 'lonGSM']

—For T96: ['Year', 'DOY', 'Hr', 'Dst', 'Pdyn', 'ByIMF', 'BzIMF', 'Lm', 'Bmirr', 'PA', 'rGSM', 'latGSM', 'lonGSM']

—For T01QUIET: ['Year', 'DOY', 'Hr', 'Dst', 'Pdyn', 'ByIMF', 'BzIMF', 'G1', 'G2', 'Lm', 'Bmirr', 'PA', 'rGSM', 'latGSM', 'lonGSM']

—For T01STORM: ['Year', 'DOY', 'Hr', 'Dst', 'Pdyn', 'ByIMF', 'BzIMF', 'G2', 'G3', 'Lm', 'Bmirr', 'PA', 'rGSM', 'latGSM', 'lonGSM']

—For T05: ['Year', 'DOY', 'Hr', 'Dst', 'Pdyn', 'ByIMF', 'BzIMF', 'W1', 'W2', 'W3', 'W4', 'W5', 'W6', 'Lm', 'Bmirr', 'PA', 'rGSM', 'latGSM', 'lonGSM']

– **For RAMSCB:** ['Year', 'DOY', 'Hr', 'Dst', 'Pdyn', 'ByIMF', 'BzIMF', 'PA', 'SMx', 'SMy', 'SMz']

Dictionaries with numpy vectors are allowed.

Returns out : dictionary

Lstar array for each key which corresponds to the specified magnetic field model.

Examples

```
>>> import spacepy.LANLstar as LS
>>>
>>> inputdict = {}
>>> inputdict['Kp']      = [2.7          ]      # Kp index
>>> inputdict['Dst']     = [7.7777       ]      # Dst index (nT)
>>> inputdict['dens']    = [4.1011       ]      # solar wind density (/cc)
>>> inputdict['velo']    = [400.1011     ]      # solar wind velocity (km/s)
>>> inputdict['Pdyn']    = [4.1011       ]      # solar wind dynamic pressure (nPa)
>>> inputdict['ByIMF']   = [3.7244       ]      # GSM y component of IMF magnetic field (nT)
>>> inputdict['BzIMF']   = [-0.1266      ]      # GSM z component of IMF magnetic field (nT)
>>> inputdict['G1']      = [1.029666    ]      # as defined in Tsganenko 2003
>>> inputdict['G2']      = [0.549334    ]
>>> inputdict['G3']      = [0.813999    ]
>>> inputdict['W1']      = [0.122444    ]      # as defined in Tsyganenko and Sitnov 2005
>>> inputdict['W2']      = [0.2514      ]
>>> inputdict['W3']      = [0.0892      ]
>>> inputdict['W4']      = [0.0478      ]
>>> inputdict['W5']      = [0.2258      ]
>>> inputdict['W6']      = [1.0461      ]
>>>
>>> inputdict['Year']    = [1996        ]
>>> inputdict['DOY']     = [6           ]
>>> inputdict['Hr']      = [1.2444      ]
>>>
>>> inputdict['Lm']      = [4.9360      ]      # McIlwain L
>>> inputdict['Bmirr']   = [315.6202    ]      # magnetic field strength at the mirror point
>>> inputdict['rGSM']    = [4.8341      ]      # radial coordinate in GSM [Re]
>>> inputdict['lonGSM']  = [-40.2663    ]      # longitude coordinate in GSM [deg]
>>> inputdict['latGSM']  = [36.44696    ]      # latitude coordiante in GSM [deg]
>>> inputdict['PA']      = [57.3874     ]      # pitch angle [deg]
>>> inputdict['SMx']     = [3.9783      ]
>>> inputdict['SMy']     = [-2.51335    ]
>>> inputdict['SMz']     = [1.106617    ]
>>>
>>> LS.LANLstar(inputdict, ['OPDYN', 'OPQUIET', 'T01QUIET', 'T01STORM', 'T89', 'T96', 'T05', 'RAMSCB'])
{'OPDYN': array([4.7171]),
 'OPQUIET': array([4.6673]),
 'T01QUIET': array([4.8427]),
 'T01STORM': array([4.8669]),
 'T89': array([4.5187]),
 'T96': array([4.6439]),
 'TS05': array([4.7174]),
 'RAMSCB': array([5.9609])}
```

2.6.2 spacepy.LANLstar.LANLmax

`spacepy.LANLstar.LANLmax` (*inputdict*, *extMag*)
Calculate last closed drift shell (Lmax)

Based on the L* artificial neural network (ANN) trained from different magnetospheric field models.

Parameters *extMag* : list of string(s)

containing one or more of the following external Magnetic field models: 'OPDYN', 'OPQUIET', 'T89', 'T96', 'T01QUIET', 'T01STORM', 'T05'

inputdict : dictionary

containing the following keys, each entry is a list or array. Note the keys for the above models are different.

—For OPDYN: ['Year', 'DOY', 'Hr', 'Dst', 'dens', 'velo', 'BzIMF', 'PA']

– For OPQUIET: ['Year', 'DOY', 'Hr', 'Dst', 'dens', 'velo', 'BzIMF', 'PA']

—For T89: ['Year', 'DOY', 'Hr', 'Kp', 'Pdyn', 'ByIMF', 'BzIMF', 'PA']

– For T96: ['Year', 'DOY', 'Hr', 'Dst', 'Pdyn', 'ByIMF', 'BzIMF', 'PA']

—For T01QUIET: ['Year', 'DOY', 'Hr', 'Dst', 'Pdyn', 'ByIMF', 'BzIMF', 'G1', 'G2', 'PA']

– For T01STORM: ['Year', 'DOY', 'Hr', 'Dst', 'Pdyn', 'ByIMF', 'BzIMF', 'G2', 'G3', 'PA']

—For T05: ['Year', 'DOY', 'Hr', 'Dst', 'Pdyn', 'ByIMF', 'BzIMF', 'W1', 'W2', 'W3', 'W4', 'W5', 'W6', 'PA']

Dictionaries with numpy vectors are allowed.

Returns *out* : dictionary

Lmax array for each key which corresponds to the specified magnetic field model.

Examples

```
>>> import spacepy.LANLstar as LS
>>>
>>> inputdict = {}
>>> inputdict['Kp']      = [2.7          ]      # Kp index
>>> inputdict['Dst']     = [7.7777      ]      # Dst index (nT)
>>> inputdict['dens']    = [4.1011      ]      # solar wind density (/cc)
>>> inputdict['velo']    = [400.1011    ]      # solar wind velocity (km/s)
>>> inputdict['Pdyn']    = [4.1011      ]      # solar wind dynamic pressure (nPa)
>>> inputdict['ByIMF']   = [3.7244      ]      # GSM y component of IMF magnetic field (nT)
>>> inputdict['BzIMF']   = [-0.1266     ]      # GSM z component of IMF magnetic field (nT)
>>> inputdict['G1']      = [1.029666    ]      # as defined in Tsganenko 2003
>>> inputdict['G2']      = [0.549334    ]
>>> inputdict['G3']      = [0.813999    ]
>>> inputdict['W1']      = [0.122444    ]      # as defined in Tsyganenko and Sitnov 2005
>>> inputdict['W2']      = [0.2514      ]
```

```
>>> inputdict['W3']      = [0.0892   ]
>>> inputdict['W4']      = [0.0478   ]
>>> inputdict['W5']      = [0.2258   ]
>>> inputdict['W6']      = [1.0461   ]
>>>
>>> inputdict['Year']     = [1996     ]
>>> inputdict['DOY']      = [6         ]
>>> inputdict['Hr']       = [1.2444   ]
>>>
>>> inputdict['PA']       = [57.3874   ]          # pitch angle [deg]
>>>
>>> LS.LANLmax(inputdict, ['OPDYN','OPQUIET','T01QUIET','T01STORM','T89','T96','T05'])
{'OPDYN': array([10.6278]),
 'OPQUIET': array([9.3352]),
 'T01QUIET': array([10.0538]),
 'T01STORM': array([9.9300]),
 'T89': array([8.2888]),
 'T96': array([9.2410]),
 'T05': array([9.9295])}
```

spacepy.LANLstar.**LANLstar** (*inputdict*, *extMag*)

Calculate Lstar

Based on the L* artificial neural network (ANN) trained from different magnetospheric field models.

Parameters *extMag* : list of string(s)

containing one or more of the following external magnetic field models: 'OPDYN', 'OPQUIET', 'T89', 'T96', 'T01QUIET', 'T01STORM', 'T05'

inputdict : dictionary

containing the following keys, each entry is a list or array. Note the keys for the above models are different.

—For OPDYN: ['Year', 'DOY', 'Hr', 'Dst', 'dens', 'velo', 'BzIMF', 'Lm', 'Bmirr', 'PA', 'rGSM', 'latGSM', 'lonGSM']

– **For OPQUIET:** ['Year', 'DOY', 'Hr', 'Dst', 'dens', 'velo', 'BzIMF', 'Lm', 'Bmirr', 'PA', 'rGSM', 'latGSM', 'lonGSM']

—For T89: ['Year', 'DOY', 'Hr', 'Kp', 'Pdyn', 'ByIMF', 'BzIMF', 'Lm', 'Bmirr', 'PA', 'rGSM', 'latGSM', 'lonGSM']

– **For T96:** ['Year', 'DOY', 'Hr', 'Dst', 'Pdyn', 'ByIMF', 'BzIMF', 'Lm', 'Bmirr', 'PA', 'rGSM', 'latGSM', 'lonGSM']

—For T01QUIET: ['Year', 'DOY', 'Hr', 'Dst', 'Pdyn', 'ByIMF', 'BzIMF', 'G1', 'G2', 'Lm', 'Bmirr', 'PA', 'rGSM', 'latGSM', 'lonGSM']

– **For T01STORM:** ['Year', 'DOY', 'Hr', 'Dst', 'Pdyn', 'ByIMF', 'BzIMF', 'G2', 'G3', 'Lm', 'Bmirr', 'PA', 'rGSM', 'latGSM', 'lonGSM']

—For T05: ['Year', 'DOY', 'Hr', 'Dst', 'Pdyn', 'ByIMF', 'BzIMF', 'W1', 'W2', 'W3', 'W4', 'W5', 'W6', 'Lm', 'Bmirr', 'PA', 'rGSM', 'latGSM', 'lonGSM']

– **For RAMSCB:** ['Year', 'DOY', 'Hr', 'Dst', 'Pdyn', 'ByIMF', 'BzIMF', 'PA', 'SMx', 'SMy', 'SMz']

Dictionaries with numpy vectors are allowed.

Returns out : dictionary

Lstar array for each key which corresponds to the specified magnetic field model.

Examples

```
>>> import spacepy.LANLstar as LS
>>>
>>> inputdict = {}
>>> inputdict['Kp'] = [2.7] # Kp index
>>> inputdict['Dst'] = [7.7777] # Dst index (nT)
>>> inputdict['dens'] = [4.1011] # solar wind density (/cc)
>>> inputdict['velo'] = [400.1011] # solar wind velocity (km/s)
>>> inputdict['Pdyn'] = [4.1011] # solar wind dynamic pressure (nPa)
>>> inputdict['ByIMF'] = [3.7244] # GSM y component of IMF magnetic field (nT)
>>> inputdict['BzIMF'] = [-0.1266] # GSM z component of IMF magnetic field (nT)
>>> inputdict['G1'] = [1.029666] # as defined in Tsganenko 2003
>>> inputdict['G2'] = [0.549334]
>>> inputdict['G3'] = [0.813999]
>>> inputdict['W1'] = [0.122444] # as defined in Tsyganenko and Sitnov 2005
>>> inputdict['W2'] = [0.2514]
>>> inputdict['W3'] = [0.0892]
>>> inputdict['W4'] = [0.0478]
>>> inputdict['W5'] = [0.2258]
>>> inputdict['W6'] = [1.0461]
>>>
>>> inputdict['Year'] = [1996]
>>> inputdict['DOY'] = [6]
>>> inputdict['Hr'] = [1.2444]
>>>
>>> inputdict['Lm'] = [4.9360] # McIlwain L
>>> inputdict['Bmirr'] = [315.6202] # magnetic field strength at the mirror point
>>> inputdict['rGSM'] = [4.8341] # radial coordinate in GSM [Re]
>>> inputdict['lonGSM'] = [-40.2663] # longitude coordrinete in GSM [deg]
>>> inputdict['latGSM'] = [36.44696] # latitude coordiante in GSM [deg]
>>> inputdict['PA'] = [57.3874] # pitch angle [deg]
>>> inputdict['SMx'] = [3.9783]
>>> inputdict['SMy'] = [-2.51335]
>>> inputdict['SMz'] = [1.106617]
>>>
>>> LS.LANLstar(inputdict, ['OPDYN', 'OPQUIET', 'T01QUIET', 'T01STORM', 'T89', 'T96', 'T05', 'RAMSCB'])
{'OPDYN': array([4.7171]),
 'OPQUIET': array([4.6673]),
 'T01QUIET': array([4.8427]),
 'T01STORM': array([4.8669]),
 'T89': array([4.5187]),
 'T96': array([4.6439]),
 'TS05': array([4.7174]),
 'RAMSCB': array([5.9609])}
```

spacepy.LANLstar.LANLmax(inputdict, extMag)
Calculate last closed drift shell (Lmax)

Based on the L* artificial neural network (ANN) trained from different magnetospheric field models.

Parameters `extMag` : list of string(s)

containing one or more of the following external Magnetic field models: 'OPDYN', 'OPQUIET', 'T89', 'T96', 'T01QUIET', 'T01STORM', 'T05'

inputdict : dictionary

containing the following keys, each entry is a list or array. Note the keys for the above models are different.

—For OPDYN: ['Year', 'DOY', 'Hr', 'Dst', 'dens', 'velo', 'BzIMF', 'PA']

– For OPQUIET: ['Year', 'DOY', 'Hr', 'Dst', 'dens', 'velo', 'BzIMF', 'PA']

—For T89: ['Year', 'DOY', 'Hr', 'Kp', 'Pdyn', 'ByIMF', 'BzIMF', 'PA']

– For T96: ['Year', 'DOY', 'Hr', 'Dst', 'Pdyn', 'ByIMF', 'BzIMF', 'PA']

—For T01QUIET: ['Year', 'DOY', 'Hr', 'Dst', 'Pdyn', 'ByIMF', 'BzIMF', 'G1', 'G2', 'PA']

– For T01STORM: ['Year', 'DOY', 'Hr', 'Dst', 'Pdyn', 'ByIMF', 'BzIMF', 'G2', 'G3', 'PA']

—For T05: ['Year', 'DOY', 'Hr', 'Dst', 'Pdyn', 'ByIMF', 'BzIMF', 'W1', 'W2', 'W3', 'W4', 'W5', 'W6', 'PA']

Dictionaries with numpy vectors are allowed.

Returns `out` : dictionary

Lmax array for each key which corresponds to the specified magnetic field model.

Examples

```
>>> import spacepy.LANLstar as LS
>>>
>>> inputdict = {}
>>> inputdict['Kp']      = [2.7          ]          # Kp index
>>> inputdict['Dst']     = [7.7777      ]          # Dst index (nT)
>>> inputdict['dens']    = [4.1011      ]          # solar wind density (/cc)
>>> inputdict['velo']    = [400.1011    ]          # solar wind velocity (km/s)
>>> inputdict['Pdyn']    = [4.1011      ]          # solar wind dynamic pressure (nPa)
>>> inputdict['ByIMF']   = [3.7244      ]          # GSM y component of IMF magnetic field (nT)
>>> inputdict['BzIMF']   = [-0.1266     ]          # GSM z component of IMF magnetic field (nT)
>>> inputdict['G1']      = [1.029666    ]          # as defined in Tsganenko 2003
>>> inputdict['G2']      = [0.549334    ]
>>> inputdict['G3']      = [0.813999    ]
>>> inputdict['W1']      = [0.122444    ]          # as defined in Tsyganenko and Sitnov 2005
>>> inputdict['W2']      = [0.2514      ]
>>> inputdict['W3']      = [0.0892      ]
>>> inputdict['W4']      = [0.0478      ]
>>> inputdict['W5']      = [0.2258      ]
>>> inputdict['W6']      = [1.0461      ]
>>>
```



```

>>> inputdict['Year'] = [1996      ]
>>> inputdict['DOY'] = [6          ]
>>> inputdict['Hr'] = [1.2444     ]
>>>
>>> inputdict['PA'] = [57.3874     ] # pitch angle [deg]
>>>
>>> LS.LANLmax(inputdict, ['OPDYN', 'OPQUIET', 'T01QUIET', 'T01STORM', 'T89', 'T96', 'T05'])
{'OPDYN': array([10.6278]),
 'OPQUIET': array([9.3352]),
 'T01QUIET': array([10.0538]),
 'T01STORM': array([9.9300]),
 'T89': array([8.2888]),
 'T96': array([9.2410]),
 'T05': array([9.9295])}

```

2.7 omni - module to read and process NASA OMNIWEB data

Tools to read and process omni data (Qin-Denton, etc.)

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2.7.1 About omni

The omni module primarily manages the hourly OMNI2 and Qin-Denton data, which are sourced from the Virtual Radiation Belt Observatory ([ViRBO](#)), who maintain these data sources. The data can be kept up-to-date in SpacePy using the `update()` function in the `spacepy.toolbox` module.

The OMNI2 data combines data from a variety of satellites that sample the solar wind (notably ACE and Wind), and propagates the data to Earth's bow shock nose. The [Qin-Denton](#) data is derived from the OMNI2 data and is designed for providing input to the Tsyganenko magnetic field models. The later Tsyganenko magnetic field models require subsidiary parameters (G- and W-parameters) that are pre-calculated in the Qin-Denton data. Further, the Qin-Denton data contains no data gaps – all gaps are filled (for details on the gap filling, see the paper by [Qin et al.](#)).

2.7.2 Advanced features

Higher resolution data, or custom data sources, can also be managed/accessed with this module, although this is considered an advanced use for this module. This is achieved using custom names for the `dbase` keyword in `get_omni`, which must be defined in the SpacePy configuration file (for a user-install on linux, this is `~/spacepy/spacepy.rc`; see [SpacePy Configuration](#)). An example of the formatting required is

```
qd1min: /usr/somedir/QinDenton/YYYY/QinDenton_YYYYMMDD_1min.txt
```

In this example the custom data source name is `qd1min`. Wildcard substitutions can be made for the year (YYYY), month (MM) and day (DD). Future updates will give more flexibility in data storage model, but currently we assume that all custom data sources follow a convention in which the data files are daily, and the files are organized into folders by year. The year, month and day must all be specified in the filename.

Currently there are some restrictions on the data format for custom data sources. The stored data must currently be stored as JSON-headed ASCII. If data conversions are required, then a valid dictionary of conversion functions must be supplied via the `convert` keyword argument. See `readJSONheadedASCII()` for details. Additionally, by default this will interpolate the data to the requested time ticks. To return only the actual recorded data values for the specified time range set the keyword argument `interp` to `False`.

<code>get_omni(ticks[, dbase])</code>	Returns Qin-Denton OMNI values, interpolated to any time-base from a default hourly resolution
<code>omnirange([dbase])</code>	Returns datetimes giving start and end times in the OMNI/Qin-Denton data

2.7.3 spacepy.omni.get_omni

`spacepy.omni.get_omni(ticks, dbase='QDhourly', **kwargs)`

Returns Qin-Denton OMNI values, interpolated to any time-base from a default hourly resolution

The update function in toolbox retrieves all available hourly Qin-Denton data, and this function accesses that and interpolates to the given times, returning the OMNI values as a SpaceData (dict-like) with Kp, Dst, dens, velo, Pdyn, ByIMF, BzIMF, G1, G2, G3, etc. (see also <http://www.dartmouth.edu/~rdenton/magpar/index.html> and <http://www.agu.org/pubs/crossref/2007/2006SW000296.shtml>)

Parameters `ticks` : Ticktock class or array-like of datetimes

time values for desired output

`dbase` : str (optional)

Select data source, options are 'QDhourly', 'OMNI2', 'Mergedhourly' Note - Custom data sources can be specified in the spacepy config file as described in the module documentation.

Returns `out` : `spacepy.datamodel.SpaceData`

containing all Qin-Denton values at times given by ticks

Notes

Note about Qbits: If the status variable is 2, the quantity you are using is fairly well determined. If it is 1, the value has some connection to measured values, but is not directly measured. These values are still better than just using an average value, but not as good as those with the status variable equal to 2. If the status variable is 0, the quantity is based on average quantities, and the values listed are no better than an average value. The lower the status variable, the less confident you should be in the value.

Examples

```
>>> import spacepy.time as spt
>>> import spacepy.omni as om
>>> ticks = spt.Ticktock(['2002-02-02T12:00:00', '2002-02-02T12:10:00'], 'ISO')
>>> d = om.get_omni(ticks)
>>> d.tree(levels=1)
+
| ____ByIMF
| ____Bz1
| ____Bz2
| ____Bz3
| ____Bz4
| ____Bz5
| ____Bz6
| ____BzIMF
| ____DOY
| ____Dst
| ____G1
| ____G2
```

```
| ____G3
| ____Hr
| ____Kp
| ____Pdyn
| ____Qbits
| ____RDT
| ____UTC
| ____W1
| ____W2
| ____W3
| ____W4
| ____W5
| ____W6
| ____Year
| ____akp3
| ____dens
| ____ticks
| ____velo
```

2.7.4 spacepy.omni.omnirange

`spacepy.omni.omnirange` (*dbase='QDhourly'*)

Returns datetimes giving start and end times in the OMNI/Qin-Denton data

The update function in toolbox retrieves all available hourly Qin-Denton data, and this function accesses that and looks up the start and end times, returning them as datetime objects.

Parameters `dbase` : string (optional)

name of omni database to check. Currently 'QDhourly' and 'OMNI2hourly'

Returns `omnirange` : tuple

containing two datetimes giving the start and end times of the available data

Examples

```
>>> import spacepy.omni as om
>>> om.omnirange()
(datetime.datetime(1963, 1, 1, 0, 0), datetime.datetime(2011, 11, 30, 23, 0))
>>> om.omnirange(dbase='OMNI2hourly')
(datetime.datetime(1963, 1, 1, 0, 0), datetime.datetime(2011, 11, 30, 23, 0))
```

2.8 plot - Plot, various specialized plotting functions and associated utilities

plot: SpacePy specialized plotting routines

This package provides classes to plot various types of space physics data.

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<code>spectrogram</code>	Create and plot generic ‘spectrograms’ for space science.
<code>utils</code>	Utility routines for plotting and related activities

2.8.1 `spacepy.plot.spectrogram`

Create and plot generic ‘spectrograms’ for space science. This is not a signal processing routine and does not apply Fourier transforms (or similar) to the data. The functionality provided here is the binning (and averaging) of multi-dimensional to provide a 2D output map of some quantity as a function of two parameters. An example would be particle data from a satellite mission: electron flux, at a given energy, can be binned as a function of both time and McIlwain L, then plotted as a 2D color-map, colloquially known as a spectrogram.

In many other settings ‘spectrogram’ refers to a transform of data from the time domain to the frequency domain, and the subsequent plotting of some quantity (e.g., power spectral density) as a function of time and frequency. To approximate this functionality for, e.g., time-series magnetic field data you would first calculate the power spectral density and then use `spectrogram` to rebin the data for visualization.

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<code>spectrogram(data, **kwargs)</code>	This class rebins data to produce a 2D data map that can be plotted as a spectrogram
--	--

`spacepy.plot.spectrogram.spectrogram`

class `spacepy.plot.spectrogram.spectrogram`(*data*, ***kwargs*)

This class rebins data to produce a 2D data map that can be plotted as a spectrogram

It is meant to be used on arbitrary data series. The first series “x” is plotted on the abscissa and second series “y” is plotted on the ordinate and the third series “z” is plotted in color.

The series are not passed in independently but instead inside a `SpaceData` container.

Parameters *data* : `SpaceData`

The data for the spectrogram, the variables to be used default to “Epoch” for x, “Energy” for y, and “Flux” for z. Other names are specified using the ‘variables’ keyword. All keywords override .attrs contents.

Other Parameters *variables* : list

keyword containing the names of the variables to use for the spectrogram the list is a list of the `SpaceData` keys in x, y, z, order

bins : list

if the name “bins” is not specified in the .attrs of the `dmarray` variable this specifies the bins for each variable in a `[[xbins], [ybins]]` format

xlim : list

if the name “lim” is not specified in the .attrs of the `dmarray` variable this specifies the limit for the x variable `[xlow, xhigh]`

ylim : list

if the name “lim” is not specified in the .attrs of the `dmarray` variable this specifies the limit for the y variable `[ylow, yhigh]`

zlim : list

if the name “lim” is not specified in the .attrs of the dmarray variable this specifies the limit for the z variable [zlow, zhigh]

extended_out : bool (optional)

if this is True add more information to the output data model (default False)

Notes

Helper routines are planned to facilitate the creation of the SpaceData container if the data are not in the format.

`plot([fignum, axis])` Plot the spectrogram

plot (*fignum=None, axis=None, **kwargs*)

Plot the spectrogram

Other Parameters **title** : str

plot title (default “”)

xlabel : str

x axis label (default “”)

ylabel : str

y axis label (default “”)

colorbar_label : str

colorbar label (default “”)

DateFormatter : matplotlib.dates.DateFormatter

The formatting to use on the dates on the x-axis (default matplotlib.dates.DateFormatter(“%d %b %Y”))

zlog : bool

plot the z variable on a log scale (default True)

colorbar : bool

plot the colorbar (default True)

axis : matplotlib axis object

axis to plot the spectrogram to

zlim : np.array

array like 2 element that overrides (interior) the spectrogram zlim (default spectrogram.specSettings[‘zlim’])

figsize : tuple (optional)

tuple of size to pass to figure(), None does the default

2.8.2 spacepy.plot.utils

Utility routines for plotting and related activities

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Classes

<code>EventClicker([ax, n_phases, interval, ...])</code>	Presents a provided figure (normally a time series) and provides an interface to mark
--	---

spacepy.plot.utils.EventClicker

```
class spacepy.plot.utils.EventClicker(ax=None,          n_phases=1,          interval=None,
                                       auto_interval=None, auto_scale=True,  ymin=None,
                                       ymax=None, line=None)
```

Presents a provided figure (normally a time series) and provides an interface to mark events shown in the plot. The user interface is explained in `analyze()` and results are returned by `get_events()`

Other Parameters `ax` : `matplotlib.axes.AxesSubplot`

The subplot to display and grab data from. If not provided, the current subplot is grabbed from `gca()` (Lookup of the current subplot is done when `analyze()` is called.)

n_phases : int (optional, default 1)

number of phases to an event, i.e. number of subevents to mark. E.g. for a storm where one wants the onset and the minimum, set `n_phases` to 2 and double click on the onset, then minimum, and then the next double-click will be onset of the next storm.

interval : (optional)

Size of the X window to show. This should be in units that can be added to/subtracted from individual elements of x (e.g. `timedelta` if x is a series of `datetime`.) Defaults to showing the entire plot.

auto_interval : boolean (optional)

Automatically adjust interval based on the average distance between selected events. Default is `True` if interval is not specified; `False` if interval is specified.

auto_scale : boolean (optional, default `True`):

Automatically adjust the Y axis to match the data as the X axis is panned.

ymin : (optional, default `None`)

If `auto_scale` is `True`, the bottom of the autoscaled Y axis will never be above `ymin` (i.e. `ymin` will always be shown on the plot). This prevents the autoscaling from blowing up very small features in mostly flat portions of the plot. The user can still manually zoom in past this point. The autoscaler will always zoom out to show the data.

ymax : (optional, default `None`)

Similar to `ymin`, but the top of the Y axis will never be below `ymax`.

line : matplotlib.lines.Line2D (optional)

Specify the matplotlib line object to use for autoscaling the Y axis. If this is not specified, the first line object on the provided subplot will be used. This should usually be correct.

Examples

```
>>> import spacepy.plot.utils
>>> import numpy
>>> import matplotlib.pyplot as plt
>>> x = numpy.arange(630) / 100.0 * numpy.pi
>>> y = numpy.sin(x)
>>> clicker = spacepy.plot.utils.EventClicker(
...     n_phases=2, #Two picks per event
...     interval=numpy.pi * 2) #Display one cycle at a time
>>> plt.plot(x, y)
>>> clicker.analyze() #Double-click on max and min of each cycle; close
>>> e = clicker.get_events()
>>> peaks = e[:, 0, 0] #x value of event starts
>>> peaks -= 2 * numpy.pi * numpy.floor(peaks / (2 * numpy.pi)) #mod 2pi
>>> max(numpy.abs(peaks - numpy.pi / 2)) < 0.2 #Peaks should be near pi/2
True
>>> troughs = e[:, 1, 0] #x value of event ends
>>> troughs -= 2 * numpy.pi * numpy.floor(troughs / (2 * numpy.pi))
>>> max(numpy.abs(peaks - 3 * numpy.pi / 2)) < 0.2 #troughs near 3pi/2
True
>>> d = clicker.get_events_data() #snap-to-data of events
>>> peakvals = d[:, 0, 1] #y value, snapped near peaks
>>> max(peakvals) <= 1.0 #should peak at 1
True
>>> min(peakvals) > 0.9 #should click near 1
True
>>> troughvals = d[:, 1, 1] #y value, snapped near peaks
>>> max(troughvals) <= -0.9 #should click near -1
True
>>> min(troughvals) <= -1.0 #should bottom-out at -1
True
```

<code>analyze()</code>	Displays the figure provided and allows the user to select events.
<code>get_events()</code>	Get back the list of events.
<code>get_events_data()</code>	Get a list of events, “snapped” to the data.

`analyze()`

Displays the figure provided and allows the user to select events.

All matplotlib controls for zooming, panning, etc. the figure remain active.

Double left click Mark this point as an event phase. One-phase events are the simplest: they occur at a particular time. Two-phase events have two times associated with them; an example is any event with a distinct start and stop time. In that case, the first double-click would mark the beginning, the second one, the end; the next double-click would mark the beginning of the next event. Each phase of an event is annotated with a vertical line on the plot; the color and line style is the same for all events, but different for each phase.

After marking the final phase of an event, the X axis will scroll and zoom to place that phase near the left of the screen and include one full interval of data (as defined in the constructor). The Y axis will

be scaled to cover the data in that X range.

Double right click or delete button Remove the last marked event phase. If an entire event (i.e., the first phase of an event) is removed, the X axis will be scrolled left to the previous event and the Y axis will be scaled to cover the data in the new range.

Space bar Scroll the X axis by one interval. Y axis will be scaled to cover the data.

When finished, close the figure window (if necessary) and call `get_events()` to get the list of events.

get_events()

Get back the list of events.

Call after `analyze()`.

Returns out : array

3-D array of (x, y) values clicked on. Shape is (n_events, n_phases, 2), i.e. indexed by event number, then phase of the event, then (x, y).

get_events_data()

Get a list of events, “snapped” to the data.

For each point selected as a phase of an event, selects the point from the original data which is closest to the clicked point. Distance from point to data is calculated based on the screen distance, not in data coordinates.

Note that this snaps to data points, not to the closest point on the line between points.

Call after `analyze()`.

Returns out : array

3-D array of (x, y) values in the data which are closest to each point clicked on. Shape is (n_events, n_phases, 2), i.e. indexed by event number, then phase of the event, then (x, y).

Functions

<code>add_logo(img[, fig, pos, margin])</code>	Add an image (logo) to one corner of a plot.
<code>annotate_xaxis(txt[, ax])</code>	Write text in-line and to the right of the x-axis tick labels
<code>applySmartTimeTicks(ax, time[, dolimit])</code>	Given an axis ‘ax’ and a list/array of datetime objects, ‘time’, use the smartTimeTicks
<code>collapse_vertical(combine[, others, leave_axis])</code>	Collapse the vertical spacing between two or more subplots.
<code>printfig(fignum[, saveonly, pngonly, clean, ...])</code>	save current figure to file and call lpr (print).
<code>shared_ylabel(axes, txt, *args, **kwargs)</code>	Create a ylabel that spans several subplots
<code>show_used([fig])</code>	Show the areas of a figure which are used/occupied by plot elements.
<code>smartTimeTicks(time)</code>	Returns major ticks, minor ticks and format for time-based plots
<code>timestamp([position, size, draw])</code>	print a timestamp on the current plot, vertical lower right

spacepy.plot.utils.add_logo

`spacepy.plot.utils.add_logo(img, fig=None, pos='br', margin=0.05)`

Add an image (logo) to one corner of a plot.

The provided image will be placed in a corner of the plot and sized to maintain its aspect ratio and be as large as possible without overlapping any existing elements of the figure. Thus this should be the last call in constructing a figure.

Parameters **img** : str or numpy.ndarray

The image to place on the figure. If a string, assumed to be a filename to be read with `imread()`; if a numpy array, assumed to be the image itself (in a similar format).

Returns `(axes, axesimg)` : tuple of Axes and AxesImage

The `Axes` object created to hold the image, and the `AxesImage` object for the image itself.

Other Parameters `fig` : matplotlib.figure.Figure

The figure on which to place the logo; if not specified, the `gcf()` function will be used.

`pos` : str

The position to place the logo. br: bottom right; bl: bottom left; tl: top left; tr: top right

`margin` : float

Margin to include on each side of figure, as a fraction of the larger dimension of the figure (width or height). Default is 0.05 (5%).

Notes

Calls `draw()` to ensure locations are up to date.

Examples

```
>>> import spacepy.plot.utils
>>> import matplotlib.pyplot as plt
>>> fig = plt.figure()
>>> ax0 = fig.add_subplot(211)
>>> ax0.plot([1, 2, 3], [1, 2, 1])
[<matplotlib.lines.Line2D at 0x00000000>]
>>> ax1 = fig.add_subplot(212)
>>> ax1.plot([1, 2, 3], [2, 1, 2])
[<matplotlib.lines.Line2D at 0x00000000>]
>>> spacepy.plot.utils.add_logo('logo.png', fig)
(<matplotlib.axes.Axes at 0x00000000>,
 <matplotlib.image.AxesImage at 0x00000000>)
```

spacepy.plot.utils.annotate_xaxis

`spacepy.plot.utils.annotate_xaxis(txt, ax=None)`

Write text in-line and to the right of the x-axis tick labels

Annotates the x axis of an `Axes` object with text placed in-line with the tick labels and immediately to the right of the last label. This is formatted to match the existing tick marks.

Parameters `txt` : str

The annotation text.

Returns `out` : matplotlib.text.Text

The `Text` object for the annotation.

Other Parameters `ax` : matplotlib.axes.Axes

The axes to annotate; if not specified, the `gca()` function will be used.

Notes

The annotation is placed *immediately* to the right of the last tick label. Generally the first character of `txt` should be a space to allow some room.

Calls `draw()` to ensure tick marker locations are up to date.

Examples

```
>>> import spacepy.plot.utils
>>> import matplotlib.pyplot as plt
>>> import datetime
>>> times = [datetime.datetime(2010, 1, 1) + datetime.timedelta(hours=i)
...         for i in range(0, 48, 3)]
>>> plt.plot(times, range(16))
[<matplotlib.lines.Line2D object at 0x0000000>]
>>> spacepy.plot.utils.annotate_xaxis(' UT') #mark that times are UT
<matplotlib.text.Text object at 0x0000000>
```

spacepy.plot.utils.applySmartTimeTicks

`spacepy.plot.utils.applySmartTimeTicks(ax, time, dolimit=True)`

Given an axis ‘ax’ and a list/array of datetime objects, ‘time’, use the `smartTimeTicks` function to build smart time ticks and then immediately apply them to the given axis. The first and last elements of the time list will be used as bounds for the x-axis range.

The range of the ‘time’ input value will be used to set the limits of the x-axis as well. Set kwarg ‘dolimit’ to False to override this behavior.

Parameters `ax` : `matplotlib.pyplot.Axes`

A `matplotlib` Axis object.

time : list

list of datetime objects

dolimit : boolean (optional)

The range of the ‘time’ input value will be used to set the limits of the x-axis as well.

Setting this overrides this behavior.

See also:

`smartTimeTicks`

spacepy.plot.utils.collapse_vertical

`spacepy.plot.utils.collapse_vertical(combine, others=[], leave_axis=False)`

Collapse the vertical spacing between two or more subplots.

Useful for a multi-panel plot where most subplots should have space between them but several adjacent ones should not (i.e., appear as a single plot.) This function will remove all the vertical space between the subplots listed in `combine` and redistribute the space between all of the subplots in both `combine` and `others` in proportion to their current size, so that the relative size of the subplots does not change.

Parameters `combine` : list

The `Axes` objects (i.e. subplots) which should be placed together with no vertical space.

Other Parameters `others` : list

The `Axes` objects (i.e. subplots) which will keep their vertical spacing, but will be expanded with the space taken away from between the elements of `combine`.

leave_axis : bool

If set to true, will leave the axis lines and tick marks between the collapsed subplots. By default, the axis line (“spine”) is removed so the two subplots appear as one.

Notes

This function can be fairly fragile and should only be used for fairly simple layouts, e.g., a one-column multi-row plot stack.

This may require some clean-up of the y axis labels, as they are likely to overlap.

Examples

```
>>> import spacepy.plot.utils
>>> import matplotlib.pyplot as plt
>>> fig = plt.figure()
>>> #Make three stacked subplots
>>> ax0 = fig.add_subplot(311)
>>> ax1 = fig.add_subplot(312)
>>> ax2 = fig.add_subplot(313)
>>> ax0.plot([1, 2, 3], [1, 2, 1]) #just make some lines
[<matplotlib.lines.Line2D object at 0x0000000>]
>>> ax1.plot([1, 2, 3], [1, 2, 1])
[<matplotlib.lines.Line2D object at 0x0000000>]
>>> ax2.plot([1, 2, 3], [1, 2, 1])
[<matplotlib.lines.Line2D object at 0x0000000>]
>>> #Collapse space between top two plots, leave bottom one alone
>>> spacepy.plot.utils.collapse_vertical([ax0, ax1], [ax2])
```

spacepy.plot.utils.printfig

`spacepy.plot.utils.printfig` (*fignum*, *saveonly=False*, *pngonly=False*, *clean=False*, *filename=None*)
save current figure to file and call `lpr` (print).

This routine will create a total of 3 files (png, ps and c.png) in the current working directory with a sequence number attached. Also, a time stamp and the location of the file will be imprinted on the figure. The file ending with c.png is clean and no directory or time stamp are attached (good for PowerPoint presentations).

Parameters `fignum` : integer

matplotlib figure number

saveonly : boolean (optional)

True (don't print and save only to file) False (print and save)

pngolny : boolean (optional)

True (only save png files and print png directly) False (print ps file, and generate png, ps; can be slow)

clean : boolean (optional)

True (print and save only clean files without directory info) False (print and save directory location as well)

filename : string (optional)

None (If specified then the filename is set and code does not use the sequence number)

Examples

```
>>> import spacepy.plot.utils
>>> import matplotlib.pyplot as plt
>>> p = plt.plot([1,2,3],[2,3,2])
>>> spacepy.plot.utils.printfig(1, pngonly=True, saveonly=True)
```

spacepy.plot.utils.shared_ylabel

spacepy.plot.utils.**shared_ylabel** (*axes, txt, *args, **kwargs*)

Create a ylabel that spans several subplots

Useful for a multi-panel plot where several subplots have the same units/quantities on the y axis.

Parameters **axes** : list

The *Axes* objects (i.e. subplots) which should share a single label

txt : str

The label to place in the middle of all the “axes” objects.

Returns **out** : matplotlib.text.Text

The *Text* object for the label.

Other Parameters Additional arguments and keywords are passed through to :

:meth:~matplotlib.axes.Axes.set_ylabel :

Notes

This function can be fairly fragile and should only be used for fairly simple layouts, e.g., a one-column multi-row plot stack.

The label is associated with the bottommost subplot in *axes*.

Examples

```
>>> import spacepy.plot.utils
>>> import matplotlib.pyplot as plt
>>> fig = plt.figure()
>>> #Make three stacked subplots
>>> ax0 = fig.add_subplot(311)
>>> ax1 = fig.add_subplot(312)
```

```
>>> ax2 = fig.add_subplot(313)
>>> ax0.plot([1, 2, 3], [1, 2, 1]) #just make some lines
[<matplotlib.lines.Line2D object at 0x0000000>]
>>> ax1.plot([1, 2, 3], [1, 2, 1])
[<matplotlib.lines.Line2D object at 0x0000000>]
>>> ax2.plot([1, 2, 3], [1, 2, 1])
[<matplotlib.lines.Line2D object at 0x0000000>]
>>> #Create a green label across all three axes
>>> spacepy.plot.utils.shared_ylabel([ax0, ax1, ax2],
... 'this is a very long label that spans all three axes', color='g')
```

spacepy.plot.utils.show_used

```
spacepy.plot.utils.show_used(fig=None)
```

Show the areas of a figure which are used/occupied by plot elements.

This function will overplot each element of a plot with a rectangle showing the full bounds of that element, to see for example the margins and such used by a text label.

Returns **boxes** : list of Rectangle

The `Rectangle` objects used for the overplot.

Other Parameters **fig** : matplotlib.figure.Figure

The figure to mark up; if not specified, the `gcf()` function will be used.

Notes

Calls `draw()` to ensure locations are up to date.

Examples

[illegible]

```
<matplotlib.patches.Rectangle at 0x0000000>,
<matplotlib.patches.Rectangle at 0x0000000>,
<matplotlib.patches.Rectangle at 0x0000000>,
<matplotlib.patches.Rectangle at 0x0000000>,
<matplotlib.patches.Rectangle at 0x0000000>,
<matplotlib.patches.Rectangle at 0x0000000>,
<matplotlib.patches.Rectangle at 0x0000000>,
<matplotlib.patches.Rectangle at 0x0000000>,
<matplotlib.patches.Rectangle at 0x0000000>,
<matplotlib.patches.Rectangle at 0x0000000>,
<matplotlib.patches.Rectangle at 0x0000000>,
<matplotlib.patches.Rectangle at 0x0000000>,
<matplotlib.patches.Rectangle at 0x0000000>,
<matplotlib.patches.Rectangle at 0x0000000>,
<matplotlib.patches.Rectangle at 0x0000000>,
<matplotlib.patches.Rectangle at 0x0000000>,
<matplotlib.patches.Rectangle at 0x0000000>,
<matplotlib.patches.Rectangle at 0x0000000>,
<matplotlib.patches.Rectangle at 0x0000000>,
<matplotlib.patches.Rectangle at 0x0000000>,
<matplotlib.patches.Rectangle at 0x0000000>,
<matplotlib.patches.Rectangle at 0x0000000>,
<matplotlib.patches.Rectangle at 0x0000000>]
```

spacepy.plot.utils.smartTimeTicks

`spacepy.plot.utils.smartTimeTicks` (*time*)

Returns major ticks, minor ticks and format for time-based plots

`smartTimeTicks` takes a list of datetime objects and uses the range to calculate the best tick spacing and format. Returned to the user is a tuple containing the major tick locator, minor tick locator, and a format string – all necessary to apply the ticks to an axis.

It is suggested that, unless the user explicitly needs this info, to use the convenience function `applySmartTimeTicks` to place the ticks directly on a given axis.

Parameters `time` : list

list of datetime objects

Returns `out` : tuple

tuple of `Mtick` - major ticks, `mtick` - minor ticks, `fnt` - format

See also:

`applySmartTimeTicks`

spacepy.plot.utils.timestamp

`spacepy.plot.utils.timestamp` (*position*=[1.003, 0.01], *size*='xx-small', *draw*=True, ***kwargs*)

print a timestamp on the current plot, vertical lower right

Parameters `position` : list

position for the timestamp

size : string (optional)

text size
draw : Boolean (optional)
 call draw to make sure it appears
kwargs : keywords
 other keywords to axis.annotate

Examples

```
>>> import spacepy.plot.utils
>>> from pylab import plot, arange
>>> plot(arange(11))
[<matplotlib.lines.Line2D object at 0x49072b0>]
>>> spacepy.plot.utils.timestamp()
```

2.9 PoPPy - Point Processes in Python

PoPPy – Point Processes in Python.

This module contains point process class types and a variety of functions for association analysis. The routines given here grew from work presented by Morley and Freeman (Geophysical Research Letters, 34, L08104, doi:10.1029/2006GL028891, 2007), which were originally written in IDL. This module is intended for application to discrete time series of events to assess statistical association between the series and to calculate confidence limits. Any mis-application or mis-interpretation by the user is the user's own fault.

```
>>> import datetime as dt
>>> import spacepy.time as spt
```

Since association analysis is rather computationally expensive, this example shows timing.

```
>>> t0 = dt.datetime.now()
>>> onsets = spt.Ticktock(onset_epochs, 'CDF')
>>> ticksR1 = spt.Ticktock(tr_list, 'CDF')
```

Each instance must be initialized

```
>>> lags = [dt.timedelta(minutes=n) for n in range(-400,401,2)]
>>> halfwindow = dt.timedelta(minutes=10)
>>> pp1 = poppy.PPro(onsets.UTC, ticksR1.UTC, lags, halfwindow)
```

To perform association analysis

```
>>> pp1.assoc()
Starting association analysis
calculating association for series of length [3494, 1323] at 401 lags
>>> t1 = dt.datetime.now()
>>> print("Elapsed: " + str(t1-t0))
Elapsed: 0:35:46.927138
```

Note that for calculating associations between long series at a large number of lags is SLOW!!

To plot

```
>>> pp1.plot(dpi=80)
Error: No confidence intervals to plot - skipping
```

To add 95% confidence limits (using 4000 bootstrap samples)

```
>>> pp1.aa_ci(95, n_boots=4000)
```

The plot method will then add the 95% confidence intervals as a semi-transparent patch.

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Classes

`PPro(process1, process2[, lags, winhalf, ...])` PoPPy point process object

2.9.1 spacepy.poppy.PPro

class `spacepy.poppy.PPro` (*process1, process2, lags=None, winhalf=None, verbose=False*)
PoPPy point process object

Initialize object with series1 and series2. These should be timeseries of events, given as lists, arrays, or lists of datetime objects. Includes method to perform association analysis of input series

Output can be nicely plotted with `plot()`.

<code>aa_ci(inter[, n_boots, seed])</code>	Get bootstrap confidence intervals for association number
<code>assoc([u, h])</code>	Perform association analysis on input series
<code>assoc_mult(windows[, inter, n_boots, seed])</code>	Association analysis w/confidence interval on multiple windows
<code>ci</code>	
<code>conf_above</code>	
<code>plot([figsize, dpi, asympt, show, norm, ...])</code>	Create basic plot of association analysis.
<code>plot_mult(windows, data[, min, max, ...])</code>	Plots a 2D function of window size and lag
<code>swap()</code>	Swaps process 1 and process 2

aa_ci (*inter, n_boots=1000, seed=None*)

Get bootstrap confidence intervals for association number

Requires input of desired confidence interval, e.g.:

```
>>> obj.aa_ci(95)
```

Upper and lower confidence limits are added to `ci`.

After calling, `conf_above` will contain the confidence (in percent) that the association number at that lag is *above* the asymptotic association number. (The confidence of being below is 100 - `conf_above`) For minor variations in `conf_above` to be meaningful, a *large* number of bootstraps is required. (Roughly, 1000 to be meaningful to the nearest percent; 10000 to be meaningful to a tenth of a percent.) A `conf_above` of 100 usually indicates an insufficient sample size to resolve, *not* perfect certainty.

Note also that a 95% chance of being above indicates an exclusion from the 90% confidence interval!

Parameters `inter` : float

percentage confidence interval to calculate

`n_boots` : int, optional

number of bootstrap iterations to run

seed : int, optional

seed for the random number generator. If not specified, Python code will use numpy's RNG and its current seed; C code will seed from the clock.

Warning: If `seed` is specified on numpy 1.5 and earlier, the available entropy is reduced to work around a random number generator bug. Upgrade to numpy 1.6 to avoid this limitation. Because of this workaround, if a seed is specified, results from numpy 1.5 are not reproducible with numpy 1.6

assoc (*u=None, h=None*)

Perform association analysis on input series

Parameters **u** : list, optional

the time lags to use

h :

association window half-width, same type as `process1`

assoc_mult (*windows, inter=95, n_boots=1000, seed=None*)

Association analysis w/confidence interval on multiple windows

Using the time sequence and lags stored in this object, perform full association analysis, including bootstrapping of confidence intervals, for every listed window half-size

Parameters **windows** : sequence

window half-size for each analysis

inter : float, optional

desired confidence interval, default 95

n_boots : int, optional

number of bootstrap iterations, default 1000

seed : int, optional

Random number generator seed. It is **STRONGLY** recommended not to specify (i.e. leave `None`) to permit multithreading.

Returns **out** : three numpy array

Three numpy arrays, (windows x lags), containing (in order) low values of confidence interval, high values of ci, percentage confidence above the asymptotic association number

Warning: This function is likely to take a LOT of time.

ci

Contains the upper and lower confidence limits for the association number as a function of lag. The first element is the array of lower limits; the second, the array of upper limits. Not available until after calling `aa_ci()`.

conf_above

Contains the confidence that the association number, as a function of lag, is above the asymptotic association number. (The confidence of being below is `100 - conf_above`.) Not available until after calling `aa_ci()`.

plot (*figsize=None, dpi=80, asympt=True, show=True, norm=True, xlabel='Time lag', xscale=None, ylabel=None, title=None, transparent=True*)
Create basic plot of association analysis.

Uses object attributes created by `assoc()` and, optionally, `aa_ci()`.

Parameters **figsize** : , optional

passed through to `matplotlib.pyplot.figure`

dpi : int, optional

passed through to `matplotlib.pyplot.figure`

asympt : boolean, optional

True to overplot the line of asymptotic association number

show : boolean, optional

Show the plot? (if false, will create without showing)

norm : boolean, optional

Normalize plot to the asymptotic association number

title : string, optional

label/title for the plot

xlabel : string, optional

label to put on the X axis of the resulting plot

xscale : float, optional

scale x-axis by this factor (e.g. 60.0 to convert seconds to minutes)

ylabel : string, optional

label to put on the Y axis of the resulting plot

transparent : boolean, optional

make c.i. patch transparent (default)

plot_mult (*windows, data, min=None, max=None, cbar_label=None, figsize=None, dpi=80, xlabel='Lag', ylabel='Window Size'*)

Plots a 2D function of window size and lag

Parameters **windows** : list

list of window sizes (y axis)

data : list

list of data, dimensioned (windows x lags)

min : float, optional

clip L{data} to this minimum value

max : float, optional

clip L{data} to this maximum value

swap ()

Swaps process 1 and process 2

Functions

<code>plot_two_ppro(pprodata, pproref[, ratio, ...])</code>	Overplots two PPro objects
<code>boots_ci(data, n, inter, func[, seed, ...])</code>	Construct bootstrap confidence interval
<code>value_percentile(sequence, target)</code>	Find the percentile of a particular value in a sequence

2.9.2 spacepy.poppy.plot_two_ppro

`spacepy.poppy.plot_two_ppro(pprodata, pproref, ratio=None, norm=False, title=None, xscale=None, figsize=None, dpi=80, ylim=[None, None], log=False, xticks=None, yticks=None)`

Overplots two PPro objects

Parameters **pprodata** : PPro

first point process to plot (in blue)

pproref : PPro

second process to plot (in red)

ratio : float

multiply $L\{pprodata\}$ by this ratio before plotting, useful for comparing processes of different magnitude

norm : boolean

normalize everything to $L\{pproref\}$, i.e. the association number for $L\{pproref\}$ will always plot as 1.

title : string

title to put on the plot

xscale : float

scale x-axis by this factor (e.g. 60.0 to convert seconds to minutes)

figsize :

passed through to `matplotlib.pyplot.figure`

dpi : int

passed through to `matplotlib.pyplot.figure`

ylim : list

[minimum, maximum] values of y for the axis

log : boolean

True for a log plot

xticks : sequence or float

if provided, a list of tickmarks for the X axis

yticks : sequence or float

if provided, a list of tickmarks for the Y axis

2.9.3 spacepy.poppy.boots_ci

`spacepy.poppy.boots_ci` (*data, n, inter, func, seed=None, target=None, sample_size=None*)
Construct bootstrap confidence interval

The bootstrap is a statistical tool that uses multiple samples derived from the original data (called surrogates) to estimate a parameter of the population from which the sample was drawn. This assumes that the sample is randomly drawn and hence is representative of the underlying distribution. The benefit of the bootstrap is that it is non-parametric and can be applied in situations where there is reasonable doubt about the characteristics of the underlying distribution. This routine uses the boot- strap for its most common application - the estimation of confidence intervals.

Parameters **data** : array like

data to bootstrap

n : int

number of surrogate series to select, i.e. number of bootstrap iterations.

inter : numerical

desired percentage confidence interval

func : callable

Function to apply to each surrogate series

sample_size : int

number of samples in the surrogate series, default length of `L{data}`. This will change the statistical properties of the bootstrap and should only be used for good reason!

seed : int

Optional seed for the random number generator. If not specified, numpy generator will not be reseeded; C generator will be seeded from the clock.

target : same as data

a 'target' value. If specified, will also calculate percentage confidence of being at or above this value.

Returns **out** : sequence of float

inter percent confidence interval on value derived from func applied to the population sampled by data. If target is specified, also the percentage confidence of being above that value.

Examples

```
>>> data, n = numpy.random.lognormal(mean=5.1, sigma=0.3, size=3000), 4000.
>>> myfunc = lambda x: numpy.median(x)
>>> ci_low, ci_high = poppy.boots_ci(data, n, 95, myfunc)
>>> ci_low, numpy.median(data), ci_high
(163.96354196633686, 165.2393331896551, 166.60491435416566) iter. 1
... repeat
(162.50379144492726, 164.15218265100233, 165.42840588032755) iter. 2
```

For comparison

```
>>> data = numpy.random.lognormal(mean=5.1, sigma=0.3, size=90000)
>>> numpy.median(data)
163.83888237895815
```

Note that the true value of the desired quantity may lie outside the 95% confidence interval one time in 20 realizations. This occurred for the first iteration here.

For the lognormal distribution, the median is found exactly by taking the exponential of the “mean” parameter. Thus here, the theoretical median is 164.022 (6 s.f.) and this is well captured by the above bootstrap confidence interval.

2.9.4 spacepy.poppy.value_percentile

`spacepy.poppy.value_percentile(sequence, target)`

Find the percentile of a particular value in a sequence

Parameters `sequence` : sequence

a sequence of values, sorted in ascending order

target : same type as sequence

a target value

Returns `out` : float

the percentile of target in sequence

2.10 pycdf - Python interface to CDF files

This package provides a Python interface to the Common Data Format (CDF) library used for many NASA missions, available at <http://cdf.gsfc.nasa.gov/>. It is targeted at Python 2.6+ and should work without change on either Python 2 or Python 3.

The interface is intended to be ‘pythonic’ rather than reproducing the C interface. To open or close a CDF and access its variables, see the `CDF` class. Accessing data within the variables is via the `Var` class. The `lib` object provides access to some routines that affect the functionality of the library in general. The `const` module contains constants useful for accessing the underlying library.

The CDF C library must be properly installed in order to use this package. The CDF distribution provides scripts meant to be called in a user’s login scripts, `definitions.B` for bash and `definitions.C` for C-shell derivatives. (See the installation instructions which come with the CDF library.) These will set environment variables specifying the location of the library; pycdf will respect these variables if they are set. Otherwise it will search the standard system library path and the default installation locations for the CDF library.

If pycdf has trouble finding the library, try setting `CDF_LIB` before importing the module, e.g. if the library is in `CDF/lib` in the user’s home directory:

```
>>> import os
>>> os.putenv("CDF_LIB", "~/CDF/lib")
>>> from spacepy import pycdf
```

If this works, make the environment setting permanent. Note that on OSX, using plists to set the environment may not carry over to Python terminal sessions; use `.cshrc` or `.bashrc` instead.

Note: If the CDF library cannot be found, pycdf will be left in a “half-imported” state. You will need to restart your Python interpreter before trying the fix above.

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2.10.1 Contents

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 - Non record-varying
 - Slicing and indexing
- Class reference

2.10.2 Quickstart

Create a CDF

This example presents the entire sequence of creating a CDF and populating it with some data; the parts are explained individually below.

```
>>> from spacepy import pycdf
>>> import datetime
>>> time = [datetime.datetime(2000, 10, 1, 1, val) for val in range(60)]
>>> import numpy as np
>>> data = np.random.random_sample(len(time))
>>> cdf = pycdf.CDF('MyCDF.cdf', '')
>>> cdf['Epoch'] = time
>>> cdf['data'] = data
>>> cdf.attrs['Author'] = 'John Doe'
>>> cdf.attrs['CreateDate'] = datetime.datetime.now()
>>> cdf['data'].attrs['units'] = 'MeV'
>>> cdf.close()
```

Import the pycdf module.

```
>>> from spacepy import pycdf
```

Make a data set of `datetime`. These will be converted into CDF_EPOCH types.

```
>>> import datetime
>>> # make a dataset every minute for a hour
>>> time = [datetime.datetime(2000, 10, 1, 1, val) for val in range(60)]
```

Warning: If you create a CDF in backwards compatibility mode (default), then `datetime` objects are degraded to CDF_EPOCH (millisecond resolution), not CDF_EPOCH16 (microsecond resolution).

Create some random data.

```
>>> import numpy as np
>>> data = np.random.random_sample(len(time))
```

Create a new empty CDF. The empty string, "", is the name of the CDF to use as a master; given an empty string, an empty CDF will be created, rather than copying from a master CDF. If a master is used, data in the master will be copied to the new CDF.

```
>>> cdf = pycdf.CDF('MyCDF.cdf', '')
```

Note: You cannot create a new CDF with a name that already exists on disk. It will throw a `NameError`

To put data into a CDF, assign it directly to an element of the CDF. CDF objects behave like Python dictionaries.

```
>>> # put time into CDF variable Epoch
>>> cdf['Epoch'] = time
>>> # and the same with data (the smallest data type that fits the data is used by default)
>>> cdf['data'] = data
```

Adding attributes is done similarly. CDF attributes are also treated as dictionaries.

```
>>> # add some attributes to the CDF and the data
>>> cdf.attrs['Author'] = 'John Doe'
>>> cdf.attrs['CreateDate'] = datetime.datetime.now()
>>> cdf['data'].attrs['units'] = 'MeV'
```

Closing the CDF ensures the new data are written to disk:

```
>>> cdf.close()
```

CDF files, like standard Python files, act as context managers

```
>>> with cdf.CDF('filename.cdf', '') as cdf_file:
...     #do brilliant things with cdf_file
>>> #cdf_file is automatically closed here
```

Read a CDF

Reading a CDF is very similar: the CDF object behaves like a dictionary. The file is only accessed when data are requested. A full example using the above CDF:

```
>>> from spacepy import pycdf
>>> cdf = pycdf.CDF('MyCDF.cdf')
>>> print(cdf)
Epoch: CDF_EPOCH [60]
data: CDF_FLOAT [60]
>>> cdf['data'][4]
0.8609974384307861
>>> data = cdf['data'][...] # don't forget the [...]
>>> cdf_dat = cdf.copy()
>>> cdf_dat.keys()
['Epoch', 'data']
>>> cdf.close()
```

Again import the pycdf module

```
>>> from spacepy import pycdf
```

Then open the CDF, this looks the same and creation, but without mention of a master CDF.

```
>>> cdf = pycdf.CDF('MyCDF.cdf')
```

The default `__str__()` and `__repr__()` behavior explains the contents, type, and size but not the data.

```
>>> print(cdf)
Epoch: CDF_EPOCH [60]
data: CDF_FLOAT [60]
```

To access the data one has to request specific elements of the variable, similar to a Python list.

```
>>> cdf['data'][4]
0.8609974384307861
>>> data = cdf['data'][...] # don't forget the [...]
```

`CDF.copy()` will return the entire contents of a CDF, including attributes, as a `SpaceData` object:

```
>>> cdf_dat = cdf.copy()
```

Since CDF objects behave like dictionaries they have a `keys()` method and iterations are over the names in `keys()`

```
>>> cdf_dat.keys()
['Epoch', 'data']
```

Close the CDF when finished:

```
>>> cdf.close()
```

Modify a CDF

An example modifying the CDF created above:

```
>>> from spacepy import pycdf
>>> cdf = pycdf.CDF('MyCDF.cdf')
>>> cdf.readonly(False)
False
>>> cdf['newVar'] = [1.0, 2.0]
>>> print(cdf)
Epoch: CDF_EPOCH [60]
data: CDF_FLOAT [60]
newVar: CDF_FLOAT [2]
>>> cdf.close()
```

As before, each step in this example will now be individually explained. Existing CDF files are opened in read-only mode and must be set to read-write before modification:

```
>>> cdf.readonly(False)
False
```

Then new variables can be added

```
>>> cdf['newVar'] = [1.0, 2.0]
```

Or contents can be changed

```
>>> cdf['data'][0] = 8675309
```

The new variables appear immediately:


```
>>> print(cdf)
Epoch: CDF_EPOCH [60]
data: CDF_FLOAT [60]
newVar: CDF_FLOAT [2]
```

Closing the CDF ensures changes are written to disk:

```
>>> cdf.close()
```

Non record-varying

Non record-varying (NRV) variables are usually used for data that does not vary with time, such as the energy channels for an instrument.

NRV variables need to be created with `CDF.new()`, specifying the keyword `recVary` as `False`.

```
>>> from spacepy import pycdf
>>> cdf = pycdf.CDF('MyCDF2.cdf', '')
>>> cdf.new('data2', [1], recVary=False)
<Var:
  CDF_BYTE [1] NRV
>
>>> cdf['data2'][...]
[1]
```

Slicing and indexing

Subsets of data in a variable can be easily referenced with Python's slicing and indexing notation.

This example uses `bisect` to read a subset of the data from the hourly data file created in earlier examples.

```
>>> from spacepy import pycdf
>>> cdf = pycdf.CDF('MyCDF.cdf')
>>> start = datetime.datetime(2000, 10, 1, 1, 9)
>>> stop = datetime.datetime(2000, 10, 1, 1, 35)
>>> import bisect
>>> start_ind = bisect.bisect_left(cdf['Epoch'], start)
>>> stop_ind = bisect.bisect_left(cdf['Epoch'], stop)
>>> # then grab the data we want
>>> time = cdf['Epoch'][start_ind:stop_ind]
>>> data = cdf['data'][start_ind:stop_ind]
>>> cdf.close()
```

The `Var` documentation has several additional examples.

Access to CDF constants and the C library

Constants defined in `cdf.h` and occasionally useful in accessing CDFs are available in the `const` module.

The underlying C library is represented by the `lib` variable.

Class reference

CDF(pathname[, masterpath])	Python object representing a CDF file.
Continued on next page	

Table 2.23 – continued from previous page

<code>Var(cdf_file, var_name, *args)</code>	A CDF variable.
<code>gAttrList(cdf_file[, special_entry])</code>	Object representing <i>all</i> the gAttributes in a CDF.
<code>zAttrList(zvar)</code>	Object representing <i>all</i> the zAttributes in a zVariable.
<code>zAttr(*args, **kwargs)</code>	zAttribute for zVariables within a CDF.
<code>gAttr(*args, **kwargs)</code>	Global Attribute for a CDF
<code>AttrList(cdf_file[, special_entry])</code>	Object representing a list of attributes.
<code>Attr(cdf_file, attr_name[, create])</code>	An attribute, g or z, for a CDF
<code>Library()</code>	Abstraction of the base CDF C library and its state.
<code>CDFCopy(cdf)</code>	A dictionary-like copy of all data and attributes in a CDF
<code>VarCopy</code>	A list-like copy of the data and attributes in a Var
<code>CDFError(status)</code>	Raised for an error in the CDF library.
<code>CDFException(status)</code>	Base class for errors or warnings in the CDF library.
<code>CDFWarning(status)</code>	Used for a warning in the CDF library.
<code>EpochError</code>	Used for errors in epoch routines

spacepy.pycdf.CDF

class `spacepy.pycdf.CDF` (*pathname*, *masterpath=None*)
Python object representing a CDF file.

Open or create a CDF file by creating an object of this class.

Parameters `pathname` : string

name of the file to open or create

masterpath : string

name of the master CDF file to use in creating a new file. If not provided, an existing file is opened; if provided but evaluates to `False` (e.g., `''`), an empty new CDF is created.

Raises `CDFError` :

if CDF library reports an error

Warns `CDFWarning` :

if CDF library reports a warning and interpreter is set to error on warnings.

Examples

Open a CDF by creating a CDF object, e.g.:

```
>>> cdf = pycdf.CDF('cdf_filename.cdf')
```

Be sure to `close()` or `save()` when done.

Note: Existing CDF files are opened read-only by default, see `readonly()` to change.

CDF supports the `with` keyword, like other file objects, so:

```
>>> with pycdf.CDF('cdf_filename.cdf') as cdf:
...     #do brilliant things with the CDF
```

will open the CDF, execute the indented statements, and close the CDF when finished or when an error occurs. The [python docs](#) include more detail on this ‘context manager’ ability.

CDF objects behave like a python [dictionary](#), where the keys are names of variables in the CDF, and the values, [Var](#) objects. As a dictionary, they are also [iterable](#) and it is easy to loop over all of the variables in a file. Some examples:

1. List the names of all variables in the open CDF `cdffile`:

```
>>> cdffile.keys()
```

Or:

```
>>> for k in cdffile:
...     print(k)
```

2. Get a [Var](#) object corresponding to the variable named `Epoch`:

```
>>> epoch = cdffile['Epoch']
```

3. Determine if a CDF contains a variable named `B_GSE`:

```
>>> if 'B_GSE' in cdffile:
...     print('B_GSE is in the file')
... else:
...     print('B_GSE is not in the file')
```

4. Find how many variables are in the file:

```
>>> print(len(cdffile))
```

5. Delete the variable `Epoch` from the open CDF file `cdffile`:

```
>>> del cdffile['Epoch']
```

6. Display a summary of variables and types in open CDF file `cdffile`:

```
>>> print(cdffile)
```

7. Open the CDF named `cdf_filename.cdf`, read *all* the data from all variables into dictionary `data`, and close it when done or if an error occurs:

```
>>> with pycdf.CDF('cdf_filename.cdf') as cdffile:
...     data = cdffile.copy()
```

This last example can be very inefficient as it reads the entire CDF. Normally it's better to treat the CDF as a dictionary and access only the data needed, which will be pulled transparently from disc. See [Var](#) for more subtle examples.

Potentially useful dictionary methods and related functions:

- [in](#)
- [keys](#)
- [len\(\)](#)
- [list comprehensions](#)
- [sorted\(\)](#)

- `dicttree()`

The CDF user's guide section 2.2 has more background information on CDF files.

The `attrs` Python attribute acts as a dictionary referencing CDF attributes (do not confuse the two); all the dictionary methods above also work on the attribute dictionary. See `gAttrList` for more on the dictionary of global attributes.

Creating a new CDF from a master (skeleton) CDF has similar syntax to opening one:

```
>>> cdf = pycdf.CDF('cdf_filename.cdf', 'master_cdf_filename.cdf')
```

This creates and opens `cdf_filename.cdf` as a copy of `master_cdf_filename.cdf`.

Using a skeleton CDF is recommended over making a CDF entirely from scratch, but this is possible by specifying a blank master:

```
>>> cdf = pycdf.CDF('cdf_filename.cdf', '')
```

When CDFs are created in this way, they are opened read-write, see `readonly()` to change.

By default, new CDFs (without a master) are created in version 2 (backward-compatible) format. To create a version 3 CDF, use `Library.set_backward()`:

```
>>> pycdf.lib.set_backward(False)
>>> cdf = pycdf.CDF('cdf_filename.cdf', '')
```

Add variables by direct assignment, which will automatically set type and dimension based on the data provided:

```
>>> cdf['new_variable_name'] = [1, 2, 3, 4]
```

or, if more control is needed over the type and dimensions, use `new()`.

<code>attrs</code>	Global attributes for this CDF in a dict-like format.
<code>CDF.backward</code>	
<code>checksum([new_val])</code>	Set or check the checksum status of this CDF.
<code>clone(zVar[, name, data])</code>	Clone a <code>zVariable</code> (from another CDF or this) into this CDF
<code>close()</code>	Closes the CDF file
<code>col_major([new_col])</code>	Finds the majority of this CDF file
<code>compress([comptype, param])</code>	Set or check the compression of this CDF
<code>copy()</code>	Make a copy of all data and attributes in this CDF
<code>from_data(filename, sd)</code>	Create a new CDF file from a <code>SpaceData</code> object or similar
<code>new(name[, data, type, recVary, dimVarys, ...])</code>	Create a new <code>zVariable</code> in this CDF
<code>raw_var(name)</code>	Get a "raw" <code>Var</code> object.
<code>readonly([ro])</code>	Sets or check the readonly status of this CDF
<code>save()</code>	Saves the CDF file but leaves it open.
<code>version()</code>	Get version of library that created this CDF

attrs

Global attributes for this CDF in a dict-like format. See `gAttrList` for details.

backward

True if this CDF was created in backward-compatible mode (for opening with CDF library before 3.x)

checksum (*new_val=None*)

Set or check the checksum status of this CDF. If checksums are enabled, the checksum will be verified every time the file is opened.

Returns out : boolean

True if the checksum is enabled or False if disabled

Other Parameters `new_val` : boolean

True to enable checksum, False to disable, or leave out to simply check.

clone (*zVar*, *name=None*, *data=True*)

Clone a `zVariable` (from another CDF or this) into this CDF

Parameters `zVar` : `Var`

variable to clone

Other Parameters `name` : str

Name of the new variable (default: name of the original)

data : boolean (optional)

Copy data, or only type, dimensions, variance, attributes? (default: True, copy data as well)

close ()

Closes the CDF file

Although called on object destruction (`__del__()`), to ensure all data are saved, the user should explicitly call `close()` or `save()`.

Raises `CDFError` : if CDF library reports an error

Warns `CDFWarning` : if CDF library reports a warning

col_major (*new_col=None*)

Finds the majority of this CDF file

Returns out : boolean

True if column-major, false if row-major

Other Parameters `new_col` : boolean

Specify True to change to column-major, False to change to row major, or do not specify to check the majority rather than changing it. (default is check only)

compress (*comptype=None*, *param=None*)

Set or check the compression of this CDF

Sets compression on entire *file*, not per-variable.

See section 2.6 of the CDF user's guide for more information on compression.

Returns out : tuple

(*comptype*, *param*) currently in effect

Other Parameters `comptype` : `ctypes.c_long`

type of compression to change to, see CDF C reference manual section 4.10. Constants for this parameter are in `const`. If not specified, will not change compression.

param : `ctypes.c_long`

Compression parameter, see CDF CRM 4.10 and `const`. If not specified, will choose reasonable default (5 for gzip; other types have only one possible parameter.)

See also:

`Var.compress()`

Examples

Set file `cdffile` to gzip compression, compression level 9:

```
>>> cdffile.compress(pycdf.const.GZIP_COMPRESSION, 9)
```

`copy()`

Make a copy of all data and attributes in this CDF

Returns out : `CDFCopy`

`SpaceData`-like object of all data

`classmethod from_data(filename, sd)`

Create a new CDF file from a `SpaceData` object or similar

The CDF named `filename` is created, opened, filled with the contents of `sd` (including attributes), and closed.

`sd` should be a dictionary-like object; each key will be made into a variable name. An attribute called `attrs`, if it exists, will be made into global attributes for the CDF.

Each value of `sd` should be array-like and will be used as the contents of the variable; an attribute called `attrs`, if it exists, will be made into attributes for that variable.

Parameters filename : string

name of the file to create

sd : `spacepy.datamodel.SpaceData`

data to put in the CDF. This structure cannot be nested, i.e., it must contain only `dmarray` and no `Spacedata` objects.

new (*name*, *data=None*, *type=None*, *recVary=True*, *dimVarys=None*, *dims=None*, *n_elements=None*, *compress=None*, *compress_param=None*)

Create a new `zVariable` in this CDF

Note: Either `data` or `type` must be specified. If `type` is not specified, it is guessed from `data`.

Parameters name : str

name of the new variable

Returns out : `Var`

the newly-created `zVariable`

Other Parameters data :

data to store in the new variable. If this has a `attrs` attribute (e.g., `dmarray`), it will be used to populate attributes of the new variable.

type : `ctypes.c_long`

CDF type of the variable, from `const`. See section 2.5 of the CDF user's guide for more information on CDF data types.

recVary : boolean

record variance of the variable (default True)

dimVarys : list of boolean

dimension variance of each dimension, default True for all dimensions.

dims : list of int

size of each dimension of this variable, default zero-dimensional. Note this is the dimensionality as defined by CDF, i.e., for record-varying variables it excludes the leading record dimension. See [Var](#).

n_elements : int

number of elements, should be 1 except for CDF_CHAR, for which it's the length of the string.

compress : ctypes.c_long

Compression to apply to this variable, default None. See [Var.compress\(\)](#).

compress_param : ctypes.c_long

Compression parameter if compression used; reasonable default is chosen. See [Var.compress\(\)](#).

Raises ValueError : if neither data nor sufficient typing information is provided.

Notes

Any given data may be representable by a range of CDF types; if the type is not specified, pycdf will guess which the CDF types which can represent this data. This breaks down to:

- 1.If input data is a numpy array, match the type of that array
- 2.Proper kind (numerical, string, time)
- 3.Proper range (stores highest and lowest number provided)
- 4.Sufficient resolution (EPOCH16 required if datetime has microseconds or below.)

If more than one value satisfies the requirements, types are returned in preferred order:

- 1.Type that matches precision of data first, then
- 2.integer type before float type, then
- 3.Smallest type first, then
- 4.signed type first, then
- 5.specifically-named (CDF_BYTE) vs. generically named (CDF_INT1)

So for example, EPOCH_16 is preferred over EPOCH if data specifies below the millisecond level (rule 1), but otherwise EPOCH is preferred (rule 2).

For floats, four-byte is preferred unless eight-byte is required:

1. absolute values between 0 and 3e-39
2. absolute values greater than 1.7e38

This will switch to an eight-byte double in some cases where four bytes would be sufficient for IEEE 754 encoding, but where DEC formats would require eight.

raw_var (*name*)

Get a “raw” `Var` object.

Normally a `Var` will perform translation of values for certain types (to/from Unicode for CHAR variables on Py3k, and to/from datetime for all time types). A “raw” object does not perform this translation, on read or write.

This does *not* affect the data on disk, and in fact it is possible to maintain multiple Python objects with access to the same `zVariable`.

Parameters *name* : str

name or number of the `zVariable`

readonly (*ro=None*)

Sets or check the readonly status of this CDF

If the CDF has been changed since opening, setting readonly mode will have no effect.

Returns out : Boolean

True if CDF is read-only, else False

Other Parameters *ro* : Boolean

True to set the CDF readonly, False to set it read/write, or leave out to check only.

Raises `CDFError` : if bad mode is set

save ()

Saves the CDF file but leaves it open.

If closing the CDF, `close()` is sufficient; there is no need to call `save()` before `close()`.

Note: Relies on an undocumented call of the CDF C library, which is also used in the Java interface.

Raises `CDFError` : if CDF library reports an error

Warns `CDFWarning` : if CDF library reports a warning

version ()

Get version of library that created this CDF

Returns out : tuple

version of CDF library, in form (version, release, increment)

`spacepy.pycdf.Var`

class `spacepy.pycdf.Var` (*cdf_file*, *var_name*, **args*)

A CDF variable.

This object does not directly store the data from the CDF; rather, it provides access to the data in a format that much like a Python list or numpy `ndarray`. General list information is available in the python docs: [1](#), [2](#), [3](#).

The CDF user’s guide, section 2.3, provides background on variables.

Note: Not intended to be created directly; use methods of `CDF` to gain access to a variable.

A record-varying variable's data are viewed as a hypercube of dimensions `n_dims+1` (the extra dimension is the record number). They are indexed in row-major fashion, i.e. the last index changes most frequently / is contiguous in memory. If the CDF is column-major, the data are transformed to row-major before return.

Non record-varying variables are similar, but do not have the extra dimension of record number.

Variables can be subscripted by a multidimensional index to return the data. Indices are in row-major order with the first dimension representing the record number. If the CDF is column major, the data are reordered to row major. Each dimension is specified by standard Python [slice](#) notation, with dimensions separated by commas. The ellipsis fills in any missing dimensions with full slices. The returned data are lists; Python represents multidimensional arrays as nested lists. The innermost set of lists represents contiguous data.

Note: numpy 'fancy indexing' is *not* supported.

Degenerate dimensions are 'collapsed', i.e. no list of only one element will be returned if a single subscript is specified instead of a range. (To avoid this, specify a slice like `1:2`, which starts with 1 and ends before 2).

Two special cases:

1. requesting a single-dimension slice for a record-varying variable will return all data for that record number (or those record numbers) for that variable.
2. Requests for multi-dimensional variables may skip the record-number dimension and simply specify the slice on the array itself. In that case, the slice of the array will be returned for all records.

In the event of ambiguity (e.g., single-dimension slice on a one-dimensional variable), case 1 takes priority. Otherwise, mismatch between the number of dimensions specified in the slice and the number of dimensions in the variable will cause an `IndexError` to be thrown.

This all sounds very complicated but it is essentially attempting to do the 'right thing' for a range of slices.

An unusual case is scalar (zero-dimensional) non-record-varying variables. Clearly they cannot be subscripted normally. In this case, use the `[...]` syntax meaning 'access all data':

```
>>> from spacepy import pycdf
>>> testcdf = pycdf.CDF('test.cdf', '')
>>> variable = testcdf.new('variable', recVary=False,
...     type=pycdf.const.CDF_INT4)
>>> variable[...] = 10
>>> variable
<Var:
CDF_INT4 [] NRV
>
>>> variable[...]
10
```

As a list type, variables are also [iterable](#); iterating over a variable returns a single complete record at a time.

This is all clearer with examples. Consider a variable `B_GSM`, with three elements per record (`x`, `y`, `z` components) and fifty records in the CDF. Then:

1. `B_GSM[0, 1]` is the `y` component of the first record.
2. `B_GSM[10, :]` is a three-element list, containing `x`, `y`, and `z` components of the 11th record.
As a shortcut, if only one dimension is specified, it is assumed to be the record number, so this

could also be written `B_GSM[10]`.

3.`B_GSM[...]` reads all data for `B_GSM` and returns it as a fifty-element list, each element itself being a three-element list of x, y, z components.

Multidimensional example: consider fluxes stored as a function of pitch angle and energy. Such a variable may be called `Flux` and stored as a two-dimensional array, with the first dimension representing (say) ten energy steps and the second, eighteen pitch angle bins (ten degrees wide, centered from 5 to 175 degrees). Assume 100 records stored in the CDF (i.e. 100 different times).

1.`Flux[4]` is a list of ten elements, one per energy step, each element being a list of 18 fluxes, one per pitch bin. All are taken from the fifth record in the CDF.

2.`Flux[4, :, 0:4]` is the same record, all energies, but only the first four pitch bins (roughly, field-aligned).

3.`Flux[... , 0:4]` is a 100-element list (one per record), each element being a ten-element list (one per energy step), each containing fluxes for the first four pitch bins.

This slicing notation is very flexible and allows reading specifically the desired data from the CDF.

All data are, on read, converted to appropriate Python data types; `EPOCH`, `EPOCH16`, and `TIME_TT2000` types are converted to `datetime`. Data are returned in numpy arrays.

Note: Although `pycdf` supports `TIME_TT2000` variables, the Python `datetime` object does not support leap seconds. Thus, on read, any seconds past 59 are truncated to 59.999999 (59 seconds, 999 milliseconds, 999 microseconds).

Potentially useful list methods and related functions:

- `count`
- `in`
- `index`
- `len`
- `list comprehensions`
- `sorted`

The topic of array majority can be very confusing; good background material is available at [IDL Array Storage and Indexing](#). In brief, *regardless of the majority stored in the CDF*, `pycdf` will always present the data in the native Python majority, row-major order, also known as C order. This is the default order in `NumPy`. However, packages that render image data may expect it in column-major order. If the axes seem ‘swapped’ this is likely the reason.

The `attrs` Python attribute acts as a dictionary referencing `zAttributes` (do not confuse the two); all the dictionary methods above also work on the attribute dictionary. See `zAttrList` for more on the dictionary of attributes.

With writing, as with reading, every attempt has been made to match the behavior of Python lists. You can write one record, many records, or even certain elements of all records. There is one restriction: only the record dimension (i.e. dimension 0) can be resized by write, as all records in a variable must have the same dimensions. Similarly, only whole records can be deleted.

For these examples, assume `Flux` has 100 records and dimensions [2, 3].

Rewrite the first record without changing the rest:

```
>>> Flux[0] = [[1, 2, 3], [4, 5, 6]]
```

Writes a new first record and delete all the rest:

```
>>> Flux[...] = [[1, 2, 3], [4, 5, 6]]
```

Write a new record in the last position and add a new record after:

```
>>> Flux[99:] = [[[1, 2, 3], [4, 5, 6]],
...               [[11, 12, 13], [14, 15, 16]]]
```

Insert two new records between the current number 5 and 6:

```
>>> Flux[5:6] = [[[1, 2, 3], [4, 5, 6]], [[11, 12, 13],
...               [14, 15, 16]]]
```

This operation can be quite slow, as it requires reading and rewriting the entire variable. (CDF does not directly support record insertion.)

Change the first element of the first two records but leave other elements alone:

```
>>> Flux[0:2, 0, 0] = [1, 2]
```

Remove the first record:

```
>>> del Flux[0]
```

Removes record 5 (the sixth):

```
>>> del Flux[5]
```

Due to the need to work around a bug in the CDF library, this operation can be quite slow.

Delete *all data* from `Flux`, but leave the variable definition intact:

```
>>> del Flux[...]
```

Note: Although this interface only directly supports `zVariables`, `zMode` is set on opening the CDF so `rVars` appear as `zVars`. See p.24 of the CDF user's guide; `pyCDF` uses `zMode 2`.

<code>attrs</code>	<code>zAttributes</code> for this <code>zVariable</code> in a dict-like format.
<code>compress([comptype, param])</code>	Set or check the compression of this variable
<code>copy()</code>	Copies all data and attributes from this variable
<code>dtype</code>	Provide the numpy dtype equivalent to the CDF type of this variable.
<code>dv([new_dv])</code>	Gets or sets dimension variance of each dimension of variable.
<code>insert(index, data)</code>	Inserts a <i>single</i> record before an index
<code>name()</code>	Returns the name of this variable
<code>rename(new_name)</code>	Renames this variable
<code>rv([new_rv])</code>	Gets or sets whether this variable has record variance
<code>shape</code>	Provides the numpy array-like shape of this variable.
<code>type([new_type])</code>	Returns or sets the CDF type of this variable

attrs

`zAttributes` for this `zVariable` in a dict-like format. See `zAttrList` for details.

compress (*comptype=None, param=None*)

Set or check the compression of this variable

Compression may not be changeable on variables with data already written; even deleting the data may not permit the change.

See section 2.6 of the CDF user's guide for more information on compression.

Returns out : tuple

the (comptype, param) currently in effect

Other Parameters comptype : ctypes.c_long

type of compression to change to, see CDF C reference manual section 4.10.

Constants for this parameter are in `const`. If not specified, will not change compression.

param : ctypes.c_long

Compression parameter, see CDF CRM 4.10 and `const`. If not specified, will choose reasonable default (5 for gzip; other types have only one possible parameter.)

copy ()

Copies all data and attributes from this variable

Returns out : `VarCopy`

list of all data in record order

dtype

Provide the numpy dtype equivalent to the CDF type of this variable.

Data from this variable will be returned in numpy arrays of this type.

See also:

`type`

dv (*new_dv=None*)

Gets or sets dimension variance of each dimension of variable.

If the variance is unknown, True is assumed (this replicates the apparent behavior of the CDF library on variable creation).

Parameters new_dv : list of boolean

Each element True to change that dimension to dimension variance, False to change to not dimension variance. (Unspecified to simply check variance.)

Returns out : list of boolean

True if that dimension has variance, else false.

insert (*index, data*)

Inserts a *single* record before an index

Parameters index : int

index before which to insert the new record

data :

the record to insert

name ()

Returns the name of this variable

Returns out : str

variable's name

rename (*new_name*)

Renames this variable

Parameters new_name : str

the new name for this variable

rv (*new_rv=None*)

Gets or sets whether this variable has record variance

If the variance is unknown, True is assumed (this replicates the apparent behavior of the CDF library on variable creation).

Returns out : Boolean

True if record varying, False if NRV

Other Parameters new_rv : boolean

True to change to record variance, False to change to NRV, unspecified to simply check variance.

shape

Provides the numpy array-like shape of this variable.

Returns a tuple; first element is number of records (RV variable only) And the rest provide the dimensionality of the variable.

Note: Assigning to this attribute will not change the shape.

type (*new_type=None*)

Returns or sets the CDF type of this variable

Parameters new_type : ctypes.c_long
the new type from `const`

Returns out : int
CDF type

spacepy.pycdf.gAttrList

class `spacepy.pycdf.gAttrList` (*cdf_file, special_entry=None*)

Object representing *all* the gAttributes in a CDF.

Normally accessed as an attribute of an open CDF:

```
>>> global_attribs = cdf_file.attrs
```

Appears as a dictionary: keys are attribute names; each value is an attribute represented by a `gAttr` object. To access the global attribute TEXT:

```
>>> text_attr = cdf_file.attrs['TEXT']
```

See also:

`AttrList`

spacepy.pycdf.zAttrList

class `spacepy.pycdf.zAttrList` (*zvar*)

Object representing *all* the zAttributes in a zVariable.

Normally accessed as an attribute of a `Var` in an open CDF:

```
>>> epoch_attribs = cdf_file['Epoch'].attrs
```

Appears as a dictionary: keys are attribute names, values are the value of the zEntry associated with the appropriate zVariable. Each vAttribute in a CDF may only have a *single* entry associated with each variable. The entry may be a string, a single numerical value, or a series of numerical values. Entries with multiple values are returned as an entire list; direct access to the individual elements is not possible.

Example: finding the first dependency of (ISTP-compliant) variable `Flux`:

```
>>> print cdffile['Flux'].attrs['DEPEND_0']
```

zAttributes are shared among zVariables, one zEntry allowed per zVariable. (pyCDF hides this detail.) Deleting the last zEntry for a zAttribute will delete the underlying zAttribute.

zEntries are created and destroyed by the usual dict methods on the zAttrlist:

```
>>> epoch_attrs['new_entry'] = [1, 2, 4] #assign a list to new zEntry
>>> del epoch_attrs['new_entry'] #delete the zEntry
```

The type of the zEntry is guessed from data provided. The type is chosen to match the data; subject to that constraint, it will try to match (in order):

- 1.existing zEntry corresponding to this zVar
- 2.other zEntries in this zAttribute
- 3.the type of this zVar
- 4.data-matching constraints described in `CDF.new()`

See also:

`AttrList`

spacepy.pycdf.zAttr

```
class spacepy.pycdf.zAttr(*args, **kwargs)
    zAttribute for zVariables within a CDF.
```

Warning: Because zAttributes are shared across all variables in a CDF, directly manipulating them may have unexpected consequences. It is safest to operate on zEntries via `zAttrList`.

Note: When accessing a zAttr, pyCDF exposes only the zEntry corresponding to the associated zVariable.

See also:

`Attr`

spacepy.pycdf.gAttr

```
class spacepy.pycdf.gAttr(*args, **kwargs)
    Global Attribute for a CDF
```

Represents a CDF attribute, providing access to the gEntries in a format that looks like a Python list. General list information is available in the python docs: [1](#), [2](#), [3](#).

Normally accessed by providing a key to a `gAttrList`:

```
>>> attribute = cdffile.attrs['attribute_name']
>>> first_gentry = attribute[0]
```

Each element of the list is a single gEntry of the appropriate type. The index to the elements is the gEntry number.

A gEntry may be either a single string or a 1D array of numerical type. Entries of numerical type (everything but CDF_CHAR and CDF_UCHAR) with a single element are returned as scalars; multiple-element entries are

returned as a list. No provision is made for accessing below the entry level; the whole list is returned at once (but Python’s slicing syntax can be used to extract individual items from that list.)

Multi-dimensional slicing is *not* supported; an entry with multiple elements will have all elements returned (and can thus be sliced itself). Example:

```
>>> first_three = attribute[5, 0:3] #will fail
>>> first_three = attribute[5][0:3] #first three elements of 5th Entry
```

gEntries are *not* necessarily contiguous; a gAttribute may have an entry 0 and entry 2 without an entry 1. `len()` will return the *number* of gEntries; use `max_idx()` to find the highest defined gEntry number and `has_entry()` to determine if a particular gEntry number exists. Iterating over all entries is also supported:

```
>>> entrylist = [entry for entry in attribute]
```

Deleting gEntries will leave a “hole”:

```
>>> attribute[0:3] = [1, 2, 3]
>>> del attribute[1]
>>> attribute.has_entry(1)
False
>>> attribute.has_entry(2)
True
>>> print attribute[0:3]
[1, None, 3]
```

Multi-element slices over nonexistent gEntries will return `None` where no entry exists. Single-element indices for nonexistent gEntries will raise `IndexError`. Assigning `None` to a gEntry will delete it.

When assigning to a gEntry, the type is chosen to match the data; subject to that constraint, it will try to match (in order):

- 1.existing gEntry of the same number in this gAttribute
- 2.other gEntries in this gAttribute
- 3.data-matching constraints described in `CDF.new()`.

See also:

`Attr`

spacepy.pycdf.AttrList

class `spacepy.pycdf.AttrList` (*cdf_file*, *special_entry=None*)
Object representing a list of attributes.

Warning: This class should not be used directly, but only via its subclasses, `gAttrList` and `zAttrList`. Methods listed here are safe to use from the subclasses.

<code>clone(master[, name, new_name])</code>	Clones another attribute list, or one attribute from it, into this list.
<code>copy()</code>	Create a copy of this attribute list
<code>from_dict(in_dict)</code>	Fill this list of attributes from a dictionary
<code>new(name[, data, type])</code>	Create a new Attr in this AttrList
<code>rename(old_name, new_name)</code>	Rename an attribute in this list

`clone` (*master*, *name=None*, *new_name=None*)

Clones another attribute list, or one attribute from it, into this list.

Parameters **master** : AttrList

the attribute list to copy from. This can be any dict-like object.

Other Parameters **name** : str (optional)

name of attribute to clone (default: clone entire list)

new_name : str (optional)

name of the new attribute, default `name`

copy ()

Create a copy of this attribute list

Returns **out** : dict

copy of the entries for all attributes in this list

from_dict (*in_dict*)

Fill this list of attributes from a dictionary

Deprecated since version 0.1.5: Use `clone()` instead; it supports cloning from dictionaries.

Parameters **in_dict** : dict

Attribute list is populated entirely from this dictionary; all existing attributes are deleted.

new (*name*, *data=None*, *type=None*)

Create a new Attr in this AttrList

Parameters **name** : str

name of the new Attribute

Other Parameters **data** :

data to put into the first entry in the new Attribute

type :

CDF type of the first entry from `const`. Only used if data are specified.

Raises **KeyError** : if the name already exists in this list

rename (*old_name*, *new_name*)

Rename an attribute in this list

Renaming a zAttribute renames it for *all* zVariables in this CDF!

Parameters **old_name** : str

the current name of the attribute

new_name : str

the new name of the attribute

spacepy.pycdf.Attr

class `spacepy.pycdf.Attr` (*cdf_file*, *attr_name*, *create=False*)

An attribute, g or z, for a CDF

Warning: This class should not be used directly, but only in its subclasses, `gAttr` and `zAttr`. The methods listed here are safe to use in the subclasses.

Represents a CDF attribute, providing access to the Entries in a format that looks like a Python list. General list information is available in the python docs: [1](#), [2](#), [3](#).

An introduction to CDF attributes can be found in section 2.4 of the CDF user's guide.

Each element of the list is a single Entry of the appropriate type. The index to the elements is the Entry number.

Multi-dimensional slicing is *not* supported; an Entry with multiple elements will have all elements returned (and can thus be sliced itself). Example:

```
>>> first_three = attribute[5, 0:3] #will fail
>>> first_three = attribute[5][0:3] #first three elements of 5th Entry
```

<code>has_entry(number)</code>	Check if this attribute has a particular Entry number
<code>max_idx()</code>	Maximum index of Entries for this Attr
<code>new(data[, type, number])</code>	Create a new Entry in this Attribute
<code>number()</code>	Find the attribute number for this attribute
<code>rename(new_name)</code>	Rename this attribute
<code>type(number[, new_type])</code>	Find or change the CDF type of a particular Entry number

has_entry (*number*)

Check if this attribute has a particular Entry number

Parameters **number** : int

number of Entry to check or change

Returns **out** : bool

True if `number` is a valid entry number; False if not

max_idx ()

Maximum index of Entries for this Attr

Returns **out** : int

maximum Entry number

new (*data*, *type=None*, *number=None*)

Create a new Entry in this Attribute

Note: If `number` is provide and an Entry with that number already exists, it will be overwritten.

Parameters **data** :

data to put in the Entry

Other Parameters **type** : int

type of the new Entry, from `const` (otherwise guessed from `data`)

number : int

Entry number to write, default is lowest available number.

number ()

Find the attribute number for this attribute

Returns out : int

attribute number

rename (*new_name*)

Rename this attribute

Renaming a zAttribute renames it for *all* zVariables in this CDF!

Parameters new_name : str

the new name of the attribute

type (*number*, *new_type=None*)

Find or change the CDF type of a particular Entry number

Parameters number : int

number of Entry to check or change

Returns out : int

CDF variable type, see `const`

Other Parameters new_type :

type to change this Entry to, from `const`. Omit to only check type.

Notes

If changing types, old and new must be equivalent, see CDF User's Guide section 2.5.5 pg. 57

spacepy.pycdf.Library

class `spacepy.pycdf.Library`

Abstraction of the base CDF C library and its state.

Not normally intended for end-user use. An instance of this class is created at package load time as the `lib` variable, providing access to the underlying C library if necessary. The CDF library itself is described in section 2.1 of the CDF user's guide, as well as the CDF C reference manual.

Calling the C library directly requires knowledge of `ctypes`.

Instantiating this object loads the C library, see *pycdf - Python interface to CDF files* docs for details.

<code>call(*args, **kwargs)</code>	Call the CDF internal interface
<code>check_status(status[, ignore])</code>	Raise exception or warning based on return status of CDF call
<code>datetime_to_epoch(dt)</code>	Converts a Python datetime to a CDF Epoch value
<code>datetime_to_epoch16(dt)</code>	Converts a Python datetime to a CDF Epoch16 value
<code>datetime_to_tt2000(dt)</code>	Converts a Python datetime to a CDF TT2000 value
<code>epoch_to_datetime(epoch)</code>	Converts a CDF epoch value to a datetime
<code>epoch_to_epoch16(epoch)</code>	Converts a CDF EPOCH to a CDF EPOCH16 value
<code>epoch_to_tt2000(epoch)</code>	Converts a CDF EPOCH to a CDF TT2000 value
<code>epoch16_to_datetime(epoch0, epoch1)</code>	Converts a CDF epoch16 value to a datetime
<code>epoch16_to_epoch(epoch16)</code>	Converts a CDF EPOCH16 to a CDF EPOCH value
<code>epoch16_to_tt2000(epoch0, epoch1)</code>	Converts a CDF epoch16 value to TT2000
<code>set_backward([backward])</code>	Set backward compatibility mode for new CDFs
<code>supports_int8</code>	

Continued on next page

Table 2.28 – continued from previous page

<code>tt2000_to_datetime(tt2000)</code>	Converts a CDF TT2000 value to a datetime
<code>tt2000_to_epoch(tt2000)</code>	Converts a CDF TT2000 value to a CDF EPOCH
<code>tt2000_to_epoch16(tt2000)</code>	Converts a CDF TT2000 value to a CDF EPOCH16
<code>v_datetime_to_epoch</code>	
<code>v_datetime_to_epoch16</code>	
<code>v_datetime_to_tt2000</code>	
<code>v_epoch_to_datetime</code>	
<code>v_epoch_to_tt2000</code>	
<code>v_epoch16_to_datetime</code>	
<code>v_epoch16_to_tt2000</code>	
<code>v_tt2000_to_datetime</code>	
<code>v_tt2000_to_epoch</code>	
<code>v_tt2000_to_epoch16</code>	
<code>Library.version</code>	

call (*args, **kwargs)

Call the CDF internal interface

Passes all parameters directly through to the CDFlib routine of the CDF library's C internal interface. Checks the return value with `check_status()`.

Terminal NULL is automatically added to args.

Parameters `args` : various, see `ctypes`

Passed directly to the CDF library interface. Useful constants are defined in the `const` module.

Returns `out` : int

CDF status from the library

Other Parameters `ignore` : sequence of CDF statuses

sequence of CDF statuses to ignore. If any of these is returned by CDF library, any related warnings or exceptions will *not* be raised.

Raises `CDFError` : if CDF library reports an error

Warns `CDFWarning` : if CDF library reports a warning

check_status (status, ignore=())

Raise exception or warning based on return status of CDF call

Parameters `status` : int

status returned by the C library

Returns `out` : int

status (unchanged)

Other Parameters `ignore` : sequence of `ctypes.c_long`

CDF statuses to ignore. If any of these is returned by CDF library, any related warnings or exceptions will *not* be raised. (Default none).

Raises `CDFError` : if `status < CDF_WARN`, indicating an error

Warns `CDFWarning` : if `CDF_WARN <= status < CDF_OK`, indicating a warning.

`datetime_to_epoch(dt)`

Converts a Python datetime to a CDF Epoch value

Parameters `dt` : `datetime.datetime`

date and time to convert

Returns `out` : float

epoch corresponding to `dt`

See also:

`v_datetime_to_epoch`

`datetime_to_epoch16(dt)`

Converts a Python datetime to a CDF Epoch16 value

Parameters `dt` : `datetime.datetime`

date and time to convert

Returns `out` : list of float

epoch16 corresponding to `dt`

See also:

`v_datetime_to_epoch16`

`datetime_to_tt2000(dt)`

Converts a Python datetime to a CDF TT2000 value

Parameters `dt` : `datetime.datetime`

date and time to convert

Returns `out` : int

tt2000 corresponding to `dt`

See also:

`v_datetime_to_tt2000`

`epoch_to_datetime(epoch)`

Converts a CDF epoch value to a datetime

Parameters `epoch` : float

epoch value from CDF

Returns `out` : `datetime.datetime`

date and time corresponding to epoch. Invalid values are set to usual epoch invalid value, i.e. last moment of year 9999.

See also:

`v_epoch_to_datetime`

`epoch_to_epoch16(epoch)`

Converts a CDF EPOCH to a CDF EPOCH16 value

Parameters `epoch` : double

EPOCH to convert. Lists and numpy arrays are acceptable.

Returns `out` : (double, double)

EPOCH16 corresponding to epoch

epoch_to_tt2000 (*epoch*)

Converts a CDF EPOCH to a CDF TT2000 value

Parameters **epoch** : double

EPOCH to convert

Returns **out** : int

tt2000 corresponding to epoch

See also:

`v_epoch_to_tt2000`

epoch16_to_datetime (*epoch0*, *epoch1*)

Converts a CDF epoch16 value to a datetime

Note: The call signature has changed since SpacePy 0.1.2. Formerly this method took a single argument with two values; now it requires two arguments (one for each value). To convert existing code, replace `epoch16_to_datetime(epoch)` with `epoch16_to_datetime(*epoch)`.

Parameters **epoch0** : float

epoch16 value from CDF, first half

epoch1 : float

epoch16 value from CDF, second half

Returns **out** : `datetime.datetime`

date and time corresponding to epoch. Invalid values are set to usual epoch invalid value, i.e. last moment of year 9999.

Raises **EpochError** : if input invalid

See also:

`v_epoch16_to_datetime`

epoch16_to_epoch (*epoch16*)

Converts a CDF EPOCH16 to a CDF EPOCH value

Parameters **epoch16** : (double, double)

EPOCH16 to convert. Lists and numpy arrays are acceptable. LAST dimension should be 2: the two pairs of EPOCH16

Returns **out** : double

EPOCH corresponding to epoch16

epoch16_to_tt2000 (*epoch0*, *epoch1*)

Converts a CDF epoch16 value to TT2000

Note: Because TT2000 does not support picoseconds, the picoseconds value in epoch is ignored (i.e., truncated.)

Parameters **epoch0** : float

epoch16 value from CDF, first half

epoch1 : float

epoch16 value from CDF, second half

Returns out : long

TT2000 corresponding to epoch.

Raises EpochError : if input invalid

See also:

`v_epoch16_to_tt2000`

set_backward (*backward=True*)

Set backward compatibility mode for new CDFs

Unless backward compatible mode is set, CDF files created by the version 3 library can not be read by V2.

Parameters backward : boolean

Set backward compatible mode if True; clear it if False.

Raises ValueError : if backward=False and underlying CDF library is V2

supports_int8

True if this library supports INT8 and TIME_TT2000 types; else False.

tt2000_to_datetime (*tt2000*)

Converts a CDF TT2000 value to a datetime

Note: Although TT2000 values support leapseconds, Python's datetime object does not. Any times after 23:59:59.999999 will be truncated to 23:59:59.999999.

Parameters tt2000 : int

TT2000 value from CDF

Returns out : `datetime.datetime`

date and time corresponding to epoch. Invalid values are set to usual epoch invalid value, i.e. last moment of year 9999.

Raises EpochError : if input invalid

See also:

`v_tt2000_to_datetime`

tt2000_to_epoch (*tt2000*)

Converts a CDF TT2000 value to a CDF EPOCH

Note: Although TT2000 values support leapseconds, CDF EPOCH values do not. Times during leapseconds are rounded up to beginning of the next day.

Parameters tt2000 : int

TT2000 value from CDF

Returns out : double

EPOCH corresponding to the TT2000 input time

Raises EpochError : if input invalid

See also:

`v_tt2000_to_epoch`

tt2000_to_epoch16 (*tt2000*)

Converts a CDF TT2000 value to a CDF EPOCH16

Note: Although TT2000 values support leapseconds, CDF EPOCH16 values do not. Times during leapseconds are rounded up to beginning of the next day.

Parameters *tt2000* : int

TT2000 value from CDF

Returns *out* : double, double

EPOCH16 corresponding to the TT2000 input time

Raises *EpochError* : if input invalid

See also:

`v_tt2000_to_epoch16`

v_datetime_to_epoch (*datetime*)

A vectorized version of `datetime_to_epoch()` which takes a numpy array of datetimes as input and returns an array of epochs.

v_datetime_to_epoch16 (*datetime*)

A vectorized version of `datetime_to_epoch16()` which takes a numpy array of datetimes as input and returns an array of epoch16.

v_datetime_to_tt2000 (*datetime*)

A vectorized version of `datetime_to_tt2000()` which takes a numpy array of datetimes as input and returns an array of TT2000.

v_epoch_to_datetime (*epoch*)

A vectorized version of `epoch_to_datetime()` which takes a numpy array of epochs as input and returns an array of datetimes.

v_epoch_to_tt2000 (*epoch*)

A vectorized version of `epoch_to_tt2000()` which takes a numpy array of epochs as input and returns an array of tt2000s.

v_epoch16_to_datetime (*epoch0, epoch1*)

A vectorized version of `epoch16_to_datetime()` which takes a numpy array of epoch16 as input and returns an array of datetimes. An epoch16 is a pair of doubles; the input array's last dimension must be two (and the returned array will have one fewer dimension).

v_epoch16_to_tt2000 (*epoch16*)

A vectorized version of `epoch16_to_tt2000()` which takes a numpy array of epoch16 as input and returns an array of tt2000s. An epoch16 is a pair of doubles; the input array's last dimension must be two (and the returned array will have one fewer dimension).

v_tt2000_to_datetime (*tt2000*)

A vectorized version of `tt2000_to_datetime()` which takes a numpy array of tt2000 as input and returns an array of datetimes.

v_tt2000_to_epoch (*tt2000*)

A vectorized version of `tt2000_to_epoch()` which takes a numpy array of tt2000 as input and returns an array of epochs.

v_tt2000_to_epoch16 (*tt2000*)

A vectorized version of `tt2000_to_epoch16()` which takes a numpy array of `tt2000` as input and returns an array of `epoch16`.

version

Version of the CDF library, (version, release, increment, subincrement)

`spacepy.pycdf.CDFCopy`

class `spacepy.pycdf.CDFCopy` (*cdf*)

A dictionary-like copy of all data and attributes in a `CDF`

Data are `VarCopy` objects, keyed by variable name. CDF attributes are in `attrs`. (I.e., data are accessed much like from a `CDF`).

Do not instantiate this class directly; use `copy()` on an existing `CDF`.

Examples

```
>>> from spacepy import pycdf
>>> with pycdf.CDF('test.cdf') as cdffile:
...     data = cdffile.copy()
```

attrs

Python dictionary containing attributes copied from the `CDF`.

`spacepy.pycdf.VarCopy`

class `spacepy.pycdf.VarCopy`

A list-like copy of the data and attributes in a `Var`

Data are in the list elements. CDF attributes are in a dict, accessed through `attrs`. (I.e., data and attributes are accessed like in a `Var`.)

Do not instantiate this class directly; use `copy()` on an existing `Var`.

attrs

Python dictionary containing attributes copied from the `zVar`

`spacepy.pycdf.CDFError`

class `spacepy.pycdf.CDFError` (*status*)

Raised for an error in the CDF library.

`spacepy.pycdf.CDFException`

class `spacepy.pycdf.CDFException` (*status*)

Base class for errors or warnings in the CDF library.

Not normally used directly, but in subclasses `CDFError` and `CDFWarning`.

Error messages provided by this class are looked up from the underlying C library.

spacepy.pycdf.CDFWarning

class spacepy.pycdf.**CDFWarning**(*status*)
Used for a warning in the CDF library.

spacepy.pycdf.EpochError

class spacepy.pycdf.**EpochError**
Used for errors in epoch routines

2.11 radbelt - Functions supporting radiation belt diffusion codes

Functions supporting radiation belt diffusion codes

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Classes

<code>RBmodel([grid, NL, const_kp])</code>	1-D Radial diffusion class
--	----------------------------

2.11.1 spacepy.radbelt.RBmodel

class spacepy.radbelt.**RBmodel**(*grid='L', NL=91, const_kp=False*)
1-D Radial diffusion class

This module contains a class for performing and visualizing 1-D radial diffusion simulations of the radiation belts.

Here is an example using the default settings of the model. Each instance must be initialized with (assuming import radbelt as rb):

```
>>> rmod = rb.RBmodel()
```

Next, set the start time, end time, and the size of the timestep:

```
>>> import datetime
>>> start = datetime.datetime(2003,10,14)
>>> end = datetime.datetime(2003,12,26)
>>> delta = datetime.timedelta(hours=1)
>>> rmod.setup_ticks(start, end, delta, dtype='UTC')
```

Now, run the model over the entire time range using the evolve method:

```
>>> rmod.evolve()
```

Finally, visualize the results:

```
>>> rmod.plot_summary()
```

`Gaussian_source()`

Gaussian source term added to radiation belt model.

Table 2.30 – continued from previous page

<code>add_Lmax(Lmax_model)</code>	add last closed drift shell Lmax
<code>add_Lpp(Lpp_model)</code>	add last closed drift shell Lmax
<code>add_PSD_obs([time, PSD, Lstar, satlist])</code>	add PSD observations
<code>add_PSD_twin([dt, Lt])</code>	add observations from PSD database using the ticks list
<code>add_omni([keylist])</code>	add omni data to instance according to the tickrange in ticks
<code>add_source([source, A, mu, sigma])</code>	add source parameters A, mu, and sigma for the Gaussian source function
<code>assimilate([method, inflation])</code>	Assimilates data for the radiation belt model using the Ensemble Kalman Filter.
<code>evolve()</code>	calculate the diffusion in L at constant mu,K coordinates
<code>get_DLL(Lgrid, params[, DLL_model])</code>	Calculate DLL as a simple power law function ($\alpha * L^{**Bbta}$) using alpha/beta
<code>plot([Lmax, Lpp, Kp, Dst, clim, title, values])</code>	Create a summary plot of the RadBelt object distribution function.
<code>plot_obs([Lmax, Lpp, Kp, Dst, clim, title, ...])</code>	Create a summary plot of the observations.
<code>set_lgrid(NL)</code>	Using NL grid points, create grid in L.
<code>setup_ticks(start, end, delta[, dtype])</code>	Add time information to the simulation by specifying a start and end time, timestep

Gaussian_source ()

Gaussian source term added to radiation belt model. The source term is given by the equation:

$$S = A \exp\{-(L-\mu)^2/(2*\sigma^2)\}$$

with $A=10^{(-8)}$, $\mu=5.0$, and $\sigma=0.5$ as default values

add_Lmax (Lmax_model)

add last closed drift shell Lmax

add_Lpp (Lpp_model)

add last closed drift shell Lmax

add_PSD_obs (time=None, PSD=None, Lstar=None, satlist=None)

add PSD observations

Parameters **time** : Ticktock datetime array

array of observation times

PSD : list of numpy arrays

PSD observational data for each time. Each entry in the list is a numpy array with the observations for the corresponding time

Lstar : list of numpy arrays

Lstar location of each PSD observations. Each entry in the list is a numpy array with the location of the observations for the corresponding time

satlist : list of satellite names

Returns **out** : list of dicts

Information of the observational data, where each entry contains the observations and locations of observations for each time specified in the time array. Each list entry is a dictionary with the following information:

Ticks : Ticktock array

time of observations

Lstar : numpy array

location of observations

PSD : numpy array

PSD observation values

sat : list of strings

satellite names

MU : scalar value

Mu value for the observations

K : scalar value

K value for the observations

add_PSD_twin (*dt=0, Lt=1*)

add observations from PSD database using the ticks list the arguments are the following:

dt = observation time delta in seconds Lt = observation space delta

add_omni (*keylist=None*)

add omni data to instance according to the tickrange in ticks

add_source (*source=True, A=1e-08, mu=5.0, sigma=0.5*)

add source parameters A, mu, and sigma for the Gaussian source function

assimilate (*method='EnKF', inflation=0*)

Assimilates data for the radiation belt model using the Ensemble Kalman Filter. The algorithm used is the SVD method presented by Evensen in 2003 (Evensen, G., Ocean dynamics, 53, pp.343–367, 2003). To compensate for model errors, three inflation algorithms are implemented. The inflation methodology is specified by the 'inflation' argument, and the options are the following:

inflation == 0: Add model error (perturbation for the ensemble) around model state values only where observations are available (DEFAULT).

inflation == 1: Add model error (perturbation for the ensemble) around observation values only where observations are available.

inflation == 2: Inflate around ensemble average for EnKF.

Prior to assimilation, a set of data values has to be specified by setting the start and end dates, and time step, using the `setup_ticks` function of the radiation belt model:

```
>>> import spacepy
>>> import datetime
>>> from spacepy import radbelt

>>> start = datetime.datetime(2002,10,23)
>>> end = datetime.datetime(2002,11,4)
>>> delta = datetime.timedelta(hours=0.5)
>>> rmod.setup_ticks(start, end, delta, dtype='UTC')
```

Once the dates and time step are specified, the data is added using the `add_PSD` function:

```
>>> rmod.add_PSD()
```

The observations are averaged over the time windows, whose interval is give by the time step.

Once the dates and data are set, the assimiation is performed using the 'assimilate' function:

```
>>> rmod.assimilate(inflation=1)
```

This function will add the PSDa values, which are the analysis state of the radiation belt using the observations within the dates. To plot the analysis simply use the `plot` function:

```
>>> rmod.plot(values=rmod.PSDa, clim=[-10, -6], Lmax=False, Kp=False, Dst=False)
```

evolve()

calculate the diffusion in L at constant mu,K coordinates

get_DLL(Lgrid, params, DLL_model='BA2000')

Calculate DLL as a simple power law function ($\alpha \cdot L^{2\beta}$) using alpha/beta values from popular models found in the literature and chosen with the kwarg "DLL_model".

The calculated DLL is returned, as is the alpha and beta values used in the calculation.

The output DLL is in units of units/day.

plot(Lmax=True, Lpp=False, Kp=True, Dst=True, clim=[0, 10], title=None, values=None)

Create a summary plot of the RadBelt object distribution function. For reference, the last closed drift shell, Dst, and Kp are all included. These can be disabled individually using the corresponding Boolean kwargs.

The clim kwarg can be used to manually set the color bar range. To use, set it equal to a two-element list containing minimum and maximum Log₁₀ value to plot. Default action is to use [0,10] as the log₁₀ of the color range. This is good enough for most applications.

The title of the top most plot defaults to 'Summary Plot' but can be customized using the title kwarg.

The figure object and all three axis objects (PSD axis, Dst axis, and Kp axis) are all returned to allow the user to further customize the plots as necessary. If any of the plots are excluded, None is returned in their stead.

Examples

```
>>> rb.plot(Lmax=False, Kp=False, clim=[2,10], title='Good work!')
```

This command would create the summary plot with a color bar range of 100 to 10¹⁰. The Lmax line and Kp values would be excluded. The title of the topmost plot (phase space density) would be set to 'Good work!'.

plot_obs(Lmax=True, Lpp=False, Kp=True, Dst=True, clim=[0, 10], title=None, values=None)

Create a summary plot of the observations. For reference, the last closed drift shell, Dst, and Kp are all included. These can be disabled individually using the corresponding boolean kwargs.

The clim kwarg can be used to manually set the color bar range. To use, set it equal to a two-element list containing minimum and maximum Log₁₀ value to plot. Default action is to use [0,10] as the log₁₀ of the color range. This is good enough for most applications.

The title of the top most plot defaults to 'Summary Plot' but can be customized using the title kwarg.

The figure object and all three axis objects (PSD axis, Dst axis, and Kp axis) are all returned to allow the user to further customize the plots as necessary. If any of the plots are excluded, None is returned in their stead.

Examples

```
>>> rb.plot_obs(Lmax=False, Kp=False, clim=[2,10], title='Observations Plot')
```

This command would create the summary plot with a color bar range of 100 to 10¹⁰. The Lmax line and Kp values would be excluded. The title of the topmost plot (phase space density) would be set to 'Good work!'.

set_lgrid (*NL=91*)

Using NL grid points, create grid in L. Default number of points is 91 (dL=0.1).

setup_ticks (*start, end, delta, dtype='ISO'*)

Add time information to the simulation by specifying a start and end time, timestep, and time type (optional).

Examples

```
>>> start = datetime.datetime(2003,10,14)
>>> end = datetime.datetime(2003,12,26)
>>> delta = datetime.timedelta(hours=1)
>>> rmod.setup_ticks(start, end, delta, dtype='UTC')
```

Functions

<code>get_modelop_L(f, L, Dm_old, Dm_new, Dp_old, ...)</code>	Advance the distribution function, f, discretized into the Lgrid, L, forward
<code>diff_LL(r, grid, f, Tdelta, Telapsed[, params])</code>	calculate the diffusion in L at constant mu,K coordinates
<code>get_local_accel(Lgrid, params[, SRC_model])</code>	calculate the diffusion coefficient D_LL

2.11.2 spacepy.radbelt.get_modelop_L

`spacepy.radbelt.get_modelop_L(f, L, Dm_old, Dm_new, Dp_old, Dp_new, Tdelta, NL)`

Advance the distribution function, f, discretized into the Lgrid, L, forward in time by a timestep, Tdelta. The off-grid current and next diffusion coefficients, D[m,p]_[old,new] will be used. The number of grid points is set by NL.

This function performs the same calculation as the C-based code, `spacepy.lib.solve_cnp`. This code is very slow and should only be used when the C code fails to compile.

2.11.3 spacepy.radbelt.diff_LL

`spacepy.radbelt.diff_LL(r, grid, f, Tdelta, Telapsed, params=None)`

calculate the diffusion in L at constant mu,K coordinates time units

2.11.4 spacepy.radbelt.get_local_accel

`spacepy.radbelt.get_local_accel(Lgrid, params, SRC_model='JKI')`

calculate the diffusion coefficient D_LL

2.12 SeaPy - Superposed Epoch in Python

SeaPy – Superposed Epoch in Python.

This module contains superposed epoch class types and a variety of functions for using on superposed epoch objects. Each instance must be initialized with (assuming import seapy as se):

```
>>> obj = se.Sea(data, times, epochs)
```

To perform a superposed epoch analysis

```
>>> obj.sea()
```

To plot

```
>>> obj.plot()
```

If multiple SeaPy objects exist, these can be combined into a single object

```
>>> objdict = seadict([obj1, obj2], ['obj1name', 'obj2name'])
```

and then used to create a multipanel plot

```
>>> multisea(objdict)
```

For two-dimensional superposed epoch analyses, initialize an Sea2d() instance

```
>>> obj = se.Sea2d(data, times, epochs, y=[4., 12.])
```

All object methods are the same as for the 1D object. Also, the multisea() function should accept both 1D and 2D objects, even mixed together. Currently, the plot() method is recommended for 2D SEA.

—++ By Steve Morley —++

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Classes

<code>Sea(data, times, epochs[, window, delta, ...])</code>	SeaPy Superposed epoch analysis object
<code>Sea2d(data, times, epochs[, window, delta, ...])</code>	SeaPy 2D Superposed epoch analysis object

2.12.1 spacepy.seapy.Sea

class `spacepy.seapy.Sea` (*data, times, epochs, window=3.0, delta=1.0, verbose=True*)
SeaPy Superposed epoch analysis object

Initialize object with data, times, epochs, window (half-width) and delta (optional). ‘times’ and epochs should be in some useful format Includes method to perform superposed epoch analysis of input data series

Parameters **data** : array_like

list or array of data

times : array_like

list of datetime objects (or list of serial times)

epochs : array_like

list of datetime objects (or serial times) for zero epochs in SEA

window : datetime.timedelta

size of the half-window for the SEA (can also be given as serial time)

delta : datetime.timedelta

resolution of the input data series, which must be uniform (can also be given as serial time)

Notes

Output can be nicely plotted with `plot()`, or for multiple objects use the `multisea()` function

<code>sea(**kwargs)</code>	Method called to perform superposed epoch analysis on data in object.
<code>plot([xquan, yquan, xunits, yunits, ...])</code>	Method called to create basic plot of superposed epoch analysis.

`sea (**kwargs)`

Method called to perform superposed epoch analysis on data in object.

Uses object attributes `obj.data`, `obj.times`, `obj.epochs`, `obj.delta`, `obj.window`, all of which must be available on instantiation.

Other Parameters `storedata` : boolean

saves matrix of epoch windows as `obj.datacube` (default = False)

quartiles : list

calculates the quartiles as the upper and lower bounds (and is default);

ci : float

will find the bootstrapped confidence intervals (and requires `ci_quan` to be set);

mad : float

will use +/- the median absolute deviation for the bounds;

ci_quan : string

can be set to 'median' or 'mean'

Notes

A basic plot can be raised with `plot()`

`plot(xquan='Time Since Epoch', yquan='', xunits='', yunits='', epochline=False, usrlimy=[], show=True, figsize=None, dpi=None, transparent=True, color='#7F7FFF')`

Method called to create basic plot of superposed epoch analysis.

Parameters Uses object attributes created by the `obj.sea()` method. :

Other Parameters `xquan` : str

(default = 'Time since epoch') - x-axis label.

yquan : str

default None - yaxus label

xunits : str

(default = None) - x-axis units.

yunits : str

(default = None) - y-axis units.

epochline : boolean

(default = False) - put vertical line at zero epoch.

usrlimy : list

(default = []) - override automatic y-limits on plot.

transparent : boolean

(default True): make patch for low/high bounds transparent

color : str

Color to use for the patch if not transparent. (default #7F7FFF, a medium blue)

Notes

If both quan and units are supplied, axis label will read 'Quantity Entered By User [Units]'

2.12.2 spacepy.seapy.Sea2d

class `spacepy.seapy.Sea2d` (*data*, *times*, *epochs*, *window*=3.0, *delta*=1.0, *verbose*=False, *y*=[])
SeaPy 2D Superposed epoch analysis object

Initialize object with data (n element vector), times(y*n array), epochs, window (half-width), delta (optional), and y (two-element vector with max and min of y;optional) 'times' and epochs should be in some useful format
Includes method to perform superposed epoch analysis of input data series

Parameters **data** : array_like

2-D array of data (0th dimension is quantity y, 1st dimension is time)

times : array_like

list of datetime objects (or list of serial times)

epochs : array_like

list of datetime objects (or serial times) for zero epochs in SEA

window : datetime.timedelta

size of the half-window for the SEA (can also be given as serial time)

delta : datetime.timedelta

resolution of the input data series, which must be uniform (can also be given as serial time)

Notes

Output can be nicely plotted with `plot()`, or for multiple objects use the `multisea()` function

<code>sea([storedata, quartiles, ci, mad, ...])</code>	Perform 2D superposed epoch analysis on data in object
<code>plot([xquan, yquan, xunits, yunits, zunits, ...])</code>	Method called to create basic plot of 2D superposed epoch analysis.

sea (*storedata*=False, *quartiles*=True, *ci*=False, *mad*=False, *ci_quan*='median', *nmask*=1, ***kwargs*)
Perform 2D superposed epoch analysis on data in object

Uses object attributes `obj.data`, `obj.times`, `obj.epochs`, `obj.delta`, `obj.window`, all of which must be available on instantiation.

Other Parameters `storedata` : boolean

saves matrix of epoch windows as `obj.datacube` (default = False)

quartiles : list

calculates the inter-quartile range to show the spread (and is default);

ci : float

will find the bootstrapped confidence interval (and requires `ci_quan` to be set)

mad : float

will use the median absolute deviation for the spread;

ci_quan : string

can be set to 'median' or 'mean'

Notes

A basic plot can be raised with `plot()`

plot (*xquan='Time Since Epoch', yquan='', xunits='', yunits='', zunits='', epochline=False, usr-
limy=[], show=True, zlog=True, figsize=None, dpi=300*)

Method called to create basic plot of 2D superposed epoch analysis.

Uses object attributes created by `sea()`.

Other Parameters `x(y)quan` : str

x(y)-axis label. (default = 'Time since epoch' (None))

x(y/z)units : str

x(y/z)-axis units. (default = None (None))

epochline : boolean

put vertical line at zero epoch. (default = False)

usrlimy : list

override automatic y-limits on plot. (default = [])

show : boolean

shows plot; set to false to output plot object to variable (default = True)

figsize : tuple

(width, height) in inches

dpi : int

figure resolution in dots per inch (default=300)

Notes

If both `quan` and `units` are supplied, axis label will read 'Quantity Entered By User [Units]'

Functions

<code>seadict(objlist, namelist)</code>	Function to create dictionary of SeaPy.Sea objects.
<code>multisea(dictobj[, n_cols, epochline, ...])</code>	Function to create multipanel plot of superposed epoch analyses.
<code>readepochs(fname[, iso, isofmt])</code>	Read epochs from text file assuming YYYY MM DD hh mm ss format
<code>sea_signif(obj1, obj2[, test, show, xquan, ...])</code>	Test for similarity between distributions at each lag in two 1-D SEAs

2.12.3 spacepy.seapy.seadict

`spacepy.seapy.seadict` (*objlist, namelist*)

Function to create dictionary of SeaPy.Sea objects.

Parameters - **objlist**: List of Sea objects. :

- **namelist**: List of variable labels for input objects.

Other Parameters **namelist** = List containing names for y-axes. :

2.12.4 spacepy.seapy.multisea

`spacepy.seapy.multisea` (*dictobj, n_cols=1, epochline=False, usrlimx=[], usrlimy=[], xunits='', show=True, zunits='', zlog=True, figsize=None, dpi=300*)

Function to create multipanel plot of superposed epoch analyses.

Parameters Dictionary of Sea objects (from `superposedepoch.seadict()`). :

Returns Plot of input object median and bounds (ci, mad, quartiles - see `sea()`). :

If keyword 'show' is False, output is a plot object. :

Other Parameters - **epochline** (default = False) - put vertical line at zero epoch. :

- **usrlimy** (default = []) - override automatic y-limits on plot (same for all plots).
- **show** (default = True) - shows plot; set to false to output plot object to variable
- **x/zunits** - Units for labeling x and z axes, if required
- **figsize** - tuple of (width, height) in inches
- **dpi** (default=300) - figure resolution in dots per inch
- **n_cols** - Number of columns: not yet implemented.

2.12.5 spacepy.seapy.readepochs

`spacepy.seapy.readepochs` (*fname, iso=False, isofmt='%Y-%m-%dT%H:%M:%S'*)

Read epochs from text file assuming YYYY MM DD hh mm ss format

Parameters Filename (include path) :

Returns epochs (type=list) :

Other Parameters **iso** (default = False), read in ISO date format :

isofmt (default is YYYY-mm-ddTHH:MM:SS, code is %Y-%m-%dT%H:%M:%S) :

2.12.6 spacepy.seapy.sea_signif

```
spacepy.seapy.sea_signif(obj1, obj2, test='KS', show=True, xquan='Time Since Epoch', yquan='',
                        xunits='', yunits='', epochline=True, usrlimy=[])
```

Test for similarity between distributions at each lag in two 1-D SEAs

Parameters Two seapy.Sea() instances for comparison :

Other Parameters - show (default = True) :

- x(y)quan (default = 'Time since epoch' (None)) - x(y)-axis label.
- x(y)units (default = None (None)) - x(y)-axis units.
- epochline (default = True) - put vertical line at zero epoch.
- usrlimy (default = []) - override automatic y-limits on plot.

Examples

```
>>> obj1 = seapy.Sea(data1, times1, epochs1)
>>> obj2 = seapy.Sea(data2, times2, epochs2)
>>> obj1.sea(storedata=True)
>>> obj2.sea(storedata=True)
>>> seapy.sea_signif(obj1, obj2)
```

2.13 time - Time conversion, manipulation and implementation of Ticktock class

Time conversion, manipulation and implementation of Ticktock class

2.13.1 Examples:

```
>>> import spacepy.time as spt
>>> import datetime as dt
```

Day of year calculations

```
>>> dts = spt.doy2date([2002]*4, range(186,190), dtobj=True)
>>> dts
[datetime.datetime(2002, 7, 5, 0, 0),
 datetime.datetime(2002, 7, 6, 0, 0),
 datetime.datetime(2002, 7, 7, 0, 0),
 datetime.datetime(2002, 7, 8, 0, 0)]

>>> dts = spt.Ticktock(dts, 'UTC')
>>> dts.DOY
array([ 186.,  187.,  188.,  189.])
```

Ticktock object creation

```
>>> isodates = ['2009-12-01T12:00:00', '2009-12-04T00:00:00', '2009-12-06T12:00:00']
>>> dts = spt.Ticktock(isodates, 'ISO')
```

OR

```
>>> dtdates = [dt.datetime(2009,12,1,12), dt.datetime(2009,12,4), dt.datetime(2009,12,6,12)]
>>> dts = spt.Ticktock(dtdates, 'UTC')
```

ISO time formatting

```
>>> dts = spt.tickrange('2009-12-01T12:00:00', '2009-12-06T12:00:00', 2.5)
```

OR

```
>>> dts = spt.tickrange(dt.datetime(2009,12,1,12), dt.datetime(2009,12,6,12), dt.timedelta(days=2.5))
```

```
>>> dts
Ticktock( ['2009-12-01T12:00:00', '2009-12-04T00:00:00', '2009-12-06T12:00:00'] ), dtype=ISO
```

```
>>> dts.isoformat()
Current ISO output format is %Y-%m-%dT%H:%M:%S
Options are: [('seconds', '%Y-%m-%dT%H:%M:%S'), ('microseconds', '%Y-%m-%dT%H:%M:%S.%f')]
```

```
>>> dts.isoformat('microseconds')
>>> dts.ISO
['2009-12-01T12:00:00.000000',
 '2009-12-04T00:00:00.000000',
 '2009-12-06T12:00:00.000000']
```

Time manipulation

```
>>> new_dts = dts + tdelt
>>> new_dts.UTC
[datetime.datetime(2009, 12, 2, 18, 0),
 datetime.datetime(2009, 12, 5, 6, 0),
 datetime.datetime(2009, 12, 7, 18, 0)]
```

Other time formats

```
>>> dts.RDT # Gregorian ordinal time
array([ 733742.5, 733745. , 733747.5])

>>> dts.GPS # GPS time
array([ 9.43704015e+08, 9.43920015e+08, 9.44136015e+08])

>>> dts.JD # Julian day
array([ 2455167. , 2455169.5, 2455172. ])
```

And so on.

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class spacepy.time.**Ticktock**(data, dtype)

Ticktock class holding various time coordinate systems (TAI, UTC, ISO, JD, MJD, UNIX, RDT, CDF, DOY, eDOY)

Possible input data types: ISO: ISO standard format like '2002-02-25T12:20:30' UTC: datetime object with UTC time TAI: elapsed seconds since 1958/1/1 (includes leap seconds) UNIX: elapsed seconds since 1970/1/1 (all days have 86400 secs sometimes unequal lengths) JD: Julian days elapsed MJD: Modified Julian days RDT: Rata Die days elapsed since 1/1/1 CDF: CDF epoch: milliseconds since 1/1/0000

Possible output data types: All those listed above, plus DOY: Integer day of year, starts with day 1 eDOY: Fractional day of year, starts at day 0

Parameters **data** : array_like (int, datetime, float, string)

time stamp

dtype : string {*CDF*, *ISO*, *UTC*, *TAI*, *UNIX*, *JD*, *MJD*, *RDT*} or function

data type for data, if a function it must convert input time format to Python datetime

Returns **out** : Ticktock

instance with self.data, self.dtype, self.UTC etc

Examples

```
>>> x = Ticktock([2452331.0142361112, 2452332.0142361112], 'JD')
>>> x.ISO
dmarray(['2002-02-25T12:20:30', '2002-02-26T12:20:30'], dtype='|S19')
>>> x.DOY # Day of year
dmarray([ 56.,  57.])
>>> y = Ticktock(['01-01-2013', '20-03-2013'], lambda x: datetime.datetime.strptime(x, '%d-%m-%Y'))
>>> y.UTC
dmarray([2013-01-01 00:00:00, 2013-03-20 00:00:00], dtype=object)
>>> y.DOY # Day of year
dmarray([ 1.,  79.])
```

<code>append(other)</code>	Will be called when another Ticktock instance has to be appended to the current one
<code>argsort()</code>	This will return the indices that would sort the Ticktock values
<code>convert(dtype)</code>	convert a Ticktock instance into a new time coordinate system provided in dtype
<code>getCDF()</code>	a.getCDF() or a.CDF
<code>getDOY()</code>	a.DOY or a.getDOY()
<code>getGPS()</code>	a.GPS or a.getGPS()
<code>getISO()</code>	a.ISO or a.getISO()
<code>getJD()</code>	a.JD or a.getJD()
<code>getMJD()</code>	a.MJD or a.getMJD()
<code>getRDT()</code>	a.RDT or a.RDT()
<code>getTAI()</code>	a.TAI or a.getTAI()
<code>getUNIX()</code>	a.UNX or a.getUNIX()
<code>getUTC()</code>	a.UTC or a.getUTC()
<code>geteDOY()</code>	a.eDOY or a.geteDOY()
<code>getleapsecs()</code>	a.leaps or a.getleapsecs()
<code>isoformat(b, attrib)</code>	This changes the self.__isofmt attribute by and subsequently this function will update the ISO attribute.
<code>now()</code>	Creates a Ticktock object with the current time, equivalent to datetime.now()
<code>sort()</code>	This will sort the Ticktock values in place
<code>update_items(b, attrib)</code>	After changing the self.data attribute by either <code>__setitem__</code> or <code>__add__</code> etc this function will update all

append (*other*)

Will be called when another Ticktock instance has to be appended to the current one

Parameters **other** : Ticktock

other (Ticktock instance)

argsort ()

This will return the indices that would sort the Ticktock values

Returns **out** : list

indices that would sort the Ticktock values

convert (*dtype*)

convert a Ticktock instance into a new time coordinate system provided in dtype

Parameters *dtype* : string

data type for new system, possible values are {*CDF*, *ISO*, *UTC*, *TAI*, *UNIX*, *JD*, *MJD*, *RDT*}

Returns *out* : Ticktock

Ticktock instance with new time coordinates

See also:

CDF, *ISO*, *UTC*

Examples

```
>>> a = Ticktock(['2002-02-02T12:00:00', '2002-02-02T12:00:00'], 'ISO')
>>> s = a.convert('TAI')
>>> type(s)
<class 'time.Ticktock'>
>>> s
Ticktock( [1391342432 1391342432] ), dtype=TAI
```

getCDF ()

a.getCDF() or *a*.CDF

Return CDF time which is milliseconds since 01-Jan-0000 00:00:00.000. “Year zero” is a convention chosen by NSSDC to measure epoch values. This date is more commonly referred to as 1 BC. Remember that 1 BC was a leap year. The CDF date/time calculations do not take into account the changes to the Gregorian calendar, and cannot be directly converted into Julian date/times.

Returns *out* : numpy array

days elapsed since Jan. 1st

See also:

getUTC, *getUNIX*, *getRDT*, *getJD*, *getMJD*, *getISO*, *getTAI*, *getDOY*, *geteDOY*

Examples

```
>>> a = Ticktock('2002-02-02T12:00:00', 'ISO')
>>> a.CDF
array([ 6.31798704e+13])
```

getDOY ()

a.DOY or *a*.getDOY()

extract DOY (days since January 1st of given year)

Returns *out* : numpy array

day of the year

See also:

getUTC, *getUNIX*, *getRDT*, *getJD*, *getMJD*, *getISO*, *getTAI*, *getDOY*, *geteDOY*

Examples

```
>>> a = Ticktock('2002-02-02T12:00:00', 'ISO')
>>> a.DOY
array([ 33])
```

getGPS()

a.GPS or a.getGPS()

return GPS epoch (0000 UT (midnight) on January 6, 1980)

Returns out : numpy array

elapsed secs since 6Jan1980 (excludes leap secs)

See also:

getUTC, getUNIX, getRDT, getJD, getMJD, getCDF, getISO, getDOY, geteDOY

Examples

```
>>> a = Ticktock('2002-02-02T12:00:00', 'ISO')
>>> a.GPS
array([])
```

getISO()

a.ISO or a.getISO()

convert dtype data into ISO string

Returns out : list of strings

date in ISO format

See also:

getUTC, getUNIX, getRDT, getJD, getMJD, getCDF, getTAI, getDOY, geteDOY

Examples

```
>>> a = Ticktock('2002-02-02T12:00:00', 'ISO')
>>> a.ISO
dmmarray(['2002-02-02T12:00:00'])
```

getJD()

a.JD or a.getJD()

convert dtype data into Julian Date (JD)

Returns out : numpy array

elapsed days since 12:00 January 1, 4713 BC

See also:

getUTC, getUNIX, getRDT, getJD, getMJD, getISO, getTAI, getDOY, geteDOY

Examples

```
>>> a = Ticktock('2002-02-02T12:00:00', 'ISO')
>>> a.JD
array([ 2452308.])
```

getMJD()

a.MJD or a.getMJD()

convert dtype data into MJD (modified Julian date)

Returns out : numpy array

elapsed days since November 17, 1858 (Julian date was 2,400 000)

See also:

getUTC, getUNIX, getRDT, getJD, getISO, getCDF, getTAI, getDOY, geteDOY

Examples

```
>>> a = Ticktock('2002-02-02T12:00:00', 'ISO')
>>> a.MJD
array([ 52307.5])
```

getRDT()

a.RDT or a.RDT()

convert dtype data into Rata Die (lat.) Time (days since 1/1/0001)

Returns out : numpy array

elapsed days since 1/1/1

See also:

getUTC, getUNIX, getISO, getJD, getMJD, getCDF, getTAI, getDOY, geteDOY

Examples

```
>>> a = Ticktock('2002-02-02T12:00:00', 'ISO')
>>> a.RDT
array([ 730883.5])
```

getTAI()

a.TAI or a.getTAI()

return TAI (International Atomic Time)

Returns out : numpy array

elapsed secs since 1958/1/1 (includes leap secs, i.e. all secs have equal lengths)

See also:

getUTC, getUNIX, getRDT, getJD, getMJD, getCDF, getISO, getDOY, geteDOY

Examples

```
>>> a = Ticktock('2002-02-02T12:00:00', 'ISO')
>>> a.TAI
array([1391342432])
```

getUNIX()

a.UNX or a.getUNIX()

convert dtype data into Unix Time (Posix Time) seconds since 1970-Jan-1 (not counting leap seconds)

Returns out : numpy array

elapsed secs since 1970/1/1 (not counting leap secs)

See also:

getUTC, getISO, getRDT, getJD, getMJD, getCDF, getTAI, getDOY, geteDOY

Examples

```
>>> a = Ticktock('2002-02-02T12:00:00', 'ISO')
>>> a.UNX
array([ 1.01265120e+09])
```

getUTC()

a.UTC or a.getUTC()

convert dtype data into UTC object a la datetime()

Returns out : list of datetime objects

datetime object in UTC time

See also:

getISO, getUNIX, getRDT, getJD, getMJD, getCDF, getTAI, getDOY, geteDOY

Examples

```
>>> a = Ticktock('2002-02-02T12:00:00', 'ISO')
>>> a.UTC
[datetime.datetime(2002, 2, 2, 12, 0)]
```

geteDOY()

a.eDOY or a.geteDOY()

extract eDOY (elapsed days since midnight January 1st of given year)

Returns out : numpy array

days elapsed since midnight bbedJan. 1st

See also:

getUTC, getUNIX, getRDT, getJD, getMJD, getISO, getTAI, getDOY, geteDOY

Examples

```
>>> a = Ticktock('2002-02-02T12:00:00', 'ISO')
>>> a.eDOY
array([ 32.5])
```

getleapsecs()

a.leaps or a.getleapsecs()

retrieve leapseconds from lookup table, used in getTAI

Returns out : numpy array

leap seconds

See also:

`getTAI`

Examples

```
>>> a = Ticktock('2002-02-02T12:00:00', 'ISO')
>>> a.leaps
array([32])
```

isoformat(b, attrib)

This changes the self.__isofmt attribute by and subsequently this function will update the ISO attribute.

Parameters fmt : string, optional

classmethod now()

Creates a Ticktock object with the current time, equivalent to datetime.now()

Returns out : ticktock

Ticktock object with the current time, equivalent to datetime.now()

See also:

`datetime.datetime.now`

sort()

This will sort the Ticktock values in place

update_items(b, attrib)

After changing the self.data attribute by either `__setitem__` or `__add__` etc this function will update all other attributes. This function is called automatically in `__add__` and `__setitem__`

Parameters cls : Ticktock

attrib : string

attribute to update

See also:

`spacepy.Ticktock.__setitem__`,
`spacepy.Ticktock.__sub__`

`spacepy.Ticktock.__add__`,

append(other)

Will be called when another Ticktock instance has to be appended to the current one

Parameters other : Ticktock

other (Ticktock instance)

argsort ()

This will return the indices that would sort the Ticktock values

Returns out : list

indices that would sort the Ticktock values

convert (dtype)

convert a Ticktock instance into a new time coordinate system provided in dtype

Parameters dtype : string

data type for new system, possible values are {*CDF*, *ISO*, *UTC*, *TAI*, *UNIX*, *JD*, *MJD*, *RDT*}

Returns out : Ticktock

Ticktock instance with new time coordinates

See also:

CDF, ISO, UTC

Examples

```
>>> a = Ticktock(['2002-02-02T12:00:00', '2002-02-02T12:00:00'], 'ISO')
>>> s = a.convert('TAI')
>>> type(s)
<class 'time.Ticktock'>
>>> s
Ticktock( [1391342432 1391342432] ), dtype=TAI
```

getCDF ()

a.getCDF() or a.CDF

Return CDF time which is milliseconds since 01-Jan-0000 00:00:00.000. “Year zero” is a convention chosen by NSSDC to measure epoch values. This date is more commonly referred to as 1 BC. Remember that 1 BC was a leap year. The CDF date/time calculations do not take into account the changes to the Gregorian calendar, and cannot be directly converted into Julian date/times.

Returns out : numpy array

days elapsed since Jan. 1st

See also:

[getUTC](#), [getUNIX](#), [getRDT](#), [getJD](#), [getMJD](#), [getISO](#), [getTAI](#), [getDOY](#), [geteDOY](#)

Examples

```
>>> a = Ticktock('2002-02-02T12:00:00', 'ISO')
>>> a.CDF
array([ 6.31798704e+13])
```

getDOY ()

a.DOY or a.getDOY()

extract DOY (days since January 1st of given year)

Returns out : numpy array

day of the year

See also:

`getUTC`, `getUNIX`, `getRDT`, `getJD`, `getMJD`, `getISO`, `getTAI`, `getDOY`, `geteDOY`

Examples

```
>>> a = Ticktock('2002-02-02T12:00:00', 'ISO')
>>> a.DOY
array([ 33])
```

`getGPS()`

`a.GPS` or `a.getGPS()`

return GPS epoch (0000 UT (midnight) on January 6, 1980)

Returns out : numpy array

elapsed secs since 6Jan1980 (excludes leap secs)

See also:

`getUTC`, `getUNIX`, `getRDT`, `getJD`, `getMJD`, `getCDF`, `getISO`, `getDOY`, `geteDOY`

Examples

```
>>> a = Ticktock('2002-02-02T12:00:00', 'ISO')
>>> a.GPS
array([])
```

`getISO()`

`a.ISO` or `a.getISO()`

convert dtype data into ISO string

Returns out : list of strings

date in ISO format

See also:

`getUTC`, `getUNIX`, `getRDT`, `getJD`, `getMJD`, `getCDF`, `getTAI`, `getDOY`, `geteDOY`

Examples

```
>>> a = Ticktock('2002-02-02T12:00:00', 'ISO')
>>> a.ISO
dmmarray(['2002-02-02T12:00:00'])
```

`getJD()`

`a.JD` or `a.getJD()`

convert dtype data into Julian Date (JD)

Returns out : numpy array

elapsed days since 12:00 January 1, 4713 BC

See also:

`getUTC`, `getUNIX`, `getRDT`, `getJD`, `getMJD`, `getISO`, `getTAI`, `getDOY`, `geteDOY`

Examples

```
>>> a = Ticktock('2002-02-02T12:00:00', 'ISO')
>>> a.JD
array([ 2452308.])
```

getMJD()

`a.MJD` or `a.getMJD()`

convert dtype data into MJD (modified Julian date)

Returns out : numpy array

elapsed days since November 17, 1858 (Julian date was 2,400 000)

See also:

`getUTC`, `getUNIX`, `getRDT`, `getJD`, `getISO`, `getCDF`, `getTAI`, `getDOY`, `geteDOY`

Examples

```
>>> a = Ticktock('2002-02-02T12:00:00', 'ISO')
>>> a.MJD
array([ 52307.5])
```

getRDT()

`a.RDT` or `a.RDT()`

convert dtype data into Rata Die (lat.) Time (days since 1/1/0001)

Returns out : numpy array

elapsed days since 1/1/1

See also:

`getUTC`, `getUNIX`, `getISO`, `getJD`, `getMJD`, `getCDF`, `getTAI`, `getDOY`, `geteDOY`

Examples

```
>>> a = Ticktock('2002-02-02T12:00:00', 'ISO')
>>> a.RDT
array([ 730883.5])
```

getTAI()

`a.TAI` or `a.getTAI()`

return TAI (International Atomic Time)

Returns out : numpy array

elapsed secs since 1958/1/1 (includes leap secs, i.e. all secs have equal lengths)

See also:

`getUTC`, `getUNIX`, `getRDT`, `getJD`, `getMJD`, `getCDF`, `getISO`, `getDOY`, `geteDOY`

Examples

```
>>> a = Ticktock('2002-02-02T12:00:00', 'ISO')
>>> a.TAI
array([1391342432])
```

getUNIX()

a.UNX or a.getUNIX()

convert dtype data into Unix Time (Posix Time) seconds since 1970-Jan-1 (not counting leap seconds)

Returns out : numpy array

elapsed secs since 1970/1/1 (not counting leap secs)

See also:

getUTC, getISO, getRDT, getJD, getMJD, getCDF, getTAI, getDOY, geteDOY

Examples

```
>>> a = Ticktock('2002-02-02T12:00:00', 'ISO')
>>> a.UNX
array([ 1.01265120e+09])
```

getUTC()

a.UTC or a.getUTC()

convert dtype data into UTC object a la datetime()

Returns out : list of datetime objects

datetime object in UTC time

See also:

getISO, getUNIX, getRDT, getJD, getMJD, getCDF, getTAI, getDOY, geteDOY

Examples

```
>>> a = Ticktock('2002-02-02T12:00:00', 'ISO')
>>> a.UTC
[datetime.datetime(2002, 2, 2, 12, 0)]
```

geteDOY()

a.eDOY or a.geteDOY()

extract eDOY (elapsed days since midnight January 1st of given year)

Returns out : numpy array

days elapsed since midnight bbedJan. 1st

See also:

getUTC, getUNIX, getRDT, getJD, getMJD, getISO, getTAI, getDOY, geteDOY

Examples

```
>>> a = Ticktock('2002-02-02T12:00:00', 'ISO')
>>> a.eDOY
array([ 32.5])
```

getleapsecs()

a.leaps or a.getleapsecs()

retrieve leapseconds from lookup table, used in getTAI

Returns out : numpy array

leap seconds

See also:

getTAI

Examples

```
>>> a = Ticktock('2002-02-02T12:00:00', 'ISO')
>>> a.leaps
array([32])
```

insert(idx, val, dtype=None)

insert values into the TickTock object

Note: If more than one value to insert a slice must be specified

as the index. See numpy.insert

Parameters idx : int, slice or sequence of ints

Object that defines the index or indices before which *val* is inserted.

val [array_like] values to insert

dtype [str (optional)] must be specified if not CDF, ISO, or UTC

isoformat(b, attrib)

This changes the self.__isofmt attribute by and subsequently this function will update the ISO attribute.

Parameters fmt : string, optional

classmethod now()

Creates a Ticktock object with the current time, equivalent to datetime.now()

Returns out : ticktock

Ticktock object with the current time, equivalent to datetime.now()

See also:

datetime.datetime.now

remove(idx)

This will remove the Ticktock value at index idx

sort()

This will sort the Ticktock values in place

update_items (*b, attrib*)

After changing the self.data attribute by either `__setitem__` or `__add__` etc this function will update all other attributes. This function is called automatically in `__add__` and `__setitem__`

Parameters `cls` : Ticktock

attrib : string

attribute to update

See also:

`spacepy.Ticktock.__setitem__`,
`spacepy.Ticktock.__sub__`

`spacepy.Ticktock.__add__`,

`spacepy.time.doy2date` (*year, doy, dtobj=False, flAns=False*)

convert integer day-of-year *doy* into a month and day after http://pleac.sourceforge.net/pleac_python/datesandtimes.html

Parameters `year` : int or array of int

`year`

doy : int or array of int

day of year

Returns `month` : int or array of int

month as integer number

day : int or array of int

as integer number

See also:

`Ticktock.getDOY`

Examples

```
>>> month, day = doy2date(2002, 186)
>>> dts = doy2date([2002]*4, range(186,190), dtobj=True)
```

`spacepy.time.extract_YYYYMMDD` (*filename*)

go through a string and extract the first valid YYYYMMDD as a datetime

Parameters `filename` : str

string to parse for a YYYYMMDD format

Returns `out` : (None, datetime.datetime)

the datetime found in the string or None

`spacepy.time.leapyear` (*year, numdays=False*)

return an array of boolean leap year, a lot faster than the mod method that is normally seen

Parameters `year` : array_like

array of years

numdays : boolean (optional)

optionally return the number of days in the year

Returns `out` : numpy array

an array of boolean leap year, or array of number of days

Examples

```
>>> import numpy
>>> import spacepy.time
>>> spacepy.time.leapyear(numpy.arange(15)+1998)
[False, False,  True, False, False, False,  True, False, False,
  False,  True, False, False, False,  True]
```

`spacepy.time.no_tzinfo(dt)`

take in an arraylike of datetime objects and return them without any tzinfo

Parameters `dt` : iterable

iterable of `datetime.datetime` objects

Returns `out` : list

list of `datetime.datetime` without tzinfo

`spacepy.time.randomDate(dt1, dt2, N=1, tzinfo=False, sorted=False)`

Return a (or many) random datetimes between two given dates, this is done under the convention $dt \leq 1$ `rand` < `dt2`

Parameters `dt1` : `datetime.datetime`

start date for the the random date

`dt2` : `datetime.datetime`

stop date for the the random date

Returns `out` : `datetime.datetime` or `numpy.ndarray` of `datetime.datetime`

the new time for the next call to `EventTimer`

Other Parameters `N` : int (optional)

the number of random dates to generate (default=1)

`tzinfo` : bool (optional)

maintain the tzinfo of the input datetimes (default=False)

`sorted` : bool (optional)

return the times sorted (default=False)

`spacepy.time.sec2hms(sec, rounding=True, days=False, dtobj=False)`

Convert seconds of day to hours, minutes, seconds

Parameters `sec` : float

Seconds of day

Returns `out` : [hours, minutes, seconds] or `datetime.timedelta`

Other Parameters `rounding` : boolean

set for integer seconds

`days` : boolean

set to wrap around day (i.e. modulo 86400)

dtobj : boolean

set to return a timedelta object

`spacepy.time.tickrange(start, end, deltadays, dtype=None)`

return a Ticktock range given the start, end, and delta

Parameters **start** : string or number

start time (ISO standard string and UTC/datetime do not require a dtype)

end : string or number

last possible time in series (excluded unless `end=start+n*step` for integer n)

deltadays : float or timedelta

step in units of days (float); or datetime timedelta object

dtype : string (optional)

data type for start, end; e.g. ISO, UTC, RTD, etc. see Ticktock for all options

Returns **out** : Ticktock instance

ticks

See also:

[Ticktock](#)

Examples

```
>>> ticks = st.tickrange('2002-02-01T00:00:00', '2002-02-10T00:00:00', deltadays = 1)
>>> ticks
Ticktock( ['2002-02-01T00:00:00', '2002-02-02T00:00:00', '2002-02-03T00:00:00',
'2002-02-04T00:00:00'] , dtype=ISO)
```

`spacepy.time.valid_YYYYMMDD(inval)`

if inval is valid YYYYMMDD return True, False otherwise

Classes

[Tickdelta](#)

[Ticktock](#)(data, dtype) Ticktock class holding various time coordinate systems

2.13.2 spacepy.time.Ticktock

class `spacepy.time.Ticktock(data, dtype)`

Ticktock class holding various time coordinate systems (TAI, UTC, ISO, JD, MJD, UNX, RDT, CDF, DOY, eDOY)

Possible input data types: ISO: ISO standard format like '2002-02-25T12:20:30' UTC: datetime object with UTC time TAI: elapsed seconds since 1958/1/1 (includes leap seconds) UNX: elapsed seconds since 1970/1/1 (all days have 86400 secs sometimes unequal lengths) JD: Julian days elapsed MJD: Modified Julian days RDT: Rata Die days elapsed since 1/1/1 CDF: CDF epoch: milliseconds since 1/1/0000

Possible output data types: All those listed above, plus DOY: Integer day of year, starts with day 1 eDOY: Fractional day of year, starts at day 0

Parameters **data** : array_like (int, datetime, float, string)

time stamp

dtype : string {*CDF, ISO, UTC, TAI, UNX, JD, MJD, RDT*} or function

data type for data, if a function it must convert input time format to Python datetime

Returns **out** : Ticktock

instance with self.data, self.dtype, self.UTC etc

Examples

```
>>> x = Ticktock([2452331.0142361112, 2452332.0142361112], 'JD')
>>> x.ISO
dmarray(['2002-02-25T12:20:30', '2002-02-26T12:20:30'], dtype='|S19')
>>> x.DOY # Day of year
dmarray([ 56.,  57.])
>>> y = Ticktock(['01-01-2013', '20-03-2013'], lambda x: datetime.datetime.strptime(x, '%d-%m-%Y'))
>>> y.UTC
dmarray([2013-01-01 00:00:00, 2013-03-20 00:00:00], dtype=object)
>>> y.DOY # Day of year
dmarray([ 1.,  79.])
```

<code>append(other)</code>	Will be called when another Ticktock instance has to be appended to the current one
<code>argsort()</code>	This will return the indices that would sort the Ticktock values
<code>convert(dtype)</code>	convert a Ticktock instance into a new time coordinate system provided in dtype
<code>getCDF()</code>	a.getCDF() or a.CDF
<code>getDOY()</code>	a.DOY or a.getDOY()
<code>getGPS()</code>	a.GPS or a.getGPS()
<code>getISO()</code>	a.ISO or a.getISO()
<code>getJD()</code>	a.JD or a.getJD()
<code>getMJD()</code>	a.MJD or a.getMJD()
<code>getRDT()</code>	a.RDT or a.RDT()
<code>getTAI()</code>	a.TAI or a.getTAI()
<code>getUNX()</code>	a.UNX or a.getUNX()
<code>getUTC()</code>	a.UTC or a.getUTC()
<code>geteDOY()</code>	a.eDOY or a.geteDOY()
<code>getleapsecs()</code>	a.leaps or a.getleapsecs()
<code>isoformat(b, attrib)</code>	This changes the self.__isofmt attribute by and subsequently this function will update the ISO attribute.
<code>now()</code>	Creates a Ticktock object with the current time, equivalent to datetime.now()
<code>sort()</code>	This will sort the Ticktock values in place
<code>update_items(b, attrib)</code>	After changing the self.data attribute by either <code>__setitem__</code> or <code>__add__</code> etc this function will update all

append (*other*)

Will be called when another Ticktock instance has to be appended to the current one

Parameters **other** : Ticktock

other (Ticktock instance)

argsort ()

This will return the indices that would sort the Ticktock values

Returns **out** : list

indices that would sort the Ticktock values

convert (*dtype*)

convert a Ticktock instance into a new time coordinate system provided in dtype

Parameters *dtype* : string

data type for new system, possible values are {*CDF*, *ISO*, *UTC*, *TAI*, *UNIX*, *JD*, *MJD*, *RDT*}

Returns *out* : Ticktock

Ticktock instance with new time coordinates

See also:

CDF, *ISO*, *UTC*

Examples

```
>>> a = Ticktock(['2002-02-02T12:00:00', '2002-02-02T12:00:00'], 'ISO')
>>> s = a.convert('TAI')
>>> type(s)
<class 'time.Ticktock'>
>>> s
Ticktock( [1391342432 1391342432] ), dtype=TAI
```

getCDF ()

a.getCDF() or *a*.CDF

Return CDF time which is milliseconds since 01-Jan-0000 00:00:00.000. “Year zero” is a convention chosen by NSSDC to measure epoch values. This date is more commonly referred to as 1 BC. Remember that 1 BC was a leap year. The CDF date/time calculations do not take into account the changes to the Gregorian calendar, and cannot be directly converted into Julian date/times.

Returns *out* : numpy array

days elapsed since Jan. 1st

See also:

getUTC, *getUNIX*, *getRDT*, *getJD*, *getMJD*, *getISO*, *getTAI*, *getDOY*, *geteDOY*

Examples

```
>>> a = Ticktock('2002-02-02T12:00:00', 'ISO')
>>> a.CDF
array([ 6.31798704e+13])
```

getDOY ()

a.DOY or *a*.getDOY()

extract DOY (days since January 1st of given year)

Returns *out* : numpy array

day of the year

See also:

getUTC, *getUNIX*, *getRDT*, *getJD*, *getMJD*, *getISO*, *getTAI*, *getDOY*, *geteDOY*

Examples

```
>>> a = Ticktock('2002-02-02T12:00:00', 'ISO')
>>> a.DOY
array([ 33])
```

getGPS()

a.GPS or a.getGPS()

return GPS epoch (0000 UT (midnight) on January 6, 1980)

Returns out : numpy array

elapsed secs since 6Jan1980 (excludes leap secs)

See also:

getUTC, getUNIX, getRDT, getJD, getMJD, getCDF, getISO, getDOY, geteDOY

Examples

```
>>> a = Ticktock('2002-02-02T12:00:00', 'ISO')
>>> a.GPS
array([])
```

getISO()

a.ISO or a.getISO()

convert dtype data into ISO string

Returns out : list of strings

date in ISO format

See also:

getUTC, getUNIX, getRDT, getJD, getMJD, getCDF, getTAI, getDOY, geteDOY

Examples

```
>>> a = Ticktock('2002-02-02T12:00:00', 'ISO')
>>> a.ISO
dmmarray(['2002-02-02T12:00:00'])
```

getJD()

a.JD or a.getJD()

convert dtype data into Julian Date (JD)

Returns out : numpy array

elapsed days since 12:00 January 1, 4713 BC

See also:

getUTC, getUNIX, getRDT, getJD, getMJD, getISO, getTAI, getDOY, geteDOY

Examples

```
>>> a = Ticktock('2002-02-02T12:00:00', 'ISO')
>>> a.JD
array([ 2452308.])
```

getMJD()

a.MJD or a.getMJD()

convert dtype data into MJD (modified Julian date)

Returns out : numpy array

elapsed days since November 17, 1858 (Julian date was 2,400 000)

See also:

getUTC, getUNIX, getRDT, getJD, getISO, getCDF, getTAI, getDOY, geteDOY

Examples

```
>>> a = Ticktock('2002-02-02T12:00:00', 'ISO')
>>> a.MJD
array([ 52307.5])
```

getRDT()

a.RDT or a.RDT()

convert dtype data into Rata Die (lat.) Time (days since 1/1/0001)

Returns out : numpy array

elapsed days since 1/1/1

See also:

getUTC, getUNIX, getISO, getJD, getMJD, getCDF, getTAI, getDOY, geteDOY

Examples

```
>>> a = Ticktock('2002-02-02T12:00:00', 'ISO')
>>> a.RDT
array([ 730883.5])
```

getTAI()

a.TAI or a.getTAI()

return TAI (International Atomic Time)

Returns out : numpy array

elapsed secs since 1958/1/1 (includes leap secs, i.e. all secs have equal lengths)

See also:

getUTC, getUNIX, getRDT, getJD, getMJD, getCDF, getISO, getDOY, geteDOY

Examples

```
>>> a = Ticktock('2002-02-02T12:00:00', 'ISO')
>>> a.TAI
array([1391342432])
```

getUNIX()

a.UNX or a.getUNIX()

convert dtype data into Unix Time (Posix Time) seconds since 1970-Jan-1 (not counting leap seconds)

Returns out : numpy array

elapsed secs since 1970/1/1 (not counting leap secs)

See also:

getUTC, getISO, getRDT, getJD, getMJD, getCDF, getTAI, getDOY, geteDOY

Examples

```
>>> a = Ticktock('2002-02-02T12:00:00', 'ISO')
>>> a.UNX
array([ 1.01265120e+09])
```

getUTC()

a.UTC or a.getUTC()

convert dtype data into UTC object a la datetime()

Returns out : list of datetime objects

datetime object in UTC time

See also:

getISO, getUNIX, getRDT, getJD, getMJD, getCDF, getTAI, getDOY, geteDOY

Examples

```
>>> a = Ticktock('2002-02-02T12:00:00', 'ISO')
>>> a.UTC
[datetime.datetime(2002, 2, 2, 12, 0)]
```

geteDOY()

a.eDOY or a.geteDOY()

extract eDOY (elapsed days since midnight January 1st of given year)

Returns out : numpy array

days elapsed since midnight bbedJan. 1st

See also:

getUTC, getUNIX, getRDT, getJD, getMJD, getISO, getTAI, getDOY, geteDOY

Examples

```
>>> a = Ticktock('2002-02-02T12:00:00', 'ISO')
>>> a.eDOY
array([ 32.5])
```

getleapsecs()

a.leaps or a.getleapsecs()

retrieve leapseconds from lookup table, used in getTAI

Returns out : numpy array

leap seconds

See also:

`getTAI`

Examples

```
>>> a = Ticktock('2002-02-02T12:00:00', 'ISO')
>>> a.leaps
array([32])
```

isoformat(b, attrib)

This changes the self.__isofmt attribute by and subsequently this function will update the ISO attribute.

Parameters fmt : string, optional

classmethod now()

Creates a Ticktock object with the current time, equivalent to datetime.now()

Returns out : ticktock

Ticktock object with the current time, equivalent to datetime.now()

See also:

`datetime.datetime.now`

sort()

This will sort the Ticktock values in place

update_items(b, attrib)

After changing the self.data attribute by either `__setitem__` or `__add__` etc this function will update all other attributes. This function is called automatically in `__add__` and `__setitem__`

Parameters cls : Ticktock

attrib : string

attribute to update

See also:

`spacepy.Ticktock.__setitem__`,
`spacepy.Ticktock.__sub__`

`spacepy.Ticktock.__add__`,

Functions

<code>date2num</code>	
<code>doy2date(year, doy[, dtobj, flAns])</code>	convert integer day-of-year doy into a month and day
<code>leapyear(year[, numdays])</code>	return an array of boolean leap year,
<code>num2date</code>	
<code>randomDate(dt1, dt2[, N, tzinfo, sorted])</code>	Return a (or many) random datetimes between two given dates, this is done under the c
<code>sec2hms(sec[, rounding, days, dtobj])</code>	Convert seconds of day to hours, minutes, seconds
<code>tickrange(start, end, deltadays[, dtype])</code>	return a Ticktock range given the start, end, and delta

2.13.3 spacepy.time.doy2date

`spacepy.time.doy2date` (*year, doy, dtobj=False, flAns=False*)

convert integer day-of-year doy into a month and day after http://pleac.sourceforge.net/pleac_python/datesandtimes.html

Parameters *year* : int or array of int

year

doy : int or array of int

day of year

Returns *month* : int or array of int

month as integer number

day : int or array of int

as integer number

See also:

`Ticktock.getDOY`

Examples

```
>>> month, day = doy2date(2002, 186)
>>> dts = doy2date([2002]*4, range(186,190), dtobj=True)
```

2.13.4 spacepy.time.leapyear

`spacepy.time.leapyear` (*year, numdays=False*)

return an array of boolean leap year, a lot faster than the mod method that is normally seen

Parameters *year* : array_like

array of years

numdays : boolean (optional)

optionally return the number of days in the year

Returns *out* : numpy array

an array of boolean leap year, or array of number of days

Examples

```
>>> import numpy
>>> import spacepy.time
>>> spacepy.time.leapyear(numpy.arange(15)+1998)
[False, False,  True, False, False, False,  True, False, False,
  False,  True, False, False, False,  True]
```

2.13.5 spacepy.time.randomDate

`spacepy.time.randomDate(dt1, dt2, N=1, tzinfo=False, sorted=False)`

Return a (or many) random datetimes between two given dates, this is done under the convention $dt \leq 1$ $\text{rand} < dt2$

Parameters **dt1** : datetime.datetime

start date for the the random date

dt2 : datetime.datetime

stop date for the the random date

Returns **out** : datetime.datetime or numpy.ndarray of datetime.datetime

the new time for the next call to EventTimer

Other Parameters **N** : int (optional)

the number of random dates to generate (default=1)

tzinfo : bool (optional)

maintain the tzinfo of the input datetimes (default=False)

sorted : bool (optional)

return the times sorted (default=False)

2.13.6 spacepy.time.sec2hms

`spacepy.time.sec2hms(sec, rounding=True, days=False, dtobj=False)`

Convert seconds of day to hours, minutes, seconds

Parameters **sec** : float

Seconds of day

Returns **out** : [hours, minutes, seconds] or datetime.timedelta

Other Parameters **rounding** : boolean

set for integer seconds

days : boolean

set to wrap around day (i.e. modulo 86400)

dtobj : boolean

set to return a timedelta object

2.13.7 spacepy.time.tickrange

`spacepy.time.tickrange` (*start, end, deltadays, dtype=None*)

return a Ticktock range given the start, end, and delta

Parameters **start** : string or number

start time (ISO standard string and UTC/datetime do not require a dtype)

end : string or number

last possible time in series (excluded unless `end=start+n*step` for integer `n`)

deltadays : float or timedelta

step in units of days (float); or datetime timedelta object

dtype : string (optional)

data type for start, end; e.g. ISO, UTC, RTD, etc. see Ticktock for all options

Returns **out** : Ticktock instance

ticks

See also:

`Ticktock`

Examples

```
>>> ticks = st.tickrange('2002-02-01T00:00:00', '2002-02-10T00:00:00', deltadays = 1)
>>> ticks
Ticktock( ['2002-02-01T00:00:00', '2002-02-02T00:00:00', '2002-02-03T00:00:00',
'2002-02-04T00:00:00'] , dtype=ISO)
```

2.14 toolbox - Toolbox of various functions and generic utilities

Toolbox of various functions and generic utilities.

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- Array binning
- Array creation
- Array searching and masking
- Other functions
- Multithreading and multiprocessing
- System tools

2.14.1 Array binning

<code>arraybin(array, bins)</code>	Split a sequence into subsequences based on value.
<code>bin_center_to_edges(centers)</code>	Convert a list of bin centers to their edges
<code>bin_edges_to_center(edges)</code>	Convert a list of bin edges to their centers
<code>binHisto(data[, verbose])</code>	Calculates bin width and number of bins for histogram using Freedman-Diaconis rule, if rule

spacepy.toolbox.arraybin

`spacepy.toolbox.arraybin(array, bins)`

Split a sequence into subsequences based on value.

Given a sequence of values and a sequence of values representing the division between bins, return the indices grouped by bin.

Parameters `array` : array_like

the input sequence to slice, must be sorted in ascending order

`bins` : array_like

dividing lines between bins. Number of bins is `len(bins)+1`, value that exactly equal a dividing value are assigned to the higher bin

Returns `out` : list

indices for each bin (list of lists)

Examples

```
>>> import spacepy.toolbox as tb
>>> tb.arraybin(range(10), [4.2])
[[0, 1, 2, 3, 4], [5, 6, 7, 8, 9]]
```

spacepy.toolbox.bin_center_to_edges

`spacepy.toolbox.bin_center_to_edges(centers)`

Convert a list of bin centers to their edges

Given a list of center values for a set of bins, finds the start and end value for each bin. (start of bin $n+1$ is assumed to be end of bin n). Useful for e.g. `matplotlib.pyplot.pcolor`.

Edge between bins n and $n+1$ is arithmetic mean of the center of n and $n+1$; edge below bin 0 and above last bin are established to make these bins symmetric about their center value.

Parameters `centers` : list

list of center values for bins

Returns `out` : list

list of edges for bins

****note:** returned list will be one element longer than `centers`** :

Examples

```
>>> import spacepy.toolbox as tb
>>> tb.bin_center_to_edges([1,2,3])
[0.5, 1.5, 2.5, 3.5]
```

spacepy.toolbox.bin_edges_to_center

spacepy.toolbox.**bin_edges_to_center**(*edges*)

Convert a list of bin edges to their centers

Given a list of edge values for a set of bins, finds the center of each bin. (start of bin $n+1$ is assumed to be end of bin n).

Center of bin n is arithmetic mean of the edges of the adjacent bins.

Parameters *edges* : list

list of edge values for bins

Returns *out* : numpy.ndarray

array of centers for bins

****note:** returned array will be one element shorter than *edges* :

Examples

```
>>> import spacepy.toolbox as tb
>>> tb.bin_center_to_edges([1,2,3])
[0.5, 1.5, 2.5, 3.5]
```

spacepy.toolbox.binHisto

spacepy.toolbox.**binHisto**(*data*, *verbose=False*)

Calculates bin width and number of bins for histogram using Freedman-Diaconis rule, if rule fails, defaults to square-root method

The Freedman-Diaconis method is detailed in: Freedman, D., and P. Diaconis (1981), On the histogram as a density estimator: L2 theory, *Z. Wahrscheinlichkeitstheor. Verw. Geb.*, 57, 453–476

and is also described by: Wilks, D. S. (2006), *Statistical Methods in the Atmospheric Sciences*, 2nd ed.

Parameters *data* : array_like

list/array of data values

verbose : boolean (optional)

print out some more information

Returns *out* : tuple

calculated width of bins using F-D rule, number of bins (nearest integer) to use for histogram

See also:

`matplotlib.pyplot.hist`

Examples

```
>>> import numpy, spacepy
>>> import matplotlib.pyplot as plt
>>> numpy.random.seed(8675301)
>>> data = numpy.random.randn(1000)
>>> binw, nbins = spacepy.toolbox.binHisto(data)
>>> print(nbins)
19.0
>>> p = plt.hist(data, bins=nbins, histtype='step', normed=True)
```

2.14.2 Array creation

<code>dist_to_list(func, length[, min, max])</code>	Convert a probability distribution function to a list of values
<code>geospace(start[, ratio, stop, num])</code>	Returns geometrically spaced numbers.
<code>linspace(min, max, num, **kwargs)</code>	Returns linear-spaced bins.
<code>logspace(min, max, num, **kwargs)</code>	Returns log-spaced bins.

spacepy.toolbox.dist_to_list

`spacepy.toolbox.dist_to_list` (*func, length, min=None, max=None*)

Convert a probability distribution function to a list of values

This is a deterministic way to produce a known-length list of values matching a certain probability distribution. It is likely to be a closer match to the distribution function than a random sampling from the distribution.

Parameters `func` : callable

function to call for each possible value, returning probability density at that value
(does not need to be normalized.)

length : int

number of elements to return

min : float

minimum value to possibly include

max : float

maximum value to possibly include

Examples

```
>>> import matplotlib
>>> import numpy
>>> import spacepy.toolbox as tb
>>> gauss = lambda x: math.exp(-(x ** 2) / (2 * 5 ** 2)) / (5 * math.sqrt(2 * math.pi))
>>> vals = tb.dist_to_list(gauss, 1000, -numpy.inf, numpy.inf)
>>> print(vals[0])
-16.45263...
>>> pl = matplotlib.pyplot.hist(vals, bins=[i - 10 for i in range(21)], facecolor='green')
>>> matplotlib.pyplot.hold(True)
>>> x = [i / 100.0 - 10.0 for i in range(2001)]
```

```
>>> p2 = matplotlib.pyplot.plot(x, [gauss(i) * 1000 for i in x], 'red')
>>> matplotlib.pyplot.draw()
```

spacepy.toolbox.geospace

`spacepy.toolbox.geospace` (*start, ratio=None, stop=False, num=50*)
Returns geometrically spaced numbers.

Parameters **start** : float

The starting value of the sequence.

ratio : float (optional)

The ratio between subsequent points

stop : float (optional)

End value, if this is selected **'num'** is overridden

num : int (optional)

Number of samples to generate. Default is 50.

Returns **seq** : array

geometrically spaced sequence

See also:

`linspace`, `logspace`

Examples

To get a geometric progression between 0.01 and 3 in 10 steps

```
>>> import spacepy.toolbox as tb
>>> tb.geospace(0.01, stop=3, num=10)
[0.01,
 0.018846716378431192,
 0.035519871824902655,
 0.066943295008216955,
 0.12616612944575134,
 0.23778172582285118,
 0.44814047465571644,
 0.84459764235318191,
 1.5917892219322083,
 2.9999999999999996]
```

To get a geometric progression with a specified ratio, say 10

```
>>> import spacepy.toolbox as tb
>>> tb.geospace(0.01, ratio=10, num=5)
[0.01, 0.10000000000000001, 1.0, 10.0, 100.0]
```

spacepy.toolbox.linspace

`spacepy.toolbox.linspace` (*min, max, num, **kwargs*)

Returns linear-spaced bins. Same as `numpy.linspace` except works with datetime and is faster

Parameters **min** : float, datetime

minimum value

max : float, datetime

maximum value

num : integer

number of linear spaced bins

Returns **out** : array

linear-spaced bins from min to max in a numpy array

Other Parameters **kwargs** : dict

additional keywords passed into matplotlib.dates.num2date

See also:

[geospace](#), [logspace](#)

Notes

This function works on both numbers and datetime objects

Examples

```
>>> import spacepy.toolbox as tb
>>> tb.linspace(1, 10, 4)
array([ 1.,  4.,  7., 10.] )
```

spacepy.toolbox.logspace

spacepy.toolbox.**logspace** (*min, max, num, **kwargs*)

Returns log-spaced bins. Same as numpy.logspace except the min and max are the min and max not log10(min) and log10(max)

Parameters **min** : float

minimum value

max : float

maximum value

num : integer

number of log spaced bins

Returns **out** : array

log-spaced bins from min to max in a numpy array

Other Parameters **kwargs** : dict

additional keywords passed into matplotlib.dates.num2date

See also:

[geospace](#), [linspace](#)

Notes

This function works on both numbers and datetime objects

Examples

```
>>> import spacepy.toolbox as tb
>>> tb.logspace(1, 100, 5)
array([ 1.          ,  3.16227766, 10.          , 31.6227766 , 100.          ])
```

2.14.3 Array searching and masking

<code>interweave(a, b)</code>	given two array-like variables interweave them together.
<code>isview(array1[, array2])</code>	Returns if an object is a view of another object.
<code>tCommon(ts1, ts2[, mask_only])</code>	Finds the elements in a list of datetime objects present in another
<code>tOverlap(ts1, ts2, *args, **kwargs)</code>	Finds the overlapping elements in two lists of datetime objects
<code>tOverlapHalf(ts1, ts2[, presort])</code>	Find overlapping elements in two lists of datetime objects

spacepy.toolbox.interweave

`spacepy.toolbox.interweave(a, b)`
 given two array-like variables interweave them together. Discussed here:
<http://stackoverflow.com/questions/5347065/interweaving-two-numpy-arrays>

Parameters **a** : array-like

first array

b : array-like

second array

Returns **out** : numpy.ndarray

interweaved array

spacepy.toolbox.isview

`spacepy.toolbox.isview(array1, array2=None)`
 Returns if an object is a view of another object. More precisely if one array argument is specified True is returned if the array owns its data. If two arrays arguments are specified a tuple is returned of if the first array owns its data and the second if they point at the same memory location

Parameters **array1** : numpy.ndarray

array to query if it owns its data

Returns **out** : bool or tuple

If one array is specified bool is returned, True if the array owns its data. If two arrays are specified a tuple where the second element is a bool of if the array points at the same memory location

Other Parameters **array2** : object (optional)

array to query if array1 is a view of this object at the specified memory location

Examples

```
import numpy
import spacepy.toolbox as tb
a = numpy.arange(100)
b = a[0:10]
tb.isview(a) # False
tb.isview(b) # True
tb.isview(b, a) # (True, True)
tb.isview(b, b) # (True, True)
# the conditions are met and numpy cannot tell this
```

spacepy.toolbox.tCommon

`spacepy.toolbox.tCommon(ts1, ts2, mask_only=True)`
Finds the elements in a list of datetime objects present in another

Parameters `ts1` : list or array-like

first set of datetime objects

`ts2` : list or array-like

second set of datetime objects

Returns `out` : tuple

Two element tuple of truth tables (of 1 present in 2, & vice versa)

See also:

`tOverlapHalf`, `tOverlap`

Examples

```
>>> import spacepy.toolbox as tb
>>> import numpy as np
>>> import datetime as dt
>>> ts1 = np.array([dt.datetime(2001,3,10)+dt.timedelta(hours=a) for a in range(20)])
>>> ts2 = np.array([dt.datetime(2001,3,10,2)+dt.timedelta(hours=a*0.5) for a in range(20)])
>>> common_inds = tb.tCommon(ts1, ts2)
>>> common_inds[0] #mask of values in ts1 common with ts2
array([False, False,  True,  True,  True,  True,  True,  True,  True,  True,
        True,  True,  True, False, False, False, False, False, False, False,
        False, False], dtype=bool)
>>> ts2[common_inds[1]] #values of ts2 also in ts1
```

The latter can be found more simply by setting the `mask_only` keyword to `False`

```
>>> common_vals = tb.tCommon(ts1, ts2, mask_only=False)
>>> common_vals[1]
array([2001-03-10 02:00:00, 2001-03-10 03:00:00, 2001-03-10 04:00:00,
       2001-03-10 05:00:00, 2001-03-10 06:00:00, 2001-03-10 07:00:00,
       2001-03-10 08:00:00, 2001-03-10 09:00:00, 2001-03-10 10:00:00,
       2001-03-10 11:00:00], dtype=object)
```

spacepy.toolbox.tOverlap

`spacepy.toolbox.tOverlap(ts1, ts2, *args, **kwargs)`
Finds the overlapping elements in two lists of datetime objects

Parameters **ts1** : datetime

first set of datetime object

ts2 : datetime

datetime object

args :

additional arguments passed to tOverlapHalf

Returns **out** : list

indices of ts1 within interval of ts2, & vice versa

See also:

tOverlapHalf, tCommon

Examples

Given two series of datetime objects, event_dates and omni['Time']:

```
>>> import spacepy.toolbox as tb
>>> from spacepy import omni
>>> import datetime
>>> event_dates = st.tickrange(datetime.datetime(2000, 1, 1), datetime.datetime(2000, 10, 1), de
>>> omni_dates = st.tickrange(datetime.datetime(2000, 1, 1), datetime.datetime(2000, 10, 1), del
>>> omni = omni.get_omni(omni_dates)
>>> [einds,oinds] = tb.tOverlap(event_dates, omni['ticks'])
>>> omni_time = omni['ticks'][oinds[0]:oinds[-1]+1]
>>> print omni_time
[datetime.datetime(2000, 1, 1, 0, 0), datetime.datetime(2000, 1, 1, 12, 0),
... , datetime.datetime(2000, 9, 30, 0, 0)]
```

spacepy.toolbox.tOverlapHalf

spacepy.toolbox.tOverlapHalf(*ts1*, *ts2*, *presort=False*)

Find overlapping elements in two lists of datetime objects

This is one-half of tOverlap, i.e. it finds only occurrences where ts2 exists within the bounds of ts1, or the second element returned by tOverlap.

Parameters **ts1** : list

first set of datetime object

ts2 : list

datetime object

presort : bool

Set to use a faster algorithm which assumes ts1 and ts2 are both sorted in ascending order. This speeds up the overlap comparison by about 50x, so it is worth sorting the list if one sort can be done for many calls to tOverlap

Returns **out** : list

indices of ts2 within interval of ts1

note: Returns empty list if no overlap found

See also:

`tOverlap`, `tCommon`

2.14.4 Other functions

<code>assemble(fln_pattern, outfln[, sortkey, verbose])</code>	assembles all pickled files matching <code>fln_pattern</code> into single file and
<code>dicttree(in_dict[, verbose, spaces, levels, ...])</code>	pretty print a dictionary tree
<code>eventTimer(Event, Time1)</code>	Times an event then prints out the time and the name of the event,
<code>feq(x, y[, precision])</code>	compare two floating point values if they are equal
<code>getNamedPath(name)</code>	Return the full path of a parent directory with name as the leaf
<code>human_sort(l)</code>	Sort the given list in the way that humans expect.
<code>hypot(*args)</code>	compute the N-dimensional hypot of an iterable or many arguments
<code>interpol(newx, x, y[, wrap])</code>	1-D linear interpolation with interpolation of hours/longitude
<code>intsolve(func, value[, start, stop, maxit])</code>	Find the function input such that definite integral is desired value.
<code>medAbsDev(series)</code>	Calculate median absolute deviation of a given input series
<code>mlt2rad(mlt[, midnight])</code>	Convert mlt values to radians for polar plotting
<code>normalize(vec)</code>	Given an input vector normalize the vector
<code>pmm(a, *b)</code>	print min and max of input arrays
<code>rad2mlt(rad[, midnight])</code>	Convert radians values to mlt
<code>windowMean(data[, time, winsize, overlap, ...])</code>	Windowing mean function, window overlap is user defined

spacepy.toolbox.assemble

`spacepy.toolbox.assemble(fln_pattern, outfln, sortkey='ticks', verbose=True)`

assembles all pickled files matching `fln_pattern` into single file and save as `outfln`. Pattern may contain simple shell-style wildcards `*?` a la `fnmatch` file will be assembled along time axis given by Ticktock (key: `'ticks'`) in dictionary If `sortkey = None`, then nothing will be sorted

Parameters `fln_pattern` : string

pattern to match filenames

`outfln` : string

filename to save combined files to

Returns `out` : dict

dictionary with combined values

Examples

```
>>> import spacepy.toolbox as tb
>>> a, b, c = {'ticks':[1,2,3]}, {'ticks':[4,5,6]}, {'ticks':[7,8,9]}
>>> tb.savepickle('input_files_2001.pkl', a)
>>> tb.savepickle('input_files_2002.pkl', b)
>>> tb.savepickle('input_files_2004.pkl', c)
>>> a = tb.assemble('input_files_*.pkl', 'combined_input.pkl')
('adding ', 'input_files_2001.pkl')
('adding ', 'input_files_2002.pkl')
('adding ', 'input_files_2004.pkl')
('\n writing: ', 'combined_input.pkl')
>>> print(a)
{'ticks': array([1, 2, 3, 4, 5, 6, 7, 8, 9])}
```

spacepy.toolbox.dicttree

`spacepy.toolbox.dicttree(in_dict, verbose=False, spaces=None, levels=True, attrs=False, **kwargs)`

pretty print a dictionary tree

Parameters `in_dict` : dict

a complex dictionary (with substructures)

verbose : boolean (optional)

print more info

spaces : string (optional)

string will added for every line

levels : integer (optional)

number of levels to recurse through (True means all)

attrs : boolean (optional)

display information for attributes

Examples

```
>>> import spacepy.toolbox as tb
>>> d = {'grade':{'level1':[4,5,6], 'level2':[2,3,4]}, 'name':['Mary', 'John', 'Chris']}
>>> tb.dicttree(d)
+
|__grade
|   |__level1
|   |   |__level2
|__name
```

More complicated example using a datamodel:

```
>>> from spacepy import datamodel
>>> counts = datamodel.darray([2,4,6], attrs={'units': 'cts/s'})
>>> data = {'counts': counts, 'PI': 'Dr Zog'}
>>> tb.dicttree(data)
+
|__PI
|__counts
>>> tb.dicttree(data, attrs=True, verbose=True)
+
|__PI (str [6])
|__counts (spacepy.datamodel.darray (3,))
:|__units (str [5])
```

Attributes of, e.g., a CDF or a datamodel type object (obj.attrs) are denoted by a colon.

spacepy.toolbox.eventTimer

`spacepy.toolbox.eventTimer(Event, Time1)`

Times an event then prints out the time and the name of the event, nice for debugging and seeing that the code is progressing

Parameters **Event** : str

Name of the event, string is printed out by function

Time1 : time.time

the time to difference in the function

Returns **Time2** : time.time

the new time for the next call to EventTimer

Examples

```
>>> import spacepy.toolbox as tb
>>> import time
>>> t1 = time.time()
>>> t1 = tb.eventTimer('Test event finished', t1)
('4.40', 'Test event finished')
```

spacepy.toolbox.feq

spacepy.toolbox.feq(*x*, *y*, *precision*=5e-07)

compare two floating point values if they are equal after: <http://www.lahey.com/float.htm>

Parameters **x** : float

a number

y : float or array of floats

other numbers to compare

precision : float (optional)

Relative precision for equal (default 0.0000005) Specified as a fraction of the sum of *x* and *y*.

Returns **out** : bool

True (equal) or False (not equal)

See also:

`numpy.allclose`

Examples

```
>>> import spacepy.toolbox as tb
>>> x = 1 + 1e-4
>>> y = 1 + 2e-4
>>> tb.feq(x, y)
False
>>> tb.feq(x, y, 1e-3)
True
```

spacepy.toolbox.getNamedPath

spacepy.toolbox.getNamedPath(*name*)

Return the full path of a parent directory with name as the leaf

Parameters *name* : string

the name of the parent directory to locate

Examples

Run from a directory /mnt/projects/dream/bin/Ephem with 'dream' as the name, this function would return '/mnt/projects/dream'

spacepy.toolbox.human_sort

spacepy.toolbox.human_sort(*l*)

Sort the given list in the way that humans expect. <http://www.codinghorror.com/blog/2007/12/sorting-for-humans-natural-sort-order.html>

Parameters *l* : list

list of objects to human sort

Returns *out* : list

sorted list

Examples

```
>>> import spacepy.toolbox as tb
>>> dat = ['r1.txt', 'r10.txt', 'r2.txt']
>>> dat.sort()
>>> print dat
['r1.txt', 'r10.txt', 'r2.txt']
>>> tb.human_sort(dat)
['r1.txt', 'r2.txt', 'r10.txt']
```

spacepy.toolbox.hypot

spacepy.toolbox.hypot(**args*)

compute the N-dimensional hypot of an iterable or many arguments

Parameters *args* : many numbers or array-like

array like or many inputs to compute from

Returns *out* : float

N-dimensional hypot of a number

Notes

This function has a complicated speed function.

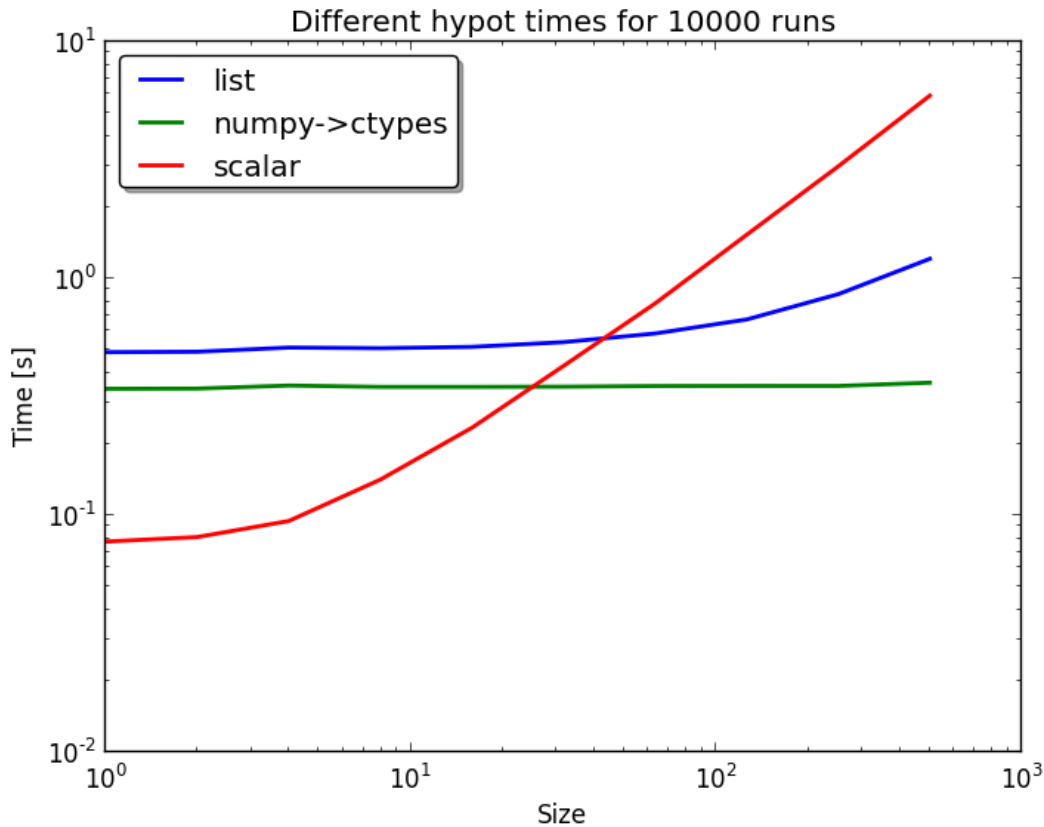
- if a numpy array of floats is input this is passed off to C
- if iterables are passed in they are made into numpy arrays and computation is done local
- if many scalar arguments are passed in calculation is done in a loop

For max speed:

- <20 elements expand them into scalars `tb.hypot(*[vals])` or `tb.hypot(vals[0], vals[1]...)`
- >20 elements premake them into a numpy array of doubles

Examples

```
>>> from spacepy import toolbox as tb
>>> print tb.hypot([3,4])
5.0
>>> print tb.hypot(3,4)
5.0
>>> # Benchmark ####
>>> from spacepy import toolbox as tb
>>> import numpy as np
>>> import timeit
>>> num_list = []
>>> num_np = []
>>> num_np_double = []
>>> num_scalar = []
>>> tot = 500
>>> for num in tb.logspace(1, tot, 10):
>>>     print num
>>>     num_list.append(timeit.timeit(stmt='tb.hypot(a)', setup='from spacepy import toolbox as tb'))
>>>     num_np.append(timeit.timeit(stmt='tb.hypot(a)', setup='from spacepy import toolbox as tb'))
>>>     num_scalar.append(timeit.timeit(stmt='tb.hypot(*a)', setup='from spacepy import toolbox as tb'))
>>> from pylab import *
>>> loglog(tb.logspace(1, tot, 10), num_list, lw=2, label='list')
>>> loglog(tb.logspace(1, tot, 10), num_np, lw=2, label='numpy->ctypes')
>>> loglog(tb.logspace(1, tot, 10), num_scalar, lw=2, label='scalar')
>>> legend(shadow=True, fancybox=1, loc='upper left')
>>> title('Different hypot times for 10000 runs')
>>> ylabel('Time [s]')
>>> xlabel('Size')
```

spacepy.toolbox.interpol

`spacepy.toolbox.interpol` (*newx*, *x*, *y*, *wrap=None*, ***kwargs*)

1-D linear interpolation with interpolation of hours/longitude

Parameters *newx* : array_like

x values where we want the interpolated values

x : array_like

x values of the original data (must be monotonically increasing or wrapping)

y : array_like

y values of the original data

wrap : string, optional

for continuous x data that wraps in y at 'hours' (24), 'longitude' (360), or arbitrary value (int, float)

kwargs : dict

additional keywords, currently accepts *baddata* that sets *baddata* for masked arrays

Returns *out* : numpy.masked_array

interpolated data values for new abscissa values

Examples

For a simple interpolation

```
>>> import spacepy.toolbox as tb
>>> import numpy
>>> x = numpy.arange(10)
>>> y = numpy.arange(10)
>>> tb.interpol(numpy.arange(5)+0.5, x, y)
array([ 0.5,  1.5,  2.5,  3.5,  4.5])
```

To use the wrap functionality, without the wrap keyword you get the wrong answer

```
>>> y = range(24)*2
>>> x = range(len(y))
>>> tb.interpol([1.5, 10.5, 23.5], x, y, wrap='hour').compressed() # compress removed the masked
array([ 1.5, 10.5, 23.5])
>>> tb.interpol([1.5, 10.5, 23.5], x, y)
array([ 1.5, 10.5, 11.5])
```

spacepy.toolbox.intsolve

`spacepy.toolbox.intsolve` (*func*, *value*, *start=None*, *stop=None*, *maxit=1000*)

Find the function input such that definite integral is desired value.

Given a function, integrate from an (optional) start point until the integral reached a desired value, and return the end point of the integration.

Parameters **func** : callable

function to integrate, must take single parameter

value : float

desired final value of the integral

start : float (optional)

value at which to start integration, default -Infinity

stop : float (optional)

value at which to stop integration, default +Infinity

maxit : integer

maximum number of iterations

Returns **out** : float

x such that the integral of L{func} from L{start} to x is L{value}

****Note:** Assumes func is everywhere positive, otherwise solution may** :

be multi-valued.

spacepy.toolbox.medAbsDev

`spacepy.toolbox.medAbsDev` (*series*)

Calculate median absolute deviation of a given input series

Median absolute deviation (MAD) is a robust and resistant measure of the spread of a sample (same purpose as standard deviation). The MAD is preferred to the inter-quartile range as the inter-quartile range only shows 50% of the data whereas the MAD uses all data but remains robust and resistant. See e.g. Wilks, Statistical methods for the Atmospheric Sciences, 1995, Ch. 3.

Parameters **series** : array_like

the input data series

Returns **out** : float

the median absolute deviation

Examples

Find the median absolute deviation of a data set. Here we use the log- normal distribution fitted to the population of sawtooth intervals, see Morley and Henderson, Comment, Geophysical Research Letters, 2009.

```
>>> import numpy
>>> import spacepy.toolbox as tb
>>> numpy.random.seed(8675301)
>>> data = numpy.random.lognormal(mean=5.1458, sigma=0.302313, size=30)
>>> print data
array([ 181.28078923, 131.18152745, ..., 141.15455416, 160.88972791])
>>> tb.medabsdev(data)
28.346646721370192
```

note This implementation is robust to presence of NaNs

spacepy.toolbox.mlt2rad

spacepy.toolbox.mlt2rad(*mlt*, *midnight=False*)

Convert mlt values to radians for polar plotting transform mlt angles to radians from -pi to pi referenced from noon by default

Parameters **mlt** : numpy array

array of mlt values

midnight : boolean (optional)

reference to midnight instead of noon

Returns **out** : numpy array

array of radians

See also:

rad2mlt

Examples

```
>>> from numpy import array
>>> mlt2rad(array([3, 6, 9, 14, 22]))
array([-2.35619449, -1.57079633, -0.78539816,  0.52359878,  2.61799388])
```

spacepy.toolbox.normalize

spacepy.toolbox.**normalize**(*vec*)

Given an input vector normalize the vector

Parameters *vec* : array_like

input vector to normalize

Returns *out* : array_like

normalized vector

Examples

```
>>> import spacepy.toolbox as tb
>>> tb.normalize([1, 2, 3])
[0.0, 0.5, 1.0]
```

spacepy.toolbox.pmm

spacepy.toolbox.**pmm**(*a, *b*)

print min and max of input arrays

Parameters *a* : numpy array

input array

b : list arguments

some additional number of arrays

Returns *out* : list

list of min, max for each array

Examples

```
>>> import spacepy.toolbox as tb
>>> from numpy import arange
>>> tb.pmm(arange(10), arange(10)+3)
[[0, 9], [3, 12]]
```

spacepy.toolbox.rad2mlt

spacepy.toolbox.**rad2mlt**(*rad, midnight=False*)

Convert radians values to mlt transform radians from -pi to pi to mlt referenced from noon by default

Parameters *rad* : numpy array

array of radian values

midnight : boolean (optional)

reference to midnight instead of noon

Returns *out* : numpy array

array of mlt values

See also:

`mlt2rad`

Examples

```
>>> rad2mlt(array([0,pi, pi/2.]))
array([ 12.,  24.,  18.])
```

spacepy.toolbox.windowMean

`spacepy.toolbox.windowMean` (*data*, *time*=[], *winsize*=0, *overlap*=0, *st_time*=None)
Windowing mean function, window overlap is user defined

Parameters *data* : array_like

1D series of points

time : list (optional)

series of timestamps, optional (format as numeric or datetime) For non-overlapping windows set overlap to zero.

winsize : integer or datetime.timedelta (optional)

window size

overlap : integer or datetime.timedelta (optional)

amount of window overlap

st_time : datetime.datetime (optional)

for time-based averaging, a start-time other than the first point can be specified

Returns *out* : tuple

the windowed mean of the data, and an associated reference time vector

Examples

For non-overlapping windows set overlap to zero. e.g. (time-based averaging) Given a data set of 100 points at hourly resolution (with the time tick in the middle of the sample), the daily average of this, with half-overlapping windows is calculated:

```
>>> import spacepy.toolbox as tb
>>> from datetime import datetime, timedelta
>>> wsize = datetime.timedelta(days=1)
>>> olap = datetime.timedelta(hours=12)
>>> data = [10, 20]*50
>>> time = [datetime.datetime(2001,1,1) + datetime.timedelta(hours=n, minutes = 30) for n in range(100)]
>>> outdata, outtime = tb.windowMean(data, time, winsize=wsize, overlap=olap, st_time=datetime.datetime(2001,1,1))
>>> outdata, outtime
([15.0, 15.0, 15.0, 15.0, 15.0, 15.0, 15.0],
 [datetime.datetime(2001, 1, 1, 12, 0),
  datetime.datetime(2001, 1, 2, 0, 0),
  datetime.datetime(2001, 1, 2, 12, 0),
```

```
datetime.datetime(2001, 1, 3, 0, 0),
datetime.datetime(2001, 1, 3, 12, 0),
datetime.datetime(2001, 1, 4, 0, 0),
datetime.datetime(2001, 1, 4, 12, 0)])
```

When using time-based averaging, ensure that the time tick corresponds to the middle of the time-bin to which the data apply. That is, if the data are hourly, say for 00:00-01:00, then the time applied should be 00:30. If this is not done, unexpected behaviour can result.

e.g. (pointwise averaging),

```
>>> outdata, outtime = tb.windowMean(data, winsize=24, overlap=12)
>>> outdata, outtime
([15.0, 15.0, 15.0, 15.0, 15.0, 15.0, 15.0], [12.0, 24.0, 36.0, 48.0, 60.0, 72.0, 84.0])
```

where winsize and overlap are numeric, in this example the window size is 24 points (as the data are hourly) and the overlap is 12 points (a half day). The output vectors start at winsize/2 and end at N-(winsize/2), the output time vector is basically a reference to the nth point in the original series.

note This is a quick and dirty function - it is NOT optimized, at all.

2.14.5 Multithreading and multiprocessing

<code>thread_job(job_size, thread_count, target, ...)</code>	Split a job into subjobs and run a thread for each
<code>thread_map(target, iterable[, thread_count])</code>	Apply a function to every element of a list, in separate threads

spacepy.toolbox.thread_job

`spacepy.toolbox.thread_job(job_size, thread_count, target, *args, **kwargs)`

Split a job into subjobs and run a thread for each

Each thread spawned will call `L{target}` to handle a slice of the job.

This is only useful if a job:

1. Can be split into completely independent subjobs
2. Relies heavily on code that does not use the Python GIL, e.g. numpy or ctypes code
3. Does not return a value. Either pass in a list/array to hold the result, or see `L{thread_map}`

Parameters `job_size` : int

Total size of the job. Often this is an array size.

`thread_count` : int

Number of threads to spawn. If =0 or None, will spawn as many threads as there are cores available on the system. (Each hyperthreading core counts as 2.) Generally this is the Right Thing to do. If **NEGATIVE**, will spawn `abs(thread_count)` threads, but will run them sequentially rather than in parallel; useful for debugging.

`target` : callable

Python callable (generally a function, may also be an imported ctypes function) to run in each thread. The *last* two positional arguments passed in will be a “start” and a “subjob size,” respectively; frequently this will be the start index and the number of elements to process in an array.

args : sequence

Arguments to pass to L{target}. If L{target} is an instance method, self must be explicitly passed in. start and subjob_size will be appended.

kwargs : dict

keyword arguments to pass to L{target}.

Examples

squaring 100 million numbers:

```
>>> import numpy
>>> import spacepy.toolbox as tb
>>> numpy.random.seed(8675301)
>>> a = numpy.random.randint(0, 100, [100000000])
>>> b = numpy.empty([100000000], dtype='int64')
>>> def targ(in_array, out_array, start, count): out_array[start:start + count] = i
>>> tb.thread_job(len(a), 0, targ, a, b)
>>> print(b[0:5])
[2704 7225 196 1521 36]
```

This example:

- Defines a target function, which will be called for each thread. It is usually necessary to define a simple “wrapper” function like this to provide the correct call signature.
- The target function receives inputs C{in_array} and C{out_array}, which are not touched directly by C{thread_job} but are passed through in the call. In this case, C{a} gets passed as C{in_array} and C{b} as C{out_array}
- The target function also receives the start and number of elements it needs to process. For each thread where the target is called, these numbers are different.

spacepy.toolbox.thread_map

spacepy.toolbox.thread_map(target, iterable, thread_count=None, *args, **kwargs)

Apply a function to every element of a list, in separate threads

Interface is similar to multiprocessing.map, except it runs in threads

Parameters target : callable

Python callable to run on each element of iterable. For each call, an element of iterable is appended to args and both args and kwargs are passed through. Note that this means the iterable element is always the *last* positional argument; this allows the specification of self as the first argument for method calls.

iterable : iterable

elements to pass to each call of L{target}

args : sequence

arguments to pass to target before each element of iterable

thread_count : integer

Number of threads to spawn; see L{thread_job}.

kwargs : dict

keyword arguments to pass to L{target}.

Returns out : list

return values of L{target} for each item from L{iterable}

Examples

find totals of several arrays

```
>>> import numpy
>>> from spacepy import toolbox
>>> inputs = range(100)
>>> totals = toolbox.thread_map(numpy.sum, inputs)
>>> print(totals[0], totals[50], totals[99])
(0, 50, 99)
```

2.14.6 System tools

<code>do_with_timeout(timeout, target, *args, **kwargs)</code>	Execute a function (or method) with a timeout.
<code>loadpickle(fln)</code>	load a pickle and return content as dictionary
<code>progressbar(count, blocksize, totalsize[, text])</code>	print a progress bar with urllib.urlretrieve reporthook functionality
<code>query_yes_no(question[, default])</code>	Ask a yes/no question via raw_input() and return their answer.
<code>savepickle(fln, dict[, compress])</code>	save dictionary variable dict to a pickle with filename fln
<code>timeout_check_call(timeout, *args, **kwargs)</code>	Call a subprocess with a timeout.
<code>TimeoutError</code>	Raised when a time-limited process times out
<code>update([all, QDomni, omni, omni2, leapsecs, ...])</code>	Download and update local database for omni, leapsecs etc

spacepy.toolbox.do_with_timeout

`spacepy.toolbox.do_with_timeout` (*timeout, target, *args, **kwargs*)

Execute a function (or method) with a timeout.

Call the function (or method) `target`, with arguments `args` and keyword arguments `kwargs`. Normally return the return value from `target`, but if `target` takes more than `timeout` seconds to execute, raises `TimeoutError`.

Note: This is, at best, a blunt instrument. Exceptions from `target` may not propagate properly (tracebacks will be hard to follow.) The function which failed to time out may continue to execute until the interpreter exits; trapping the `TimeoutError` and continuing normally is not recommended.

Parameters timeout : float

Timeout, in seconds.

target : callable

Python callable (generally a function, may also be an imported ctypes function) to run.

args : sequence

Arguments to pass to `target`.

kwargs : dict

keyword arguments to pass to target.

Returns out : :

return value of target

Raises TimeoutError : If target does not return in timeout seconds.

Examples

```
>>> import spacepy.toolbox as tb
>>> import time
>>> def time_me_out():
...     time.sleep(5)
>>> tb.do_with_timeout(0.5, time_me_out) #raises TimeoutError
```

spacepy.toolbox.loadpickle

spacepy.toolbox.**loadpickle** (*fln*)

load a pickle and return content as dictionary

Parameters fln : string

filename

Returns out : dict

dictionary with content from file

See also:

savepickle

Examples

note: If *fln* is not found, but the same filename with **‘.gz’** is found, will attempt to open the .gz as a gzipped file.

```
>>> d = loadpickle('test.pbin')
```

spacepy.toolbox.progressbar

spacepy.toolbox.**progressbar** (*count, blocksize, totalsize, text=‘Download Progress’*)

print a progress bar with urllib.urlretrieve reporthook functionality

Examples

```
>>> import spacepy.toolbox as tb
>>> import urllib
>>> urllib.urlretrieve(config['psddata_url'], PSDdata_fname, reporthook=tb.progressbar)
```

spacepy.toolbox.query_yes_no

`spacepy.toolbox.query_yes_no(question, default='yes')`

Ask a yes/no question via `raw_input()` and return their answer.

“question” is a string that is presented to the user. “default” is the presumed answer if the user just hits <Enter>. It must be “yes” (the default), “no” or None (meaning an answer is required of the user).

The “answer” return value is one of “yes” or “no”.

Parameters **question** : string

the question to ask

default : string (optional)

Returns **out** : string

answer (‘yes’ or ‘no’)

Examples

```
>>> import spacepy.toolbox as tb
>>> tb.query_yes_no('Ready to go?')
Ready to go? [Y/n] y
'yes'
```

spacepy.toolbox.savepickle

`spacepy.toolbox.savepickle(fln, dict, compress=None)`

save dictionary variable dict to a pickle with filename fln

Parameters **fln** : string

filename

dict : dict

container with stuff

compress : bool

write as a gzip-compressed file (.gz will be added to L{fln}). If not specified, defaults to uncompressed, unless the compressed file exists and the uncompressed does not.

See also:

`loadpickle`

Examples

```
>>> d = {'grade':[1,2,3], 'name':['Mary', 'John', 'Chris']}
>>> savepickle('test.pbin', d)
```

spacepy.toolbox.timeout_check_call

`spacepy.toolbox.timeout_check_call(timeout, *args, **kwargs)`

Call a subprocess with a timeout.

Like `subprocess.check_call()`, but will terminate the process and raise `TimeoutError` if it runs for too long.

This will only terminate the single process started; any child processes will remain running (this has implications for, say, spawning shells.)

Parameters `timeout` : float

Timeout, in seconds. Fractions are acceptable but the resolution is of order 100ms.

`args` : sequence

Arguments passed through to `subprocess.Popen`

`kwargs` : dict

keyword arguments to pass to `subprocess.Popen`

Returns `out` : int

0 on successful completion

Raises `TimeoutError` : If subprocess does not return in `timeout` seconds.

`CalledProcessError` : if command has non-zero exit status

Examples

```
>>> import spacepy.toolbox as tb
>>> tb.timeout_check_call(1, 'sleep 30', shell=True) #raises TimeoutError
```

spacepy.toolbox.TimeoutError

exception `spacepy.toolbox.TimeoutError`

Raised when a time-limited process times out

spacepy.toolbox.update

`spacepy.toolbox.update(all=True, QDomni=False, omni=False, omni2=False, leapsecs=False, PS-Ddata=False)`

Download and update local database for omni, leapsecs etc

Parameters `all` : boolean (optional)

if True, update OMNI2, Qin-Denton and leapsecs

`omni` : boolean (optional)

if True, update only omni (Qin-Denton)

`omni2` : boolean (optional)

if True, update only original OMNI2

`QDomni` : boolean (optional)

if True, update OMNI2 and Qin-Denton

leapsecs : boolean (optional)

if True, update only leapseconds

Returns out : string

data directory where things are saved

Examples

```
>>> import spacepy.toolbox as tb
>>> tb.update(omni=True)
```

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